TESTS AND ANALYSIS OF PHOTOGRAMMETRICALLY PRODUCED DIGITAL DATA FOR CADASTRAL MAPPING IN GREECE

By

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CHAPTER ONE

Chapter 1

Introduction

1.1 Photogrammetry and Cadastre in General

Photogrammetry is a method which has been applied to various types of land survey and other measurement applications. Although photogrammetry has been used extensively in the production of topographic maps, its adoption in cadastral surveys has been much slower. However, the lack of confidence of some cadastral authorities concerning the adoption of photogrammetry for their surveys, has been mainly due to their limited knowledge of the more modern photogrammetric instrumentation and procedures and the results that can be achieved with them. Yet there exists a very substantial literature and evidence that shows that photogrammetric procedures can be implemented successfully to meet the requirements of cadastral surveys and mapping tasks.

Cadastral surveys have to serve different cadastral system types and the specific requirements of a particular system is the determining factor for the selection of the appropriate cadastral survey technique. On the other hand, a cadastral system has to be organised in such a way that its demands can be satisfied by a cadastral survey technique which it will be feasible to apply. The primary task of a cadastral survey is to produce a description of each parcel of land. Although photogrammetry started originally to be used as a graphical method, it was soon adapted in such a way to serve the needs of either a numerical or a graphical form of a parcel description or both. The need for the cadastral data to be in one or other of the forms mentioned above, is influenced directly by the accuracy required for the cadastral data. In each case, these accuracy requirements are determined by the cadastral regulations of the system which are a prerequisite for its proper function. The required accuracy itself is affected to a great extent by the value and the use of the land. Different accuracy specifications are usually set for urban and rural areas, which in turn may result in the adoption of different types of survey techniques for different types of terrain and land use.

The matter of the accuracy of photogrammetry in cadastral surveys, has been a subject for investigation over many years and successful examples of implementations like that in Switzerland have shown that, by using the appropriate technique, high standards of accuracy can be maintained. Assuming that the accuracy standards being set by the cadastral regulations can be achieved both by a suitable ground survey method or a photogrammetric technique, the advantage of choosing photogrammetry should be the gains it can offer in terms of speed, efficiency, flexibility and low cost - provided of course that the area requiring survey reaches a certain minimum size. However, it should be stated that photogrammetry cannot completely replace ground survey, since the latter will be required for the establishment of the photogrammetric control and for field completion operations. Furthermore, the survey of a small area or an individual plot using photogrammetric methods would be wholly uneconomic and the use of ground survey techniques on such a task would be both obvious and sensible.

Apart from accuracy, another factor which may influence the selection of a particular photogrammetric technique is whether a cadastral system operates on a centralised or a decentralised basis. Generally speaking, given the need for the optimum use of very expensive equipment such as aircraft, cameras, stereoplotting equipment, etc., the use of photogrammetry is best done on a centralised basis. However if the collection of cadastral data is organised at a regional level, there will be certain advantages of performing the measurements at the regional cadastral offices. Given the very high costs and the necessary resources for buying and running more advanced photogrammetric systems, alternative techniques should be considered if data capture has to be done on a regional basis. In this respect, photogrammetry can indeed offer alternative techniques, for example, the techniques of monoplotting or orthophoto which require lower cost investments and less photogrammetric expertise at least for the cadastral data capture operations.

The increasing demands for data suitable for input to modern land information systems (LIS), which are usually organised on the basis of the cadastral parcel, have imposed the requirement for the cadastral map data to be in digital form. This requirement has had a direct influence on survey instrumentation and procedures which increasingly have been developed specifically to allow the acquisition of data in this form. Thus photogrammetry, no less than ground survey, has been adapted to the needs for digital data, so that the current instrumentation and techniques can satisfy the needs of a modern land information system.

1.2 The Cadastral Situation in Greece.

This project and dissertation has been concerned with Greece and its cadastre. In the first place, this arises because the author is Greek and has a strong personal interest in undertaking a project which is of direct concern to his country and its people at the present time. Secondly, there is a long history of attempting to introduce a cadastral system in Greece, which meets the needs of its people, legal system, particular terrain types and land use. The many attempts to do so in the past have been unsatisfactory and have had many shortcomings. Now at present, another serious attempt is being made to rectify the situation and introduce a much improved system. In particular, the opportunity to establish a modern computer-based LIS should be considered carefully. Unfortunately, so far, the quite recent establishment of the Hellenic Mapping and Cadastral Organisation (HMCO), has made little progress towards the creation of a cadastre on a national basis.

Photogrammetry has not been used for cadastral work in Greece up until now. However the need to investigate the potential use of newer photogrammetric techniques was considered to be a matter of great importance, at least by the present author. Based on all the above factors, the decision was taken to undertake the present research topic.

1.3 An Overview of the Thesis

In Chapter 2, a historic account is given about land ownership and registration in Greece, the latter being a Register of Deeds. Information is also given about the Deed Registries which are distributed all over the country and operate on a decentralised basis. This is followed by an account of the relatively recent legislation about the supplementation of deeds and covenants by cadastral plans. The various cadastral information sources in Greece and their operation are covered, with particular attention given to the HMCO. Finally in this Chapter, a short description is given of a research programme carried out in Greece in the mid 1970s about the potential contribution of photogrammetry to the solution of the Greek cadastral problem.

The two basic cadastral survey systems being the numerical and the graphical cadastre, are described in Chapter 3, as well as their requirements in terms of surveys, coordinate information, maps and their respective accuracies.

A review of the past and present application of photogrammetry to cadastral surveys is given in Chapter 4 where the photogrammetric techniques ranging from the most simple and economical to the most sophisticated and expensive are examined through a variety of test projects and application examples from various countries. The first part of the chapter deals with purely graphical photogrammetric techniques, whereas the second deals with numerical photogrammetric techniques which can be used for both graphical and numerical applications.

The chapters following Chapter 4 deal with tests of three photogrammetric techniques, namely, digital stereoplotting, monoplotting from digitally rectified images and digital data derived from orthophotography, which were believed to have a good potential application for cadastral work in Greece. The selection of these specific photogrammetric techniques was based on the assumption that the cadastral system to be established would require the acquisition of digital data and, if possible, should follow the decentralised basis of the present Greek deeds registration system, in order to be more easily adapted to this existing structure. Also, the selection was based on the types of boundary likely to be encountered in Greece, which are defined by physical features. The terrain of Greece, being to a great extent mountainous, is probably the single most important factor in making the selection of the appropriate photogrammetric technique with respect to the obtainable accuracies.

Photogrammetric material of two test areas of moderate and hilly terrain in Greece was used for a comparative evaluation of the three tested methods. This material is described at the beginning of Chapter 5 and was used for all the tested photogrammetric techniques. For the selection of individual techniques, considerable importance was given to their relatively modest requirements in terms of the money and photogrammetric expertise needed for their implementation, as well as the need to capture data in digital form to serve a modern land information system. All these techniques were tested for direct production use in cadastral surveys and their relative accuracies, merits and drawbacks were investigated.

Chapter 5 deals with stereoplotting using digitally encoded analogue stereoplotting machines. The tests were made to verify the suitability of these stereoplotters to capture data in the required digital form with many information levels, and the need for further editing of this data prior to its entry into a digital cadastral database. The use of stereoplotting was considered to be the most appropriate photogrammetric technique, at least for the more mountainous areas of Greece or those parts requiring high accuracy standards, as required in urban areas. The stereoplotting tests also served as the basis or standard for the comparative evaluation of the other two photogrammetric techniques tested in this project.

In Chapter 6, an evaluation is given of a more modern technique, that of monoplotting from digital rectified images. This technique seemed potentially to be very interesting for application both in rural areas with lower accuracy requirements and for its implementation on a decentralised basis. This potential of digital monoplotting was based on the assumption that it not only requires relatively low photogrammetric expertise but also needs easily and cheaply available computer hardware for its implementation.

The last technique tested, that of acquiring digital data from orthophotographs produced from stereopairs, is discussed in Chapter 7. Orthophotography could be considered as a possible solution for cadastral surveys in Greece, at least for the largest part of the rural areas. Although this has traditionally been regarded as a purely graphical technique, the high production rates that can be achieved and the possibility of capturing cadastral data in digital form by direct measurement and digitising on the orthophoto document itself make it very attractive for serving the needs of a modern cadastre in those areas having graphical accuracy demands.

A comparative analysis of the test results is given in Chapter 8, where both the accuracy and the relative completeness of the plotted detail among the tested techniques is examined.

The final concluding remarks about the potential application of the examined methodology in cadastral surveys, especially in the case of Greece, are given in Chapter 9. Also recommendations are made for further investigations and developments that should be undertaken, prior to the adoption of photogrammetry for cadastral mapping in Greece.

CHAPTER TWO

Chapter 2

The Problem of Cadastre in Greece Today

2.1 An Historic Assessment of the Attempts to Constitute the Cadastre in Greece

A critical analysis of the attempts to confront the cadastral problem in Greece might prove to be a positive contribution to and a correct starting point for an effective and total solution of that problem. Such an analysis should include an objective assessment of the reasons for the failure to tackle the problem at both the scientific and socio-economic levels as well as the identification of the principal points of the problem.

The great quantity of laws pertaining to the Greek cadastre, enacted since 1836, shows a purely mechanical attempt to transfer foreign prototypes into the Greek environment, without any links to the specific necessities of the country. In particular, they appear to pay little or no respect to the political and socio-economic environment of Greece or to its development state in general.

In many countries, there is a clear and complete institutional framework relevant to the prevailing form of land ownership. This covers the technical, juridical and socio-economic aspects of such ownership as well as the state of its use and management. Furthermore, the system which is implemented attempts to incorporate the constitutional and social limitations of the exploitation of land within the country. By contrast, Greece has only temporarily, occasionally and inconsistently implemented a series of laws on land ownership that either were not valid or have contributed to the chaotic condition of recent times. These laws began with the decree of 2.12.1836 "About Cadastres" followed by about twenty five decrees and other laws on this subject area up to the most recent one of the 19.6.1961 (A175). Most of these only came about as a result of national economic and social happenings or disasters. Essentially they tried, without success, to tackle a work of national extent without an essential preliminary study and programme that would have classified the priorities and the necessities of the country. Furthermore, the laws governing land ownership in Greece appear to lack any perspective regarding its multi-dimensional and dynamic nature. The institutional framework, comprising the organisation, management and renovation of land; the process of data collection, including the quantitative and qualitative elements of the land and its use; the control of natural resources; etc, are all matters that have received minimal attention in Greek legislation pertaining to land.

From the days of the revolution for independence (1821), a series of technicians and professionals have made very strong efforts for the implementation of legislation for a "National Cadastre" resulting in the approval successively of legislation based on Prussian, French, Australian and other models of the times. In each case, the possibility for their direct adoption was frustrated by the obviously different Greek reality. As a result, the cadastres of Athens and Tricala which were decided to be established in 1910 by a royal decree were never established. These are non-existent even though governments have legislated since then for the institution of the "Council of Urban Cadastre", the "Office of Cadastre Keeping" and the "Central Cadastral Archives".

Coming to the most recent period, starting in 1959, Sokos published his proposal about the registration of urban properties. There was no continuation of this proposal in terms of legislation or implementation. In 1970, without any institutional framework or prior study, the dictatorship then in power in Greece, began the compilation of a cadastre which ended with its decline and removal from power. In 1974, a collective effort undertaken by the government with the representatives of T.E.E. (The Technical Chambers of Greece) and the Society of Topographic Engineers, ended with the legislation of a "Forest Cadastre," despite the opposition of the T.E.E.. In parallel, without any authority or publicity and without any technical specification, the Ministry of Agriculture executed the "Vinecultural Cadastre" under the government's efforts to bring Greece into the EEC.

In 1976, the Ministry of Public Works started the formulation of a draft law for the Greek Cadastre taking into account some of the basic considerations of the engineers mentioned above, but rejecting until today their essential contribution to its development. Unfortunately the latest governments continue to ignore the suggestions of the T.E.E. with a view to confronting the problem of the Greek Cadastre. In this manner, they repeat the errors of the previous governments and consciously neglect the specific needs but also the potential of the country by failing to provide the framework of a policy for its social and economic development.

2.2 The Lack of Cadastre and the Consequences

The lack of a cadastre leads to a series of very important consequences. First of all, the extent of public property was and will remain unknown and unregistered despite the management of only a small fraction of it. The same applies for the ecclesiastic property which in Greece is enormous in extent. Furthermore, the encroachment of individuals into public lands and the lands of the local authorities remains unquantified and uncontrolled. The expense of a public project then becomes double due to the costs for the alienation of land which in fact belongs to the public domain. Without any knowledge of the cadastral element, and therefore of the structure of the rural land holdings and the traditional production of one area, the study of any one project can only assess the economic and not the social value of the land. The result will be a decrease of productivity or possibly a very intense social disturbance. More importantly, the development and imposition of a land policy remains restricted and, as a consequence, the following are instigated:

i) The excessive subdivision of urban and rural lands, and the uncontrolled and un-scheduled increases in land values;
ii) The deterioration of the life quality in towns (e.g. no parks and overexploitation of constraints with respect to the building height);
iii) The abandonment of agrarian lands, as they become more and more subdivided and cannot keep the farmers, as a result of the slow rate of land consolidation that does not assure the long term enlargement of the lots; and
iv) The inability to protect and manage the coasts, the forests and the natural environment of the country.

2.3 Land Ownership in Greece

2.3.1 Land Policies in Greece Since Independence (1821)

A critical consideration of the Greek Constitution and legislation with respect to land ownership that have applied from 1821 until now, can reveal the framework within which the main aspects of Land Policies have been operated.

The "Legal Decree of the East Mainland" of the 15th of November 1821, constituted the first integrated attempt to draw up a land policy. The aims of it were;

i) to obtain an exact knowledge and assurance of the National Lands,
ii) the creation of a cadastre at least for the National Lands,
iii) the selection of the appropriate agricultural land use in order to optimise the productivity and the economy of those lands; and
iv) to institute a centralised control and maintenance of National lands and of public buildings.

The majority of the land which was liberated belonged to the Turkish state, or was owned by Islamic religious organisations. Other land was in dispute between Turkish and Greek farmers (feuds). The former group became the first Public Parcels, the National Lands of Greece. These lands and the way that they were distributed and used have formed the principal elements of the land policy since 1821.

The law of 1835 and the Royal Decree of 1843, allowed farmers to buy pieces of these National Lands at public auctions.

The constitution of 1844 protected private land and accepted the idea of a social limitation over the individual's rights on this type of land, for the benefit of public need, but only after an appropriate compensation had been given.

The first free cession or disposal of National Land was given by the law of 1848 for the restitution or rehabilitation of farmers. In the period up to 1882, a total of 3,146,500 acres was distributed by the laws of 1835, 1836 and 1871, all having titles related to "the National land distribution and endowment of the citizens".

With the constitution of 1907, for the first time, the land owner had the right to protest to the courts regarding matters relevant to the state compensation that he acquired for the alienation of his land. Special orders of the constitution of 1907 covering the autonomous state of Crete, attempted to regulate the sale of lands and give compensation for the damages caused by the rebellions of the time (1896 -1897). It also proposed a programme of public works as an attempt for development. A general confiscation of land was forbidden for the first time.

Later constitutions (from 1911 up to 1952) attempted to improve and regulate matters of land ownership and the protection of individual rights. They also covered land distribution for the indigenous population and placed restrictions on land alienation. During the military dictatorship of 1967-1974, specific laws allowed the alienation of land in the cases of public works of common interest and the possibility for land consolidation and reallotment of rural lands for their "optimum use".

The latest constitution of 1975 sets the basis for urban development with the rendering of a percentage of the new buildings, or the benefit of using the new developments (e.g. public roads) as a return, instead of monetary compensation and only potentially legalises land consolidation policies. The potential distribution of abandoned land and the later compensation of its traced owner is also legislated for, as well as the responsibility of the state to protect the environment and the forest by reserving the forest lands and establishing development programmes. Finally, the organisation of the state on a decentralised basis (Article 101), the management subdivisions and the establishment of the local authorities as legislated, follow the concept of a decentralised model of development and promise to optimise the efficiency of the relevant programmes.

2.3.2 Transfer of Land Ownership

Having given a brief account of the legislation and overall policies concerning the land and its distribution in Greece, as traced through the various constitutions, laws and decrees enacted since independence, it is now time to see how this land is being transferred from one owner to the other; to describe the system of land registration; and to see in effect the assurance, if any, this registration gives to the owner of the land.

2.3.2.1 Registration of Deeds

According to the Article 1033 of the Civil Code (CC), being last revised in 2/1945, the conveyance of the land parcel demands an agreement (covenant) between the vendor and the new owner to certify that the transfer is done for a legal reason. This agreement is conducted through a notarial deed which is subject to registration.

This notarial deed, is not a proof of the agreement, but it is a constituent element of it. Hence, with the non-existence of a legal national cadastral system, this should prove with its data the validity of the ownership rights. However, these notary deeds of conveyance of land ownership, may be internally defective and so they cannot be regarded as legal titles.

The registration of deeds is the sealing of the real agreement of ownership transfer. According to the Article 1200 of the CC, the registration is done in public books which are available to every citizen to consult via a lawyer.

The law of 29/10-6/11 of 1856 "About the registration of the ownership of land and the overlying real rights" as well as the law of 11-23/8.1836 "About mortgages" were in effect a transfer of the French law of that time into Greece.

With respect to the Articles 1192 and 1193, the following are liable to registration:

- the legal acts for the transfer of ownership or any other real right on a parcel, whether it is about a sale, an exchange, a grant, etc.;
- the legal acts with which a real right is created or abolished over a land parcel;
- the adjudications, or ratifications of ownership;
- the reports for a juridical distribution of land;
- the acceptance of a heritage or bequeathment;

Having considered the lack of a definition of the land identity as a result of the absence of a National Cadastre, the law 533 of 14/21.9.1963 orders that, for a registration, every parcel must be described by:

- its kind (urban, rural, mine, etc.);
- its administrative location (municipality, parish)
- its exact(?) geographic location (name of location, postal address, quarter, etc.);
- its physical limits and neighbours;
- its approximate extent;
- the percentage ab indiviso of the land to which the act applies;
- the percentage of sharing and the number in the case of a building flat

2.3.2.2 The Process of Registration - The Deeds Registers

Initially, with the law 31.10.1856, Article 1, and for about one hundred years afterwards, the registration of the deeds of conveyance was performed, by being entered into the Registry Books as well as in the Index of Registries which were considered as a unity.

In practice however, the Registry book was not kept up to date or nor was it complete due to limitations in terms of space. This could mean that the registrations were legally void.

So today, with the law 533 of 1963, the following were established.

(a) The General Book of Statements (Article 1 of the law 4201/1961). In this, all the paperwork submitted for the entry in the Registries is entered by order of submission.

(b) The Special Index of Registrations (Article 19 of the law 533/1963), in which a separate section is given to every person who is involved in a legal act to be registered. The identification of the above persons, the description of the parcel and the subject of the registered act are recorded there.

(c) The General Alphabetic Index (Article 3 of the law 4201/1961) where the names of all the persons related in any way to the registered acts, are entered in a strict alphabetic order.

(d) The Book of Registrations or "The Volume" (Article 6 of the law 4201/1961), in which all the registered paperwork is bound.

Every entry in the Registries' books, is done after the submission of a written application by the person concerned. A registration can be done any time and this is a defect of this system, since at any time, somebody else might not be considered as the true owner.

According now to the Article 1198 of the CC, "without registration, the transfer of ownership of a parcel or the formation, transfer and abolishment of a real right on that parcel, is not allowed".

Today there are 380 Registries, under the control of the Courts in the first instance. The selection, distribution and structure of these Registries, is made with respect to the extent of the district they cover, the number of plots, the population, the number of transfers per year, etc. From the above, it should be clear that this is a highly decentralised system of deed registration.

2.3.3 Deeds of Conveyance (Covenants) and Cadastral Plans

The covenant of sale between the vendor and the new owner is the actual document that the latter has in his hands. This is an exact copy of the prototype which is kept at the archives of the notary from which it is issued. It is a summary of this covenant that is sent to the Deeds Registry for the registration. The original Deed Registry certificate which states that the land has been conveyed is also kept by the notary. The notaries now, are juridical persons assigned by the state.

After 1977, with the law 651/77, every legal act related to the conveyance of a land parcel must be accompanied by a cadastral plan (this is actually referred to as a topographic plan), signed by the issuing surveyor, and the covenantors.

According to the above law, on the cadastral plan, the boundaries with the adjacent owners are demarcated with their corresponding lengths and the names of each of them. The legend on the plan should include information on the location of the parcel, and in the case of urban areas, the number of the parcel block, the name of the owner, the parcel area and a declaration by the surveyor that the parcel fulfils the building regulations. The surveyor also certifies whether or not the relevant parcel is a part of a larger parcel and can still fulfil the above regulations. It is also noted that the boundaries were indicated to the surveyor at the responsibility of the owner or with respect to another, specified covenant.

Three copies of the plot are produced. The first copy is held at the Deeds Registry, the second by the owner and the last by the surveyor, who also has the original plan on a transparent base. The cadastral plan cannot be altered during the ten first years after its issue and any copies required must come from the original transparency.

According to Article 2 of the law 105/1969, the surveyor or the signing covenantors can be prosecuted in those cases where they declare fallacies.

Referring back to the covenants again, these are lengthy verbal descriptions. Each covenant states the identity of the issuing notary and its number. The following information is also included:

- the identities of the vendor and the new owner;
- details of the covenant of the vendor;
- details of payment;
- parcel description;
- details of the transaction and also any other agreements, conditions, or easements relevant to the parcel.

2.4 The Various Cadastral Data Sources in Greece Today

After the reference to the Deeds Registries, the various cadastral data sources will be presented here (Rokos, 1981, Arvanitis, 1992).

i) The first source is the Cadastral Offices of Rhodes and Kos, that have been in operation since the times that the Dodecanese Islands were under the Italian occupation. These Cadastral Offices, like the Deeds Registries, are under the Ministry of Justice.

ii) The second source is the Cadastral Office of Athens, where cadastral data of the quarters of Kallithea and Faliro can be found. Cadastral operations had already been carried out there before the World War II. This office is under the Ministry of Environment, Planning and Public Works (MEPPW).

iii) Other relevant departments are also under this Ministry. One of these is the Department of Topographic Surveys and Cadastre (DTSC) which was founded in 1918. This Department employs the greatest number of the Survey Engineer graduates produced by the universities and is supposed to be the main civil department for the production of topographic and photogrammetric maps.

iv) The Urban Development Company (UDC) is also under this Ministry which produces cadastral data for the application of the urban plan expansion projects.

v) Finally the Hellenic Mapping and Cadastral Organisation (HMCO) which will be described in more detail later is also under this Ministry.

vi) The Ministry of Agriculture now also produces cadastral data concerned with:

(a) The land consolidation and reallotment programmes.

(b) The distribution of lands for cultivation and settlement.

(c) The vine-register. This holds vineyard related information (who owns them, where they are and their extent) and has been developed with the cooperation of the EEC. An olive-tree and a citrus-tree register is also under development.

(d) The Department of Forest and Forest Land Registration.

vii) The Ministry of Finance with the Departments of Public Lands and Alienations, keeps as well cadastral data within its public land lists.

iii) Various other Ministries produce cadastral data such as the Ministry of Culture with the registration of ancient ruins and monuments; the Ministry of Education under which is the School Buildings Organisation; the Ministry of Domestic Affairs with the technical services of the municipalities or parishes all of whom do public works.

ix) Other publicly owned organisations such as the Public Electricity Company, the Organisation of Telecommunications, the Hellenic Tourist Organisation, etc., have land survey departments and produce some sort of cadastral data.

2.4.1 The Hellenic Mapping and Cadastral Organisation (HMCO)

The purpose of the HMCO as stated by its foundation law 1647/86 is to compile, keep and update a uniform cadastre of Greece, the geodetic cover and survey of the country, the registration and mapping of the natural resources and the establishment of a land and environment information data bank.

Within the jurisdiction of the HMCO are the following:

(a) The coverage of the country by the basic cadastral maps that will be the cartographic basis for a uniform cadastre of Greece, the expansion of the natural resources and the databank for land and the environment.

(b) The programming and execution of the photogrammetric operations, from the acquisition of the aerial photographs up to the final restitution (plotting) for the fulfilment of its own requirements as well as the programmes for development of the national organisations, services and local authorities.

(c) The compilation, systematic updating and printing of thematic maps.

(d) The programming and execution of all the operations for the compilation, keeping and updating of the national cadastre of Greece.

(e) The compilation of standards, regulations and fees, lists for its operations.

(f) To develop research into matters related to each purpose.

(g) The execution of any other work necessary for its purpose.

In order to legislate for and allow the efficient operation of the HMCO, it was considered appropriate that any development should come directly under the Department of Mapping and Cadastre (DMC) of the Ministry of Environment, Planning and Public Works (MEPPW). Its role was coordinative and temporarily executive for the covering of needs until the HMCO become fully operative.

Hence, the Department of Mapping and Cadastre (DMC) of the MEPPW was constituted, taking over from the DTSC, with the prospect to be later fully integrated with the HMCO. Through the DMC, the following departments are now under the HMCO.

a) The Department of Cadastre
b) The Department of Mapping
c) The Department of Geodesy
d) The Department of Photogrammetry
e) The Department of Aerial Photography

The HMCO has already made studies for the organisation of the cadastre on a national basis. It is planned and legislated for by a decree that also stipulates that local cadastral offices can be established. Hence although the HMCO was legislated as a centralised authority, decentralisation will, in this way, be promoted. Before this is done however, the cadastral survey of a municipality must be complete (Livieratos, 1993). Such a task has been already performed as an experiment at the municipalities of Kallithea and Faliro in Athens by the Cadastral Office of Athens, as has been mentioned earlier. The surveys of Kifissia in Athens and Komotini in the north-east region of Greece are going to follow.

The legal aspect of the cadastre with respect to the land registries will be studied by a committee. This committee will be formed by members of the Ministry of Justice (judges, professors) and the MEPPW. All these matters have already been covered by legislation.

2.5 Land Consolidation and Reallotment

As a starting point, it should be noted that land consolidation projects are one of the most important sources of cadastral data in Greece. Land consolidation has a close relation to cadastral surveys, since these are a pre-requisite of it. A brief consideration will be given here for the situation in Greece. Land consolidation now, is a land policy implemented according to the last law 674/1977 "About land consolidation and the enlargement of agricultural exploitation". An exact knowledge of the cadastral state of the areas concerned is needed for the implementation of such a policy. This necessitates the existence of a National Cadastre for a Land Consolidation which should be a programme of national extent.

In Greece, before a land reallotment project can be implemented, the necessary cadastral surveys are made according to the provisions of the above law. The Topographic Department of the Ministry of Agriculture is responsible for the above operations. The methods which are followed, are the traditional ground survey methods. Only after a special decision of the Minister, can the photogrammetric method be used.

2.5.1 Urban Land Consolidation

The idea of land consolidation may also apply in urban areas where it contributes to urban planning and development.

The first legal framework in Greece for the Urban Consolidation started with the Articles 49 to 51 of the law of 1923 "About town plans, cities and quarters of the country and their building", and were followed by the adjustments given by later laws. These regulations however, only applied to those cases concerning a great number of parcels, and were rarely applied.

Today the law 947/1979 "About habitation areas" (which is still to be revised), states the meaning, and sets out the ways, the publicity for and the process of an urban consolidation. Such a task can be undertaken either directly by a public organisation or service, a public town-planning agency or by a building association after a presidential decree announced by the government.

2.6 Cadastral Survey Regulations

The regulations and standards for a cadastral survey in Greece, coincide to a great extent with those for geodetic, topographic and photogrammetric surveys. Since a cadastre of national extent has not yet been developed, these existing survey standards cover only those individual cadastral surveys that have been undertaken.

The presidential decree 696 of 1974 "About payment of surveyor engineers... ...and related standards", regulates the payments for cadastral surveys. Also, in its second part, it includes the standards which are required for the geodetic, topographic, cadastral and cartographic operations. According to the later Article 108, they are liable to adopt the latest technological improvements and to regulate the accuracy standards and uniformity of the above surveys.

According to the Article 116 of the same presidential decree of 1974, the purpose of a cadastral survey is the exact determination of the parcel boundaries; the depiction of these and of the "natural and artificial features of the ground"; the compilation of a cadastral plan "at an appropriate scale"; the inscription of the parcel identity number; the compilation of areas and owners' lists; and finally contouring, where the height measurement is not restricted by dense settlements.

The determination of parcel boundaries is done after their designation by their owners, or a rural judge being placed in charge by a public, municipal or parish authority.

The scale of a cadastral plan according to Article 116 is a function of the extent, the size and the value of the parcels and is determined by the constructor of the plan. At the same time, by the Article 119, the scale is fixed at 1:500 for the densely settled areas and 1:1,000 or 1:2,000 for the "urban areas".

The methodology that "should be used" in the case of urban areas is the survey by rectangular coordinates, and in the case of rural areas by tacheometry.

An "appropriate" photogrammetric method, may be used in any of the above cases. For the optional case, where photogrammetric methods are used, the limits of the ratio C of the photograph scale to the final map scale are given by the formula:

$$C = \frac{M_b}{\sqrt{M_k}}$$

where $100<C<300$; M_b the photograph scale denominator; and M_k the map scale denominator respectively.

This formula relates to graphical stereoplotting using analogue photogrammetric instruments and does not consider the numerical, analytical or orthophotogrammetric methodology.

The cadastral survey regulations for the urban areas make no comment on or provision for the use of photogrammetric methods. The only exception is the use of enlarged photographs for the preliminary operations. Since the cadastral surveys of urban areas usually relate to individual cases of small areas, for which photogrammetry is not suitable or legalised, this absence of regulations is justified.

With the legislation however of the HMCO which is given the responsibility to keep and update an archive of aerial photographs of the country for planning and development programmes, this comes in to a direct conflict.

2.7 An Attempt at Assessment

As can be seen from the above and by a closer inspection of the regulations, the latter cannot be considered as sufficient or efficient even in the case of individual surveys which are made here and there under no commonly organised schedule.

The "authority" or "constructor" which undertakes an individual cadastral work for example, will inevitably specify his own arbitrary and obviously independent way of measuring and plotting a cadastral plan.

By inspecting Article 116 of the decree 696/74, it is clear that the regulations make no comments for the clarification of the titles of ownership or their easements, the land use or value and other qualitative information for the ownership and legal status of it. In general, there is not yet a regulation for the desired accuracy of demarcation or recording of the parcel boundaries or for their standard deviation values.

The consideration of a different quality and weight of the cadastral surveys becomes most evident with Article 119 of the decree 696. This Article states that cadastral surveys are not made for the lands owned by the state or those that have been conceded to municipalities or parishes and are free from buildings and crops. Hence, the areas that demand the greatest attention and protection, the National land according to the law, are not surveyed and registered and are left free to fall into the hands of squatters.

It should be stated however, that the HMCO is now developing new standards and regulations that will eventually have a universal application in Greece. However what has been done so far does not have such an application, since it is not complete and most importantly, it has not been legislated.

2.8 The Potential Contribution of Photogrammetry to the Solution of the Greek Cadastral Problem

In order to assess the potential contribution of photogrammetry for the formation of the Greek cadastre, a research programme had been carried out from 1973 until 1977 (Rokos, 1981). This research programme was carried out after the order of the MEPPW by a team of graduate surveyors under the supervision of the DTSC and the Technical Chambers of Greece (T.E.E.). A starting point for the design of this programme had been the systematic survey of the conditions and construction of the rural ownership carried out during the period 1963 to 1973. A further impetus was given by the employment of professionally qualified personnel in the sectors of cartography, topography, photogrammetry and cadastral surveys within a great number of areas in Greece.

Enlarged aerial photographs of scale 1:5,000 were utilised for this test, obtained from the Geographic Agency of the (Greek) Army (GGA). These photographs had been previously used by the GGA for the photogrammetric stereoplotting of topographic maps at 1:5,000 scale.

A detailed critical analysis of the relation of the field conditions with the corresponding images on the available photographs, created first of all a general picture of the situation. This then had to be checked and evaluated quantitatively within specific areas which were, as far as possible, uniform and representative for the whole country.

Thus seventeen municipalities of West Peloponnese were selected that could be said to represent to a smaller or greater extent, the economic, social, geographic, goemorphological, topographic and demographic characteristics, encountered over the greater part of Greece. In total, these comprised 8 areas of flat terrain, 7 semi-mountainous areas, and 2 mountainous areas.

For these specimen areas, the following items were designated on magnifications of the original photographs at 1:5,000 scale.

(a) using photogrammetric methods, the possible ownership limits were delineated by graduate surveyors, as the directly visible or the reasonably designated natural limits of rural land plots.

(b) with ground measurements (i.e. traversing) and investigations, the specific limits of ownership of land were designated, computed and drawn.

Consequently, the data obtained by these two methods were compared in order to investigate the quality, the extent and the degree of coincidences and deviations of the physical boundary limits, that were interpreted as being the ownership limits with those that were really proved to be the cadastral limits.

The implementation of this programme was carried out under Greek conditions without any effort at the idealisation of the materials, means and processes that were followed, and despite the fact that they might be considered as inappropriate in many developed countries. Rural judges were used as designators of the parcel limits, since they were considered to be the most reliable, informed and authoritative persons available for this job. The problems concerning the insufficient identification of the physical parcel boundaries due to the progressive abandonment of the rural land were solved during the ground survey operations, so the exact status of the boundaries of the investigation area was known.

The given conditions even involved the use of 12-16 year old photographs. By the use of the photo-interpretation method, the following were verified. The 48.9% in terms of number and the 49.8% in terms of area of the photogrammetrically determined parcel limits were in coincidence within the actual accuracy limits set for the experiment. For the flat areas, the agreement was up to 49.7%, while for the mountainous terrain, it was up to 47.9% in terms of number of ownerships. This roughly indicated that, if the production of topographic maps at 1/5,000 scale through the use of photogrammetry, and with appropriate standards is decided upon, then 50% of the cadastral diagrams of Greece will be produced as a by-product.

For 31.7% of the number of properties and 28.3% of the area out of the total, there was a reliable coincidence of the photogrammetrically determined parcel limits with the cadastral limits of a single ownership. So for these percentages, a simple graphical joining on the plot, after the indications of the approved designators would suffice to produce the diagrams of the true ownerships.

For 7.4% of the number of properties or plots and 9.4% of the area out of the total, there was a coincidence of the photogrammetrically determined parcel limits of one ownership with the actual limits of more than one ownership. Hence for those percentages, field operations are necessitated for the subdivision of parcels, after the indication of the true limits by the owners or rural judges and their drawing on the obtained photogrammetric plots.

Finally, for the remaining 12%, both of the number and of the area of the total, there was a complete deviation of the photo-interpreted limits from the actual limits. For this percentage, a complete cadastral survey, based on traditional ground methods, will be necessary.

These results were considered as the basis for legislating the Hellenic Mapping and Cadastral Organisation (HMCO) as well as for the presumption of the claims of T.E.E. in terms of the accuracy, economy and speed of the photogrammetric method.

2.9 An Evaluation of the Cadastral Situation Today

As can be seen from paragraph 2.4, there are a number of sources or organisations producing cadastral data. However, all this data remains useless and indeed has never been gathered by the HMCO despite the fact that there is a requirement to do so in its constitutional law. Also, such data will become or remain useless since there is no plan for updating it by any of the bodies which produces it. Indeed these surveys were only produced occasionally to cover the specific needs of the times. Furthermore, each one of them produces cadastral data which comply to their own (if any) standards, something which greatly restricts their gathering.

According to the opinion of the president of the HMCO, D. Katsieris, after a conversation in person with the author of this dissertation (4/1993), and also the opinion of a great part of the public, this situation is first of all the result of lack of political willingness. The fears of political repercussions restrains the government from taking any essential steps to rectify the present situation.

A relevant example of this inaction is that of the Department of Mapping and Cadastre (DMC), which, according to the constitutional law of the HMCO, was going to be fully taken over by the latter. A conventional problem was the transfer of the employees to the recently established HMCO. They reacted against their transfer since this was going to have an effect on their pensions.

Similarly, despite the last regulations for the creation of the Cadastral Offices, their operation will be very restrictive. When an agreement of ownership transfer is made, the notary will have to submit a summary of the agreement at the local Cadastral Office first and then to the Deeds Registry. Merging the planned Cadastral Offices with the Deeds Registries would be an obvious solution, but for the same reason as before, something like that has not happened yet.

Similarly, another reason for the delay of any positive step towards the creation of the National Cadastre is the need for the HMCO to invest a great amount of money for a long term result. Since this will not give a return very quickly, it causes the organisation itself to be very inert or inactive over this subject. Also the attitude of the lawyers and notaries who are supposed to benefit from the disputes arising between land owners is important. The lack of a cadastre might increase the number of such disputes.

There are however other opinions for the inaction of the HMCO. According to D. Kalimeris, head of the Department of Cadastre of HMCO, after a personal contact with the author (4/1993), there is a lack of organisation within the HMCO itself which restricts any remedial actions. According to him as well, there is no knowledge and especially no experience, even within the HMCO of how the cadastre will operate when this becomes systematic (as it is intended to be) and has a national extent. Finally he reckons that lawyers and notaries will actually benefit from the establishment of a National Cadastre since any disputes that may arise, will be more easy to resolve.

The latest news concerning the lack of the cadastre in Greece (4/1993), is that the government is now planning to entrust its formation to a private company that will have the necessary experience on the matter. Rumours say that this will probably be an Italian company, but this is where all the relevant information ends.

CHAPTER THREE

Chapter 3

Cadastral Survey Systems

3.1 The Two Methods of Parcel Definition

The relationship of boundaries on the ground to the corresponding maps, plans, diagrams and their written descriptions which define the registered unit of property has often caused great controversy.

There is a wide range of terms used, such as general boundaries, guaranteed boundaries, fixed boundaries, general map, etc, which have evolved from the establishment of various land registration systems. These terms are often used in different senses and even the word boundary has two quite different meanings. Thus, a boundary can be an invisible line showing the limit of what somebody owns and is only marked at turning points on the ground, or it can be a physical feature, such as a wall, a ditch, a row of trees, by which that limit is marked. Going on from this, boundaries have been divided into natural and artificial, in the case when the physical objects have or not been created by the man.

Whatever the case for the use of the above terms, there are two quite distinct methods of parcel definition and an attempt will be made here to indicate their relative merits and drawbacks.

3.1.1 Parcel Definition by Officially Emplaced and Mathematically Coordinated Boundary Monuments.

In this case, the authorised surveyor places monuments at corners or turning points along the boundaries of the properties so that the parcel is precisely delineated and carries out a survey that links these points to the national triangulation control. These monuments are mathematically coordinated and a deed plan is prepared on the basis of these coordinated points and then authenticated by the state survey authority.

The points favouring the use of this method, are that the monuments are precisely and unambiguously defined in terms of the national coordinate system. They can be reinstated at any time to the prescribed error limits by reference to survey records. In this way, the surveyors should be able to settle disputes relatively easily - provided of course that no mistakes were made in the initial surveys. These initial surveys can be carried out when the registration is required and in a fast manner since the coordination of boundary beacons is a task with a limited and specific purpose (not involving the survey or mapping of topographic detail).

In terms of survey charges, the landowner pays the full cost of the work and not the state. Normally a professional surveyor will carry out such a work, but it will be checked and verified by the state cadastral authority, since usually the survey errors can be detected by rigorous office computations. With respect to further checking, field checks will reassure the accuracy of the survey quite apart from the office checks.

On the other hand, if the accuracy of the control network proves to be low, or if surveys are not kept to the specified acceptable standards, the reinstatement of monuments might not be easy and disputes may arise due to the mismatch between documents and the owners' accepted boundaries.

Also, the sporadic surveys employed are expensive and are more prone to errors than systematic surveys of land parcel blocks. Furthermore, the high costs of these surveys tend to inhibit land dealing.

3.1.2 Parcel Definition by Reference to Topographic Detail

In this latter method, the state survey authority produces large scale maps containing all the relevant topographic detail. These are used to produce special cadastral maps with explanatory notes entered in the case where property boundaries do not coincide with the physical detail shown on the map. Since the state pays usually for the production of the topographic maps, the contribution of the owner to the survey costs might be smaller. If this is the case, land transactions are not inhibited.

This method has the advantage that the location of physical features such as walls, fences and hedges is known to land owners while the surveyed beacons might not be known or become overgrown or are destroyed. These physical features are less likely to be moved by someone and any such movements will normally be apparent. Registration can take place systematically, as soon as the topographic maps are complete which also serve many other purposes.

The negative points of this method are that the boundaries can be replaced only to the plottable accuracy of the topographic map or plan, and also physical features are not always present to define the parcel boundaries.

Also, registration is not possible until the topographic mapping is complete, which can result in long delays. Furthermore the payment of the surveys by the state benefits the owners who only contribute to the survey costs to the same extent as any other citizen who does not own a land parcel. Also the continuous revision which will be necessary, is expensive even when it is carried out by technicians, since it will involve the revision of the topographic base map which carries much more information than the physical features that are or also serve as boundaries. If the topographic maps do not serve cadastral purposes, their revision cycles might be longer, whereas a map with only boundary information can perhaps be revised more quickly. Furthermore there is no absolute guarantee of accuracy without an extensive checking system.

Having considered these points, it should be noted that it is the actual form of parcel demarcation carried out on the ground that will determine the parcel definition method used for the register. Further determining factors can be matters such as the form of land use, the feasibility of enclosure, and the social attitudes, since there are cases (Africa), where the erection of boundaries would be considered anti-social.

3.2 Cadastral Survey System Types

There are two ways in which cadastral surveys can be carried out and classified. Based on what has already been written above, these are the essentially graphical or pictorial system and the essentially mathematical or numerical system. These are quite distinct types, although some meshing may result when, for example, a numerical system appears to be purely graphical simply because all the measurements are omitted from the corresponding plan.

3.2.1 Graphical Cadastral Systems.

What distinguishes these cadastral systems is that, with them, the land holdings recorded on the register are illustrated in a graphical or pictorial manner. The degree of precision of that depiction is directly proportional to the selected scale.

Such a system will be favoured in the cases where linear features such as walls, hedges, fences, etc which are visible on the ground, define the majority of the properties and the main role of the map in the registration system is one of acting as an index map, without intending to give any guarantee of the exact location of the boundary corners of land . If this remains the only role of the map, then there are only a few survey constraints on the overall consistency, of a survey over the whole country - keeping the appropriate standards and techniques, being the primary one.

Graphical methods and products can be easily and effectively comprehended even by less skilled users. Most of the relevant information can be obtained in a relatively quick and inexpensive way. Obviously, numerical values such as coordinates, distances and angles can always be read or measured from the map but only a limited accuracy can be expected from the graphical map.

The larger the scale employed for the maps or plans, the more expensive these will be to produce. One suggestion for these scales is given in the Table 3.1 below (Dale and McLaughlin, 1988).

TYPE OF AREA	CUSTOMARY PLOT FRONTAGE	IMPERIAL MAP SCALES	METRIC MAP SCALES
Urban	5m to 15m	1:600 (1"=50')	1:500
Urban	15m to 30m	1:1200 (1"=100')	1:1000
Suburban	30m to 60m	1:2400 (1"=200')	1:2000;1:2500
Rural	60m & greater	1:4800 (1"=400')	1:2000;1:5000
Resources		1:12 000;1:24 000	1:10 000;1:25 000

Table 3.1 Property maps - Suggested scales.

3.2.2 Numerical Cadastral Systems

The distinctive feature of these systems as opposed to the graphical systems, is that although data may also be presented in a map form, with or without the addition of dimensions, the boundary data can be recorded or presented primarily in the form of printed or digitally stored lists of coordinates, bearings and distances between boundary monuments. Maps produced by a numerical system as compared to those produced by a graphical system have an essential difference. When the boundary data are recorded in numerical form to the measurement standards specified by the system, they are quite independent of the map scale. Hence, the maps can be produced at any convenient scale and the dimensions do not need to be scaled off the graphical plan.

It is clear that the intrinsic qualities or characteristics of the numerical systems may extend to satisfy needs other than merely those of a registry index map. Apart from supporting a register of land rights, they can be utilised in such a way to give additional benefits to the land owner or to the state. Hence, they can potentially satisfy the needs of a legal cadastre in which the positions of the boundaries are the most important element rather than simply the surface area of the land holding.

Also, if the boundaries in the field are later endangered, then it will be possible for them to be reconstructed with an accuracy in accordance with that of the original survey. So, in addition to providing a land register support, these survey systems may translate more accurately the plan to the ground, and furthermore allow for the better planning of a plot layout, as well as giving a positive location and recording of the positions of services and individual plots.

It will also be apparent that, in areas such as certain rural parts of the North European plain, where there are no physical boundaries (such as walls, fences, hedges, etc) between parcels, a numerical system based on the use of monuments is a very obvious solution to the problem of boundary definition within a cadastral system.

3.3 Factors Which Affect Cadastral Survey Methods

The matter of the different parcel definition methods which have been discussed earlier affects directly the selection of the methods and techniques to be used in the survey stage. In the case of using physical features to define boundaries, no matter how imprecise the measurements, it is likely that the features will still be there; the danger of total destruction of a boundary is usually minimal. In the case of invisible boundaries, the surveyor will either:

(a) record the positions of corner marks which are shown to him as delimiting the property, in which case, if these disappear, their correct re-establishment depends on the accuracy of the survey and the control network on which this survey was based, and hence the survey is critical; or

(b) the local marks can be of a permanent nature, emplaced prior to a survey, in which case, the responsibility is shared between the survey evidence and the owner.

Hence the kind of boundary and how this is treated by the law will affect the cadastral survey method employed.

Accuracy will inevitably be another decisive factor - but also derivative with respect to the possible boundary type. However there are various other relevant aspects which have to be considered. It is frequently believed for example, by the cadastral authorities, that if the owner of valuable land can afford accurate - and so, expensive - survey, then the more valuable the land, the more expensive the survey should be. However, it should be made clear that, as far as boundary definition is concerned, much importance is focussed on the permanence or otherwise of the demarcation on the ground. In practice, more valuable land is more likely to be demarcated by solid features. So, although extraordinary, the need for survey in connection with boundary definition may be inversely proportional to the value of the land (Simpson, 1976).

Whatever the case, there will never be an absolute accuracy that can be stated. Instead there should be a meaningful and useful accuracy that the administration can guarantee to the owner.

The question of accuracy can be debated endlessly. Even in the case of the more "strict" systems, as for example the Torrens system (Simpson, 1976), where high accuracy of boundary coordinates can give a positive and hopefully unchallengable setting out survey for the settling of a dispute over a minute subdivision between adjacent owners, the question is how often such a dispute will arise. Even if this is the case, it can be only then that the accuracy requirements will seriously affect the survey.

In any case, a cadastral survey system should allow for well defined, maintained and acceptable standards of accuracy. If all the surveys are carried out by a single government organisation, then there will be in a sense a "self-control". If others, such as private contractors are involved, then more formal arrangements are necessary and a legal provision should be made, although standards should be kept by anyone who carries out a cadastral survey. This leads to another factor which affects the survey method which is the survey law. The survey law sets the survey regulations defining the standards to be achieved and hence can restrict the possible methods to be applied to one or two alternatives. Certain methods (e.g. photogrammetric) have been forbidden in some countries due to previous bad experience encountered through their use or simply due to ignorance and hence a lack of trust of these methods.

Another decisive factor is the method by which the survey data are kept. The exact nature of the survey data recorded and the method of storing it will vary with respect to the requirements of the registration system. Data which supports the maintenance of a registry index map, as for example in the case of general boundaries, will be different to whatever data is necessary for a numerical cadastre.

3.4 Cadastral Survey Methods

It is now time to classify the various cadastral survey methods that can be employed to satisfy the requirements of the cadastral systems into two categories. These are the ground survey techniques and the photogrammetric survey techniques.

3.4.1 The Ground Survey Techniques

These can be either graphical, graphical-numerical or numerical surveys, according to the criteria needed to satisfy requirements of the cadastral system.

One first approach is that involving the annotation of existing topographic maps. If properties can be identified unambiguously from the map and only an index to the register is needed, then the technique might be satisfactory. When no suitable topographic maps exist, then the graphical survey method based on the use of a plane table might be employed. This is a simple and effective method but with limited accuracy and is rather tedious and slow in terms of its execution. It could still be seen used in India or in the Nile Valley at least up to the mid 1970s (Simpson, 1976).

The next technique which could be considered, is a graphical-numerical survey by compass and tape or, as a development, by a tacheometer. The latter will suit even the cases of non-flat terrain since distances can readily be reduced to the horizontal. The angles and distances which are recorded can be converted to rectangular coordinates or the boundary points can be plotted directly with polar coordinates. This technique has been adopted in Greece for the production of the individual Land Registry parcel plans. However, since it utilises measurements only for the production of a graphical plan, there is no provision for adjustment.

The last ground survey alternative is the use of more rigorous field survey techniques, whether a theodolite and EDM, catenary taping or precise tacheometry are used. If all the coordinates obtained are expressed in the local or national coordinate system, adjustment is possible and thus, the greater accuracy that can be achieved does not restrict its use only for index map purposes.

3.4.2 The Photogrammetric Survey Method

This method is the alternative to the ground survey method. Although the various possibilities which photogrammetry offers for each cadastral system will be examined in detail in Chapter 4, it is worthwhile to make the following notes at this point.

First of all, photogrammetry can not completely replace the ground survey techniques. The need for survey control as well as the establishment of the scale relationship between the Earth and the air photographs remains. It is also undeniable that the photograph cannot record invisible boundaries any better than the field surveyor. Both the surveyor and the air photograph can only record what has been indicated or signalised to them. In the case of photography, no further clarification is possible during the survey process. In terms of economics nowadays, photogrammetric surveys are favoured for large scale (i.e. extensive) operations since flights and equipment are expensive. Once such a photogrammetric survey is complete, ground surveys may then be used additionally, something which will prove to be much cheaper.

Other advantages associated with the use of photogrammetry is that the process is not affected by the weather (apart from cloud interference during flying) and the terrain. Also, the photographs are a permanent record and can be consulted at any time. What is more however, is that with photographs, other information besides the actual boundary information can be obtained, as for example in urban areas, power or sewage lines can be identified. This can be of particular interest for inclusion in the more advanced land information systems. Part of the story is the possibility of multiple uses being made of the photography which leads to the sharing of costs between users. On the other hand, it should be noted that photogrammetry is also of benefit to systematic survey (as required for a cadastre) since all plots join up with one another at the plotting stage and possible mismatching is eliminated. Individual ground surveys will obviously measure common cadastral points more than once to allow linking of data. Such a task of creating some redundancies could mean a lack of data consistency.

However, photogrammetry cannot only be used to produce maps of physical boundaries with or without other topographic detail. Perhaps most importantly, taking account of the way in which it has evolved after its first stages, photogrammetry can produce numerical coordinate data which is of particular interest both for the signalised boundary points of a numerical cadastral system and for the mapping of the physical boundaries if these are required by the system.

3.4.3 Field Survey Versus Photogrammetry

The establishment of the Napoleon's cadastre in various European countries initially meant that simple field surveying, based either on the use of tapes and chains or on plane table mapping, was the method used. More modern procedures such as optical and later electro-optical distance measuring instruments, subsequently replaced these first methods. This approach may be the correct one even now in cities and densely populated areas. Especially in Europe, there are many regions which are extremely densely built up where the use of field survey methods is optimal for the purpose as well as satisfying long standing traditional technical systems concerning the cadastre.

However, tradition can sometimes be against progress and in developing countries, with the increased need for cadastral and large scale maps, the use of photogrammetry seems to be the only alternative. Photogrammetric methods can also offer superior, comprehensive products by making available additional thematic or attribute data, a necessity of the modern cadastre. Apart from the time savings, the provision of all of these items can be achieved with good absolute accuracy. Technical projects and planning are greatly in favour of this.

Various experiments have been carried out in many countries to assess the suitability of photogrammetry as an alternative method to carry out cadastral surveys. Some significant ones from the late fifties being in fact discussed in Chapter 4, were the Chesa experiment in Zimbabwe, the Bulacan photogrammetric project in Philippines, the Tahoe experiments in U.S.A. and many others. The common points of such early experiments were to find out whether this method can give the desired acceleration of cadastral survey, a decrease in its cost and an acceptable accuracy in the final results.

Photogrammetric and ground survey techniques should probably be seen as complementary and a combination of them is often ideal. Some boundary corners of land parcels will inevitably not be visible on aerial photographs even if signalisation is carried out on the ground. There should be a careful selection of signalised point dimensions and clearing of surrounding areas when such points are used. The use of higher flying heights with longer focal length cameras can also help to reduce the obstruction of some boundary points from other high standing objects, but even so, some points will be missed out.

The relative accuracy of photogrammetry and ground survey has been a matter of repeated discussion and investigation. It is important however to visualise the importance of what can be achieved for a given cost in the given circumstance. Some techniques will be more favourable than others for specific circumstances and very often this is not catered for by the relevant cadastral survey regulations. The legal validity of photogrammetric evidence can often complicate the matter of applying of photogrammetry as an alternative method to ground survey techniques. Again, lack of confidence and familiarity with photogrammetric techniques and measurements can make them unacceptable as evidence before a court. Further opposition to photogrammetry can be seen in countries where the licensed surveyor by custom or by law, claims responsibility for the surveys under his supervision and their quality. In Kenya for example, a licensed surveyor has to sign on each land title survey the following: "I certify that in person made... ....and completed the survey represented by this plan on which are written the bearings and lengths of the lines surveyed by me....". Hence, a photogrammetrist is not likely to be able to acquire such a licence or to make such a statement.

In the following chapter, various alternative photogrammetric techniques for cadastral surveys will be examined. Relevant examples of comparative tests with ground surveys from various countries will be given, as well as the extent to which photogrammetry has been adopted by these countries for the execution of their cadastral surveys.

CHAPTER FOUR

Chapter 4

Cadastral Surveys and Photogrammetry
Possible Techniques and Examples from Various Countries

4.1 Photogrammetry and Property

Photogrammetry and cadastre have grown up in different environments. Property surveying began in ancient times and has always been closely related to law, sociology and economics. Photogrammetry was born in a scientific family and grew to serve mankind with quantitative spatial data. During the past generation, photogrammetry has been a boon to topographic mapping, and this success allowed this science to be considered as a tool for cadastral surveys.

Perhaps the earliest use made of photogrammetry for cadastral surveys was that performed in Italy in 1931. Prior to World War II, it was also used in Germany with success for reallotment surveys. As it will be seen in this chapter, similar surveys were also performed in the Netherlands, Sweden, France and Belgium (Masters, 1960). In Austria, a quite sophisticated survey was conducted for land registration (Eldridge, 1967). Several experiments were also carried out in California and Utah in the United States in the 1950s (King, 1957, Zandt, 1959). A number of such surveys have been carried out in the 1970s in Canada, New Zealand, Australia, Sri Lanka, Malawi, Kenya, Uganda and Jamaica (Dale, 1976). By and large, however, the cadastral systems in many countries have not been adapted to allow for the efficient use of photogrammetry, since there has been a fear that the results would be inadequate or the costs too high.

Photogrammetry is the science of determining metric data from photographs. Virtually anything that can be registered on or sensed by the photographic film or plate can be measured in distance, direction and elevation. However, before photogrammetry can be used for cadastral surveys, several points must be considered:

1. The accuracy and reliability of photogrammetric measurements.
2. The adaptability of the photogrammetric method to property surveying procedures.
3. Economy.
4. The advantages of photogrammetry over conventional field survey procedures.
5. The effect and implications of using photogrammetry on the professional

responsibility of the person conducting the survey.

6. Legality.

Each of these matters is interrelated with the others and overlaps exist, but a careful examination of each will help the cadastral surveyor decide for himself to what extent photogrammetric methods should be employed when locating property lines.

In accommodating the use of photogrammetric techniques, a look should first be taken at survey regulations. According to Stirling, quoted by Dale (1976), these are a form of indicative planning and can do much to influence the survey methods of the future. At present, they tend to press on photogrammetry at its weakest point - that is its larger proportionate error over short lines - and to disregard its strength in terms of its uniform accuracy of position.

In cadastral surveying, the present standards of accuracy have not been derived from any theoretical investigation as to how much error may be tolerated in boundary positions. Usually no such investigation has taken place. The general practice in surveying has always been that tolerances have been set with respect to the average precision that can be achieved by the available equipment and not by social requirements. The primary requirement is of course to ensure that the cadastral system is free from gross errors. In some countries, a relaxation of standards is allowed in those areas where the land value is low or where survey by ground methods is difficult. But, in general, photogrammetry is treated as an exceptional technique to be used only when ground survey methods are unacceptable rather than as a possible alternative which should, at all times, be considered.

However it can be said that indeed photogrammetry can and is being used for cadastral surveying. It is a rare cadastral survey that cannot be aided by photographs both for qualitative and quantitative information (Eldrigde, 1967). It is imperative, therefore, that cadastral surveyors understand photogrammetric principles and are able to discuss the merits of this science with proper intelligence and knowledge.

4.2 Remarks Concerning the Accuracy of Photogrammetry in Cadastral Surveys

As noted above, a large number of studies have been made to assess the accuracy of a photogrammetrically-based cadastre. Many of these have made the assumption that the ground information is correct and compare the photogrammetric results as if they were the ones containing the errors, which is not necessarily the case.

Early tests had shown a number of big discrepancies between the positions of points obtained by photogrammetry and the positions of the same points from conventional ground surveys. At the same time though, it was realised that first order stereoplotting machines were entirely capable of meeting the most exacting accuracy requirements. Often such requirements for greater accuracy meant simply an increase in the photographic scale and a lower flying height. Of course, this meant that more models and more control points needed to be measured - which did impact on the economy of the method.

The results of the early tests such as the Alnwick test in Canada (Blachut, 1959) and the Chesa or St. Faiths' experiments in Southern Rhodesia (Dale, 1976), showed that there had been a steady increase in the accuracy of photogrammetric cadastral surveys and a decrease in their costs relative to that of ground survey since the early pre- World War II tests. The point had been reached where, over sufficiently large areas, photogrammetry could be regarded as one of the most serious options open to the cadastral surveyor in selecting the most appropriate technique for any particular task. Brown (1973) also demonstrated that the use of analytical aerial triangulation methods could be extended to produce accuracies competitive with those of first order ground surveying. Even at that time, horizontal accuracies equivalent to D/238,000, where D is the base length (the distance between the two stations from which the photographs were taken), have been realised. More recent tests by Brown have resulted in still higher accuracies being achieved.

Furthermore nowadays, it should be realised that the coordinates, being only one (admittedly major) evidence of the location of the boundary points, do not have to reach a higher accuracy than what is possible within reasonable economic constraints. There is also a practical rule applied in progressive cadastral systems, which tries to establish the accuracy of cadastral work as a function of the value of the land being surveyed. Thus, for example, the required accuracy of cadastral work in urban areas can be higher than the accuracy required in remote and undeveloped regions of the country by the order of a few magnitudes. In other words, the prescribed accuracy in cadastral work should not simply reflect the capability of modern technology in surveying, but rather the realistic needs of the surveys. Abstract thinking should be replaced by common sense.

4.2.1 Unrectified Photos

The first and simplest approach of photogrammetry as a method for cadastral surveys is that one of using unrectified photos. Often these will take the form of an uncontrolled mosaic made of aerial photographs which are enlarged accordingly to approximate the scale of some known distances. Since the photographs are simply enlarged and not differentially rectified, the scale is not uniform due to the tilts of the camera at the moment of exposure and the relief of the terrain. Simple analytical transformations of the digitised enlarged photograph can give corrections of scale due to tilts of the photograph. Since the influence of the terrain relief is not eliminated in any way, so this approach is best suited to applications in areas of moderate relief.

There have been occasional attempts in some African countries to use uncontrolled photo mosaics on which the physical boundaries are marked or overlaid. The main requirements for ownership in rural land being the provision of title to land, the identification of the occupied land using aerial photographs and the promotion in a timely fashion, could be satisfied by less high standards of accuracy.

A pilot project carried out in 1986 at the University of Zambia (Bujakiewicz, 1988) used enlarged photographs at a scale of 1:5,000. Results which have been obtained from this pilot project in Zambia showed that, for terrain with a moderate relief, the use of the uncontrolled mosaic can be considered for the cadastral surveys in the case of extensive rural areas. However, the results of the actual project being based on a controlled photomosaic, suggested that if a tolerable accuracy of boundary corners of e.g. ±0.5m is to be obtained, the measured mosaic coordinates should be transformed by either a projective or an affine transformation based on the use of control points. In other words, the case of rectified photographs should be considered. Furthermore, the very important stage of the identification of the boundary corners on the aerial photographs has to be done in the field very carefully. Obviously the photographs used for such cadastral surveys, apart from being up-to-date, should be taken at the time of minimum vegetation. Experience showed that, in bush areas, the beacons have to be premarked and the surrounding areas carefully cleared. In terms of time, the premarking should be done as close as possible to the time of taking the aerial photography to avoid destruction of the marks either by lapse of time or by human activities in the area.

One other example of the use of unrectified photos or photomosaics is that successfully undertaken in Thailand (Konecny and Kost, 1988). With this method, photographic enlargements were produced at an approximate scale of 1:4,000 to 1:5,000 and, if time permits, rectifications can be also produced for flat terrain, which are already exact at the final map scale. This can be done very quickly and independent of the progress in aerotriangulation. From the legal point of view, the monumentation of parcel corners in the field can start, based on these enlargements or rectifications.

Only the clearly identifiable parcel corner points have been pricked in the enlargement. Points not directly visible on the photogrammetric image are measured on the ground and recorded on a special sketch. The viewing of stereopairs using a stereoscope is used to assist the photoidentification process.

The enlargements can be used as preliminary map-related products, but not as a real map substitute due to the inevitable changes in the scale, while the product resulting from later rectifications for flat terrain can completely replace a map.

4.2.2 Rectified Photos

Rectified photographs are normally used for the construction of controlled mosaics, or as the means to produce a planimetric map by tracing methods. If such a map is produced and height differences are also known, relief rectification can be also introduced.

The pilot project carried out in Zambia mentioned in the previous section (4.2.1), also allowed the comparison of boundary coordinates obtained from controlled photomosaics with the corresponding coordinates obtained from field measurements and also from stereoplotting.

The test area had moderate relief of ±20m around the photograph and consisted of 28 land parcels. The photographic scale was 1:30,000, from which enlargements to an approximate scale of 1:5,000 were produced on the basis of two distances known from field measurement. All boundary corners were marked on the ground. The field control points and boundary points were measured by traversing and the polar method respectively. The actual rectification of the photos consisted of an affine transformation of the photo coordinate system to the field coordinate system based on the control points. The comparison of the boundary coordinates between the three sets of coordinates gave rmse values of $m_x = \pm 0.46$m, $m_y = \pm 0.41$m between field and rectified photograph data and rmse values of $m_x = \pm 0.46$m, $m_y = \pm 0.32$m between stereoplotting and rectified photograph data (Table 4.1).

Tracing methods from rectified photographs of flat terrain with the use of a tracing stereoscope have also been used successfully in the Netherlands at scales up to of 1:5,000 (Visser, 1958).

In the case of non-flat terrain, different techniques have been applied to single photographs. One method is that devised by Dr B. Dubuisson of the French Ministry of Reconstruction, which has been applied in urban cadastral mapping in France at 1:2,500 scale during the late 1940s and 1950s (Visser, 1958). With this method, a rather dense network of ground elevations must be measured on the ground, by using tacheometric levelling for example, and interpolated contours shown on the rectified photos. Tests showed that the rectification of the zone between each pair of contours for the above scale gave radial displacement errors of ±0.12mm.

No. of Boundary	Differences between Field and Mosaic Points'Coordinates		Differences between Stereoplotting & Mosaic Points' Coordinates		No. of Parcels	Differences in Areas Obtained from Stereo-Plotting & Mosaic Map	
	dx(m)	dy(m)	dx(m)	dy(m)		$dA=A_s-A_m$ (m^2)	$\frac{dA}{A}$ (in%)
1	2	3	4	5	6	7	8
1			-0.69	0.53	2	2	0.6
2	-0.29	0.67	-0.48	0.50	3	0	0.0
3			-0.46	0.51	4	4	3.5
4	0.42	0.46	0.53	0.26	5	2	2.3
5.	0.19	0.23	0.33	0.02	6	2	0.7
6	0.20	0.66	0.38	0.48	7	2	0.6
7	-0.06	0.36	-0.83	0.37	8	4	2.2
8	0.19	0.33	-0.83	0.34	9	6	2.3
9	-0.96	0.42	-0.36	0.22	11	0	0.0
10			-0.41	0.16	12	2	3.4
11			-0.28	0.37	13	0	0.0
12			-0.34	0.47	14	6	3.8
13			-0.46	0.28	15	2	4.6
14			0.43	0.13	16	2	4.2
15	-0.92	0.11	-0.39	0.00	17	4	0.7
16			0.36	0.35	18	10	2.1
17			-0.40	0.11	19	6	2.3
18			0.47	0.61	20	18	1.6
19			-0.44	0.19	21	6	1.0
20	-0.27	0.40	-0.40	-0.22	22	4	1.9
21	-0.55	0.70	-0.46	0.22	23	4	1.2

Table 4.1 Results of measurement of the boundary corners and areas of the parcels.

No. of Boundary	Differences between Field and Mosaic Points'Coordinates		Differences between Stereoplotting & Mosaic Points' Coordinates		No. of Parcels	Differences in Areas Obtained from Stereo-Plotting & Mosaic Map	
	dx (m)	dy (m)	dx (m)	dy (m)		$dA=A_s-A_m$ (m^2)	$\frac{dA}{A}$ (in %)
1	2	3	4	5	6	7	8
22	-0.27	-0.32	-0.32	-0.20	24	2	0.4
23	0.43	0.23	0.47	0.33	25	6	3.6
24	-0.50	0.24	-0.34	0.17	26	24	2.2
25			-0.39	0.23	27	4	0.3
26	-0.62	-0.52	-0.46	-0.40	28	2	0.4
27	0.32	0.42	0.32	0.42			
28			0.35	0.48			
29	-0.36	-0.56	-0.47	0.09			
30	0.50	-0.50	0.35	-0.38			
31	-0.52	-0.34	-0.64	-0.26			
32	-0.37	-0.29	-0.44	-0.20			
33			-0.08	-0.43			
34			-0.47	-0.22			
35	0.43	-0.25	0.43	-0.25			
36			-0.26	-0.40			
37			-0.36	-0.07			
38			-0.38	-0.17			
39	0.08	-0.34	0.18	-0.50			

Table 4.1(cont.) Results of measurement of the boundary corners and aerias of the parcels.

Another method which is even more specific to the subject area is that of the French Cadastral Service itself (Visser, 1958). In this case, the terrain is assumed to be divided into facets and the corresponding photos were perspectively rectified with the help of four control points with known X,Y,H coordinates. Ground elevations were obtained with aneroid barometers for the facet corner points, which are converted from a central projection to an orthogonal projection by radial shifting of the amount,

$$\frac{h_1 - h_0}{Z_R} \cdot r$$

where r is the radial distance from the nadir point, h_1 the height of a corner point, h_0 the height of the reference plane and Z_R the flying height. These facet corner points are then transferred on to the drawing sheet with the aid of the plotted control points. The original image is then introduced into a special projecting apparatus (rectifier) so that the corners of each facet coincide. Then the image detail of each facet is traced off graphically on to this compilation sheet directly from this image.

An accuracy test of this method has been carried out by comparing the lengths of lines derived from the resulting map with the corresponding distances measured in the field. The probable error of parcel width was ±0.25m which gives an rmse of ±0.38m. In the map scale (1:2,500), this is ±0.15mm which is remarkably good. However, when compared to stereoplotting, these 38cm correspond to 76µm at a 1:5,000 photo scale. Hence, this method proves to be five times less accurate than stereoplotting where the total error using fine marked points will remain less than 15µm. However for many purposes, this accuracy of just under 40cm may be thoroughly acceptable.

In India (Agarwal, 1980), methods using rectified photos are also used. The initial essential steps involved were:

a) Acquisition of aerial photography
b) Preparation of contact prints and enlargements
c) Traversing, enough to provide control for each photograph
d) Marking up on enlargements of all details required on the map by the settlement staff in the field
e) Rectification of photographs
f) Inking up of all details on a rectified print
g) Tracing of the boundary detail on to transparent material for each village sheet
h) Printing by Vandyke process (at that time)

The economy of such air surveys over standard field surveys was estimated to be about 20 to 30%. Later tests also showed that the ground control required for each photograph need not be provided by ground methods but aerial triangulation techniques could be appropriate.

The advantages of using this method in Indian conditions seemed to be many and can be summarised as follows:

1) It is a very quick, economical and reliable method to obtain dimensional data in respect of individual plots.
2) It gives the opportunity for a full check if it is necessary, to ensure justice and fair play among the cultivators.
3) It allows the use of photographs for other regional development and planning purposes.
4) Supervising officers of some experience will be able to analyse the soil related information in a scientific manner at least in the case of adjacent fields.

	Planetable method	Rectification	Photogrammetric plotting method
Provision of control	60 hrs.	40 hrs.	40 hrs.
Verification of plot boundaries	--	48 hrs.	48 hrs.
Plotting in the field	280 hrs.	--	95 hrs.
Rectification	--	4 hrs.	--
Transfer of boundaries on photos (Rectified)	--	6 hrs.	6 hrs.
Total time taken	340 hrs.	98 hrs.	189 hrs.
Saving in time	--	71%	44.5%

Table 4.2 Time comparison of three different techniques.

Tests had been carried out employing the use of the plane table method, the rectification method and the graphical stereoplotting method. Although the latter method was beyond doubt the most accurate, the rectification method gave greater savings in time of about

70% over the normal plane table method, proving it to be the speediest and the most economical of the three. The accuracy of tracing the detail was considered adequate from the point of revenue assessment, the area of the property being only one factor of judgment (soil, irrigation facilities, being the others). Also for the purposes of exact property rights, it was believed that the data for each field could to be collected by field visits which would not add much in terms of time and money. A comparison of the time needed by the different methods is given in Table 4.2.

4.2.2.1 Digital Monoplotting of Single Photographs

The availability of Digital Terrain Model (DTM) data, has made possible new approaches to the production of line maps using rectification procedures. In particular, the development of methods of plotting from single photographs using analytical photogrammetric procedures was pioneered by Makarovic, (1973 a). This method is called digital monoplotting. In this procedure, the rectification of single photographs is carried out on the data derived from direct measurements on hard copy photographs. This kind of digital monoplotting system (DMP) comprises a measuring / digitising unit, a digital computer and a plotter for the graphical output of vector line data in the form of a map.

This approach is based on the assumption that the DTM of the area to be plotted is either given or can be derived from an existing contoured map. The computations carried out by the computer can either be carried out on-line during data capture from the photos or later as an off-line operation. In any case, two basic tasks are carried out.

a) The computation of orientation parameters
b) The transformation of the measured image coordinates into ground coordinate values

A space resection will give the solution to the first task. A minimum of 3 known ground control point coordinates will be needed for the solution of this space resection (Methley, 1986). For the digital monoplotting approach, three sets of input data are required. These are the digitised data (i.e. photo coordinates) of the cadastral detail to be plotted, the orientation parameters of the photograph concerned and the DTM of the area covered by the photograph. The photo coordinates of the data to be plotted are measured by the use of a digitising tablet. Hence a DMP system comprises of three basic units; (i) a digitiser, (ii) a digital computer and (iii) a vector plotter for the hard copy output.

An approximate value for the height Z of a point will be needed and the computational process is iterative, selecting the corresponding height from DTM data. The transformation can be performed directly, or in phases (Figures 4.1, 4.2)

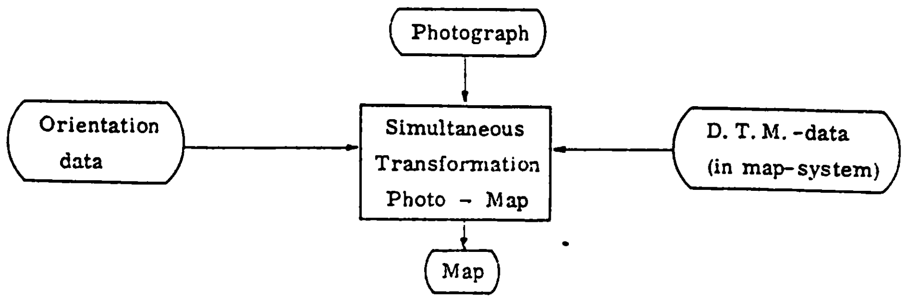


Figure 4.1 One stage photo to map transformation.

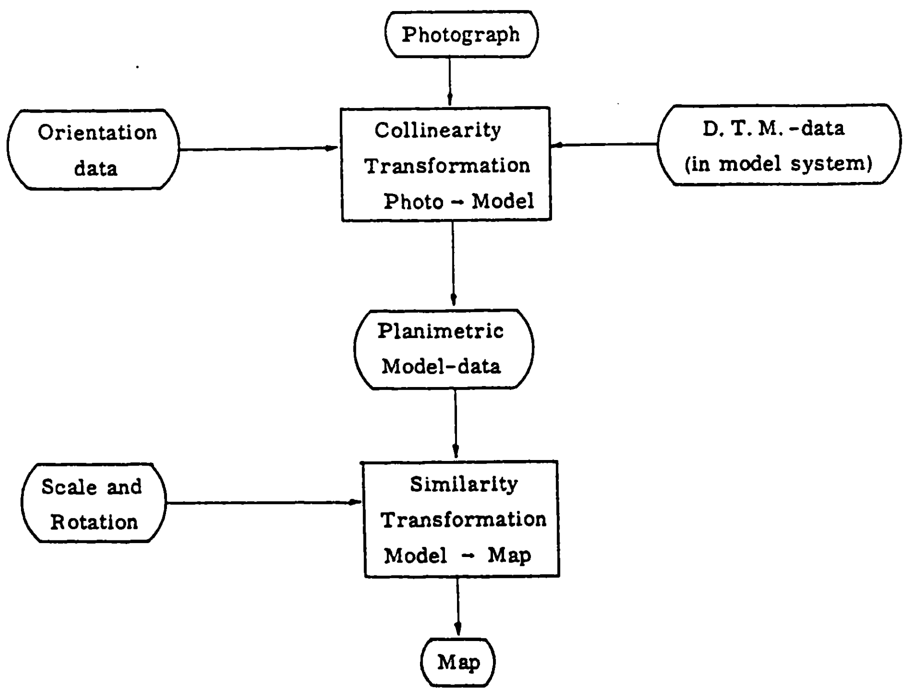


Figure 4.2 Transformation in phases.

DMP can be considered as a more sequential technique (Figure 4.3) as compared with other photogrammetric methods. This involves the acquisition of DTM and control data, identification and digitising of the feature data, computations and finally output of plotting data. Hence, for each stage, specialists with the appropriate knowledge and skills can be employed and a better overall performance can presumably be achieved. The centre of the DMP human operations, the actual measurement of data using the digitising tablet, will merely require a knowledge of and familiarity with the kind of data required to be measured.

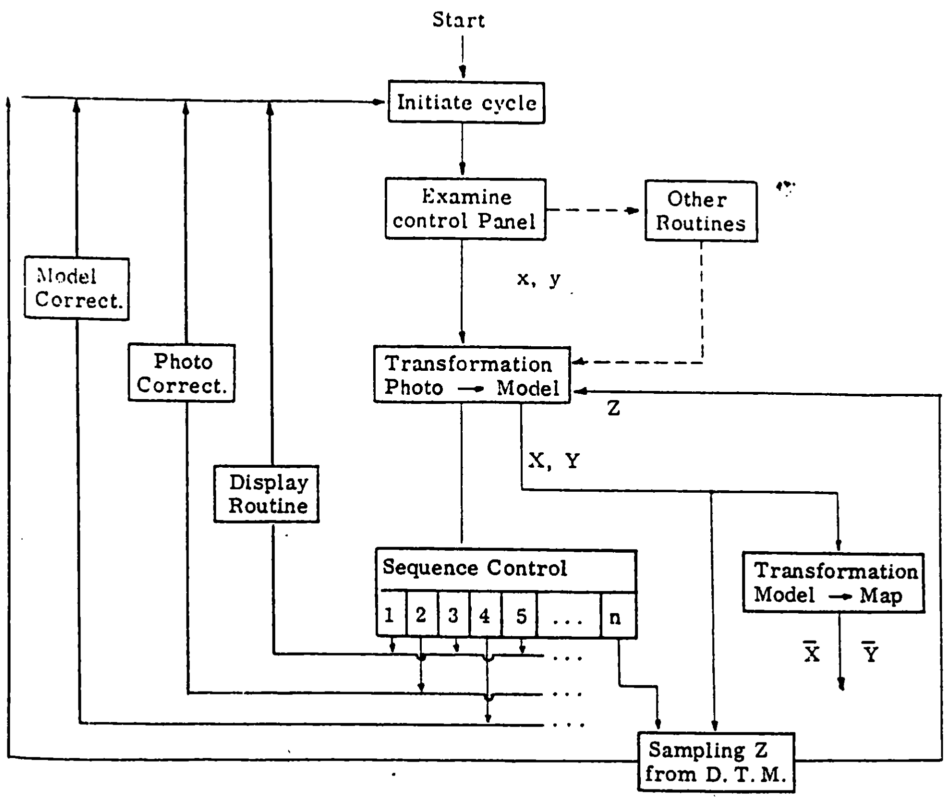


Figure 4.3 Monoplotting as a sequential technique.

Virtually no knowledge of photogrammetry is needed at that stage. On the other hand for the separate phase of the DTM acquisition, no further knowledge with respect to boundaries and cadastral data in general will be required. The fact that DTM data need to be acquired only once (assuming that the terrain relief remains unchanged), as well as the use of relatively cheaper equipment as compared with other photogrammetric methods, make the digital monoplotting method a viable alternative solution for a decentralised cadastral system, especially considering the aspect of revision. A quicker and more efficient updating of the cadastral data base will be feasible using this method.

A summary of the results of the tests (Radwan and Makarovic, 1980) concerning the use of the digital monoplotting method over the Oberschwaben and Pency areas used for the other ISPRS tests will be given here (Table 4.3).

The main purpose of these tests was to test the feasibility of the DMP method for operational use, rather than to produce extensive data for a wider statistical analysis. Hence, the extent of these tests was limited to small but diversified test areas. Particular importance was placed on the planimetric accuracy of the data obtained by DTM and especially for the stationary mode of operation. Tests like these can allow the identification

3.1 Inputs

Terrain	Area Relief H max Max slope	Oberschwaben smooth and flat 63 m 33° (for d=20 m)	Pecny undulated 120 m 45° (for d=12 m)
Photographs	Format Principal distance Scale Flying height	23 x 23 cm 153 mm 1:28 000 4300 m	23 x 23 cm 152 mm 1:6 000 900 m
Control data	Ground control	4 points (X, Y, Z)	4 points (X, Y, Z)
DTM data	DTM type Recorded on Accuracy	20 m square grid *(Figure 5a)* paper tape see *Figures 6a, 6b*	12 m square grid *(Figure 5b)* mag-tap see *Figures 7a, 7b*
Reference data	Radial zones Sample areas Type Recorded on	3 *(Figure 8)* No 1: X=400 m Y= 700 m No 2: 1000 800 No 3: 900 960 No 4: 1000 880 No 5: 1100 920 In total 116 check points: zone 1: 42 points zone 2: 74 points paper tape	3 *(Figure 9)* whole photograph 100 check points: zone 1: 20 points zone 2: 48 points zone 3: 32 points Plot of planimetric features mag-tape

3.2 Digitising

Area	Oberschwaben	Pecny
Check points: – operation: – equipment:	Stationary . Gradicon digitiser: resolution 10 μm accuracy = 0,15 μm fallibility*F = 3.2% paper tape unit . Wild STK-1 Comparator: resolution 2 μm accuracy = 3 μm fallibility F = 2.4% paper tape unit	Stationary the same Fallibility*F = 4% mag-tape unit
Planimetric features: – operation – equipment:		dynamic Gradicon digitiser mag-tape unit

Table 4.3 Monoplotting. Summary of tests.

of shortcomings, which are otherwise difficult to isolate and, based on their results, it is possible to optimise the operational procedure by the selection of the appropriate equipment. The Pency area test however, was of particular interest, since photographs of a large scale (1:6,000) have been used, as would be the case for cadastral applications. Furthermore the terrain is undulating and predominately smooth. The DTM data were also dense and accurate, so the attained accuracy of the planimetric features was determined mainly by the accuracy of measuring planimetric features by the use of the Gradicon digitiser. Reduced to the photo plane, the planimetric accuracy was m_{pl} = ±58μm and as seen from the Table 4.3, the density of DTM grid, up to the interval of 60m, only slightly influenced the accuracy. For the Oberschwaben area, a significant improvement of accuracy

Verification of raw data:	. Interpolating heights for check points from DTM . Graphic display and inspection	the same
Transformations inherent in DMP	. Digitiser to photo . Photo to model . Model to terrain	the same . Model to map (affine)
Mapping		. Preparation for drafting . Automatic drafting

*) Fallibility = probability of failing

3.4 Outputs

Check points – Digital files for:	. Heights determined by bilinear interpolation from: 20, 40, 60, 80 and 100 m square grid. . Planimetric locations determined by the DMP system	. Heights determined by bilinear interpolation from 12, 24, 36, 48 and 60 m square grid DTM . Planimetric locations determined by the DMP system
– Accuracy estimates for:	. Planimetric locations (overall and zonal): . Standard and max errors . Distributions of discrepancies	the same
Planimetric features		. Digital files (prepared and supplemented for drafting) . Planimetric plot *(Figure 10)*

Table 4.3 (Cont.) Monoplotting. Summary of tests.

was obtained using the Wild STK - 1 comparator where the average accuracy achieved was $m_{pl} = \pm 33 \mu m$. However such an instrument with its $1 \mu m$ measuring resolution and its cost amounting to at least ten times that of the tablet digitiser is hardly appropriate to the DMP approach.

The planimetric accuracy obtained from DMP is not homogeneous since the errors tend to increase with the radial distance from the nadir point. These errors also depend on the terrain roughness, which is not represented by the DTM, and on the angular field of the camera. When the terrain is smooth, and the DTM more accurate, the measurement of planimetric features by a digitiser may dominate the overall accuracy and so it will be of primary importance. DMP has been regarded mainly as a supplementary technique rather than a substitute for conventional stereoplotting, even for applications such as a graphical cadastre. The alternative to DMP has been seen the compilation of cadastral line maps from orthophotographs produced from stereo-pairs.

However, further developments have brought monoplotting methods closer to those involving hard copy orthophotographs through the rectification of digital images and the generation of digital orthophotos from single photographs. Hence, the results from digital image monoplotting and traditional production of orthophotographs by stereoplotters have come closer even though the process is quite different.

4.2.2.2 Rectification of Digital Imagery

The all-digital photogrammetric systems have been the centre of development in the field of photogrammetry in recent years. However, the need for the input into these systems of images in purely digital form causes some problems mainly with respect to the acquisition of digital images that can compare in terms of resolution, coverage and geometric stability with the equivalent hard copy images produced by aerial photographic cameras. At the present stage, the highest resolution solid state frame camera using an areal array has a resolution of only 1,000 x 1,000 pixels giving 1M pixels as compared with the 530M pixels resolution that the present highly developed aerial photogrammetric cameras can give. So the time when all-digital cameras will give the same resolution as the photogrammetric camera still seems far off.

Consequently, digital image acquisition from aircraft or spacecraft is concentrated on the use of scanners. Currently digital data is also obtained by scanning the standard hard-copy aerial photographs on a high resolution micro-densitometer. Based on these digital images, a number of methods have been developed for the rectification of digital imagery.

Image processing systems designed for digital mapping, provide routines for digital rectification utilising mathematical models ranging from simple affine transformations, through higher order polynomial and projective transformations, to differential rectification with relief displacement correction (Novak, 1992).

The transformation of a digital image by an analytical function can utilise either a direct or an indirect approach. The indirect method takes each image pixel location of the result image (orthophoto), determines its position in the original image by the selected transformation and interpolates the grey pixel values. This interpolation of grey values is known as resampling. On the other hand, the direct method considers the pixel location in the original image and transforms its coordinates into the result image, placing the grey value to the nearest integer pixel (Figure 4.4).

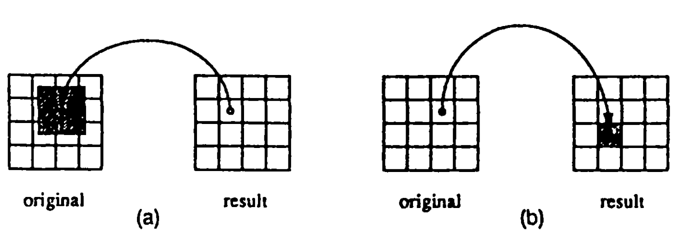


Figure 4.4 Indirect (a) and (b) direct pixel transformation.

The most popular resampling methods are the nearest neighbour, the bilinear, and the cubic convolution (Eckert, 1992). The latter methods, although giving better results, are more demanding in computational terms.

There are three commonly used rectification methods. The first approach is the polynomial rectification, which is essentially a 2-D transformation, represented by the equations

$$x = x'^{T} A x' = fx(x', y')$$
$$y = y'^{T} B y' = fy(x', y')$$

where x,y are the original image coordinates, x', y' are the rectification coordinates, and A, B are the coefficient matrices.

Although polynomials are easy to use and provide a perfect fit at the control points, they may result in large errors due to existing undulations between them.

The second approach is the projective transformation utilising the equations

$$x = \frac{a_1 x' + a_2 y' + a_3}{c_1 x' + c_2 y' + 1} = f_x(x', y')$$

$$y = \frac{b_1 x' + b_2 y' + b_3}{c_1 x' + c_2 y' + 1} = f_x(x', y')$$

where a_1, a_2, a_3, b_1, b_2, b_3, c_1, c_2 are the projective parameters.

None of these two approaches consider the geometry and orientation of the camera, nor do they consider the relief present on the ground, and hence are approximate solutions.

The best solution of the three digital rectification procedures is the differential rectification. For this process, a DTM is needed to correct for relief displacements in the image. For the differential rectification, the collinearity equations (Methley, 1986) are used initially for a space resection procedure, by which the exterior orientation parameters of the digital image are determined on the basis of at least three ground control points with known coordinates. Once the exterior orientation parameters have been determined, the ground coordinates of any point on the image can be determined again using the collinearity equations in their inverse form. However, in the case of the differential rectification of a digital image, the objective of the rectification is the assignment of grey values to each DTM pixel. To determine the grey values, the 3-dimensional coordinates (X, Y, Z) defined by a DTM pixel are transformed into the image by the collinearity equations. At the image position (x, y), the grey value is interpolated by one of the resampling methods and the density is stored at the X, Y location of the digital orthophoto. This outlines the indirect approach of a digital image transformation which has been preferred by many packages. With this approach, computational time is shortened as compared with the computational time needed for the direct approach where the input to the solution is the image coordinates. For the transformation, the following parameters have to be available.

- the interior orientation of the camera
- the exterior orientation of the camera's perspective centre, (including the XYZ values and the R rotation matrix)
- the pixel-spacing of the digital image in camera units
- the cell-size of the DTM pixels in ground units
- the reference coordinates of one DTM pixel in the required ground coordinate system.

Comparison of the rectification methods (Novak, 1992) has shown the obvious superiority of the differential rectification.

Steiner (1992) states that a number of systems for the production of digital orthophotos have appeared in the market in the recent years. These systems have been designed mainly to run on hardware platforms such as mainframes, mini computers or graphics workstations, but there are even systems developed to run on PCs.

A prototype PC - based program written in Microsoft C has been described by Steiner (1992) and the results of a test concerning its performance will be summarised here. The flow diagram of the program operation is shown in Figure 4.5.

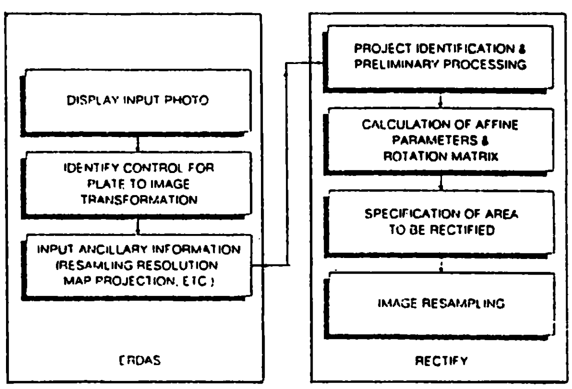


Figure 4.5 Orthorectification processing flow.

The test utilised digital image from the Rye area, New York, on the basis of evaluating the positional accuracies obtained by the program and to provide a comparison between the geometric quality of the two programmed solutions of the orthorectified and polynomial rectified photos. The test area for which photography at 1:7,200 scale was available, had been mapped earlier (1989). A standard diapositive was digitised on an Eikonix scanner at its maximum resolution of 55μm. This resolution relates to an effective ground resolution cell size of 38 cm. To aid identification, photo control points on the diapositive were pugged with oversize (60μm) pug holes. Elevation data were collected on a DSR-11 analytical plotter producing an irregular triangulation network for the model areas concerned. A comparison vector map file of the test area which had been compiled during the original mapping project in 1989 was also provided. These data files were loaded onto a Dell System 310 microcomputer equipped with an 80387 math co-processor. Resampling was at a ground resolution cell size of 30x30 cm using bilinear interpolation. With respect to the accuracy testing, the positional accuracy in the test images was evaluated using both the photo control point coordinates obtained from aerotriangulation and a more extensive set of photo identifiable feature points, such as road / driveway intersections or building corners.

RMSE	Rye1		Rye2		Rectrye	
	(m)	(ft)	(m)	(ft)	(m)	(ft)
x	0.76	2.5	0.70	2.3	3.87	12.7
y	0.82	2.7	0.46	1.5	8.67	28.4
xy	1.10	3.6	0.85	2.8	9.48	31.1

Table 4.4 Accuracy test results.

The map coordinates from the existing vector file and the aerotriangulation output were compared with those obtained from the image and the resulting residuals as well as rmse values were computed. The results are shown in Table 4.4.

The positional errors remaining after differential rectification were such that the method can be considered for cadastral mapping applications to lower, graphical accuracy standards. The errors after differential rectification showed a random distribution all over the rectified image in both direction and magnitude and made the assumption that scanned images at higher resolution would have improved the results. The assumption is based on the fact that for an image of higher resolution, the smaller pixel size represents a higher ground resolution at whatever the scale of the image is. It should be noted however, that the processing of the 16 million pixels of the 23x23 cm photographs scanned at the resolution used in the above investigation already requires long processing times. Efforts should be made for the optimisation of the rectification algorithms while hardware improvements such as extended memory for buffering and add-on array processors can improve the processing speeds. However, the use of specialised hardware should be considered carefully since it may restrict the applicability of such a system.

Once the orthophoto has been produced and displayed on the graphics screen of the computer, extraction of cadastral information can begin by manual on-screen measurement of vector features by the use of a mouse as a positioning device. This manual extraction of information from a single image is a straight forward task and resembles the manual measurement of map features on a tablet digitiser.

With respect to the production of a hardcopy output of a digital orthophotography that can go to the user, writing systems giving a raster output can be used in the same way as remotely sensed imagery is obtained as a hard copy. The possibility of digital orthophoto mosaicking is an other important aspect to be considered if such a rectification system is intended for production applications and integration in to a digital cadastral database system.

Steiner's prototype discussed above, did not yet allow such an option. Eckert (1992) explains that the grey value differences along the digital orthophoto boundaries create a problem that can be solved by relative radiometric rectification. The efficiency of this method was demonstrated by the joining of two orthophotos obtained from two aerial photos at 1:6,000 scale. However so much experience has been gained from the digital image processing of satellite imagery (Albertz and Kahler, 1987) that the whole matter of geometric mosaicing can be regarded as having been solved.

Trying to answer the question as to whether this type of rectification can be applied to cadastre, the answer would be probably be no for a legal cadastre in many countries. However the experience from past applications in a mainly tax-based cadastre such as that in France and the necessity for a systematic approach especially in the cases where the land area to be surveyed is very large, as with the African countries and India, may cause this attitude to be revised. The same may be true when there has not been such a systematic attempt for land registration in the past, as in the case of Greece.

In these situations, the urgent need for the creation of a Land Data System imposes the need for the simplification of cadastral surveys. The factors for selecting the most appropriate method should be the topography, the size and location of the terrain to be surveyed or mapped, the distribution and size of the parcels, the existing land use and its value, the availability of existing survey data and, of course, the cost and viability of the survey. Hence, any approach should allow for flexibility and, in this context, this is where this type of digital rectification should be considered.

4.2.3 Orthophotographs from Stereo-Pairs.

It was in 1955 when orthophotography based on the use of stereo-pairs of aerial photography was introduced as a new photogrammetric technique (Petrie, 1977). An orthophoto combines the advantages of a line map with those of photomosaics, since it is characterised by the geometric fidelity of the traditional map and the completeness of the aerial photo image. With this technique, both the tilt and relief displacements are removed using stereopairs of photos and the result is a constant scale all over the final image. Hence the geometrically distorted aerial photographs are rectified into new, precise images with a map-like geometry.

Considering these numerous advantages, this purely graphical photogrammetric product may prove to be very favourable for a graphical cadastre. It is obvious too that digital coordinate information can be derived from this product if required. In terms of time, usually 4 to 5 instrument hours are required per stereomodel for the production of a 1:5,000 scale orthophoto, as compared to some 20 to 40 hours (depending on the type of terrain being mapped) for graphical vector line plotting at the same scale. In terms of investment costs however, a stereo-plotter with an orthophoto attachment might cost 1.4 times the cost of a precision stereo-plotter. Considering the fidelity and completeness of the final information, the orthophoto has almost the same characteristics as those of the deriving photo. But of course, comparing this with the line map, the whole matter of interpreting the orthophotograph is thrown on to the user, whereas with stereoplotting the photogrammetrist and cartographer between them have already carried out much of the identification, selection and classification of individual features and added names, etc, so that these tasks have already been carried out prior to the publication of the line map.

From many past tests, the accuracy obtainable with orthophoto maps, is generally cited as a "graphical" accuracy (rmse) of $m_{pl} = \pm 0.3$mm on the map, thus about ±1.5 metre on the ground for a 1:5,000 scale orthophoto map or ±0.75m at 1:2,500 scale.

However, as noted above, photo maps have certain disadvantages, some others of which can be mentioned as follows. Since objects appear in the form of their photographic image, many irrelevant images will also appear. More importantly, high standing objects, such as the buildings of urban areas become radially displaced and also create "dead" areas. So if urban coverage is planned, the use of a narrow angle camera is strongly recommended. Even then, high rise buildings will create problems in terms of such a rectification of their upper parts and the inevitable residual dead areas.

Regarding the application of the orthophoto technique in various countries, it can be seen that in France, for example, some 5,000 orthophoto map sheets (one sheet per stereomodel) of French cities have been produced per annum (Visser, 1976). The principal orthophoto scale is 1:2,000 while that of the original photos is 1:8,000. A narrow angle camera is utilised. Output is reported to be 10 to 15 times faster than line maps and came from 45 private photogrammetric companies. In Germany, 1:5,000 scale orthophotos are produced and applied to re-allotment, but also to other non-cadastral applications such as regional planning, road administration, forest administration etc. Copies are provided with minimum of annotation - typically contours, road classification and names - (Visser, 1976).

The author mentioned above also states that orthophoto maps produced in Australia at scales 1:2,000 and 1:4,000, have shown that the restrictions of orthophotos in urban areas can be overcome to a great extent. The mapping of Sydney gave satisfactory results for buildings up to 4 floors with wide angle (f=152mm) camera, at 1:2,000 scale.

In Belgium (Visser, 1976), photomaps at 1:2,000 are used for a multi-purpose ecological cadastre. The belief there is that, as agrarian re-development proceeds, it results in a transformation of the rural areas. In turn, this requires a regular up-dating and short map revision cycles. Photo maps are regarded as the answer to these needs. Indeed the whole of Belgium has now been covered by a series of so-called orthophotoplans at 1:10,000 scale.

In the case of these Belgian maps, there are two groups of annotations made on the photo maps or on special overlays. These are the permanent and the changeable elements.

a) permanent elements

- height information, in the form of contours and spot heights
- the network of reference points
- the names
- the classification of land
- the map grid

b) changeable elements

- the structure of the cadastral parcels
- the pattern of land use
- the rural areas classified into agricultural zones with an economic function and others with a social function

- forest areas, forest inventory data
- road classification

In the United States, (Visser, 1976) the 1:4,800 scale orthophotos produced for the entire land area of San Mateo County under a multi-purpose mapping programme, showed that the many conflicting user demands can be met with multiple overlay techniques for different types of information (boundaries, drainage etc), which are extracted from these orthophotos. Comparison of property boundaries from the orthophotos with existing records for land tax surveys derived from field surveys, revealed innumerable errors in the latter. Photomaps at 1:2,400 scale have been also produced for the same application in the Jackson County.

The suitability of the orthophotographs to serve the agrarian cadastre had been also a matter of investigation in Brazil (Costa, 1984). In this country, an area of about 1,800,000 square kms is facing the problem of re- distribution and regularisation of properties. The objective of the test project was to establish a comparison among three different methods for the registration of rural properties, that is by graphical stereoplotting, orthophotomaps and ground surveys.

With respect to the orthophotography, the following technical data are given, which are the same however for the graphical stereoplotting method.

Photo scale: 1:25,000

Camera: Wild RC 10, focal length 152mm

Longitudinal overlap: 60% - lateral 30%

Semi - analytical aerotriangulation

Map scale: 1:5,000

Once an orthophoto was produced, the operator had to visit the field to execute the identification of the limits of the properties, giving distinct detail as to their limits and pricking the places where the boundary marks should be positioned. This image with the points and lines indicated in the field was used for the direct digitising of the property boundaries over the orthophotomap.

The time needed in workdays for all the steps involved using the three different processes can be seen in the Table 4.5. These figures relate to a total rural area of 50,000 hectares corresponding to 4,200 properties. As can be seen from the table, a gain in production of 53% is obtained if orthophotography is used.

- PRODUCTIVITY — MAN/HOUR

ACTIVITY	RESTITUTION	ORTHOPHOTOMAP	TOPOGRAPHY
Planning	402 ha	402 ha	402 ha
Photogrammetric Flight	138 ha	138 ha	-
Ground Control	21 ha	21 ha	21 ha
Identification of Properties	12 ha	15 ha	5 ha
Boundary Monumentation	8 ha	8 ha	5 ha
Restitution	23 ha	63 ha	-
Digitizing	42 ha	747 ha	-
Survey of unidentified points	8 ha	16 ha	5 ha
Individual Maps	37 ha	37 ha	37 ha
Calculations and Memorials	19 ha	19 ha	19 ha
General Map	22 ha	38 ha	5 ha

- WORKDAYS NECESSARY FOR EACH ACTIVITY

ACTIVITY	RESTITUTION	ORTHOPHOTOMAP	TOPOGRAPHY
Planning	16	16	16
Photogrammetric Flight	45	45	-
Ground Control	298	298	298
Identification of Properties	521	417	1250
Boundary Monumentation	781	781	1250
Restitution	272	99	-
Digitizing	149	8	-
Survey of Unidentified points	781	391	1250
Individual Maps	169	169	169
Calculations and Memorials	329	329	329
General Map	284	164	1250
TOTAL	3645	2717	5812

Table 4.5 Productivity and execution time estimations.

Comparisons of the point coordinates obtained by the three methods with a higher accuracy ground survey for a sample of properties showed an average difference in the coordinates values of the same points of +2.5% for the orthophotomap, being slightly superior even to the differences of +2.7% for stereoplotting.

In this Brazilian investigation, it was considered that the method used for the registration of rural land is related to a number of variables such as:

-Dimension of the area

-Availability of financial and technical resources

-Extent of the land

-High index of rural population

-Urgency in the solution of agrarian problems

-Scarcity of financial resources

Having these variables in mind and the results obtained for the three different methods studied, it was concluded that the use of orthophotomaps was the one to be recommended.

The single, rectified photograph can inevitably offer various interesting possibilities, but it does have certain restrictions. First of all, the readability and definition of features on one photograph is not as good as with the stereopair and also a single photograph does not provide information on the heights of the terrain features.

Another well proven example of the use of orthophotos in cadastral surveys is one carried out in Canada (McEntyre, 1984). Property maps in rural areas have been produced on an orthophoto base at 1:10,000 scale with boundaries, rights of way, drainage patterns, property identifiers and cadastral monuments mapped directly on the orthophoto positive using an ink drawing process. These orthophoto maps have proven to be successful for portraying and discussing property boundaries with individual landowners. Another interesting application of orthophotography in cadastral surveys has been carried out in Finland (Jaakkola, 1984). Investigations carried out in the 1970s indicated the importance of the boundary evidence recorded on maps. These investigations resulted in a proposal to start development work on a new map type at a scale of 1:5,000. This map type includes two elements, the orthophoto base map and the boundary element. The boundary element is presented in two ways, first as a numerical boundary element, which is the primary output of the process, and secondly as a graphical map. The base mapping at 1:5,000 scale is oriented towards a computer-based coordinate cadastre - in other words, numerical accuracies are to be obtained. This is evident from the fact that boundary coordinate data will be obtained by photogrammetric measurements of the signalised boundary marks. Despite this numerical approach, the continuing use of orthophotos as a base map is interesting, revealing the intention to make multiple use of this map. The other activities that the map will serve in rural areas will be planning, fiscal purposes, forestry, agriculture, etc. For each specific purpose, the user of the map has to prepare his own additional element and carry the relevant cost. According to the experience obtained in Finland, the method mentioned here seems to be accurate and reliable enough for multi-purpose mapping and also represents the only reasonable solution from the economic part of view.

A flow diagram of the production process is given in Figure 4.6 and the expected coverage by the year 2000 in Figure 4.7.

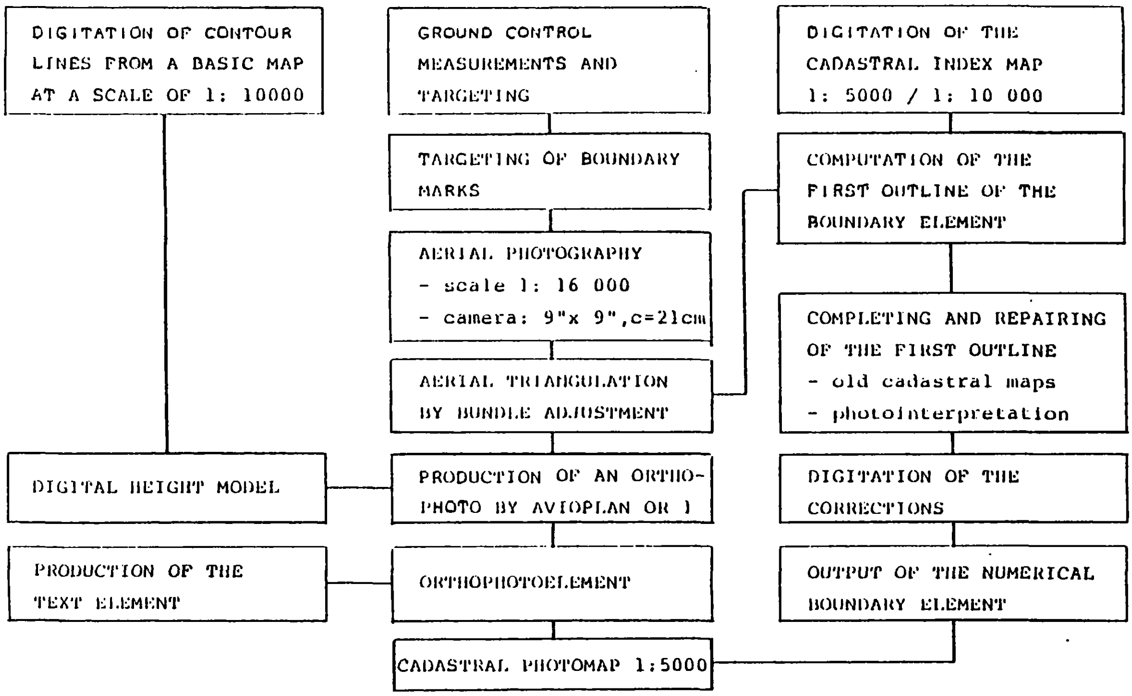


Figure 4.6 Cadastral photomap production flow diagram.

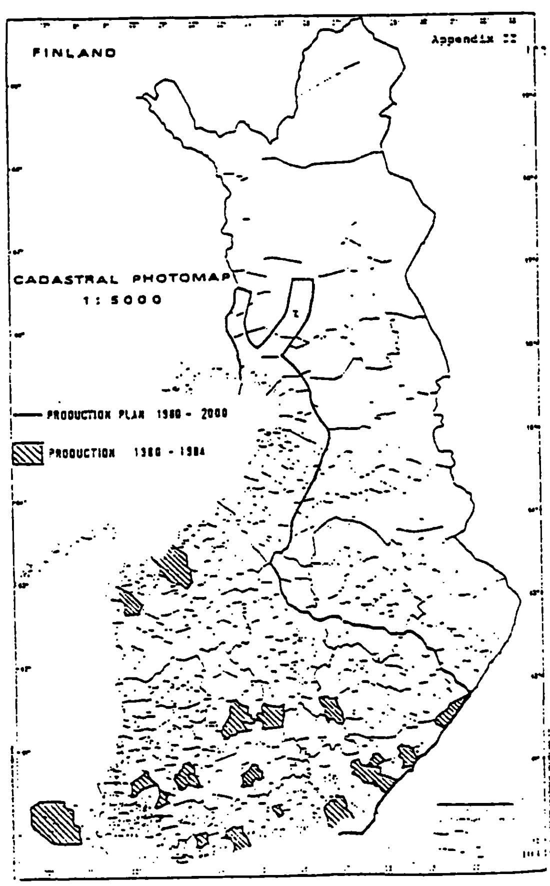


Figure 4.7 Photomap expected coverage.

4.2.3.1 An account of the Methods for the Production of Orthophotographs

Production of orthophotos is possible from both analogue and analytical stereoplotters (Kennie & Petrie, 1990). However an important distinction as to how an orthophoto is produced, is whether the orthophoto is produced on-line during the scanning of the stereomodel, or it is produced off-line at a later stage assuming that the DTM data for the corresponding orthophoto already exists in digital form.

The off-line operation is considered to be superior in a mass production, since previously available DTM data (e.g. from existing maps) can be used, personnel and equipment can be optimally employed and operations can be modularly arranged. Furthermore, errors in the data made during the data capture can be eliminated, while a slope correction facility is only available in most off-line equipment (Jerie, 1977). All the above advantages result in a higher flexibility and production rate, and a better performance than in the case of on-line operation.

Subject of comparison: Production cost for a standard model of orthophotography in the following modes.

a) On-line mode (no lateral slope correction)
b) Off line mode: Profiling manually on an analogue plotter, orthophotoprinting off-line (lateral slope correction)
c) Off-line mode: Profiling automatically on an analogue plotter, orthophotoprinting off line (lateral slope correction)
d) Off-line mode: Profiling manually on an analytical plotter, orthophotoprinting off-line (lateral slope correction)
e) Off-line mode: Profiling automatically on an analytical plotter (fictitiously), orthophotoprinting off line (lateral slope correction)

Two types of terrain: A) relatively easy terrain
B) difficult, mountainous terrain (figures in square brackets)

Assuming identical accuracy requirements for all cases, the following assumptions have been made

- The scan width is twice as large for off-line mode (with lateral slope correction) than for on line mode
- The scan speed is five times faster for automatic profiling (correlator) than for manual profiling

The equipment cost/year = 20% of the purchase cost; equipment cost/hour = 1/2000 of equipment cost/year

Terrain type	Scanning speed (mm/sec in photography			Scan width (mm in photography)	
	manually	automatically	in off-line printer	on line	off line
A	2 mm/sec	10 mm/sec	10 mm/sec	1 mm	2 mm
B	1 mm/sec	5 mm/sec	10 mm/sec	0.5 mm	1 mm

	a) On-line	b) Anal plotter man prof	c) Anal. plotter autom. prof	d) Anal plotter man prof	e) Anal plotter autom prof	Off line ortho pr
Equipment cost/hour $	9	9	16	12	18	12
Operator cost/hour $	10	10	10	10	10	10
Σ	19	19	26	22	28	22
Rel.& abs orient in min.	60	60	60	20	20	
Setting up orthoph unit in min	20					
Profiling/Scanning in min.	140[560]	70[280]	14[56]	70[280]	14[56]	14[28]
Σ	220[640]	130[340]	74[116]	90[300]	34[76]	24[38]
Cost $	70[203]	41[108]	32[50]	33[110]	16[35]	
$		+ 9[14]	+ 9[14]	+ 9[14]	+ 9[14]	+ 9[14]
Total Cost $	70[203]	50[122]	41[64]	42[124]	25[49]	9[14]

Figure 4.8 Orthophotography. A fictitious cost example.

A fictitious cost example given in Figure 4.8, shows various approaches for the production of orthophotos utilising analogue and analytical plotters at different modes of operation. The use of the off-line mode, apart from preserving accuracy to a greater extent, involves considerably less cost.

The option for the off-line mode of operation has led to the development of the analytically controlled orthophotoprinters (Kennie & Petrie, 1990).

As can be seen, orthophotos have a very good potential as a cadastral survey technique. The accuracy of the coordinates of boundary points derived from orthophotos might not be sufficient for locating or staking out the boundaries on the ground, but the graphical accuracy of coordinates should be sufficient in many cases for the purposes of the plans accompanying title deeds, the computation of property taxes and for most administrative and technical operations, particularly in the planning sector. The capability for fast coverage over large areas and of the recording of other information like land use are the greatest advantages.

4.2.3.2 Stereo Orthophotographs

The use of stereo-orthophotographs, or stereopairs of orthophotos (Blachut, 1985), removes the disadvantages mentioned above. From each stereomodel, one normal orthophoto and one pseudo-orthophoto, the stereomate, are produced. These can be observed with a stereoscope to obtain a metrically correct and levelled model.

The examples from the various countries which were discussed previously, show that for any multi-purpose photo mapping, height information in the form of overprints or overlays will be needed.

The feasibility of orthophotography and stereo-orthophotography as a more efficient and less time consuming method compared to the production of conventional graphic cadastral maps, has been a matter of investigation in Colombia (Gonzalez, 1980, Jaksic & Van Wijk, 1983, Van Wijk, 1984). A pilot project "Cadastre Latin America" was conducted jointly by the Instituto Geographico "Agustin Codazzi" (ICAG) of Colombia and the National Research Council of Canada (NRCC), and was supported financially by the Colombian and Canadian Governments. The study area was approximately 2,000km^2 containing about 20,000 parcels and has a variety of topography, climate, vegetation, land use and sizes of land parcels. Aerial photographs taken with 90% forward overlap were used in order to adequately select the position of the orthophotographs to fit the map sheets. The project consisted of four blocks with the photographic scales ranging from

1:50,000 to 1:6,000 and the corresponding map scales ranging from 1:25,000 to 1:2,000.

Control points for the production of the stereo-orthophotos were obtained by aerial triangulation on a Helava US-2 analytical plotter. The stereo-orthophotos and DTMs were produced by automatic image correlation on the Gestalt Photomapper. The orthophotos which were obtained could then be enlarged to the required map scale (2 to 5 times magnification) and combined into orthophoto mosaics according to the cadastral map sheet system. Such a task allows for a convenient use of orthophotos in the cadastral regional offices and offers the possibility of a systematic sheet by sheet revision process. The enlarged orthophotos are used for the identification of the cadastral information in the field. Parcel and field boundaries are marked on the orthophotos to support the later digitising. The associated attribute information on the parcel address, ownership, value, etc was also recorded on special forms. Additional information on cultivation types, buildings, road classifications, etc was indicated.

The actual compilation of the cadastral data was performed after the completion of surveys by measurements on the stereo-orthophoto transparencies done on four NRC Stereocompilers (Van Wijk, 1982). The stereo-orthophotos were enlarged by a factor 2.5x. Using the Stereocompiler, a plot manuscript was produced on a transparent overlay placed over the orthophoto during the digitising process. The use of this overlay reduces the chance of errors due to double digitising and omissions. Measurements were carried "on-line" to a PDP 11/44 mini computer which also served as the data bank computer. Hence, model coordinates were transformed into the ground coordinate system, based on a linear conformal transformation. During this on-line operation, feature coding was performed which also allowed discrimination of the lines common to various features and avoided duplicate measurements.

The stereocompilers are capable of numerical, i.e. digital recording of the coordinates of measured detail which agrees with the latest trend in photogrammetry and mapping towards numerical recording and subsequent automatic plotting. An outline of the operational scheme of this integrated mapping system, including cadastre, utilising stereo-orthophoto techniques can be seen in Figure 4.9.

An accuracy analysis of the Colombian stereo-orthophotos was based on approximately 75 points, on each pair, which were artificially marked on one of the stereo-orthophoto transparencies. The ground coordinates of these points were determined from stereo-comparator measurements and the available ground control points.

The accuracy of various technical operations at IGAC, including the accuracies obtained

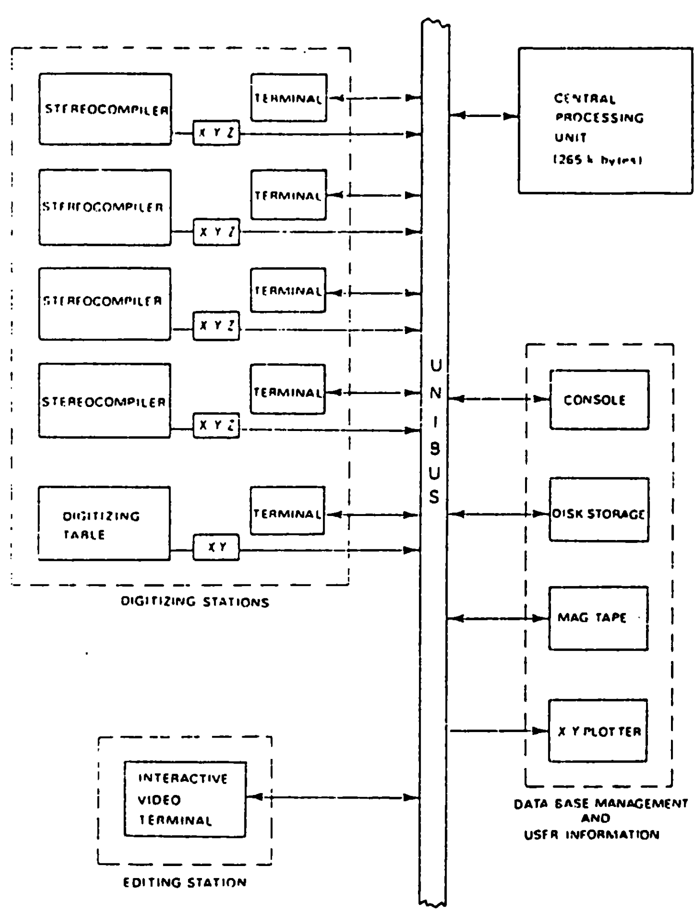


Figure 4.9 Operational scheme of data acquisition from orthophotos and stereo-orthophotos.

from the orthophoto enlargements and the stereo compilers, was also tested on the Sudbury stereomodel in Canada. In order to produce the necessary comparative data, the contact size stereo- orthophotos were measured on a Zeiss PSK Stereocomparator while the 2.5x enlarged stereo-orthophoto transparencies were measured on the NRC Stereocompiler which is of a similar design to the Stereocompiler used at IGAC. In each model, half of the number of 92 targeted ground control points were used to compute the orientation parameters necessary for the transformation of the image coordinates to ground coordinate values. The remaining half served as check points. For both groups of data, the calculated rms errors were m_p= ±66μm and m_z= ±52μm for the planimetry and height respectively, expressed at the 1:16,000 scale of the original images.

The test based on the stereomodels within the Colombian terrain showed a slight deterioration of results due to the vegetation and the higher elevation differences typical of the Colombian terrain. The rms errors obtained for all the test models can be seen on Figure 4.10.

The results are indicative of the accuracy that the stereo-orthophoto technique can give,

test model	relative elevation difference	p_x/h	image scale	rms error at image scale		number of points
				m_p	m_z	
Sudbury	2.3%H	0.6455 (= base/height)	1:16 000	68 μm	49 μm	95
-	2.3%H	0.4317	1:16 000	72 μm	57 μm	108
-	2.3%H	0.2891	1:16 000	85 μm	64 μm	96
Colombian	8.4%H	0.6254 (= base/height)	1:20 000	81 μm	76 μm	56
-	8.4%H	0.2811	1:20 000	98 μm	112 μm	60
-	2.2%H	0.5995 (= base/height)	1:53 000	44 μm	44 μm	72
-	2.2%H	0.2957	1:53 000	45 μm	83 μm	65

Figure 4.10 Test area accuracy results.

but not for the effect of error sources such as the identification and measurement of physical boundaries. A separate model formed from original photos at the scale 1:20,000 had been tested for the effect of these latter error sources and standard errors of ±100μm in position and ±57μm in elevation had been obtained. The errors exceeded the error values obtained from the previous models and indicate that the measurement of non-targeted boundaries is indeed a limiting factor in the acquisition of digital cadastral data. The tests indicated that the advantages of improved image quality by the use of smaller base-to-height ratios in the generation of stereo- orthophotos must be carefully weighed egainst the subsequent drop in vertical accuracy, which may have a significant effect on the final overall accuracy.

However, in the opinion of Visser (1977), considering the larger investment for their production, the use of stereo-orthophoto pairs may not be really necessary for the field identification of cadastral boundaries formed by physical topographic objects. Simple enlargements of the neighbouring photographs, allowing stereo-observations in conjunction with the orthophoto would suffice for such identification. Nevertheless, quite apart from the photo-interpretation advantage, potentially stereo-orthophoto pairs would seem to offer a very attractive solution for cities and built-up areas, because in a simple orthophoto solution, points above the terrain height, such as roof tops, are radially displaced and hence depicted incorrectly.

4.2.4 Graphical Stereoplotting

When compared to the other graphical photogrammetric techniques and especially these of unrectified or rectified photos, it can be seen that graphical stereoplotting has been far more popular due to the much higher accuracy that the method can provide, something which was always considered to be closely related to cadastral needs.

However, despite the fact that stereoplotting can give high accuracy output, the fact that graphical plotting is involved will always restrict the finally obtained accuracy and if the plotting accuracy is $s = \pm0.15mm$ at the map scale, then for a map scale of 1:1,000, there will be an error of ±15cm on the ground arising solely from the plotting.

Highest precision first-order analogue stereoplotting instruments give grid point coordinate errors of $m_x=m_y= \pm5$ to $\pm7\mu m$ in the negative plane and, in the case of the most precise modern analytical plotters (Kennie & Petrie, 1990), these errors can be even less than ±3μm. When using actual photos instead of grid plates, the accuracy on well signalised points falls off slightly to circa ±10 to ±12μm. This is ten times better than graphical plotting but of course only applies to well marked (signalised) points.

However the overall accuracy for cadastral work has been a subject of many investigations over the years. Having a look at the examples of various countries (Visser, 1958; Dale, 1976) which have followed this technique, it can be seen that the case of Italy was one of the first to implement a stereo-plotting procedure. The nature of the Italian cadastre, being graphical, was a decisive factor in this. Starting in 1933, this systematic process finished in 1952 after having covered 750,000ha.

Since its full operation in the early 1950s, the Italian cadastre has been a matter of updating the existing and of investigating modern methodology. From 1973 onwards, the General Administration of the Italian Cadastre began a programme aiming to implement the operation of a Digital Cadastre (Dequal, 1976).

Four sources of information can be identified. These are existing maps, the ground survey data, the photogrammetric surveys and the archives of the administrative data. For each source of information, there is a corresponding instrument and a way of data collection. Existing graphical maps are converted to digital form by a digitiser, while ground survey and administrative data can be converted into digital form through keyboard entry to the computer. Surveys utilising photogrammetric stereoplotting can give digital output via the installation of digitising encoders on the existing analogue stereoplotters. This is certainly the current approach with high accuracy stereoplotters. As will be seen later on, it has evolved and been adopted in various countries, e.g. Sweden, for the completion and updating of their cadastral data, quite apart from the case of Italy.

In Italy, the cadastral maps are produced with contour lines thus extending the photogrammetric plotting work. Their execution was carried out mainly by the private sector at the scales 1:1,000, 1:2,000 and 1:4,000, while an accurate and extensive marking of boundary corners was required to obtain sufficient interpretability and to improve accuracy.

The planimetry was tested by comparison of the lines between the intersections of details with their known values measured on the ground. Tolerances formulae for distance differences (within the map-field) are given as functions of both distance and scale. For a 50m line and the scale 1:1,000, the tolerance in rmse will be ±0.60m, and a map will only be accepted if less than 10% of the tested distances exceed these tolerances. As compared with other tolerances such as these adopted in Switzerland and the Netherlands, the Italian tolerances are considerably wider and do not reflect the possibilities of high-precision stereoplotters. However, since there are also no indications for coordinate tolerances, they reflect the needs of the Italian graphical cadastral system.

In Switzerland, photogrammetry was also applied for cadastre, although more gradually. The Civil Law (1912) introduced three survey classes and certain experimental photogrammetric surveys started in 1926. Most of them however were made on reallotment surveys which started before World War II.

Area I : Towns with ground of very high value. Highest precision of the survey. Tolerance 3 cm on a distance of 100 m. Covering of the area with traverses. Rectangular method. Analytical treatment of representation of boundaries and computation of all area surfaces. Total ± 1 °/o of the whole country.

Area II : Villages, industrial and agricultural areas with normal value of the land. Tolerance 6 cm on 100 m. Survey by means of tacheometry (Bosshardt Zeiss Redta) Polar coordinates. Graphical treatment of boundaries and area surfaces on non shrinkable material. About 33 °/o of the country.

Area III. : Alps, meadows, forest. Small villages in the high mountains. Arable land with low value. Tolerance 20 cm. on 100 m. Survey by photogrammetry or polar coordinates. Completely graphical treatment on non shrinkable material. Scale will be smaller i.e. up to 1:5000. This covers 66°/o of the country.

Figure 4.11 Swiss cadastral survey area classification.

With the three classes being introduced (Figure 4.11), the value of the land and the cost of the cadastral surveys and registration were to be balanced. Survey costs should be between 0.9 and 1.5% of the land value.

A review of the Swiss cadastral photogrammetric work by Harry in 1953, as stated in Visser (1958), gave the influence of the various sources of errors as seen below (Table 4.6).

Exp. Malvaglia

Source of errors	mean sq. error cm	μ in neg.	m.sq.e. in neg. desirable
1) determination of passpoints.	5.3	8	5
2) due to errors in camera, atmosphere etc.	5.2	8	3
3) restitution in the autograph	11.3	17	6
4) transfer of mach. to drawing table.	9.2	14	
5) total in mach. coord.	13.5	21	9
6) " " drawing table	16.3	25	

Table 4.6 Sources of errors. Swiss experiment results.

Dr. Harry also made the remark that for certain classes, survey costs can considerably decrease by using a smaller scale of photography. This is an advantage of using high precision instruments for this type of work.

With respect to the precision obtained, it was somewhat lower than the Austrian and Dutch results and poorer instrument maintenance could be the answer for that. Bosshart's tests as early as in the thirties using a Zeiss Stereoautograph, showed that aerial survey was sufficient and satisfactory for Class III.

The Netherlands also has a graphical cadastre and, even from as long ago as 1933-34, tests showed that photogrammetry could support it (Visser, 1958). Instructions from 1954 give a standard error of d = ±0.14mm in the map due to drawing. One of the main reasons for adopting photogrammetry was the difficulty experienced in utilising ground survey techniques especially in reallotment work. As a result, regular applications of photogrammetry started in 1938. The photographic scale used was 1:5,000 and the graphical plots were obtained at 1:1,000 scale using a Zeiss Stereoplanigraph analogue stereo-plotter. Obtainable accuracies of ±21cm (at the plot scale 1:1,000) were already within the tolerances of 1954.

In 1952-53, the Beltrum reallotment experiment was carried out (Schermerhorn, 1954). The photography was taken at 1:9,200 scale by a Wild RC7 camera equipped with an Aviotar narrow angle lens. Identification of linear features was difficult especially due to the thick hedges. Hence, 156 control and traverse points, as well as 60 arbitrary points, were premarked by white plates of 50cm diameter or 30x30cm in size. Plotting was performed at 1:2,000 scale by a Wild A 7 analogue stereoplotter and an accuracy test was carried out as follows. With respect to the absolute orientation on control points, the results are as on the Table 4.7 below.

	Pair	m_x	m_y	m_s	n
	78-79	11.9	13.2	17.9	5
	79-80	7.2	7.5	10.4	5
	80-81	3.1	7.8	8.4	5
	93-94	6.9	7.0	9.8	6
	94-95	3.3	1.8	3.8	4
	95-96	6.5	8.8	10.9	5
	Average	7.1	8.4	11.0	= 12.5μ in negative
compared with:	Harry Malvaglia	7.6	9.3	12.0	= 18.6μ " "

Table 4.7 Rmse values at control points.

Repetitions indicated one bad control point without which results could have been even better. Regarding the precision of coordinates of arbitrary marked points (derived by a numerical solution from measured machine coordinates), for 48 out of the 60 measured control points, errors equivalent to ±10μm on the negative were found. The accuracy of distances was evaluated by computing them from the coordinates and the ground measurements. The results (Table 4.8) are as follows.

Distance	n	mean square error	maximum error	
0-10	4	3.1cm	4	Average 0-100 m 4.6cm = 5 μ
10-20	7	3.8	8	
20-30	8	3.2	5	
30-50	19	5.1	10	
50-75	21	4.5	8	
75-100	15	5.3	10	
100-150	17	4.5	8	100-200m 5.1cm = 5.5 μ
150-200	17	5.6	9	
200-300	22	6.9	15	200-640m 8.8cm = 9.5 μ
300-400	16	6.3	11	
400-500	13	10.4	21	
500-640	9	8.4	15	

Table 4.8 Accuracy of distances.

The Beltrum experiment results encouraged the Directorate of the Netherlands Cadastre to accept photogrammetry for the survey of Class II and III areas, nearly 40 years ago!

In <u>Germany</u> the situation was very similar to that in the Netherlands. After World War

II, the first successful experiment was at the Bergen area (Visser,1958).

The stereoplotting programme included graphical output at 1:2,000 scale of all signalised points plus topographic detail; numerical output from machine coordinates and graphical plotting of these signalised points at 1:1,000 scale. Control points were signalised as 30cm diameter marks and the boundary points as 14x14cm marks. The accuracy derived from the difference (d) between two successive measurements of the same point gave the following results (Table 4.9).

	m in cm			m in microns		
H	m_x	m_y	m_s	m_x	m_y	m_s
1300	2.1	3.0	3.7	7	10	12
1750	2.4	4.4	5.0	6	11	12 1/2
2100	3.0	5.5	6.3	6	11	12 1/2

Table 4.9 Stereoplotting. Measurement accuracies.

The time required for mapping 1,000ha from 1:8,500 scale photographs was computed by Brucklacher. The total number of instrument-man hours spent on the stereoplotting was 144, while drawing necessitated 135 hours and computation 228 hours. The scales used required 23 photographs and 7 sheets to cover the whole area.

After the 1960's, the use of photogrammetry for cadastral surveys in various countries increased considerably. Wide angle cameras have been used to a greater extent to give better base:height ratios, as well as short exposure intervals giving up to 90% forward overlap. Most of the mapping was carried out by means of first and second order analogue stereoplotters. Electronic recording devices coupled to analogue instruments and the use of electronic computers for data processing started to be used for the photogrammetric measurement of coordinates nearly everywhere by that time. This meant that stereoplotting, a method that originally only gave a direct graphical output, had started to give a numerical output even though it served a graphical cadastre.

One fairly recent example of a test concerning graphical photogrammetry, is the one for the Agrarian Cadastre in Brazil, as described in Section 4.2.3. The photo details are similar to those for the production of orthophotos, as described in that section. When stereoplotting was used, the operator worked with enlarged photos in the scale of the map (1:5,000) where the corners of those properties not identified by natural details were punched on the photos in a previous stage of field photo annotation. Once the property boundaries were identified, it became possible to measure them, by measuring their defining points with the stereoplotter. The point coordinates thus obtained, allowed the drafting of each property separately. The resulting plots contain the land marks and the azimuths and distances between points which, together with other information relative to the properties, comprise the description of each parcel that accompanies the property title to be provided to the owner of the land. Considering the obtainable accuracy of stereoplotting, there were not very specific results from that test. As is so often the case, because almost always the boundaries were determined by natural features (hedges, water divides, etc) and not by sharp artificial marks, "numerical" accuracy could not by obtained. However, a variation of +2.7%, was quoted for the stereoplotting of some reference properties as compared with the results from high accuracy ground methods - though most photogrammetrists must wonder how such boundaries (hedges, etc) can be surveyed to a higher accuracy using field survey methods.

One other example of a European country with a graphical cadastre (involving the registration of deeds) is Sweden (Visser, 1958). The Swedish cadastre has followed the Swiss example concerning the structure of its specifications, however with much wider tolerances. Between 1948 and 1953, a total of 58,107ha had been plotted using a Wild A6 at scales between 1:1,000 and 1:8,000, with most of the work at the scale 1:2,000. Since 1978, digital mapping techniques have been used for the production of cadastral and other large scale maps (at scales of 1:400 to 1:2,000). An investigation (Moren, 1980) showed that digital methods are economically well justified compared to the use of direct graphical methods for the large scale photogrammetric mapping of planimetric detail.

In Moren's account, three analogue stereoplotters were dedicated to planimetric detail mapping. Encoders attached to the stereo-plotters were used for the capture of data in digital form, while the graphics screen of the dedicated desk computer is used for the display and verification of what has been plotted. The computer is also used for the implementation of a computer assisted relative and absolute orientation.

In order to investigate the production costs of stereoplotting with digital output as compared with the conventional graphical stereoplotting output, a comparison test was carried out in Sweden in 1980. The comparison was between the production of the planimetric layer for urban maps at scales of 1:400 and 1:500 for three different areas using the two methods mentioned above (Moren, 1980). The Tables 4.10 and 4.11 summarise some of the technical data involved in this test and the relative times required.

Although the investigation was really too limited to give definite conclusions as to whether one method is more profitable than the other, at least it gave a clear indication that the digital output method is reasonably competitive for large scale photogrammetric

Technical data	Area		
	Kiruna	Märsta	Vänersborg
Scale	1:500	1:500	1:400
Sheet format, m^2	0.5x0.5	0.5x0.8	0.6x0.8
Degree of complexity	easy	relatively complex	complex
Number of registrations per hectare	215	280	615

Table 4.10 Graphical and digital stereoplotting. Technical data.

Working steps	Kiruna	Märsta	Vänersborg
Conventional plotting	12.5 hectares	20 hectares	30.7 hectares
Stereo plotting	10 h	40 h	63 h
Fair drawing	9 h	32 h	49 h
Digital mapping	50 hectares	20 hectares	30.7 hectares
Data capture	33.5 h	12.5 h	64.5 h
Check, editing	14.5 h	9.7 h	6.6 h
Flatbed plotting	6 h	3 h	9 h
Computer, CPU	1160 sec	610 sec	1340 sec

Table 4.11 Graphical and digital stereoplotting. Required time comparison.

mapping. It was also assumed that since personnel costs tend to increase faster than hardware costs, the trend will be in favour of digital methods. Furthermore, working methods and software can be improved to make digital data capture and manipulation more competitive. Most photogrammerists will agree that this has indeed been the case, especially with the huge increase in computer power and in graphical display technology that has taken place since these Swedish tests were carried out in 1980.

4.2.5 Numerical Photogrammetry

As has been seen in Chapter 3, the accuracy required for particular cadastral purposes is a primary factor for the selection of numerical photogrammetry as the appropriate method to be applied in such a context. The need for higher accuracy will arise from the fact that the measured data are to be used as the basis for a numerical cadastre. The coordinate values can be used for the reconstruction of lost or disputed boundaries, or they can be used for a more accurate computation of areas, something which may be important for the trade in real estate.

Also, the usual way to obtain values for areas might be computation from numerical data, distances or coordinates. Although these data could be derived from the map and prepared for numerical processing, this would entail another set of measurements. It would be much more sensible and more economic if these data were collected directly at the stage of the stereoplotting of the photographs.

The earliest attempts towards numerical photogrammetry had been the acquisition of numerical data by reading off the appropriate dials of the instrument, followed by reduction and calculation using hand-operated calculators. Hence, it was possible to deal with photogrammetry, traditionally a graphical procedure, in a similar way to that involved in a numerically-based field survey. This consideration of numerical treatment of the data measured in a stereo-model was actually related mainly to the planimetric (X,Y) coordinates since the spot height readings obtained from the Z-counter were often not required by the cadastral authorities.

The development of modern equipment has increased the obtainable accuracy and also the possibility of automatic registration gave the additional advantage of avoiding reading and writing errors. Initially the additional devices used to record the coordinate values took the form of punched cards and paper tape. Since then, the situation has changed enormously and the most advanced storage of coordinate data in digital form nowadays (disks of various types) can cope not only with individual points but with the whole data set that formerly would have been purely graphical.

As with the case of the countries that carried out experimental surveys for the evaluation of the graphical photogrammetric techniques, the results of similar experiments of numerical photogrammetry for cadastral purposes will be discussed here.

An early experiment concerning the use of photogrammetry as an alternative and more beneficial survey method, was the Chesa experiment of Zimbabwe, carried out in 1959 (Southern Rhodesia Dept. of the Surveyor General, 1960). Although the Roman Dutch law principles that have been adopted in this country for the registration of land give primary importance to the undisturbed boundary evidence shown on the ground more than the evidence on the cadastral diagram, an accurate relocation of a missing boundary will require a high degree of accuracy for the survey data. The Chesa photogrammetric experiment tried to assess both the cost and the time parameters that photogrammetry could give in those days, as well as ascertaining whether it could meet the accuracy demands of ground cadastral survey regulations. The experiment was based on the acquisition of machine coordinates obtained from analogue stereoplotting machines (Zeiss Stereoplanigraph C8) of pre-signalised boundary corners, and later adjusted by the ITC/Jerie Analogue Computer.

The boundary corners surveyed by photogrammetry were the corners of 50 farms covering an area of 14,000 acres. The farm sizes varied between 180 to 500 acres. The great part of the area was hilly with elevation differences of 200 to 400 feet. All the boundary corners had been surveyed previously by ground traversing/triangulation techniques, and the coordinates were tied into the National triangulation network for the comparison of the ground and photogrammetric methods. The aerial photography used to cover the test area had a 60% longitudinal overlap and was obtained by a Wild RC 5A wide angle camera equipped with f=152mm lens. The photo scale was 1:7,500. The boundary corners had been signalised by "L" shaped, whitewashed stone marks, but no attempt was made for the premarking of control points.

Machine model coordinates were measured in the analogue stereoplotter for the pre-marked boundary corners of the 50 farm properties. These coordinate values, as well as the cost and time parameters, were then compared with the values obtained from ground techniques such as traverse and triangulation. Comparison of the absolute coordinate values obtained by the ground and the photogrammetric methods showed small discrepancies. However, from the cadastral view point, the accuracy obtained in the values for distance and direction between related beacons is often of greater importance than the individual absolute coordinate values of the beacons. The great majority of the values of the distances as determined from the respective lists of coordinates of the two methods, showed an agreement better than 1 part per 2,000. In general, the order of accuracy obtained, appeared to be such that no individual property owner would have any complaints for the use of photogrammetric methods. This also became clear after a comparison of the values of the areas of the farms, as computed from the coordinate values. An investigation for short distances was also performed. This investigation was performed to test the accuracy that photogrammetry can give for the smaller farm properties in this country of size between six and twenty acres. For distances less than 1,000 feet, rmse's of about 1:300 were obtained.

In general, as a result of this test, it was considered even from those early times that photogrammetry could compete with ground surveys even when high numerical accuracy of boundary corners is required. With respect to the examination of accuracies of distances reduced from photogrammetrically obtained coordinate values, rmse's of ±10μm were obtained in the plane of the negative. This suggested that a photo scale of 1:5,000 would give a rmse of ±0.15ft on the ground, which was within the permissible traverse misclosure for distances greater than 100 feet. It seemed from that experiment that shorter distances determined by photogrammetry could not meet the ground survey tolerances.

To compare the relative costs of the ground and air survey methods, two exercises were performed:

1) The overall area of the 50 farms has been considered to be an absolute quantity and the effect of reducing the sizes of the farms (i.e. increasing the density of beacons) was investigated.

2) The average size of the farms has been regarded as an economic minimum for the area and the effect of increasing the number of farms (and hence the overall area) has been investigated.

The results obtained were considered to be satisfactory, although a better form of pre-marking and the use of pre-marked control points (there were no pre-marked control points) was suggested in order to improve the obtained accuracy. Air survey accuracies seemed to suffice for the framing of diagrams without affecting the security of title of Zimbabwean land owners. The cost exercises made, showed the adaptability of the air survey methods in areas with low development density and large areas in general.

It is noteworthy now to see another relative example of the early 1950's carried out in Europe, in a country, Austria, which implements a purely numerical cadastre. This particular test was carried out in 1950/51 on an area of 95ha (Visser, 1958). Boundary corners were signalised as 12x12cm whitewashed stones. The ground survey was made both by the orthogonal method (i.e. precision taping) and by the polar coordinate method (i.e. precision tacheometry) and the two sets of results compared. The mean square error in position of a point in the ground survey was calculated as mpl = ±3.9cm assuming equal accuracy for both ground surveys. Table 4.12 below, gives the details concerning the flying heights, photo and model scales, other photogrammetric parameters and the obtained mean square errors. The photographs were taken with a Wild RC7 plate camera equipped with an Aviotar lens on Gaevert Avi-Microgram plates, and each model was measured and plotted in a Wild A5 analogue stereoplotter.

A linear transformation with the use of 5 or 6 control points in each stereo-pair was carried out for the measured machine coordinates prior to their comparison with the ground survey values.

The conclusion was that the root mean square errors (m_x=m_y) in the average of two observations of the transformed machine coordinates in the plane of the negative are between ±10 and ±12μm.

Comparisons made for the determination of accuracy of short distances between 0 and

20m measured on the ground with steel tapes and considered to be error free, gave an rmse

1	2	3	4	5	6	7	8	9	10	11	12	13	
H in m.	Scale of the photographs 1 :	Form of floating mark	Number of test points	Scale of the model	With or without compensat. plate	Average diff. in x and y cm.	Average diff. in position in cm.	m.sq.values of diff. in cm in x m_x	y m_y	pos m_p	m_p in μ in plane of neg.	m_p on neg. after subcontracting m''_p	m.sq.er. in height m_h in cm
800	4700	•	314	3000	no	3,9	5.7	4,6	5,0	6,8	14.4	11,8	
1000	5900	•	303	3000	no	4,9	7,9	6,2	6,5	8,7	14,7	13,2	
1000	5900	•	297	3000	with	3,8	6,2	5,2	4,8	7.1	12,0	10,0	9,1
1400	8250	•	219	4000	no	6,2	10,3	8,5	7,4	12,6	15,3	14,5	
1400	8250	o	219	4000	no	-	-	7,7	6,8	10,2	12,4	10,8	
1800	10600	•	196	6000	no	8,0	12,5	10,8	9,6	13,6	12,8	12,3	
1000			113		with			4,7	4,4	6,5	11,0	9,0	6,6 average of 2 models

Table 4.12 Austrian test. Photogrammetric parameters.

of ±4.3cm for a total of 243 measured distances. For 138 distances obtained from H = 1,400m, the rmse was ±5.8cm. When these values are reduced to the negatives for the accuracy of a single point, these become ±7.0 and ±7.3µm respectively which, being much smaller than the values in column 13 of Table 4.12, shows that their relative accuracy is much higher.

A check of photogrammetrically determined triangulation points by traverse measurements showed that the precision obtained by photogrammetry is more than sufficient and probably as an average better than the coordinates determined by the usual ground survey methods. Hence, the conclusion was then that no further traversing should be carried out since the points required for the cadastral revision surveys could be determined by the numerical photogrammetric method.

Apart from this early experiment in Austria, there is really a wealth of other experimental and production data on the accuracy of numerical stereo-measurements of signalised points, e.g. those published by Commission C of OEEPE (European Organisation for Experimental Photogrammetric Research) which supervised the Reichenbach Experiment (Visser, 1976) gave the following results, which were derived from the cooperative work of many European organisations using different makes of instruments.

For five signalised ground control points per model, the following standard deviations (σ) were found in the planimetric coordinates ($m_x = m_y = m_c$) and of their distances (m_d) between the signalised points.

$m_c = \pm 12.5\mu m$

$m_d(\text{short}) = \pm 11\mu m$

$m_d(\text{long}) = \pm 15\mu m$

In cadastral surveys, the relative accuracy, that is the accuracy of distances, is often regarded as being of greater importance than the absolute accuracy. In the Reichenbach Experiment, short distances are distances between 40 and 240 metres and long distances are from 250 to 575 metres. Assuming no correlation between the errors in the two end points of a distance, then md would have been equal to ±17.5μm. For extremely short distances, md only includes the effect of the setting errors of the two points, because, in that case, the instrumental errors and photo errors in both points are practically identical and thus $m_d = \sqrt{2}(m_c)$ setting. In the Reichenbach experiment, it was found from repeated settings that the mc setting = ±4μm, and hence $m_d \approx \pm 6\mu m$.

From that experiment, the following had been concluded. Shorter distances have significantly smaller errors than longer distances, thanks to their high positive correlation in the stereo-model. However, this is only true for distances with end points in the same stereo model. In this experiment, it was found that short as well as long distances, with end points in different stereo models, had an rmse (m_d) of the order of ±17.5μm. This is as large as one would expect for errors in very long distances with end points in the same model. This is caused by the effect of different instrumental errors and different photo errors in the two end points situated in different stereo models, and by the unavoidable closing errors in fitting each model to its ground control points during absolute orientation.

There have been many proposals, and several procedures applied, for computational methods to improve the accuracy of distances with end points in neighbouring models such as the interpolation method of Sander (Visser, 1976). On the other hand, says Visser, since 1972, a more refined and more general method of interpolation has become available for application to photogrammetric problems, the method of linear squares interpolation. This fitting is fundamentally better than that of Sanders because the method of linear least squares interpolation automatically distinguishes between the systematic and accidental error components and only corrects for the former.

In many countries however, the cadastral boundaries are formed by natural or man-made features such as hedges, ditches, fences, walls, etc. As will have been seen from the accounts given above, the identification "errors" in these boundaries experienced in an aerial survey are of the same order as those encountered in a field survey. Expressed in errors in distances, relative to reference points, the values of the rmse errors due to identification may be of the order of ±2-10 cms for walls, ±5-25 cms for hedges, ±10- 40 cms for ditches, etc. An economic proposition for the measuring accuracy of a boundary survey would be to require that this should be no better than the accuracy of the identification.

Assuming an area where the cadastral boundaries are mostly features with $m_d = \pm 20cm$, as the error due to identification. If numerical measurement is being considered using an analogue stereo-plotting instrument, the distance measuring accuracy md may be up to ±17.5μm due to photogrammetry (a conservative estimate). Accepting a 1:1 ratio between measuring accuracy and the accuracy of identification, the photo scale to be used will be 1:11,500 computed from the ratio ±17.5μm = 20cm of the accuracy in the image plane and in the ground system. The final accuracy of the distances is then:

$$m = \sqrt{400+400} = \pm 28cm .$$

The combination of numerical and graphical photogrammetry will be useful in those cases where the photogrammetric procedure is mainly used to determine the coordinates of a number of pre-signalised points which are destined to serve as the control points for setting out procedures, for terrestrial measurements, or for the absolute orientation of models in a later stage. These cases occur, e.g. in reallotment procedures where photogrammetry may be used in one or more of the following phases.

a) Before the work starts to provide a good base map.
b) After the setting out or construction of the main features of the new layout (land and waterways) to serve as its base for the determination of the new cadastral map.
c) After the completion of the work to provide the new cadastral map.

As can be seen from all these examples of the countries using numerical photogrammetry for the establishment of their cadastre, analogue stereoplotting machines have been utilised to carry out the photogrammetric operations. Numerical output from early analogue stereoplotters was impossible when these instruments did not carry the necessary scales or dials from which coordinate readings could be obtained. This demand for numerical output resulted to the production of analogue plotters capable of such a numerical output. A considerable improvement however came with the adoption of digital encoders on analogue stereoplotters allowing them to be used in conjunction with a computer, as seen at the example of Sweden quoted in 4.2.4. Progress in computer technology with the introduction of low cost PCs and graphics workstations, allowed the attachment of the latter on analogue stereoplotting machines (Kennie & Petrie, 1990). This integration allowed the direct checking and interactive editing of the measured data which is displayed on the graphics screen. Furthermore the recorded data could be transformed using the exterior orientation elements of one of the photos and injected from an auxiliary screen into the optics of the stereoplotter. In this way, errors or omissions can be corrected by the operator from the superimposition of the 2D image onto the 3D model of the instrument. .

All these technological improvements in photogrammetry, have given new alternative solutions for cadastral mapping and mapping in general. However, the feasibility of the adoption of the more modern instrumentation has to be examined for every application. The benefits that these modern alternative solutions can give, has to be balanced with the requirements of the cadastral system that they will serve and the available resources for their purchase and operation.

4.2.6 Analytical Instrumentation Utilising Stereopairs of Photographs as Input Images.

The early sixties opened new horizons for photogrammetry with the publishing of the original concept by Helava and the first appearance of analytical plotters. The implementation of the analytical plotters to the production however, was not rapid and it was not until the early 1980s that analytical instrumentation came to full power. By 1989, the analogue stereoplotters ceased to be produced through enormous numbers continue to be used in production work. This delay for their implementation was the result of the slow development in the relevant sector of computer technology. During the early years of analytical instrumentation the computers associated with the operation of these instruments which requires real time computations, were very expensive to produce (Kennie & Petrie, 1990). As a result, military mapping agencies were the main users that could afford and hence benefit from the use of these instruments. The advent of relatively inexpensive and fast mini-computers in the mid 1970's, meant that all the photogrammetric instrument manufacturers started to build analytical plotters. In the 1980s, the development and widespread use of powerful but low cost microcomputers, allowed the development of low cost analytical plotters. On the other hand, the development of powerful graphics work stations allowed the evolution of very sophisticated analytical instruments with capabilities such as stereo-superimposition, something which in the past was either impossible or impractical to implement.

4.2.6.1 Stereocomparators

The simplest approach of analytical stereophotogrammetry can be given by a stereocomparator. This is an analytically based instrument which has no oriented stereomodel (Kennie & Petrie, 1990). These instruments have in fact preceded the analytical plotters mentioned in the previous paragraph, by many years. The use of high precision stereocomparators has mainly been confined to analytical aerial triangulation. The reason why the stereocomparators were not popular for high-accuracy plotting requiring primarily a numerical output is probably due to the intrinsic restrictions arising from their basic principle and design. In particular, the need to eliminate parallax which has to be implemented manually, is an important restriction. This means that only a point-by-point measurement can be conducted if accuracy is to be preserved. Even then, measuring times will inevitably increase as compared to the use of analytical or analogue stereoplotters with oriented models. For the specific application of stereocomparators to cadastre, if the boundaries to be plotted are composed of long straight line segments with pre-marked points, and not curved or complicated lines, then accuracy will be preserved and the processing time reduced.

In spite of all these restrictions (and the consequent lack of interest on the part of most users), an interesting example of the use of stereocomparators in cadastral surveys is one carried out in Romania (Zegheru, 1980). The tests published in this work, showed that 1:2,000 scale cadastral maps have been produced using a Zeiss Jena Stecometer as the measuring unit. The success of these tests led to the design of an automated photogrammetric system for cadastral mapping (Zegheru, 1984). Input data were to be obtained by the use of the Stecometer and recording on a G - type Coordimeter. A flow diagram of the off-line processing of the measured data is shown in Figure 4.12.

So today, the analytical photogrammetric method is used in Romania for the compilation of the 1:5,000, 1:2,000 and 1:1,000 scale graphical cadastral maps in

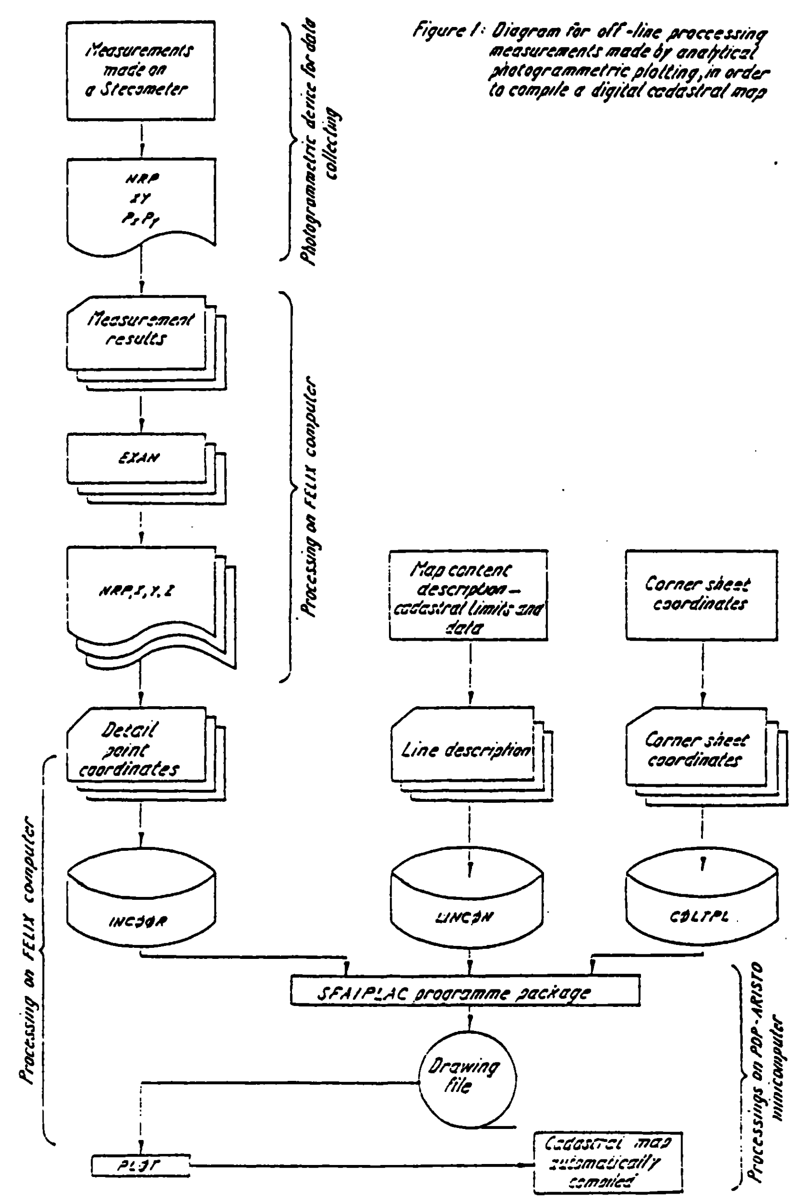


Figure 4.12 Off-line data processing for digital cadastral map generation.

conjunction with numerical topographic measurements and existing plan and map digitising. One must presume that the economy of this particular method cannot be high.

4.2.6.2 Analytical Stereoplotters

The mainstream of analytically based instruments comprises different types of analytical stereoplotters (Kennie & Petrie, 1990), in which the optical or mechanical models of the analogue approach are replaced by purely numerical models based on analytical/mathematical solutions. Analytical plotters are fully integrated with the controlling computer giving the numerical solution which is always an on-line process, executed in real time and resulting in a continuously oriented stereomodel. There are two different computational solutions. The first is based on the use of image coordinates as the input data to the computational process, while the second is based on the use of object (model or terrain) coordinates as the input data to a corresponding but different computational process (Helava, 1980). This differentiation of solutions affects the design of the analytical plotters as well as the software which is required for their implementation Figures 4.13 and 4.14, illustrate the general layout of both the analytical plotter with image coordinates primary and the analytical plotter with object coordinates primary.

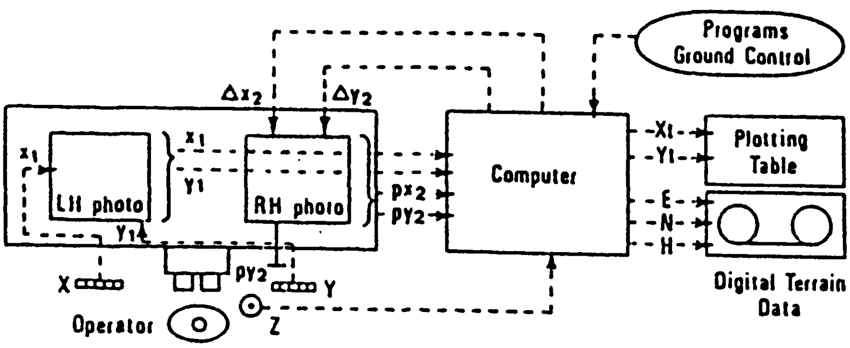


Figure 4.13 Analytical plotter with image coordinates primary.

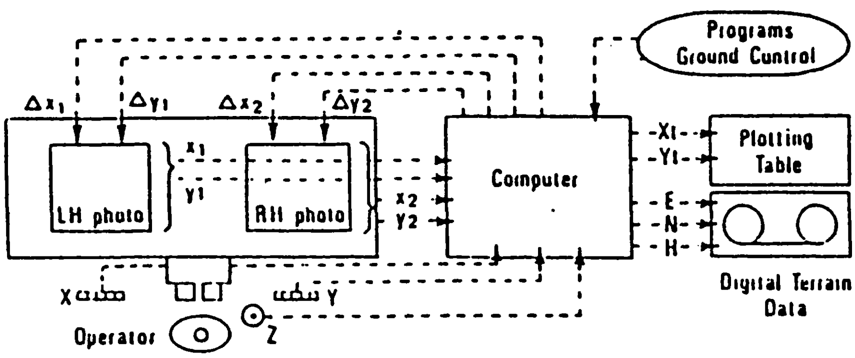


Figure 4.14 Analytical plotter with object coordinates primary.

The potential of an analytical plotter with object coordinates primary is greater as compared to that with image coordinates primary. Only with the former kind of plotter, can operations such as the acquisition of a digital terrain model (DTM) be performed at specified positions within an area. However these operations, may not be considered as critical for cadastral applications, especially if the cadastre does not serve multiple purposes.

The potential of the analytical stereoplotter for cadastral survey applications has been examined by various countries. In Turkey (Unal, 1990), cadastral works started in 1934 and by the year 1990, 68% of the country had been covered at scales 1:5,000 and 1:1,000 using numerical ground and graphical photogrammetric methods. Again, following the example of other countries, modern technology has oriented the cadastral operations towards the handling of data in digital form. Concerning now the actual survey methods for the cadastre, the field survey method has dominated in most of the work, but more recently, analytical photogrammetric plotting has started to be used for the production of large scale cadastral maps. New regulations introduced in 1988 allowed the use of analytical instruments for the control point densification by photogrammetry in the first stage.

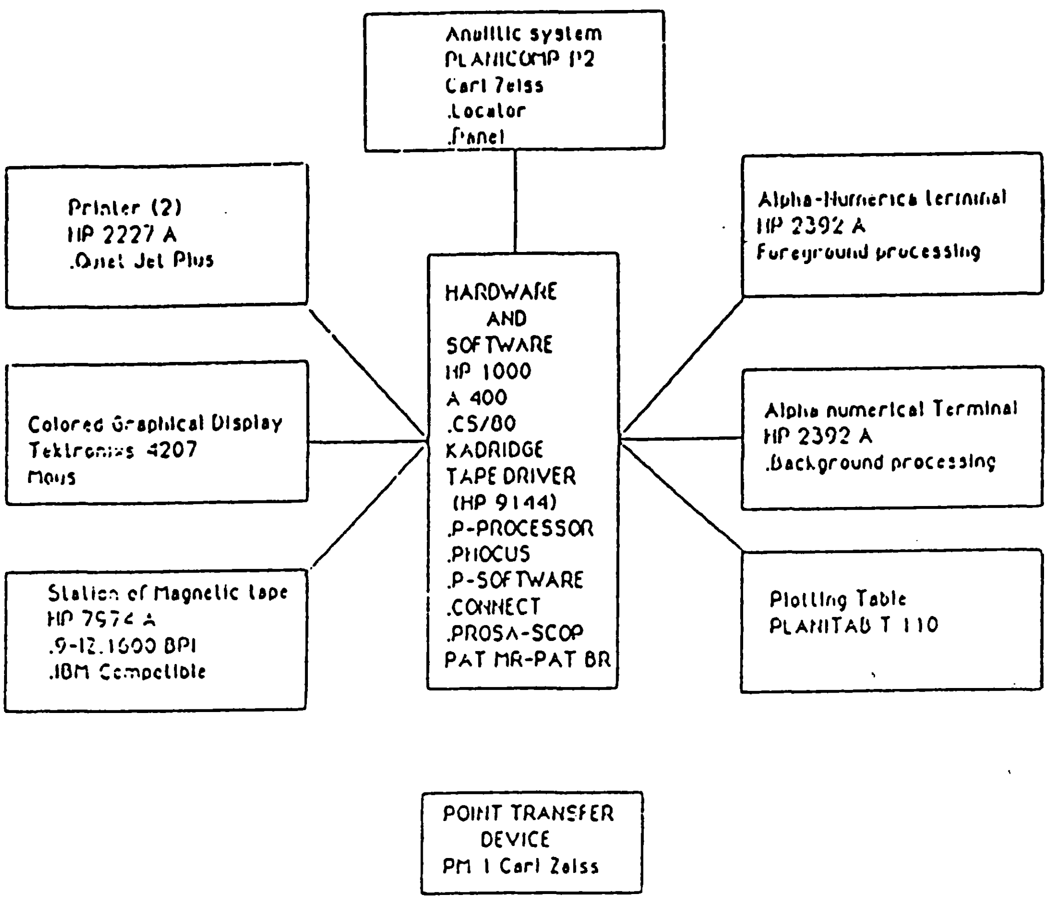


Figure 4.15 Aerial triangulation and digital processing.

The instrument being used is a Carl Zeiss Planicomp P2 analytical plotter and the production of large scale boundary maps is planned as the second stage of operations. Gains in terms of cost as well as the acceleration of work are foreseen with the use of the analytical photogrammetric methodology as compared to the ground survey operations. The system configuration for aerial triangulation and analytical stereoplotting as designed in Turkey (Unal, 1990) can be seen in Figure 4.15.

As has already been discussed, Italy has a graphical cadastre. Apart from the mapping of ownership boundaries however, other information have been included such as public roads, constructions, water features, etc. Having realised the usefulness of cadastral cartography for civil projects, the Cadastral Administration has taken initiatives (Cannafoglia and Catalani, 1984), for the integration of cadastral maps with height information and to recover the metric accuracy of the geometric information, being a subject of constant and dynamic evolution. The need to satisfy the above requirements, caused the Cadastral Administration to subcontract this work to independent professional specialists, to cope with the need of closely following the changes on the large scale thematic maps which give a graphic representation of some 65 million individual parcels. The entrusting of the above operations to professional specialists, resulted in a considerable degradation of the geometric quality of the cartographic documentation. Consequently, a number of initiatives were taken with the aim to improve the situation. These included the setting of rules for the analytical acquisition of control point coordinates, and the study and use of analytical stereoplotting techniques and data processing. This research study had the double purpose of verifying the map revision process for large areas of massive urban development and of using the analytical aerial triangulation technique for the definition of control points, serving also for further surveys. This research study was centred on the use of OMI APC4 analytical stereoplotters.

Concerning the test of the map revision process using the analytical plotter, one of the most interesting experiences obtained was the analysis of quality and costs for numerical cartographic product by comparing the results from analogue stereoplotters plus digitisers and those obtained from analytical stereoplotters. The test area for revision was a 1,240 acre heavily urbanised area, originally mapped on four 1:2,000 scale sheets. The technical and economic elements to be verified were as follows.

- Verification of the geodetic triangulation net, and the definition of the coordinates of the photographic control points obtained both by ground surveys and by analytical aerial triangulation.

- Suitability of the aerial photogrammetric method for the revision of existing cadastral maps
- Verification of the possibility of superimposition and integration of existing cadastral maps, converted to the 1:1,000 scale of the new plotting, with the corresponding photogrammetrically plotted drafts.
- Qualitative and quantitative analysis of the discrepancies observed from the superimposition and analysis (under certain topographically defined criteria) of the mathematical deformation models.
- Qualitative and quantitative investigation into the detection of these property boundaries, which do not materialise on the ground but are identifiable in the stereomodel. In other words, this was an investigation of the linear features that never or do not any more, serve as boundaries on the ground.

4.2.6.3 The Use of Interactive Graphics Workstations with Analytical Stereoplotters

As in the case of analogue stereoplotters, graphics workstations had been integrated with analytical stereoplotting machines to allow the direct checking and interactive editing of the measured data. This integration of graphics workstations with analytical plotters however, allows the implementation of the stereo-superimposition technique (Kennie & Petrie, 1990). With this technique, direct checking is possible in three dimensions by stereo-superimposition of the plotted detail on the stereomodel, and so a significantly higher quality in the capture data is obtained. Superimposition on existing digitised cartographic data is also possible. This technology is available only at very a considerable cost, which perhaps cannot be afforded for its implementation into a cadastral survey project in certain countries. However this technology confirms the ability of modern photogrammetry to play the role not only of a data capture technique but as a tool for the verification and revision of geometric data as stored in a modern property cadastre, but also for attribute data as in environmental studies. The integration of all these geometric and attribute data is the requirement for the establishment of a full multi-purpose cadastral system (Mitchell, 1985). Furthermore the solution for the three-dimensional requirements of such a system can be given with the integration of photogrammetry with the information database. The interactive processing of data in this way will bring out the maximum information needed from the photographs, allowing the editing and analysing of data (Bill & Exl, 1989). These requirements can be fulfilled most successfully with interactive graphics workstations with analytical stereoplotters allowing the stereo-superimposition technique.

4.3 Conclusion

This chapter has dealt with the various photogrammetric techniques that can have a practical application to cadastral surveys with respect to the primary requirements for the latter. These different photogrammetric techniques have each been examined separatelly mainly through the various examples of the countries which have already experimented on, and employed these techniques. In particular, in the first part of the chapter, graphical photogrammetric methodology has been discussed, being of interest for graphical cadastral systems, whereas the last part of the chapter has dealt with the photogrammetric techniques that can satisfy the needs of a numerical cadastre. Among the examples from the various countries there is a great diversity of situations with respect to the extent and type of land to be surveyed, the technical-economical resources available and the specific requirements of the cadastral system employed in a particular country.

For those who examine the suitability of photogrammetry as an alternative technique to serve their cadastral surveys, this chapter should be of special interest.

For countries like Greece with an established but poorly functioning land registration system and having the intention to upgrade it to the more systematic and integrated approach of a full cadastre, a fairly conservative and realistic approach could be that of a graphical cadastre.

Having such a cadastral system in mind and considering some practical limitations such as the available photographic material from Greece having no pre-marked boundaries, and the available instrumentation, a number of experiments based on photogrammetric techniques generating numerical digital data have been carried out in this project using photographic material from two areas in Greece. The first photogrammetric technique which is covered in the next Chapter 5, is that of digital stereo-plotting using digitally encoded analogue stereoplotting instruments.

This technique was used to verify its suitability for capturing data in digital form in many different information levels. Most importantly, stereoplotting was and is still believed to be the only technique for accurate plotting as it is required in cadastral mapping at rough and mountainous terrain. Furthermore its testing served also as a basis for the evaluation of the photogrammetric techniques of monoplotting and of orthophotography, which will be discussed in Chapters 6 and 7 respectively. These latter techniques were considered as potential alternative techniques for cadastral surveys in Greece, at least for the less mountainous areas.

CHAPTER FIVE

Chapter 5

Tests Utilising Digitally Encoded Analogue Stereoplotting Machines for Cadastral Surveys

5.1 Introduction

In order to investigate the use of digitally encoded analogue stereoplotting instruments for data capture intended for cadastral work, tests were carried out using two such instruments, the Galileo Stereosimplex IIc and a Kern PG-2 in the Department of Topographic Science.

As discussed earlier in Chapter 4, the use of an analogue stereoplotter capable of digital output means that accuracies of about ±10μm in the plane of the photograph can be obtained from well signalised points. If stereoplotting of physical features is considered, the obtainable accuracies will be closer to ±20μm due to the identification errors in the boundary corners of the physical features. When continuously plotting boundary lines, due to the dynamic nature of stereoplotting, the accuracy will be rather less - perhaps ±25 to 50μm. Hence, the potential accuracy of this technique is often just as high if not higher than what can be achieved with any other method. Furthermore, if only graphical accuracy is required, then stereoplotting should not only satisfy the surveying standards for cadastral mapping, but do it more easily than any other technique. In any case, stereoplotting will probably be the only possible technique for the survey or mapping of areas of very mountainous terrain with steep, breaking slopes. Since this type of terrain is very common in Greece, stereoplotting should be of primary consideration, at least for this type of area, even if only graphical accuracy is required. On the other hand, the common trend nowadays is to collect new data or convert existing data into digital form, suitable for entry into a digital land information database or as an extension into a LIS. Also, the digital encoding of the readily available analogue stereoplotters for the above purposes has become a relatively cheap and straightforward conversion which is being adopted by an ever increasing number of users. All these considerations were the reasons for conducting a test with digitally encoded analogue instruments in the Department.

Furthermore, the functionality of the digital encoding of the instruments could be evaluated for cadastral production applications throughout the whole process of plotting. This would include the assistance given by the system during absolute orientation operations, through the measurement stage and all the other operations up to the final output. Consideration could also be given to the consistency, the quality and the format of the output data, as well as the savings in terms of operational times.

The digital output from the stereoplotters was then input into the MicroStation 4 graphics software in order to examine the quality and completeness of the data, and hence verify the need for and the suitability of such a software for data editing prior to the generation of hard copy output and the input of the data to a digital database.

Another important aim for the stereoplotting tests was to provide a set of data of superior accuracy that could serve as the basis for a comparison of the output from both digital image monoplotting and orthophotography that were also tested in this project as alternative techniques for a cadastre of graphical accuracy based on data in digital form.

5.2 The Test

The test concerned the stereo-plotting of those air visible boundaries which were represented by physical features, mainly of human construction (e.g. walls) or comprising other natural features (e.g. trees, hedges). Hence, there was no signalisation of the boundaries nor a pre-marking of the ground control points, the coordinates of which had been obtained by ground survey techniques and linked to the national coordinate network. The location and the numerical information for the control points had been provided on diagrams as used for the production of the topographic maps in Greece using the graphical stereo-plotting method.

5.2.1 The Test Areas

Two separate models were used for the tests, one model being plotted by each instrument. The areas covered by both models are situated in Greece. This selection was made so that the system could be evaluated with the peculiarities of the Greek terrain and features. This evaluation was to be made on the basis of plotting unsignalised natural boundaries with the intention to acquire data in digital form for the needs of a cadastral system such as that which will possibly be implemented in Greece.

The photographs, comprising both paper prints and film diapositives, and the ground control point coordinates and diagrams were obtained directly from the HMCO which can be considered the most appropriate organisation for cadastral affairs in Greece. The contacts with the HMCO were facilitated by Professor Badekas of the National Technical University in Athens.

The photographs obtained were at the largest scale (1:6,000) available for both areas and had been already used by HMCO for the graphical production of topographic maps at the scale 1:1,000. The technical characteristics of the photographs are as follows:

Focal length	: 152.13mm
Flying Height	: approx. 900m
B:H ratio approx.	: 0.55
Photoscale	: 1:6,000

These photos of the two sample areas were selected from the archives of HMCO with the assistance of one of its personnel (M. Kalakos), having regard to the need to cover areas which are representative of the Greek terrain, and contain a variety of boundary types and area types, varying terrain flatness and other features.

The two model areas are the following:

I - Archaia Corinthos. The area covered by this model is semi-urban with a great variety of building, boundary and road types. This model also has the greatest variations in height of the two test models, with an even slope being easily noticed. It cannot however be characterised as a hilly or mountainous model.

II - The second model area is that of Omvria Achaias. This is a rural area comprising many land parcels used for agriculture. The area is relatively flat and covered to a great extent by citrus trees. There is only a basic communication network but there are a considerable number of buildings.

5.3 The RPLOT Digital Encoding System

5.3.1 In General

RPLOT is a digital data capture, display and plotting system designed and supplied by Ross Instruments for the conversion of analogue stereoplotting machines into an instrument capable of output in digital form.

5.3.2 The Hardware Configuration of RPLOT

The digital encoding of an analogue stereoplotter for the acquisition of coordinate values in digital form involves the attachment of encoders to the moving mechanical/measuring components in the model space of the stereoplotter. Due to the different construction of the various stereoplotters, alternative arrangements for the attachment of digital encoders can be made.

The Galileo Stereosimplex IIc, the first instrument used during this project, has a cross slide system built into it. There are no hand wheels and no racks for the X and Y movements. It is a pure manual motion which takes place in the model space. As a consequence, three Acurite linear encoders made by Bausch and Lomb are mounted on the instrument to allow the measurement of coordinates along the three axes (XYZ) perpendicular to one another. These incremental linear encoders are fitted with an auxiliary scale, which generates moire fringes which are detected by a reading head. With these incremental encoders, an absolute zero can be set, and their least count is 5μm. Each encoder head sends its signals on a separate cable to a floor-mounted electronics box which also receives a fourth cable from a footswitch used for digitising. A single cable connects the electronics box to a PC. Through this cable, the signals are transferred to an encoder card in a PC, which decodes the encoder signals, generates the X,Y,Z model coordinates and correctly formats them prior to their input to the RPLOT software for the necessary computations. The MCC Encoder Interface Card provided by Ross Instruments for this purpose is a standard full size PC compatible plug-in board with all connections from the umbilical cable from the electronics box being made through a 37-way D-type connector. The whole system is integrated through the use of a PC AT 286 computer, made by Clyde Technology and equipped with a colour graphics screen.

The configuration of the RPLOT system can be seen in Figure 5.1.

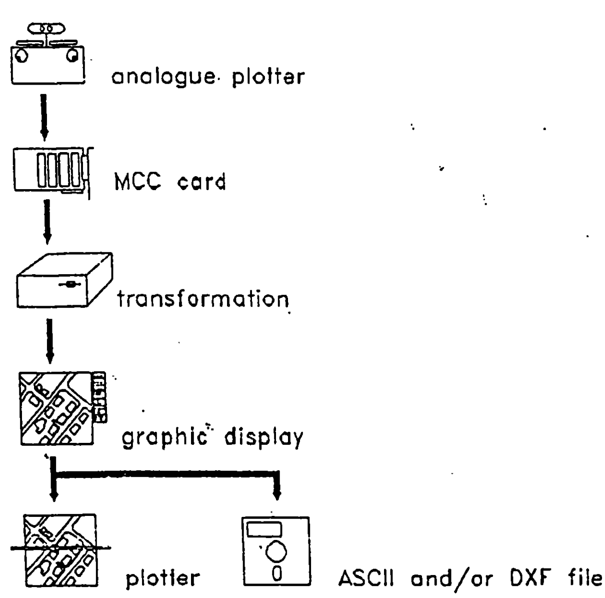


Figure 5.1 The RPLOT system configuration.

The second instrument used during this project, one of the department's four Kern PG2s, has a different arrangement of encoders to that described for the Stereosimplex. The PG2 has no cross slide system. The free moving measuring stand of the instrument normally moves with a parallel guidance. However this particular example has a cross slide system especially added to it to separate out the X and Y movements. This cross slide which permits the movement in X sits on a single fixed rail in Y. Both the X and Y movements have a rack and pinion mechanism. The pinion while it is in motion, turns a rotary incremental encoder which is made by Ross Instruments with some Hewlett Packard parts. This accounts for both the X and Y movements. On the tracing/measuring stand of the PG2, a thumb wheel is used for the Z motion. A tiny rotary encoder is attached to the axis of the thumb wheel movement for the encoding of any Z movement. All of the above encoders have a least count of 5µm. The separate outputs from each encoder pass down to a floor mounted electronics box which, as in the case of the Stereosimplex, also receives signals from a foot switch. Output from this box is again through a single thick cable connected to a PC which, in this case, is a PC 486 33Mhz machine made by Viglen, which is much faster than the PC-AT computer attached to the Stereosimplex.

5.3.3 The RPLOT Software

5.3.3.1 Introduction

RPLOT is the necessary software package developed by Ross Instruments Ltd for users of analogue photogrammertic plotters fitted with encoders and connected to a Ross MCC card. A number of versions of RPLOT have been developed; all of them serve the same purpose, with the later ones being more friendly to the user. This software will run, as already mentioned, on any IBM compatible (286, 386, 486, etc.) equipped with EGA, CGA, VGA or Hercules graphic cards and occupies approximately 0.8Mb of hard disk memory space.

The steps for the acquisition of 3 dimensional coordinates in digital form from a stereoplotter being digitally encoded with RPLOT can be outlined as follows.

The first operations of the inner and relative orientation of the model are carried out in the usual way as with the stereo-plotters not being digitally encoded. For the absolute orientation, the encoding system provides an aid, since it can compute corrections for the settings of bx, common phi and omega, after a 3 dimensional transformation which is based on the digitally measured model coordinates of the control points. Once this iterative process is complete and the transformation parameters computed by the software are accepted as final, measurement of the point and line data can begin. For each point being measured, its model coordinates are transformed into the corresponding ground coordinate values with respect to the established transformation parameters. The transformed data is displayed graphically on the PC display screen and a plot can be generated either during the data capture or after the end of the job. RPLOT files can be converted to ASCII or DXF format for input into packages such as AutoCAD, MicroStation, or ArcInfo.

5.3.3.2 Running the System - The Preliminaries

In order to run the system for the first time, the software must be installed by creating a directory on the computer hard disk and copying the program files from the floppy disks into this directory. The first task then is to configure the system to the specific hardware of the PC employed to run the RPLOT software. The details that have to be specified during the configuration include the analogue plotter type; the factors employed to convert encoder counts to millimetres; the type of graphics screen used; the communications protocol in use for the stereoplotter (its RS232 string format); and the MCC card.

When RPLOT is already running, the 'Utilities' option from the <u>first menu</u> is selected. From there, the next selection is to 'Configure RPLOT'. The items mentioned above are shown and any changes and data should be entered then. Next, the <u>main menu</u> can be fired up by entering the command RPLOT, which offers the following choices:

Create/Edit control files
Observe control points
Observe model
Create ASCII file
Create DXF file
Utilities
Quit

A short description will be given here of the actions which can be implemented for each of the above options.

(a) Create/Edit Control File

The control files contain the coordinates of the ground control points. By comparing these with the corresponding set of measured model coordinates, the transformation parameters for the model coordinates are derived.

Control files can contain up to 105 points, each of them having a point ID (or name), a point type and X, Y, Z coordinates. Point types can be XYZ, plan or height. Not all the points in the control file have to be used in the calculation of the transformations for each overlap. The sequence by which the point coordinates are entered in the file is the same as the sequence in which the points will be displayed for measurement.

Having completed the inner and relative orientation operations for the model to be plotted, the process of absolute orientation can start. This is facilitated by the corrections for bx, common phi and omega, that RPLOT can provide.

(b) Observe Control Points - The Absolute Orientation.

The comparison of the measured model coordinates and the corresponding set of ground coordinates of the control points produces a set of transformation parameters which is stored in the parameters file, RPLOT.PAR.

A general 3D transformation will perform a 3D rotation, translation and scale change from the model coordinate system to the ground coordinate system and the Omega, Phi and Kappa rotations will be displayed.

The initial step is to specify the control file to be used. Secondly the system will ask for details of the job. These are, job name, project, numbers of the photographs, focal length, photoscale and model scale. This data can also be entered prior to the inner and relative orientation. The next screen requests the instrument orientation settings and although not mandatory, if these parameters are entered, corrections for the absolute orientation settings will be calculated and the new values will be displayed. The digitise control screen which follows shows control points IDs, calculated control point coordinates and residuals that will appear after a minimum of three control points are digitised. These will be the basis for the three dimensional transformation which will give the parameters for tilts and base setting so that the model can be absolutely oriented. At the bottom of the screen, there is a continuous display of the position of the mark in the ground coordinate system. Below that, a root mean square error figure for the X, Y and Z residuals is given as well as a vector of the three. This gives an instantaneous estimation of the quality of the measurements being made up to that point.

A point is measured by locating the point in the model and digitising it by pressing footswitch one. A bleep from the computer signalises a successful point capture.

The transformations are recalculated every time a new point is measured and the new transformations applied to the points measured so far. The calculated scale is displayed on the screen.

If a point is measured more than once, then all the model coordinates measured so far for this point are meaned and these mean values are used to calculate the transformations. So there is no limit to the number of times a point can be remeasured.

As soon as the new settings required to level the model are displayed on the screen, these recommended changes should be made on the instrument, the new settings entered and the control remeasured. The process of entering new instrument settings and remeasuring control points can be performed as often as necessary.

(c) Measurement of Data - The "Observe Model" Command

Observe model is the data input routine selected from the main menu. A job name has to be selected which will be the name of the file for the captured data. To resume a job, an old job name is selected. Once the job name has been established, data capture can start by selecting 'start data input'.

(d) Features and Events

One press of the footswitches corresponds to the recording of a measurement into the memory of the computer. Such a record contains the X, Y, and Z coordinates of the measuring mark in the ground coordinate system, a feature name, a pre-event number and an event number.

The <u>feature name</u> is an alphanumeric string used to identify the type of point which is being measured such as house, wall, road, contour, etc. Feature names may have up to 8 characters and are set by pressing 'F'. The pre-event number indicates the feature currently measured and the event number the next point to be measured. For example, 'Contour 4-12' means that the 12th point of the 4th contour is to be measured.

(e) Data Capture

The system can be used with one, two or three <u>footswitches</u> for the data capture. The advantage of using more than one footswitch is that the operator does not need to attend to the computer except to change the feature name. Footswitch one can increment the event counter and is used for all points in a feature except the last point. Footswitch 2 increments the pre-event counter and resets the event counter to 1. It is used for the last point of each feature and for single points. A third footswitch can be optionally utilised, to perform the close polygon function. The use of three different footswiches is often found confusing by users and indeed, a third footswitch was not employed in this project.

A stream mode of operation is possible if the footswitch is held down for more than one second. Points are then digitised automatically and the rate at which they are digitised can be made time and or distance dependent. The smallest time interval setting is 0.1 seconds and the units of the displacement settings are the units of the ground coordinate display. A combination of stream and point modes is also possible.

A close polygon function is available by merely pressing the spacebar of the PC keyboard. The last point of the feature will then have the same coordinates as the first.

Zooming and centring functions of the screen are possible to allow flexibility during digitising and when examining very large files. The action of pressing a single arrow key on the keyboard will double or half the scale of the display. The data capture area of the screen is a square and the actual scale value indicated is the distance in ground control units from one edge to any adjacent one.

Another important feature is the possibility to snap. The first and/or last point of a feature can be snapped onto, while the latter remains unaffected and part of the original feature. In order to snap, the file is searched for the nearest single point or point at the beginning of a line segment. When such a point is found, the cursor moves to this point and the system prompts for confirmation.

Editing facilities are available on RPLOT to allow the editing of a feature before or after its measurement has been completed. The backspace key removes the last point digitised. When a feature is selected for editing, it will be highlighted by its flashing on and off on the display screen. If the correct feature has been selected, but not the correct line segment, stepping through the feature is possible by using the arrow keys. In this way, it is possible to change the feature name, delete/undelete segments or complete features and also break features into line segments.

Although the normal operation is to have the system on-line to the stereoplotter, in off-line mode, a mouse can become the coordinating device and used to add or edit features. If the Z coordinates have to be altered while adding points off-line, these have to be entered using the keyboard. To toggle between on-line and off-line is a single button operation.

(f) Plot Output

Plotting of files created by RPLOT is possible on vector plotters which can process the data under instructions from the HPGL language. This language is used also by other plotters, besides those from Hewlet Packard.

There are two ways to produce a plot. Either (i) a complete file stored on disk can be plotted, or (ii) the plotter can plot points and lines in real time, as they are measured.

(i) When a disk file is plotted, the conversion factor for the plotter has first to be specified from the data capture menu. This comprises the number of ground coordinates which will be represented by one millimetre on the plot. An XY swap is also possible which allows the plotter to accommodate data which does not neatly fit into a square. The file is searched for the lowest X and Y values which define the plot origin. Points falling outside the plotting area as a result of the conversion factor selection, will be ignored.

(ii) Alternatively a plot can be generated in real time. As soon as the real time plotting is initialised, the current position of the encoders is taken as the origin. The next points which are measured are sent to the plotter as well as the screen. However, in this case, the HPGL commands sent to the plotter are not saved.

(g) File Conversions and Data Transfer

Data captured using RPLOT is stored in RPT files. These files contain coordinates and feature name data and can be seen on the RPLOT directory. Although with this internal format they can be quickly and efficiently used by RPLOT, they may be incompatible with software such as AutoCAD or MicroStation. Hence, conversion into another format is necessary, if data is to be accessed by other software.

There are two file formats that can be created within RPLOT - ASCII files and DXF files. The advantages of ASCII files are that they can be viewed and edited using text editors, printed out using the DOS print command and they can be used as the input to other programs. The alternative DXF files, a special type of ASCII file developed for use with the AutoCAD package, has become a standard for transferring data between most CAD packages as well as mapping packages. The DXF file created consists of an 'entities' section only. This is suitable for input into some CAD packages but dummy header and tables sections may be required for other CAD systems.

(h) DXF Attribute Tables

The creation of ASCII files from RPT files is a straight forward action initiated from the main menu. The process for a DXF file creation is similar, but there is an option for a 2D or a 3D file, the former not containing Z coordinates.

The conversion of a RPLOT drawing file into a DXF file is controlled by a DXF attributes table which is kept in the file DXF.SET. Modifications of this table are possible by using the DXF attributes routine which is selected from the Utilities menu from the Main Menu. This DXF attributes table links layer names, point types and the 'show Z' option to the feature names. In the first versions however, only 9 different records could be held.

The layer name can be the same as the feature name or it can be different. As the 'Create DXF' routine reads the RPLOT drawing file, it checks each feature name against the DXF Attributes table. If the feature name is found in the table, then the feature is placed on a layer with the name given in the table. If the feature name is not found in the table, then the feature will be placed on a layer with the same name as the feature name.

5.3.3.3 The Latest Version of RPLOT

RPLOT has been the subject of improvement during the time it has been used in the Department and a number of different versions been available. The latest version (4.2) has been provided when the Department's Kern PG2 stereoplotter was digitised (March, 1992). A summary of all the general layout will be given here.

First of all, the general layout of the menus has been changed and also the appearance of the screens improved. Changing the various screens and menus which are available is now made easier by the use of function keys.

To run RPLOT, the command RPGO should be entered, and the Main Menu offers the following options:

Select Project
Utilities
End

After a project name has been selected (typed in, or chosen), the Job Menu provides the following options:

Create/Edit control file
Observe control file
Observe model
File conversions
Plot file
Other facilities
End

The 'Other Facilities' option opens the corresponding menu, which has the options:

File maintenance

Archive

Resume

Feature table

End

The Archive option can give details of previous models. These include project details, model details, instrument settings, transformation parameters, calculated control point values, residuals and rms errors. The other options are self-explanatory or have been described above for the earlier RPLOT version.

Concerning the control files, these can now contain up to 50 points which is fewer than before but it is perhaps more realistic.

The transformations performed yielded three-dimensional coordinates. If however only the X and Y coordinates of the data are required, this can be specified at the DXF translation process, by selecting the "2D" option.

It is now possible to select the colour used to display captured data according to user selected feature names. In the earlier versions of RPLOT, although different features could be displayed in colour, these should have a number in the range 1-15, which is the range of the available colours. With the latest version, before data are captured, a file containing a table of the feature names and colours to be used during the data capture operation should be created from the 'Feature Table' option. This file is called COLOURS.DAT and sits in the project directory. One Feature Code/Colour table file can now be created for each project. This allows different projects to use different colour schemes if required. Such a file has to be created only once for each project and, if the file is not found, then the old colour scheme (using colours for feature names 1 to 15) will be used. If the file exists, then only data with feature names found in the table will be displayed in colour. All other data will be displayed in white.

An other important feature of the latest version is that during data capture, reference files which have been previously captured can be loaded into the system. They can be snapped onto or loaded for display only. Up to nine reference files can be loaded. Loading a reference file is by a single button operation. The file needed is then simply selected from a table.

DXF files can now be created now by selecting the file conversions option from the Job Menu. The conversion routine however will not run unless the 'Program Path' has been set. This is an option from the Utilities menu and its function is to tell the system where to find the file RPHEADER.DXF. This file contains a minimal DXF header and table sections needed by some CAD packages. Although the minimal header needed is a variable, the supplied file has been proven for AutoCAD 10 and MicroStation 3.

5.4 The Archaia Corinthos (ACOR) Model Measured Using the Galileo Stereosimplex IIc.

a) Orientation

The first step was obviously to perform the inner and relative orientation empirically using the standard analogue procedures. These did not impose any great difficulties and the rotations which were required were relatively small in value. After this was done, the stereoplotter was used in conjunction with the computer attached and the RPLOT software to carry out the absolute orientation.

A control file with the relevant points and data for the model was created and the control points measured and digitised using the footswitch. An initial gross error appeared in the computed rmse values which was sorted out by changing the encoder conversion factors on the table from the utilities menu. After this, the residuals obtained were fairly small and they improved still more after a number of iterative observations, as the operator became more accustomed to the instrument. The best value of the rmse vector of the XYZ at the control points obtained throughout the test was ±1.698m, which is a rather high value, equivalent to ±0.28mm (280μm) at the scale of the photography (1:6,000) and ±0.34mm at the model scale of 1:5,000.

With the transformations being calculated and the transformation parameters displayed on the screen, it was possible to level and scale the model with the recommended changes given by the computer. The changes for the common phi however given in degrees, had to be converted to radians before being set on the Stereosimplex. This process was iterative but it converged fairly quickly after two or three cycles.

Despite the fact that data were going to be captured digitally and the final map scale could be set within a wide range of values, a model scale of 1:5,000 was selected and the corresponding gearing for the Z values to be read directly in metres was installed on the instrument.

b) Observing the model

As soon as the orientations were complete, data capture was possible and this turned out to be a straight forward task. This was tried initially by the present author using a very limited number of feature types, entered with their full name. It was very soon realised that this way of naming was inappropriate, giving no flexibility whatsoever for the transfer and further manipulation of data by other data handling packages. Hence, a coding system was devised to overcome this defect.

5.4.1 Feature Types. Aims and Objectives

It was decided that a rather large number of feature types should be captured in separate layers. The various feature types existing in the model were noted after a closer inspection of the model and interpretation of the detail present in the area using the high magnification lenses of the instrument.

The selection of these specific types, although arbitrary, was made in such a way that the boundaries, buildings and communication networks were classified into as many categories as possible.

The reason for this was to cover the intended needs of a cadastral database, even when this database is in its most advanced form and serves multiple purposes. Also the idea of creating as many information levels as possible was in order to visualise how the system can handle a large number of layers, especially when their volume increases. Also, it would allow any problems concerning their transfer to other packages for editing and further manipulation to be identified. In other words, the potential of this photogrammetric method to discriminate features and of the whole system to capture and transfer that data was to be investigated.

5.4.2 Feature Coding System

In order to establish the specific feature coding system to be used for cadastral purposes, a number of points had to be considered. The codes had to be as short and simple as possible in order to save space and time. Also they should have a logical sequence according to the importance of the feature or the frequency of their occurrence and exhibit some kind of consistency between the subclasses. In other words, an attempt was made to achieve a short of hierarchy in the feature coding. Another aspect which was considered was the ability of the coding system to expand in a uniform manner. In other words, it was necessary to ensure that the system could accept new features with their codes, if these should appear later and needed to be included. All this should be possible while still retaining the existing hierarchy.

Communication Features

Roads	Rail	Canal
101 Highway	130	140
102 Main road		
103 Secondary road		
104 Track		
105 Private		
106 Unclassified		
107 Path		
110 Bridge		

Boundaries

200 Any other coded feature	211 Barrier
201 High wall >1m	212 Metal palisade
202 Short wall <1m	213 Timber palisade
203 Retaining wall	214 Fence
204 Wall + Fence	215 Ditch
205 Ruined wall	216 Edge of cultivation/terrain type
206 Break of slope	217 Tree Row
207 Gate	220 Other boundary
210 Hedge	230 Estimated boundary

Buildings

301 Ground floor, flat top	321 Church
302 Ground floor, tile roof	322 School
303 One floor, flat top	330 Ruins
304 One floor, tile roof	340 Ancient Ruins
305 Multifloor	350 Industrial Building
306 Unfinished	360 Gas Station
310 Shed/store	370 Other

Water Features

401 Sea
402 Lake
410 River
411 Stream

Table 5.1 Feature Codes

As can be seen in Table 5.1, the coding system which was established comprises 3-digit codes. Four main feature categories are clearly seen, namely (i) the communication features; (ii) the boundaries; (iii) the buildings; and (iv) the water features. The first digit of each of the codes is assigned to these categories.

It was quickly realised that those features belonging to the communications or buildings category, might also act a boundary. To cater for this, the code 200 was assigned to all those features which had to be digitised or, more accurately duplicated by the use of the "snap" command for the end points of each line segment to be duplicated. This had to be done for all the features with a common edge, where a single line had to be measured in order to ensure consistency of the data and avoid unwanted gaps and overlaps. This had to be done with all the lines that were common to more than one feature. For example, when a single line was a road, a boundary and a building at the same time.

However snapping along a line is a tedious job and, as will be seen, proved to be very troublesome. Hence, a slight alternation was made to the coding for the second model which improved things significantly. In this case, the code 230 was used as an estimated boundary when there was an uncertainty as to where a boundary was running, or where there was no physical evidence but it was fairly obvious that a boundary must exist there. The "other boundary / unidentified" code 230 was used when there was a difficulty in classifying a possible boundary into any of the other categories.

The features identified in this model were the following:

Communication	Boundaries		Buildings	
101	200	207	301	310
102	201	210	302	321
103	202	215	303	322
104	203	216	304	330
105	204	217	305	340
110	205	220	306	360
	206	230		

Table 5.2 Corinth - Feature codes.

5.4.3 Data Acquisition

Once the main feature code table was established, the measurement and digitisation of individual features begun. This was done point-by-point and not in stream mode since most of the features, houses, plot sides, etc., consist of long straight line segments. Thus accuracy was optimised and the amount of data captured was kept to minimum. As will be seen later, the stream mode of operation could cause significant difficulties with the existing coding using the current version of RPLOT, even with features of a curved nature such as tracks or rivers.

The manner in which the measurement of the features digitising was performed was as follows. The model was subdivided into smaller sections, usually blocks surrounded by roads and an attempt was made to ensure that all the features of the same type were digitised in sequence. This saved time since it reduced the need to turn to the computer and continually change the feature code, but the complexity of the lines very often imposed this latter solution.

A small defect of the software was noted here with respect to the pre-event counter. This was continuously incrementing each time a swap was made from one feature to the other, even if no points were digitised. The final result that a huge number of features were indicated as having been digitised, something which was far away from reality.

As it had been noted previously, some lines being common to a number of features, have to appear in their corresponding layer. A simple digitisation over the same line at a second or later pass cannot be the solution since this will produce gaps and overlaps (slivers) which, even if not obvious at the scale of interest, will cause problems at the stage of structuring the data.

For this reason, the next feature line was snapped point by point to the previously digitised common line of another feature. This however was not as straight forward a task as it might look. In relatively straight or curved lines made up of many segments, as in the case of a road, it was very easy to miss one or more points of the "underlying" line which immediately produced sliver polygons. A solution for this might be the use of crosses for the points being digitised. Since this can be confusing in areas of great line complexity, toggling between crosses and points would seem to be very helpful.

Deletion of the last segment once it is snapped is not a "one button" operation. Editing of course is possible, on- or off-line, but here is the weakest point of the RPLOT package, according to the present author. Even when the cursor is placed exactly on the line to be edited, it is very usual that another line is selected instead of the intended one. This problem gets considerably worse as the data file gets larger. Increasing the scale of the detail displayed on the screen is often not an effective solution and so the selection of the specific line which is required becomes impossible, even when the density of the surrounding lines is relatively small.

The only solution then is to delete any of the adjacent line segments which are selected first, until the required segment is finally highlighted. Obviously at the very least, this doubles the digitising time and proves to be very tedious for the operator, especially if the lines which have to be deleted appear on many layers.

The considerable searching time through the file required for operations like that described above is another matter to consider. Searching is performed by passing through the whole file. This becomes a very time consuming operation especially when data files exceed a size of about 0.2Mb.

Operations such as zooming and display centring are also very slow with large data files. The only solution is to try and keep the files small by subdividing the model into smaller areas which is also essential for the DXF translations - as will be seen later.

5.4.4 The Peculiarities of the Corinth Model

With respect to the model itself, the following points can be made.

A pattern of disordered (and perhaps uncontrolled and illegal) buildings characterises a great part of the model. This probably reflects the reality of a large number of areas in Greece. The uneven shapes of many plots as well as the frequent lack of a physical boundary on the ground, limited the number of the parcels for which all the sides were visible or could be estimated. The exact degree of incompleteness however is something which can only be estimated after the field completion operations have been made.

5.4.5 Translation of Files to DXF Format

In order to create a DXF file and transfer the stored data into other packages, the DXF attribute table has to be filled in order to relate the feature names with the layers to be created. However, this version of RPLOT handling only nine different record types did not allow for an ordered translation of all the feature types which had been digitised.

A DXF file takes about 3 times the memory space of the RPT file from which it is derived. The large data volume generated by this model resulting in long searching times and previous experience of overflowing during translations to DXF files, suggested the splitting of the model into 2 files, ACOR1 and ACOR11, of unequal size. The file ACOR.RPT demands 265kb of memory space, and this is the largest file size which does not give any trouble at the translation stage. These files were later merged into one during editing using MicroStation.

5.5 The Omvria Achaias (OA) Model - Measured Using a Kern PG-2

The procedures followed for the OA model were basically the same as those for the previous model.

A relative orientation was performed, the working files were opened and filled and the control points measured. With respect to the absolute orientation, very small corrections were necessary for the common phi and omega settings, which were applied empirically since it was found to be more effective to do this for these small corrections. After two iterative cycles, the rmse values obtained for the measured control points were very small. The rmse vector obtained had a magnitude of ±0.524m.

5.5.1 Observing the Model.- Coding and the Peculiarities of the Model

Concerning the feature coding required for this model, a few changes had to be made. The features, track (104) and path (107), which often served also as a boundary, were encountered frequently in this model. Having the experience of the previous model, it was considered much more helpful if their coding was given the extension "b", whenever these served also as a boundary. This action greatly reduced the digitising times but, most importantly, it eliminated the confusion experienced during the snapping of the "boundary" code 200.

The same tactic could possibly have been followed for all these linear features which also constituted a boundary. However, this would have virtually doubled the number of codes and was therefore avoided. Obviously it is up to the user's judgment as to whether or not this modification should be used, but it can be recommended for the long multisegment features.

The features identified in this model were as follows:

Communication	Boundaries		Buildings	
103	104b	205	301	310
104	107b	207	302	330
104b	200	210	303	340
107b	201	214	304	350
	202	215	305	
	203	216	306	
	204	217		
	220	230		

Table 5.3 Achaia - Feature codes.

Regarding the terrain covered by this model, it consisted mainly of rural plots, often surrounded by rows of trees. The identification of the boundaries was quite a difficult task and even if the operator was more experienced, he would have again to estimate their position in many cases. Obviously this would need detailed verification and perhaps additional measurements on the ground.

A feature of the PG-2, the facility to change the optical magnification proved to be very helpful for the whole process. Once a boundary was identified at the lower magnification (x2 or x4) by having a broader view of the terrain, it could then be accurately measured at the higher (x8) magnification provided by the instrument.

Concerning the measurement of various features, this was a similar task to that of the ACOR model. However the construction of the Kern PG-2 allows only a 1:1 movement in the model space. The more compact design of the instrument makes it more sensitive to X and Y movements in the model space as compared with the Galileo or other stereo-plotters. This made the measurements a slightly more difficult task.

Again, as with the previous model and using the earlier version of RPLOT, the selection of a segment for editing was often a complicated task. Once a feature was "snapped", there was no backspace facility and many previously digitised segments had to be deleted. This combined with the "sensitive" XY model movement and the diversities of the houses in the model, made the digitising of the various house categories a time-consuming task.

5.5.2 Translation of OA File to DXF Format

Based on the previous experience, the translation of the OA file to DXF format was less troublesome than it was with the first model. The attributes table could handle all the feature types and their translation kept the specified order.

5.6 Data Editing through the Use of the MicroStation PC 4 Graphics Software Package

A direct plot output is possible within RPLOT if such is required. However, if further extensive editing and manipulation of data is required, then their transfer to other software which has better facilities than RPLOT should be carried out. Intergraph MicroStation PC 4, is such an efficient, versatile and easy-to-use PC graphics software package and was utilised for the sorting out of the data previously captured by the two analogue stereoplotting instruments in conjunction with RPLOT.

Originally the MicroStation PC software package was developed mainly as a Computer

Aided Design (CAD) system, for applications such as architecture, engineering drawing, mechanical drawing, electronic circuit designs, etc. Since it incorporates powerful general purpose digitising and editing facilities for digital data capture and manipulation, it has also been used extensively in the field of digital mapping and related applications. In fact, it has also been further developed into the MGE (MicroStation GIS Environment) package which is now one of Intergraph's main products in the GIS/LIS market.

5.6.1 Hardware Requirements for MicroStation PC 4

A variety of IBM compatible personal computers using the PC-DOS or MS-DOS operating systems (Version 3 or later) can be used to operate MicroStation PC 4 starting from the IBM PC/XT up to the more powerful IBM PC and PS/2 386/486 compatibles. A minimum of 640kb of RAM is required for the basic operations, although extra memory can increase the speed of many of them. A hard disk with a minimum of 10Mb is also needed, to store the programs and the working files, though usually a larger disk is preferred. The graphical input to MicroStation can be from a variety of devices. Either the keyboard can be used where commands or coordinate values can be keyed in or a digitising tablet may be used for rapid data placement. Alternatively a mouse/trackerball can be utilised in a much the same way as a digitiser cursor, although not for digitising existing graphical data, due to the lack of fine control using these devices.

Finally data can be imported from other software packages as files in DXF or ASCII format, as has been done in this project. In terms of graphics display, MicroStation requires a supported graphics display controller and a compatible monitor. A wide variety of such graphics cards and display monitors can be used, starting from cheap low resolution monochrome displays up to high performance colour displays.

5.6.2 Basic Concepts

5.6.2.1 Importing of Data

The possibility to import data in DXF format to MicroStation was borne in mind during the stereo-plotting stage described in 5.4.5, so DXF files were created at that stage. In practice, to import a DXF or ASCII input file is usually a straightforward operation implemented by selecting the import command from one of the pull down menus. However, this manner of data import did not prove to be successful with RPLOT. DXF files carry a header at their beginning with relevant information concerning their contents. In the event, the header that RPLOT produced was not appropriate for MicroStation 4. Experience of previous users of RPLOT had shown that these DXF files could be imported successfully into the previous version (3) of MicroStation. This procedure was adopted as a preliminary step before data manipulation was possible within MicroStation 4.

In fact, MicroStation 3 was still loaded on a couple of PCs in the Department, one of them being the PC dedicated to the Galileo stereoplotter. A special menu called the Microstation Command Environment (MCE) is used to start this version, but is also available in Version 4 of MicroStation. From MCE, files can be created and opened for manipulation or plotting procedures can be activated.

5.6.2.2 The Design File

The first step to be performed prior to data import is to open a design file. The MicroStation "design files", contain the data input by the user to represent the component elements of a design, such as lines, line strings and shapes. Design files are created from the MCE Utilities option.

For this project, 3D design files were created. However, prior to the creation of a design file, a seed file has to be specified which sets the units of size and area, so that the internal units utilised by the system are related to the user units. Various seed files exist for different applications and the metric mapping seed file was selected to relate the ground coordinates in metres with the internal positional units of the system.

5.6.2.3 Levels

A principle used in the majority of map digitising packages, as in the case of RPLOT, is to differentiate the various map features, i.e. whether these are boundaries, building outlines, etc. This differentiation is made, as was mentioned for example in 5.4.1, through the use of feature codes, where each map feature is assigned a numeric or alphanumeric code. MicroStation however, does not employ such feature codes, reflecting its CADD origins, but allows for a feature separation on 63 different levels. Hence the feature codes devised earlier in this project had to be translated into level values ranging from 1 up to 63. This relation is specified in the appropriate table of the input/output utilities (Figure 5.2).

In that sense, levels are a simple and easily understood means of sub-dividing the data contained in the design files and all or any combination of individual levels can be displayed on the screen at any one time. However, only one level at a time is the ACTIVE LEVEL, which means that new data entry and all the possible manipulation of data can only be carried out for that level. However, functions such as line attribute changes (colour, etc.) of any level or the copying of lines from other levels is possible even though these other levels are not currently active. So care must be taken to verify which is the active level before any work is carried out, since data may be inadvertently added to the wrong level.

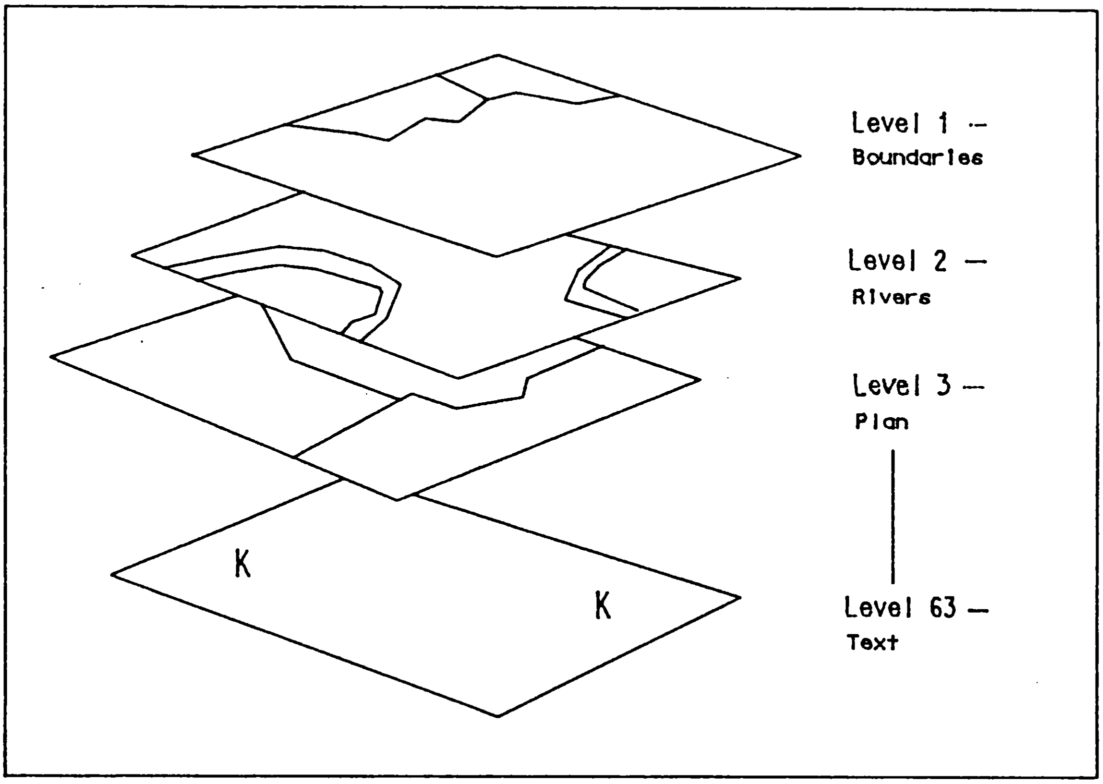


Figure 5.2 Levels.

5.6.2.4 Graphic Elements Employed in MicroStation

A group of graphic elements go to make up the digital map. These are the following, (Figure 5.3): a point, a line, a line string, a closed shape, a single line text, an ellipse, an arc, a curve, and a B-spline curve are those available to the user. Those elements which were the main concern of this project were the line, the line string and the closed shapes and so these will be described here in more detail.

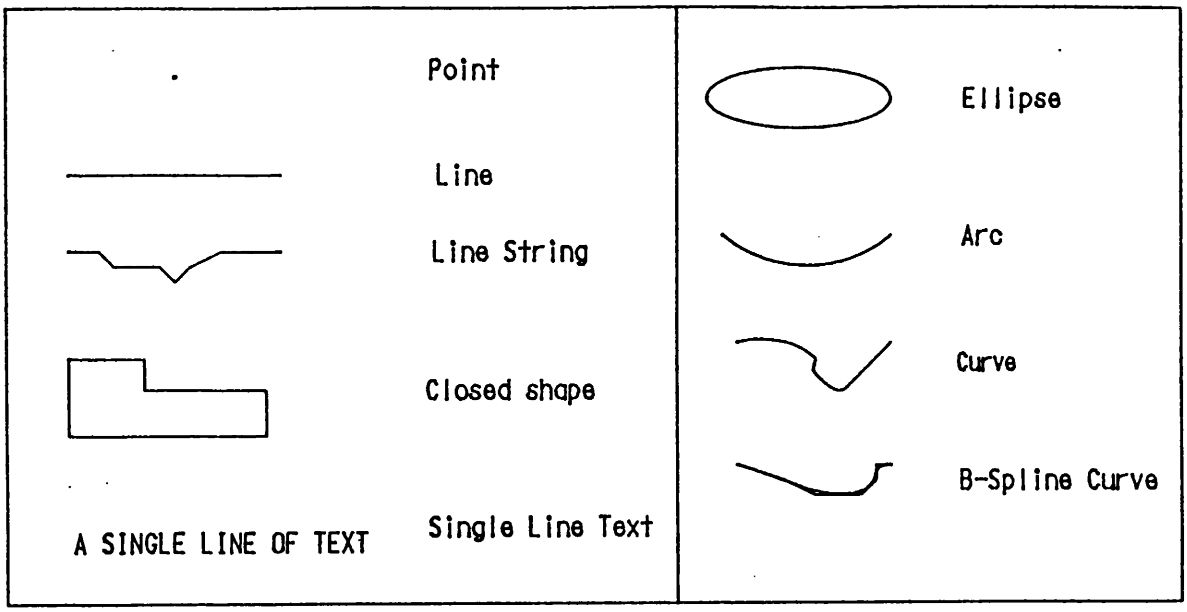


Figure 5.3 Graphic elements.

5.6.2.5 Lines

As stated above, there are two types of lines defined by MicroStation - the line element and the line string element. Each line element is recognised as an individual element upon which manipulations can be carried out (Figure 5.4).

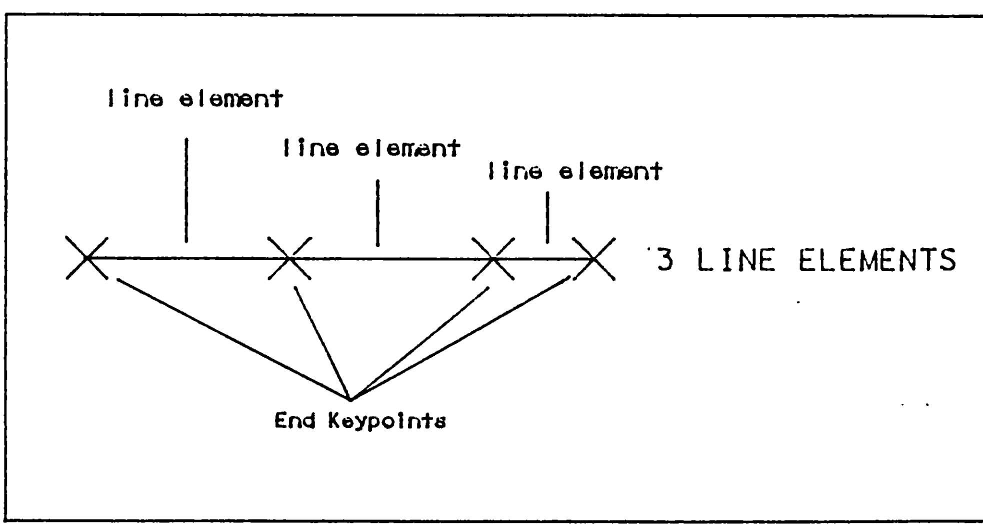


Figure 5.4 Line element.

The use of the line string element is similar to that of the line element, although if the former is utilised for the line digitising of a series of line elements (known more widely as line segments), the system will recognise the resulting line as a single element (Figure 5.5).

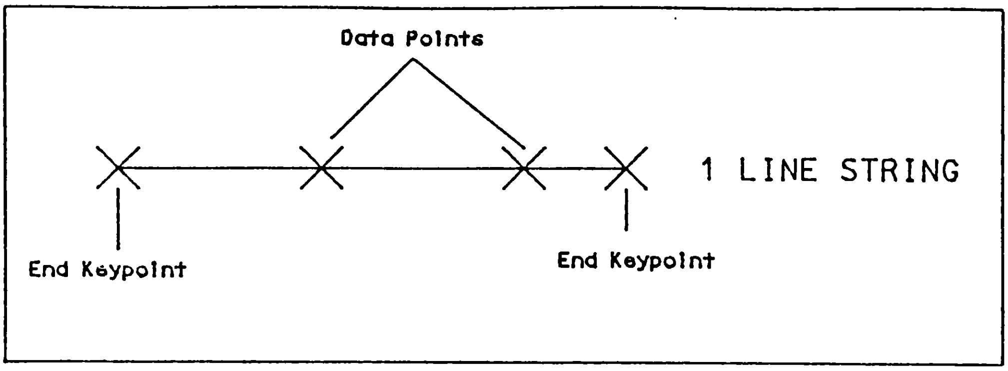


Figure 5.5 Line string element.

The selection of the line string element has two main advantages over the line element. Firstly, due to the way that data is stored, it uses less memory space. The second advantage is related to the manipulation of the line string element, which, being recognised as a single element, allows quicker manipulations.

5.6.2.6 Closed Shapes

The element which defines a closed polygon is referred to in MicroStation as a closed shape. If an area is enclosed by individual line segments or one line string element, then even if the start and end points are the same, that area will not be recognised as a shape. The shape has to be defined specifically as being closed.

In order to define a shape, either the command Place Shape is selected prior to digitisation or the command Construct Shape is used to build shapes from previously digitised line elements and/or strings. For this latter command, two options exist, where either each line element has to be identified by the cursor (manual construction) or the system is automatically searching for the next elements in order to construct the shape. In this latter case, the operator is prompted to accept the highlighted element, where, at junctions, the Fork-Accept/reject Path appears.

Choosing the appropriate method to construct a shape, depends on the type, size and complexity of the area outline. For areas with common boundaries with other shapes, the Construct Shape command is preferable and the manual option is selected when each line or line string element is clearly identifiable on the screen. The automatic option is more suitable for large areas formed by many small line elements, where perhaps the screen resolution may not allow for a clear identification of each line element. As will be seen, this latter option was preferred for the construction of shapes in this project.

5.6.3 Data Manipulation

As soon as the data is in the form of a Design file, editing and manipulation is possible. Element attributes such as colour, style and weight can be changed or the elements can be transferred or copied into another level, deleted and so on.

The following manipulation options were mainly utilised in this project:

1) Change Colour- changes the colour of an element to the active colour.
2) Change Level- changes the level of an element to the active level.
3) Construct Shape- builds a shape from a series of open elements. The end point of each element must coincide with the first point of the next element.
4) Delete- deletes an element from the display.
5) Delete Partial- deletes a portion of an element.
6) Place Fence Block- places a rectangular 'Fence' (i.e. a box), defined by two diagonally placed points which encompass the selected elements.
7) Fence Copy- copies elements within the 'Active Fence' and places them elsewhere.
8) Drop Complex- drops the complex status of a complex element, as a Constructed Shape, back to its original form, either line strings or line elements.
9) Drop String- drops the single element status of a line string into individual line elements.

5.6.3.1 Linking of Line Elements

Lines or line elements, being common to various features or having common interesting or closing points, should share the same coordinates for these common points, not only because gaps and overlaps will be apparent on the graphic output, but also because this is a necessary prerequisite for the later building of a structured database.

In MicroStation, the manipulation known as Snapping can fulfil the above requirement, by linking the end point of one linear element with another linear element. This can be achieved by the use of what is known as a Tentative Point.

5.6.4 The Manipulation of the Two Test Area Files Derived from RPLOT

5.6.4.1 The Preliminaries

As was stated in section 5.4.5, the files ACOR1.DXF, ACOR11.DXF obtained from the Corinth test area, and the file OA.DXF obtained from the Achaia test area, were input to

MicroStation 3 and the relevant Design (DGN) files were produced for further manipulation in Version 4, the latest version of MicroStation.

As was mentioned in section 5.4.5, there is a restriction to only nine different feature names in the attribute table of the early version of the RPLOT package. The result of this restriction became obvious at this stage, when the design files ACOR1 and ACOR11.DGN were created within MicroStation. When the levels were examined, it was seen that various levels were occupied at random by various feature types, although the features themselves were distinct and not mixed with each other at each level.

The random occupation of levels by the various features was not repeated with the file OA.DXF obtained by the later RPLOT version. With this version, there was an ordered relation of the MicroStation levels with respect to the other feature types.

5.6.5 The Corinth Test Area Files Manipulation

5.6.5.1 Merging of Files

Once the ACOR1 and ACOR11 Design files were created, they were copied into MicroStation 4.

The first step was to merge the two files together in order to create an uniform file of the Corinth test area. However, as explained earlier, the random allocation of levels for the various feature types, meant that the same feature types occupied different levels in these two Design files which were intended to be merged together. So, before merging the files, each feature type represented in each level, had to be identified. This operation was somewhat troublesome, especially in the case of the identification of the building types of which there was a total of twelve. By inspecting the paper prints of the area using a stereoscope, all the feature types of each level were eventually identified. Soon after that, the various features were rearranged within the available 63 levels to enable merging to take place. The Place Fence Block, Copy Fence and Change Level were the main options used for that operation.

After the tidying up of the features, merging of the files became possible. This was done by entering the Utilities Sub-directory of MicroStation and typing the command

Merge c:\dgn.A \dgn.B

where A is the initial file and B is the derived file

Hence the file ACOR11.DGN was created by merging files ACOR1.DGN and ACOR11.DGN together. This new file was then viewed and checked for completeness and the correct ordering of features within the levels.

5.6.5.2 Data Manipulation, Polygon Checking, Construction of Shapes

After finishing the above, checking was carried out within each individual level to verify that all the polygons were complete and closing. This careful examination was carried out by zooming in on small area patches, and by selecting each line element and line string element of the intended shape. Only in very rare cases did a gap exist, but sometimes a second line element had be snapped over another within the same level.

In general, at this stage, it was seen that a careful digitising of the measured data with RPLOT will require a minimum manipulation of the former. This was valid even in the case of a model such as Corinth with a rather great complexity of lines and their multiple occurrence on various levels. The manipulation options Delete, Delete Partial, Place Fence, Change Level and Place Line were mainly used here.

At this stage, it was time to Construct the individual shapes. Since each shape had been checked for completeness earlier, the Construct Shape Automatic option was mainly selected to construct the shape from the relevant series of line elements.

Care had to be taken at line junctions where the operator is asked to select the specific path to be followed in order to construct the shape which is really required (Figure 5.6).

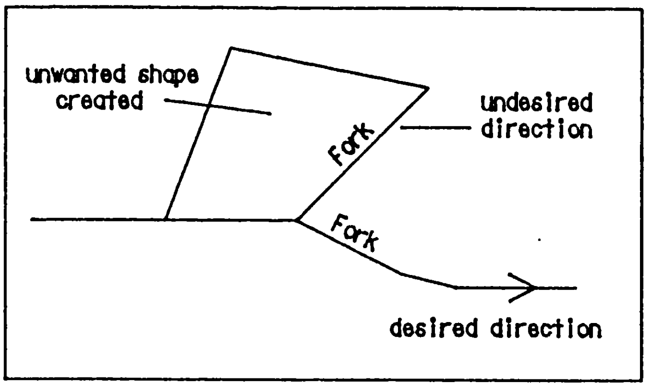


Figure 5.6 Selection of path.

However some cases were encountered when the display of the line elements needed to construct the appropriate shape was not correct, in which case, the line strings had to be dropped to single elements. Similarly, the complex status of a constructed shape or line with multiple occurrence on various levels had to be dropped in some cases. The commands Drop String and Drop Complex had been utilised for these operations, followed by the Construct Shape Automatic. The above operations were carried out for all the shapes on all the different levels and a final check was then made.

5.6.5.3 Line Colour Attributes

Once all the editing of lines and the construction of shapes was complete, a colour value obtained from the Colour Palette sub-menu was assigned to each feature level. It was decided to subdivide all data into four major groups and assign to them a different colour. In that way, data would also appear to be subdivided into these four major groups on the hard copy maps which were going to be produced. Hence, all the boundary feature types (feature code class 200) were given a black colour except the two layers of "other boundary" (220) and "estimated" (230) which were given a blue colour. All the communication features (feature code class 100) were given a green colour and all the buildings (feature code class 300) had a red colour.

5.6.6 The OA File from the Achaia Model

Almost the same kind of operations as those described above for Corinth were followed for the manipulation of the file OA.DGN obtained from the Achaia test area model. This file, being smaller in size, was the only output file from that model, so no merging of files was necessary in this case. The actual editing of the OA file followed the steps of the previously edited ACOR file, although the comparatively small complexity of lines and the few multiple occurrences of lines in various levels made these operations much quicker.

5.6.7 Generation of Plots

In order to obtain a hard copy plot from MicroStation, a plot file has to be generated as a first stage in the process and then this file has to be sent to a plotter. The plot file holds all the data intended to be plotted as well as the drawing commands for the plotter. However, prior to the creation of a plot file, the screen display has first to be checked for the completeness of these levels that need to be plotted. Then either the whole view, or part of the view defined within a 'Fence' (i.e. box), as in this project, can be plotted.

Once the Plot command has been selected, a window is displayed which contains a number of parameters which have to be specified by the user. This include the plot file name; whether data comes from a Fence or not; the plot size specification including the scale factor, X and Y size, paper size and options for the plot origin.

In conjunction with the above, a plotter configuration file has to be assigned with respect to the plotter to be used, and after that, a plot file is written. This plot file can be sent to the plotter by selecting the relevant command from the MCE menu. However, during this project, a link was not found between the sub-directory where the plot files are generated and the one from which they are sent to the plotter. Hence, the files had to be copied from the sub- directory

c:\USTATION\plotting\pltfiles\

to the subdirectory

c:\USTATION\tmp

Initially test plots were produced for the two test areas at the largest possible scale for each file to fit onto the A1 size paper that the HP Draftpro plotter can accommodate. For the Corinth area, a 1:2,000 scale plot was generated, whereas the Achaia area could fit an A1 size plot only at a scale up to 1:2,500. This resulted from the orientation of the model, which was not in parallel but was skewed with respect to the National Grid.

5.7 Conclusions

The capture of cadastral data of the two test areas of this project by the digitally encoded stereo-plotters and the subsequent editing of the data within the MicroStation system, allowed the operator to gain considerable experience concerning their operation and possible application in cadastral surveys.

Despite the difficulties encountered, the photogrammetric system which was examined showed its capabilities for the identification of a high percentage of cadastral information, although an accurate assessment will necessitate the use of a comprehensive field completion and verification. Undeniably the capability that the digital encoding system gives for numerical output provides great potential and extends the use of those analogue stereo-plotters which were used for the test. The coordinates obtained in digital form can be input directly to a modern digital cadastral database. The data obtained from the two test areas concerning natural feature boundaries might be of lower accuracy than the maximum accuracy that the stereoplotter could possibly give, if the appropriate signalised points could have been used. This signalisation would have been necessary for a numerical cadastre requiring the highest accuracy that these stereo-plotters can offer, as has been discussed in Chapter 4. On the other hand, signalisation can "simply" increase the percentage of the land parcels being identified clearly and hence plotted no matter which cadastral system is being considered.

However, in any case, digitally encoded stereo-plotting will be a must, since the plotting of highly elevated or steeply situated boundaries in cadastral surveys (likely to be encountered in Greece) will still have high accuracy requirements whatever system they serve. As mentioned above, the need for digital output will be an essential requirement for the automation of operations which is something of vital importance, especially in those cases where a cadastral system has to be established from the beginning, as in the case of Greece. Furthermore, the ability of systems such as the RPLOT to capture and successfully handle data in a large number of separate information layers (as was proved in these tests), can extend its use for those cadastral applications which are serving multiple purposes. The capability to measure and digitise different types of features and place them into different information levels, was greatly facilitated with the system examined.

Although some problems started to occur, especially with the increased volume and complexity of digitised lines, this is really a matter of system improvement and is not something which can be characterised as a major drawback. The gain in terms of operational time is considerable when this method is compared with conventional stereo-plotting, especially when corrections to the detail plotted during the data acquisition operation are considered. Plotting is more accurate and furthermore, all polygon lines close exactly with the snapping of their first and last points. This saves a tremendous amount of time during the later editing operations for the probable input structure of the data in a digital data base, if this is required. In any case, plotting times will increase considerably with the increased number of information levels required.

The actual time which was taken by the operator who plotted the two test models, should not be of any interest having regard to his inexperience both as a photogrammetrist and as a user of the RPLOT system, but also due to the increased number of feature levels used. The assistance that the RPLOT system gives during the absolute orientation of the models is another welcome and time-saving feature of the system.

The transfer and editing of the digital data output from the photogrammetric system examined, did show up a small number of difficulties, being even less for the later version of RPLOT. During the later manipulation of this data within MicroStation, it was seen that only a minimum amount of editing was required, confirming once more the functionality of the digitally encoded photogrammetric plotter for the cadastral mapping application.

CHAPTER SIX

Chapter 6

Application Tests for Cadastral Surveys based on Monoplotting from Rectified Digital Photographs

6.1 Introduction

The production of orthophotography from digital rectification of single photographs as well as from stereopairs for cadastral survey applications had been introduced in Chapter 4, with examples of production systems as tested and implemented in various countries to serve their own cadastral needs.

The part of the project which is described in Chapters 6 and 7 concerns the application tests of orthophotography for a newly established cadastral system as foreseen for a case such as that of Greece. In this Chapter (6), the acquisition of linear cadastral information from a digitally rectified image using an on-screen mode of operation was tested. These tests were based on the use of a digital monoplotting system, called the Geocoding Aerial Photo System (GAPS), developed at the GeoData Institute of the University of Southampton. This system was originally developed on the basis of a simple projective transformation, applying corrections for tilts but not for relief displacements. It has since been improved and extended to offer differential rectification of single photographs, utilising height information in the form of a digital terrain model (DTM). This second option provided by GAPS was of primary interest considering the relatively large relief displacements that will be produced by the highly undulated terrain of Greece.

The tests of the GAPS package that have been undertaken for the present study are the first which have been conducted outside the GeoData Institute and can be viewed as being an independent check on the practical use of the package. The specific aim of testing GAPS was to verify the suitability of the package as a production system for cadastral surveys, giving particular attention both to the accuracy that can be achieved, but also to the practicality of its implementation for the needs of a cadastre as in the case of Greece. Indeed the assumption was made that the hardware necessary for the implementation of GAPS would be readily and cheaply available and hence GAPS could possibly have practical implementation, especially in the context of a decentralised cadastral system, as is the case with the existing land registration system currently in operation in Greece.

In particular, two versions of GAPS were made available for this project, both of which have been produced quite recently. The first version has been developed for implementation on a PC microcomputer and the second is a Unix-based version, especially developed for use on an IBM RS 6000 graphics workstation. However, as will be seen in this chapter, both versions of GAPS revealed very important restrictions in their practical implementation within an extensive cadastral programme considering their current stage of development. For the testing of GAPS, as with all the other tests in this project, the same photographic material covering two test areas in Greece has been utilised. However, the two test area photographs had been scanned to produce the necessary input to the system in digital form.

6.2 Image Acquisition and Accuracy Considerations for the Digital Monoplotting of the Test Areas

The two test area photos, one from each stereopair, which were used during stereoplotting, were sent to the GeoData Institute of the University of Southampton which developed the GAPS software. The two photographs were scanned on the A4 size IBM PageScanner which was available there. This produced the digital image files in TIFF (Tagged Image File Format), the necessary input for GAPS. The selection of this particular scanner was based on the troubles experienced during a previous M. App. Sci. degree project in the Department which included some unsuccessful attempts to import into GAPS image files, which had been scanned both on an IBM 8117 scanner producing bilevel TIFF image files and on an Apple scanner.

The photographs were scanned at 300 dots per inch (dpi), the maximum resolution that the scanner could give. Scanning at 300dpi corresponds to a resolution of 85μm in the plane of the image. Considering the scale of the test photographs (1:6,000), 85μm on the image, represents 51cm on the ground. This resolution can be considered to be relatively low for cadastral surveys, even if these surveys serve a graphical cadastre. Furthermore, the accuracy of the cadastral data measured within GAPS on such a rectified image was expected to be lower than the resolution of the scanned image, and the actual rmse values for the data might easily be double or even more than this resolution. The sources of error causing the deterioration of accuracy will be (i) the quality of the photographic image; (ii) the possible deformations and systematic errors of the image in digital form; (iii) the accuracy of the control data set necessary for the rectification; (iv) the accuracy of identification of the measured objects and (v) the rigour of the computational models used for the rectification.

However, scanning at higher resolutions has the major disadvantage of requiring more memory space in the computer, which increases rapidly for a relatively small increase of the scanning resolution. For the scanning of a single photograph on the A4 sized scanner at 300dpi, a memory space of approximately 3.6Mb was required. A slight increase of resolution to 400dpi would mean almost doubling the required memory space. Furthermore, the processing times for the rectification of an image on a given computer will also increase rapidly for a slightly increase in resolution.

All the above considerations had to be balanced and the decision was taken to experiment with the images of 300dpi resolution. If the rmse values obtainable in the image plane, were double that of the image resolution (i.e. 85μm), this would mean rmse values of approximately 1m on the ground. Such rmse values approximate to the tolerances given for cadastral mapping at the scale of 1:2,500 by say the Italian graphical cadastre regulations and were considered of practical value. Of course, larger scale photographs could be used if higher accuracies were required in the final results.

6.3 Rectification of Single Photographs in Digital Form

As it was mentioned in Chapter 4 (4.2.2.2), there are three commonly used rectification methods for digital imagery. The GAPS digital monoplotting system which was tested in this project utilises either a simple projective transformation (developed by Azizi), or a differential rectification by the use of a bilinear interpolation of point heights from a DTM. Bilinear interpolation of heights, although it is less demanding in computational times than the higher order polynomials, is said to suit satisfactorily terrains types of hilly nature.

GAPS offers two possible modes of operation which are quite different to that usually employed by digital monoplotting programs using hard copy photographs such as that developed by Nicklin (1988). In the hard copy on-line solution, each point which is measured during the data capture, is rectified for tilt and relief from heights interpolated from the DTM in real time. Such a continuous rectification and generation of the measured point and line information is not implemented with GAPS, where either:

i) the features are measured on the unrectified digital photograph and the rectification is performed on the captured set of vector data, or

ii) the digital image is corrected for tilts (and relief) first and the features are then measured on the rectified image (i.e. orthophoto) to obtain the vector data in the relevant map coordinate system.

6.3.1 Rectification of Vector Data

The rectification of vector data is in close relation to the off-line solution of hard copy digital monoplotting systems as described as early as 1973(a) by Makarovic. As soon as the full set of vector data has been measured, it is then corrected for tilts and also for relief if a DTM is available, using the exterior orientation parameters obtained after the capture of image coordinate values for the control points. If a DTM is used for the rectification, a height value is interpolated (Figure 6.1) for every feature data point in an iterative process.

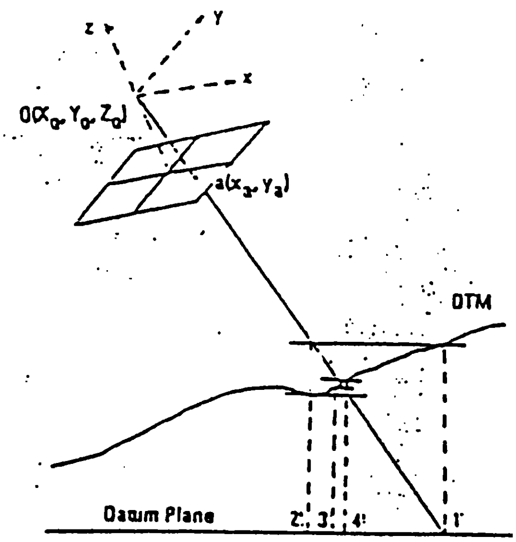


Figure 6.1 Interpolation of height from DTM.

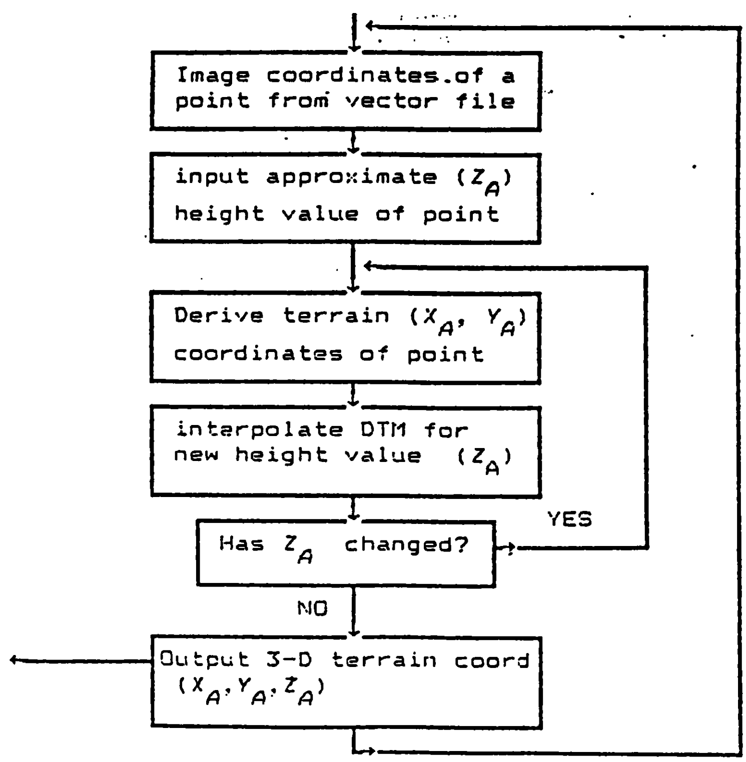


Figure 6.2 DMP process utilising DTM data.

Although the rectification is not done in real-time, but after the measurement of the vector features in an off-line mode, this mode of operation is analogous to the DMP solution mentioned above and can be seen in Figure 6.2.

An initial approximate height value for each point is necessary for the generation of an initial set of the planimetric coordinates of the point, which is obtained as the mean value of the highest and the lowest height values within the DTM. This value is used to trigger the iterative cycles and the same operations are repeated for each input point of the vector data.

6.3.2 Rectification of the Digital Image

The second rectification option of the GAPS system is the rectification of the digital image, which either (i) removes the tilts present in the input image to produce a simple analytically rectified image or (ii) performs a differential rectification to form a digital orthophoto image. As mentioned in 4.2.2.2, either a direct or an indirect process for the rectification is possible. The direct method resembles to a great extent the transformation of vector data, although resampling operations are needed to assign correct brightness values to the image pixels.

In the case of the GAPS system, the second, that is the indirect approach, is implemented. This is a less costly approach in terms of computational time. The inputs to the system are terrain values and not image values as in the direct approach and the process using projective transformation or differential rectification can be seen in Figures 6.3 (a) and (b) respectively.

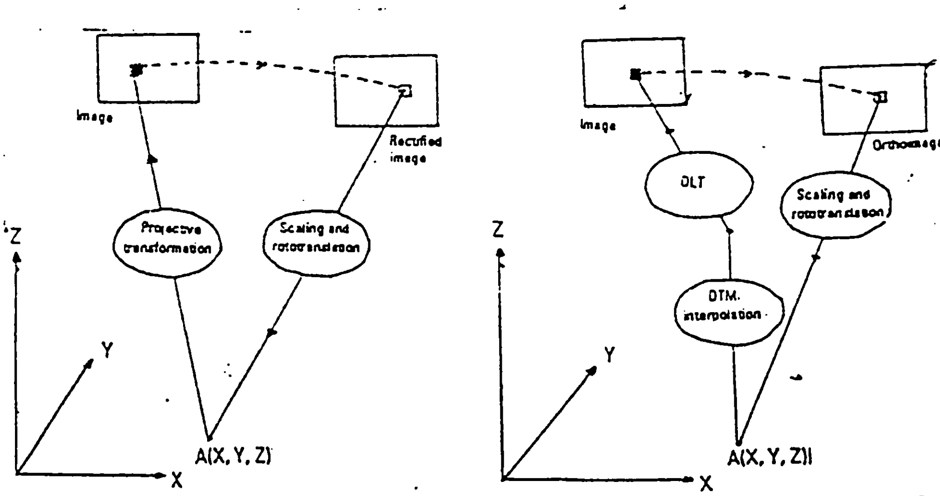


Figure 6.3 (a)Image rectification (b) Orthophoto image generation.

For the output of an orthophotoimage, the DTM interpolation process is much simpler than in the case mentioned in the previous paragraph (6.3.1). Every pixel is transformed into the terrain coordinate system from which the height value is interpolated using a bilinear interpolation algorithm. This algorithm is based on a four term polynomial (Kennie & Petrie, 1990). Once the XYZ coordinates of each point are determined, they are projected into the image coordinate system (Figure 6.4) by the use of collinearity equations. The image coordinates are transformed into the original pixel coordinate system of the digital image using an affine transformation. This affine transformation serves as a means to correct for film distortion (shrinkage) as well as non-orthogonality or different scale factors of the scanning device. Finally, the image is resampled either using the nearest neighbour or the bilinear interpolation.

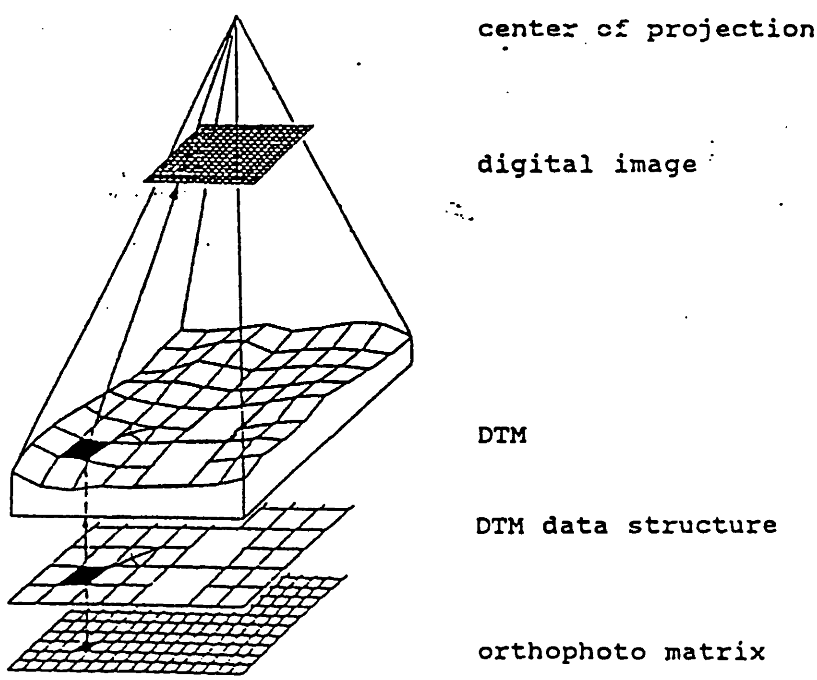


Figure 6.4 Orthophoto image generation.

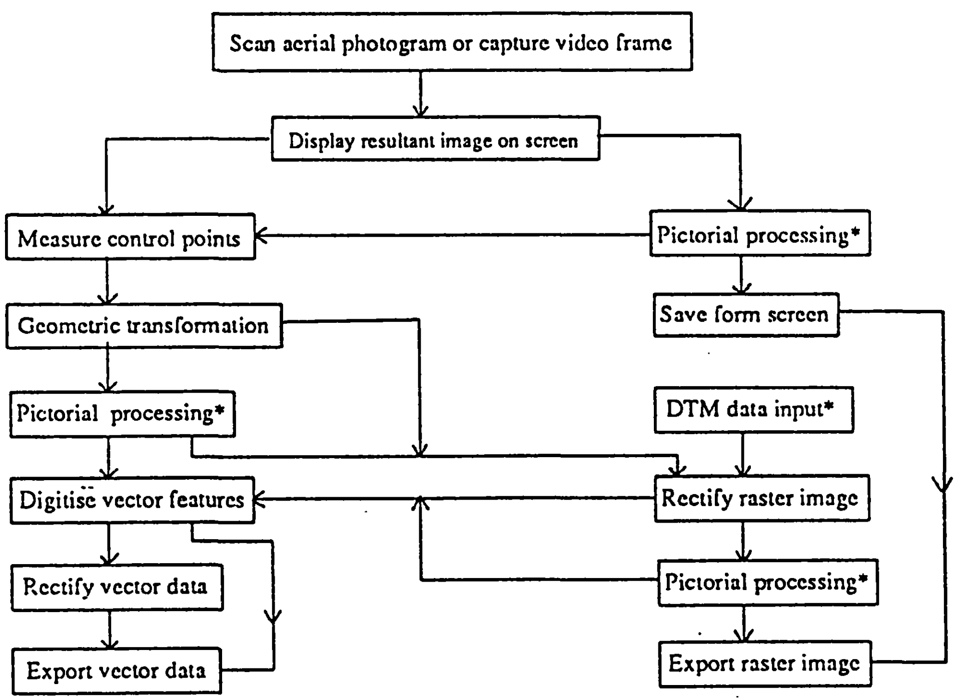
6.3.3 Principles of the PC Implementation of GAPS

The GAPS system, being written in C++ programming language, has been developed to run on an IBM PS/2 or compatible equipped with an IBM 8514 or similar graphics adapter and suitable display. There is also a PC compatible version designed for use with a high or low resolution VGA graphics display; however the modules of this version were not all fully operational on the version tested. The design of these systems is aimed at their use in a production environment, hence the options for export of the output data to a GIS (SPANS) or image processing system (ERDAS).

The input data for GAPS are images in TIFF (Tagged image File Format) obtained from scanned aerial photographs or captured video images. The image can be enhanced optionally by pictorial processing routines (contrast enhancement, filtering, etc). The other type of input data required for the operation of the system is the set of ground control point coordinates necessary for the rectification of input data.

As soon as these two sets of data are input into the system, a geometric transformation and rectification of the image is performed so that the image data being measured can fit the relevant ground coordinate system. Thematic information can be extracted from the displayed image by tracing features on the top of the image, by the use of a mouse.

The diagram below summarises the sequence of steps to be followed with the system.



* This is an optional processing

Figure 6.5 GAPS. Operations flow diagram.

6.3.3.1 Description and Evaluation of the GAPS PC Modules

The following Table 6.1 shows the function menus given in GAPS.

Main Menu	Sub-Menu	Description
- System	- Clear	(Clear the screen)
	- DOS_shell	(Go to DOS Shell)
	- Exit	(Exit this system)
	- Sound_on	(Turn audible feedback on, default)
	- Sound_off	(Turn audible feedback off)
	- Main_menu	(Return to main menu)
- Import	- Image	(Read in an image and store it in internal format)
	- DTM	(Read in DTM in NTF and store it in internal format)
	- Main_menu	(Return to main menu)
- Visualise	- Image	(Display an image)
	- Map	(Display a line map)
	- Grid	(Display a referencing grid)
	- DTM	(Display isometric view of DTM surface)
	- Clear	(Clear the screen)
	- Main_menu	(Return to main menu)
- Process	- Density	(Classification according to pixel density)
	- Filter	(Filters for smoothing and sharpening)
	- Contrast	(Contrast enhancement)
	- Edge	(Edge sharpening)
	- Save	(Save the image on screen)
	- Main_menu	(Return to main menu)
- Rectify	- Vector	(Rectify vector map)
	- Raster	(Rectify image)
	- Transform	(Geometric transformation)
	- Main_menu	(Return to main menu)
- Digitise	- Line	(Add line feature)
	- Polygon	(Add polygon feature)
	- Control	(Digitise control points for transformation)
	Pointing	
	Deleting	
	Saving	
	Cancel	
	- Main_menu	(Return to main Menu
- Graphics	- Line_width	(Select thickness for line)
	- Pen_colour	(Select pen colour for line)
	- Window_on	(Display an enlarged window near cursor);
	- Window_off	(Close down the window)
	- Main_menu	(Return to main menu)

Table 6.1 GAPS - Function menus.

- Export	- Raster		(Export raster image)
		SPANS	
		ERDAS	
		Cancel	
	- Vector		(Export vector data)
		Plotter	
		SPANS	
	- Main_menu		(Return to main menu)

Table 6.1(Cont.) GAPS - Function menus.

1) The "System" functions are those that allow the control of the system or its interface with a host computer. There are options for clearing the screen from the display of a map, a DTM or an image. The use of DOS commands without leaving GAPS is another option, as well as the possibility to receive an audible feedback on the completion of certain operations.

2) The Data Import Functions

An image or a DTM is imported by being read and stored in an internal format, to facilitate data retrieval and display. For the imported images, there are four options available. Either

i) a raw TIFF image,

ii) a rectified image,

iii) a processed and unrectified image, or

iv) a processed and rectified image

can be imported. The processed image options refer to the images saved from the screen, after having received some kind of pictorial image processing.

A DTM import function is also available. This function imports data in the OS standard format, known as National Transfer Format (NTF) and again data are stored in an internal format for visualisation of an isometric DTM view or the interpolation of image point heights for the production of orthophotos. One important restriction of GAPS for being considered as a production software package as it stands is this requirement for input data to be in NTF. This requirement does not only forbid the use of GAPS outside the UK but also greatly restricts its use within UK since only the Ordnance Survey produces DTM data in this format. Furthermore, more than one NTF version has been developed and there is also a great likelihood that more versions are to follow. For the PC version of GAPS examined in this project, the specific version of NTF that is compatible with it is not specified anywhere in the accompanying users manual. However, since the imported DTM data are held in an internal format, one easier way to bypass the use of NTF would be the transformation of the DTM data into the internal GAPS format.

It should be noted here, that digital vector data cannot be imported, and this can be considered as an important drawback especially for map revision applications. Hence, no superimposition of existing data over more recent photographs is possible for the detection of any changes.

3) The Data Display (Visualise) Functions

Images, vector data, map grids and isometric views of DTMs can all be viewed with this function. Again, the four types of images described in the previous paragraph, can be displayed and indeed this can be done much faster than at the stage of data import. This is because data are in the internal format files at this stage, which is less complex than TIFF. The visualisation of a map is important, since either rectification or exporting of vector map data which have been previously measured or traced out on the screen is allowed.

A rectified image can have a grid superimposed on it; the optional grid intervals available for this version of GAPS are 10, 50, 100, 500m, 1km and 5km respectively. In order to change the grid interval for an image, the image and the line map files will have to be redrawn.

The GAPS user's manual states that a large DTM file will first of all slow down the process of displaying the DTM isometric view but will also cause memory problems. It is thus suggested that a DTM should have a size smaller than 150 x 100 = 15,000 points. Previous experience of Matambanadzo (a former student), showed that DTMs of size 90 x 100 = 9,000 points could not be visualised. Despite that, the two DTM files (ACOR and OA) produced during this project (see 6.4.1), displayed well on the IBM 8514 graphics screen of the IBM PS/2 Model 80 available at the Department of Electrical Engineering. Their sizes were 100 x 80 and 90 x 80 points respectively. It was not possible however to visualise any DTM file on the PC VGA version of GAPS loaded on the PC in the Topographic Science Department.

4) The Image Processing Functions

A number of processing operations exist within GAPS for improving the pictorial quality of the aerial photographic image which is input into GAPS.

One first option is the density slicing operation during which the user can select colours and assign them to specific ranges of grey scale. The result is then a colour classified image on the basis of the different grey scale or colour bands. This particular kind of operation may not be applicable to cadastral surveys but it can prove very useful if thematic mapping is foreseen, where area features such as floodplains could be classified and extracted.

There is also a spatial filtering option with three types of filters implemented - a high pass, a low pass and a median filter. The high pass filter can enhance the high frequency components of the image. The low pass filter can filter out the high frequency component of the image, so that it results in a smoother looking image. The median filter is used for the removal of the so called salt and pepper noise of the image. These operations are applied pixel by pixel and are usually slow.

Contrast enhancement of the image based on a simple linear stretch is also possible within this software. This is a simpler operation for improving image quality and it is based on making use of the full range of grey levels provided by the computer. In this way, each pixel is assigned a new grey value within the range of 0 to 63. To do so, either the low limit (L) can be defined, below which all the grey values will be modified to be zero, or the high limit can be defined, over which all grey values will be modified to be 63. The values between L and H are then stretched and fitted into the range 0 to 63.

The last processing operation which has been implemented is that of edge enhancement. With this option, the edges of features such as buildings, roads, etc, are sharpened to allow better measurement or a better identification of the feature being plotted. However, it is likely that details of other content may be lost due to this operation, and the contrast of the image degraded. In that case, the contrast enhancement option can be used subsequently. Edge enhancement is again a pixel by pixel operation and so tends to be slow.

5) The Rectification Functions

With this option, the geometric transformation and rectification of either vector or raster images can be carried out. The first choice available in this option is the rectification of vector data which have been captured by measuring the unrectified image directly on the screen. Prior to this operation, the positions of the control points for the image concerned must be determined by measuring them using the digitise/control option described in the following section. Once this is done, two files are created. The one file stores the values of the control points in the image coordinate system. The second file contains the ground coordinate values (X,Y,Z) of the control points. A minimum of 6 control points is necessary for a 3D spatial transformation; if more points are used, the residuals will be computed in the same units of the ground coordinate system, and displayed on the screen. A solution can be also obtained with a minimum of 4 control points if height information is ignored and the area is considered as flat.

6) The Digitising and Graphics Functions

With these functions, the measurement of data can be performed whether these are control points, line features or polygon features. Different graphic elements such as line thickness and colour can be selected during measurement to differentiate between different feature types. When the measurement of polygons is selected, a closed vector string is created with the first point of the string being recorded automatically as its last point. A convenient option of an enlarged window centred at the cursor position can be used for high precision measurement.

The image at the location of the measuring mark can be magnified ten times; at the centre of the image is the measuring mark. This is a very useful option especially during the digitising of the control points.

Once measured, data are automatically saved to disk without a specific request by the user. However, this can be considered to be a disadvantage of the system, since any segment that needs to be remeasured cannot be deleted. Line editing is not possible in the system.

7) The Data Export Function

Data which are captured within the system can be exported to other systems. As already stated, rectified raster data, can be exported in SPANS or ERDAS format. Rectified vector data can be exported as a plotter file or a SPANS vector file.

6.3.4 The Attempt for Monoplotting Using the PC Version of GAPS

A test of the PC version of GAPS was carried out both on a IBM PC 486 compatible microcomputer equipped with a high resolution VGA graphics screen which was available in the Department of Topographic Science and also on one of the IBM PS/2 machines equipped with an IBM 8514 graphics adapter which was available in the Department of Electrical Engineering of the University.

The attempt to import into GAPS the two digital images obtained from the scanned aerial photographs of the test areas in Greece, revealed a very important restriction of PC GAPS. This restriction concerns the display and hence the possibility for any kind of manipulation of an image exceeding a certain size. For the available TIFF files of the two areas, only a small fraction of the corresponding aerial photos could be displayed on the screen. This comprised the first corner of the photographs being scanned and most importantly, the program did not allow for panning or scrolling through the entire scanned image. The same problem was encountered in both the PC VGA and the PS/2 8514 versions of GAPS, although a larger area could be displayed on the higher resolution IBM 8514 screen as compared with the display on the VGA screen of lower resolution.

By relating the areas displayed on the two screens to the corresponding hard-copy photographs, it was estimated that roughly a 2"x1.5" (on the VGA) and a 3"x2.5" (on the 8514) part of the complete photograph image could be visualised on the screen. Considering also the fact that the images were of 300 dots per inch (dpi) resolution and that the resolution of the screens is 640 x 480 pixels (VGA) and 1,024 x 768 pixels for the 8514, it was clear that there was a direct 1:1 relationship between the scanned image dots and the screen pixels. Although this relationship is necessary in order to be able to get maximum benefit of the image resolution during measurement on the screen, it shows clearly that, if there is no provision for panning, the software will be very restrictive for applications using aerial photographs of 23x23 format being scanned at 300dpi or higher resolution. If this is the case, then the aerial photographs will need to be scanned patch by patch with the location of each of the patches being carefully selected, or else the complete image will have to be chopped - a troublesome operation for digital images. The trouble would not end there either, since each of these patches would require a full set of ground control points to allow rectification - something which it would be impossible to supply or obtain in practice. Apart from the above, the necessity to match together the digital vector data obtained from each patch would be a very time consuming task and also impossible in the cases where mapping of very large areas is foreseen whether the mapping is for a cadastral application or some other application.

6.3.5 The Unix Version of GAPS, and its Implementation on IBM RS 6000 Workstations

Apart from the version of GAPS developed to run on a PC computer, another version has been developed by Dr. Li at the GeoData Institute of the University of Southampton, for implementation on IBM RS 6000 workstations. This version of GAPS, being based on the Unix operational system, is in actual operational use on IBM RS 6000 machines available at the GeoData Institute itself and at the Thames Water Board. Considering the difficulties encountered with the PC version of GAPS during this project, Prof. Petrie requested a working copy of this version from the GeoData Institute. The aim was to carry out the test based on the digital images of the two test areas in Greece, using this particular version of GAPS.

After the necessary contacts and arrangements had been made with the GeoData Institute in Southampton, the software modules of the Unix version of GAPS in their source code version, were sent from Southampton to Glasgow University over the Janet network. The software modules of GAPS were then compiled for the IBM RS 6000 by Mr

Higgins of the University Computing Service.

The actual IBM RS 6000 in the Computing Service is a stand alone processing unit. It has a physical memory of 16Mb but no graphics screen and can be accessed for operation from remote computers connected to the University's high-speed network. During this project, the above RS 6000 unit was accessed for the running of GAPS from a Viglen 486 PC compatible, which was situated in the Topographic Science Department. This PC is equipped with the EXCEED package which acts as an X-windows server.

6.3.5.1 The Unix Version of GAPS. Functions, Command Options and Display

For the Unix version of GAPS, no user's manual supplied. However, the basic principles of operation being the same as that of the PC version, this did not impose great difficulties and the user can soon become familiar with the operational functions of the system. However, the detailed layout of the commands displayed on the screen are quite different as compared with these of the PC version. In the Unix version, there are three vertical menu bars assigned respectively to the main menu, the colour choice palette and the vector parameters, the last two serving to discriminate the different features being measured. The various specific functions available in GAPS can be selected from the main menu and, for each one of them, a menu of executable options is displayed. The following Table illustrates all the options which are available.

Menu	Colour	Vector
Main Menu	Black	Line width 1
System	Green	2
Import	Red	3
Visualise	Cyan	Line style
Process	Magenta	(continuous)
Rectify	Yellow	(interrupted)
Digitise	White	Fill choice
Merge	Blue Violet	
Export	Brown	
	Coral	
Execute	Gold	
	Grey	
(A to H)	Med Blue	
	Med Slate Blue	
	Orange	
	Orchid	
	Slate blue	
	Tan	
	Violet Red	

A:System	B:Import	C:Visualise
Screen clear	Image (TIFF)	Image (raw)
Screen refresh	DTM (NTF 1.0)	Image (rect)
Grid display	DTM (NTF 1.1)	Image (sav+rect)
Grid erase		Vector (raw)
Area erase		Vector (rect)
Screen save		DTM (image)
		DTM (3d-view)

D:Process	E:Rectify	F:Digitise
Classification	Transformation	Vector feature
H-Pass Filter	Vector (no DTM)	Reconnaissance
Median-filter	Image (+DTM)	Control points
L-pass filter	Image (no DTM)	Control clear
Contrast enhance		Control display
Edge enhance		
Screen save		
Undo		

G:Merge	H:Export
DTM (imported)	Image -Spans
DTM (interpolated)	Image -Erdas
Image (rect)	DTM -Spans
Image (sav+rect)	Vector-Spans
	Vector-HPGL

Table 6.2 Option menu - Unix version of GAPS.

After an inspection of the above tables, the various different options offered by the Unix version of GAPS as compared to the PC version can be visualised. Two rather important differences will be noticed. With respect to the Import functions, a DTM can be imported either in version 1.0 or 1.1 of NTF in this version of GAPS. Although the exact version of the NTF is stated to the user, the restrictions related to this specific format, remain as in the case of the PC GAPS implementation.

The second function which is unique to the Unix version of GAPS is the Merge function. Imported or interpolated DTM data as well as rectified images can be merged. This function seems to be an important advantage since it can allow the joined plotting of adjacent image areas. However, since only two separate image areas were to be examined in this project, this function was not going to be evaluated.

With respect to the graphics elements, the Unix version offers a much wider choice of colours for the representation and display of measured features. These are obtainable from the colour menu bar. Also a choice for a continuous or interrupted line is available, besides the line width and polygon filling choices.

6.3.5.2 The Functionality of the Unix Version of GAPS on the IBM RS 6000

The first attempt to operate the GAPS Unix version was made by trying to import into the system the two TIFF files of Achaia and Corinth. This proved to be unsuccessful, showing an overflow of the TIFF files during the process of producing the relevant GAPS internal format image files, (the .IMG files). The GAPS system was crashing after prolonged periods of assumed processing times.

During the attempts to trace the cause of this problem, it was noted that the memory space of the output .IMG files that the system was intending to generate, was of about 20Mb as compared to the original 3.5Mb TIFF files. This was something unexpected and rather unexplainable at the time, showing the inability of the system to generate the "image" files within the University of Glasgow hardware configuration.

At that stage, the TIFF files used by the former student Matambanadzo, being of much lower size (0.3Mb) were tried to be imported to the system and this proved to be a successful operation. The image could be displayed on the X-windows graphics screen of the PC.

D. Higgins of the University Computing Services was consulted at an attempt to overcome the problem of the importing of TIFF files into GAPS. At that stage, an effort was made to compile the GAPS modules for implementation on a Sun SparcStation graphics work station, a number of which are available in the University. This attempt was unfruitful, showing that, in spite of both machines running the Unix operating system, it was not possible to compile the original GAPS source code into an object code suitable for a Sun workstation. A further effort was made to access the RS 6000 from other X terminals, revealing other problems with respect to the display of the image on these terminals. With most of the other window managers tried, the commands displayed on the menus displayed, were in black over a black background, making any practical operation of the system impossible.

At that point and as an attempt to check whether or not the actual size of the TIFF files was the source of the problem, one of the two test area TIFF files (achaia.tif) was sent from Glasgow to the GeoData Institute over JANET, to see if the corresponding .IMG (image) file could be produced there. This gave a positive result and the generated .IMG file was then sent back to Glasgow for visualisation and further processing. This achaia.img file produced in Southampton, could be displayed successfully when implemented in the RS 6000 in the University of Glasgow. Most importantly, it was possible to pan around the whole image just by bringing the cursor to the edge of the part of the image currently being displayed on the screen using the mouse. The image was then updated rather slowly, revealing the next image patch.

The fact that .IMG files could be successfully generated on the RS 6000 unit at the GeoData Institute but not on the equivalent unit at the University of Glasgow, raised the question as to what could be the difference between these two units. It was then discovered that the memory capacity of the RS 6000 unit at the GeoData Institute was 128Mb. This can be considered as an exceptionally large number by most standards and is definitely huge when it is compared with the 16Mb of the unit in the Computing Service of the University of Glasgow. However, 16Mb is the physical memory (RAM) of the unit, the available virtual memory being many times more than this value. Thus it was not clear whether the size of the physical memory (RAM) was really the restricting factor for the operation of GAPS.

As in the case of the achaia.tif file, the corinth.tif file was also imported from Southampton for further processing in Glasgow. This operation was not equally successful, and the image could not be displayed. At that stage, the situation with the importing of the files started to be questioned; the only source of error seemed to be the transfer of the files over JANET. However, after further work was undertaken, it was seen that even the initial achaia.img file could not be displayed, which really made the situation still more complicated. The only noticeable change was an attempt to compress the data files in order to save memory space. The compressing and uncompressing of data are straight forward operations, and as confirmed by the specialist staff at the Computing Service in Glasgow, these operations should not, by any means, alter or deteriorate the data. However, previous experience in the Department had shown that the compressing and uncompressing of TIFF files can give a rise to problems, so this created some uncertainty.

A last attempt was made to import the TIFF files from Southampton, this still this did not have any better effect on their display on the PC in the Department at the University of Glasgow. In every case, the .img files failed to import, the program crashing after prolonged periods (half an hour or more) of being seemingly inactive, and sending a huge list of failed requests for display to the X-terminal with error codes which could not be interpreted, since there was no provision of an error code list for the GAPS software.

In order to find a possible explanation for the bad behaviour of GAPS with all the different hardware configurations and in the University, the GAPS software was accessed once more from a similar PC to the one used in the Department which was located in the University Computing Service and had 8Mb RAM as compared to the 4Mb RAM of the PC in the Department. Indeed, the image files did display on that PC, although a considerable amount of time was needed for the image to be displayed. The display was completed with a number of error messages again being sent to the X-terminal, although their number was less in this case. The success of this attempt, gave some encourragment to the author, although the Computing Service PC could not be made available for the carrying out of the tests on GAPS, planned for this thesis. Some other alternative had to be found for the implementation of GAPS on the appropriate hardware and hence the rectification and plotting of the two digital images which were available.

6.3.5.3 The Testing of GAPS on the IBM RS 6000 Compatible at the Turing Institute

Having already invested up to that point a very large amount of time on this abortive work to get GAPS to function properly, a solution was finally achieved by transferring the Unix version of GAPS onto the IBM RS 6000 compatible belonging to The Turing Institute in Glasgow - an independent research institute with which the Topographic Science Department collaborates on a number of research topics in photogrammetry, digital mapping and GIS.

Among the hardware facilities available in the Institute, are a number of Sun SPARCstation LX and Hewlett Packard graphics work stations. Some thought was given to use these machines for the tests of GAPS, but in the end they were carried out on an IBM RS 6000 (with a Bull badge). It was initially believed that this machine had a larger memory than the IBM RS 6000 at the University of Glasgow, but in fact this Bull workstation also had only 16Mb of available memory (RAM).

6.3.5.4 Configuring GAPS in the Turing Institute

All the GAPS modules in their source code were transferred from the University to the Turing Institute on magnetic tape. The modules compiled successfully on the RS 6000 and entry into the program environment was possible. However, as soon as attempts were made to import any of the TIFF files of the test areas into GAPS, the system crashed once again, and the same resulted even when attempts were made to visualise the existing image (IMG) files.

The next step which was performed, was to again access GAPS, this time remotely from one of the Sun SPARCstations in the Institute, all of which are linked onto the same local

Ethernet network as the Bull/IBM RS 6000. This method of accessing GAPS remotely was at that time successful.

Based on all the experience gained up to that point with respect to the behaviour of the Unix version of GAPS, it was believed that the software was trying to allocate a large amount, of perhaps 8Mb of the available memory for the processing operations and also to allocate, separately, another 8Mb of memory required for the size of images being processed, for the actual unit controlling the image display. Hence, the system was crashing when less than 8Mb were reserved only for the display.

When logged into any of the workstations in the Institute, a list appears giving the user a choice of a window manager. Although all of the available window managers were tested, none of them gave really satisfactory results for the display of the GAPS command windows or the image itself. Again, as with the PC version, with some window managers, only a part of the whole image could be displayed on the screen and there was no provision for panning. With other window managers, panning was possible, but the image itself displayed some unwanted image noise. As it proved later, this occurred both before and after rectification due to the particular pixel colour range assigned by the window manager corresponding to the intensity values of the digital image. The most suitable window manager which was eventually selected from the large choice available was the twm manager. With this manager, panning of a noise-free image was possible. However, a very important restriction was associated with this window manager. Text was displayed in black over a black background, so selection of commands and most importantly, the entering of text, as for example control point data, had to be done "blind" estimating the location of the commands required for their selection with the mouse, using the experience gained previously when other window managers were utilised.

Both test area images displayed satisfactorily with the window manager selected. The image had enough contrast for the identification of the various features of primary interest, i.e. the field and other boundaries and the buildings, and a good display of the grey levels was achieved with a minimum of noise being present. However, it was not possible to assess the image improvements that the radiometric processing functions available within GAPS could give on the two tested digital images. At each attempt to select any of the above functions, the program crashed without any display of the image.

6.3.5.5 The Rectification of the Test Area Images

In the initial phase of testing GAPS, it was planned to measure the boundary data on the two available images after these had been through a 3D transformation without the use of a DTM. The aim of the task described above was to compare the plot outputs from a simple rectification of the area images as compared to the output obtained from the stereoplotting of the same areas carried out previously. Moreover, such an output from GAPS would be a good basis for assessing the improvement in the accuracy of the same boundary data when these were measured on the images after having been corrected also for relief displacement, i.e. when a DTM was used for their rectification.

The principles of the transformation carried out with the Unix version of GAPS are in effect the same as those of the PC version. Hence a minimum of 6 control points have to be used for the three dimensional projective transformation. The available control for each image was only 4 control points, so three more control points for each image were obtained by scaling off the coordinates of three well defined and distributed points from the 1/2,000 scale plots of the same areas obtained from stereoplotting.

For each control point measured on the screen, the corresponding ground coordinate values were entered in turn. This was a troublesome operation since, as explained above, the typing in of these values was done without any visual check, and a simple mistake meant the repetition of the whole operation. Furthermore, in order to check the residuals of the measured control points, it was necessary to exit the system and login again using a different window manager which allowed a good display of the command windows but no panning through the image to allow measurement of the control points.

6.3.5.6 The Achaia Test Area Image

The residuals obtained for the 7 control points of the Achaia image were all less than ±0.5m despite the fact that three of them were scaled from the 1/2,000 scale plot. The actual transformation of the image was performed as soon as the area to be transformed was defined by two diagonally emplaced points and the selection of the interpolation function. For the transformation of the image using the simpler nearest-neighbour, a time of about 20 to 30 minutes was needed. The resulting image of the Achaia test area was skewed to fit the ground coordinate system, the north being towards the top of the screen. The size of the actual rectified image can be adjusted with respect to the size of the original image and the program prompts the operator to set a value within the maximum given range. However, for the Achaia image, being skewed and elongated after rectification, there was a reduction of scale of the displayed image with respect to the original image. A considerable number of iterative cycles were performed until a rectified image was obtained giving the required content and the maximum possible scale to facilitate more precise measurements.

After the rectification of the image, the direct measurement of boundary features was carried out on that image. Considering the difficulties concerning the manual entry of data and the need for a quick plot output, the measured boundary features were not given an attribute value. The measuring of features was straightforward, although within GAPS there is only a graphical link between adjacent polygon lines. There is no "snapping" or a "point recall" function, so those points which are common to two or more line strings cannot share the same coordinate values to allow consistency and avoid duplication of data. Only the last segment being measured can be deleted and, once the measurement of a vector is complete, no editing of or modifications to the dataset are possible. What has just been described can be considered to be another important restriction of GAPS as a system for production application. As was already seen during the stereoplotting test, the Achaia test area was covered by a large number of possible boundaries represented by rows of trees or thick hedges. Furthermore, the illumination of the digital image was not very good, especially in the upper part of the image, which showed low contrast of the features displayed. These factors made the precise measurement of boundaries a difficult task. In some few cases, boundaries which could be identified during stereoplotting could not be discriminated among others on the image. Another restricting factor causing the acquisition of less precise measurements was obviously the lack of stereoscopic view. This causes certain restrictions resulting from shadows and obstructions caused by overhanging features. Also the lower magnification and resolution of the digital image was another restricting factor when carrying out the measurements.

6.3.5.7 The Corinth Test Area Image

The second test area image, that of Corinth, was transformed prior to plotting in the same manner as the Achaia image. Hence, 7 ground control points were used, the coordinates for the three of them having been scaled off the corresponding plot obtained previously from stereoplotting. As with the Achaia image, boundary features were measured without assigning different attribute codes to them. Once again the on-screen measuring of data on the monoscopic image was more restricting in terms of both interpretation and measurement as compared with stereoplotting. As perhaps should be expected, it would be difficult, if not impossible, to discriminate between high or low walls on a monoscopic view, especially if these are located in the central part of the image.

Moreover it was difficult to say in some cases whether a fence, a hedge or a similar feature was forming a boundary, though the existence of such a linear feature was fairly obvious. Given the lack of order or pattern in the built-up areas which characterise the Corinth test area in conjunction with the mono-plotting approach, a relatively high number of estimations for the location of parcel boundaries was made during the measurements.

6.4.1 The Acquisition of Digital Terrain Data for the Analytical Rectification of the Digital Images

The need to obtain a DTM for an input to the GAPS program imposed the use of a program which could generate a grid DTM. PANACEA is a program capable of this kind of output, and it was used in this project.

This program was initially developed by McCullagh (1988) and distributed by his Siren Systems company. There are several versions of PANACEA in existence; three of them are available in the Topographic Science Department - for the ICL 3980 mainframe, a VAXstation work station and for PCs. The PC version was the one used for this test.

The PC version is designed to operate on an IBM PC-AT clone equipped with EGA or VGA graphics display adapters and screens; A minimum of 640kb RAM is required for the computer while an at least 5Mb spare capacity is required on the hard disk.The availability of a maths co-processor greatly increases the speed of operations.

The input data for PANACEA can be the contour lines of the area of interest being available in digital form as strings of coordinate data. During this project, the strings with X and Y coordinates obtained from the PG-2 RPLOT stereoplotter for the Achaia (OA) test area and the MapData digitising system for the Corinth (ACOR) area in ASCII format were the input into PANACEA.

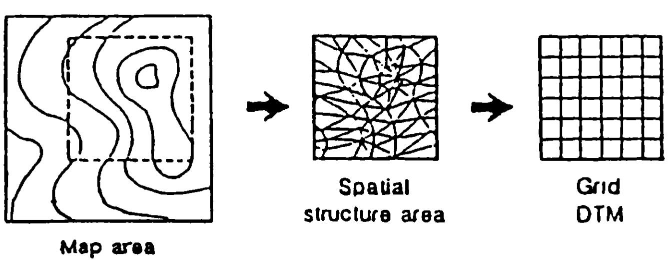


Figure 6.6 Contours to triangulation to grid.

The functions of PANACEA are implemented by a series of modules, all integrated under the PANACEA control program. As it can be seen in Figure 6.6, the input contours in digital form are used to generate a DTM in the form of a triangulation network as a first stage, and from there on, a regular grid based DTM can be interpolated.

However, the input data format for PANACEA is quite different to the format of the ASCII files obtained from MapData and RPLOT. A small program called CONCONV had been developed by Matambanadzo which converts the output form of data from MapData into the PANACEA input format. This program was not available during the transfer of data to PANACEA for this test, and so the input files were edited manually, which was a time consuming process. The required input format consists of a 3 value header, each one of them specifying the number of data points in the string, the type of string (X, Y coordinates) and a default Z value for this contour line string accordingly (Figure 6.7).

```
50 1 26              header
    22156.80  -7635.20
    22156.30  -7641.17   x,y coordinate string
       :          :
       :          :
```

Figure 6.7 Input format of data for PANACEA.

The first module to be implemented is PANCHECK which filters the input data and also makes a check for the consistency and accuracy of the data. However, for this particular project, PANCHECK was not really beneficial, as the data proved to be consistent.

The heart of the whole software is the module PANIC, the system triangulation program. This module reads a set of data points and performs a Delaunay triangulation for the area they cover (Kennie & Petrie, 1990). A quick attempt to use PANIC directly showed that the contours obtained from the PG-2 consisted of a rather large number of points, resulting from the attempt to follow the contour indentations as closely as possible during the data capture process. The result after the triangulation by PANIC was a dense set of elongated triangles, something which in some areas could have been avoided. Hence, the graphic editor of the system, PANDEMON, was used to edit the two input files of the test areas. Using PANDEMON, some contour points were deleted, especially in the case where contours were fairly smooth and evenly spaced. Apart from the deletion of these points, the second most important editing operation which was carried out was the swapping of the quadrilateral diagonals made up by two adjacent triangles. This allowed the reforming of triangles in order to ensure that contours do not split and that all the available data points were used for the DTM formation optimally.

Once the triangulation is completed, logical strings may not remain continuous but their continuity can be preserved by the use of another module, PANZER. This module is also the derivative responsible for the estimation of slopes at each point. Their values, together with the height data values, are used to generate surface patches such that a smooth surface results both inside the triangle but also across neighbouring triangles.

The actual grid output required from PANACEA comes from the use of the PANDORA module, which generates the final gridded output data of heights by interpolation within the triangular network. An isometric display of the generated height grid as a wire frame block diagram can be obtained through the use of the module PANORAMA. The visual check provided by this module, ensures that the height grids generated are correct and free of any noise, before any further manipulation.

Apart from these already mentioned, there are a few other modules concerned with the display of the gridded DTM data. As a further check on the generated grid of heights, interpolated contours can be obtained using the PANACHE module. These should match closely with the input contours. Volumetric determinations can be carried out by PANURGY; STRUCTUR is a variogram estimator module; and the plotting output module is known as PANTO.

6.4.1.1 The Conversion of the PANACEA Grid Data for Implementation in GAPS

As it has been already stated, both versions of GAPS require the DTM data to be in NTF, the National Transfer Format. As soon as this data is entered into GAPS, a transformation into an internal system format has to be carried out. Hence, there are two possible ways to input the DTM data into GAPS. Either it can be imported as NTF data or directly in the internal GAPS format. The second of the two options was considered to be more appropriate for the conversion of DTM data, since the internal format of the DTM files as well as their header was known from the users manual for the PC version of GAPS. It was assumed to be the same for the Unix version of the package considering that they both have the same principles of operation. More importantly a program called PANGAPS had been already developed by Li in the GeoData Institute for the conversion of the PANACEA output into the internal GAPS format. In any case, the approach of converting the DTM data into the internal GAPS format seemed a more reasonable approach to follow, since it by-passes the very restrictive requirement to use a specific early version of

NTF.

A considerable amount of time was spent searching for the PANGAPS program. Eventually it was found in its object code form on one of the IBM PS/2 machines in the Electrical Engineering Department. This program, written in C for use on a PC, had the restriction that the number of the data columns used for the input DTM data from PANACEA should be a multiple of ten. Furthermore, since it is stated in the PC's user's guide, that too large a DTM may cause memory problems, so it is desirable that the number of rows and columns are kept less than 150 and 100 respectively.

The number of rows and columns is a variable that can be adjusted when the gridded height output data are produced. However, for a given DTM area, a change in the number of rows and columns of the generated DTM will have an effect on the dimensions of each grid cell. In an attempt not to distort the DTMs generated for the two test areas, PANACEA was run for a number of iterations in order to produce grid data to fit the largest possible area while maintaining the appropriate number of rows and columns, as well as square, undistorted grid cells.

These PANACEA output files were entered into PANGAPS on a PC for the necessary conversion. The parameters which had to be specified were in effect the information gathered in the header of the internal GAPS DTM files, including the grid cell size, the coordinates of the lower left corner of the grid and the range of heights.

Unfortunately none of the files produced by PANGAPS were suitable for import into the Unix version of GAPS, despite the fact that the necessary byte order conversion for the files from the PC to the UNIX system was performed.

The possibility of compiling the PANGAPS program on the RS 6000 and converting the PANACEA files on this computer was then considered. However, the source code of PANGAPS was not available in the University of Glasgow, and it was only after a long search of the back-up tapes in the GeoData Institute of Southampton that it was found and sent to Glasgow over JANET. Being written on a PC, the PANGAPS source code required a thorough "clearing" before it would compile on the RS6000. However, not even after that process was completed, could the output DTM files from PANGAPS be imported successfully into GAPS. Similar error messages were obtained on the RS 6000 of the Turing Institute to these encountered in the case of importing TIFF files or in the transformation of the images on the University's RS 6000.

A final effort to generate the appropriate DTM files was made by rewriting the PANGAPS program, a task carried out by Mr T. Ibbs a professional computer programmer employed in the Topographic Science Department. Apart from the attempt to correct for the byte order and the restriction with respect to the multiples of 10 values for the DTM rows, the program was reconstructed which made it a more tidy and hence more convenient basis for future development, if such a requirement arose.

This later version of PANGAPS -renamed as PAN2GAPS- was then run on the RS 6000 of the Turing Institute. However, the transformed DTM files produced by PAN2GAPS were still not accepted by the GAPS program, causing the latter to crash at the attempt to visualise these DTM files.

At that point, it became apparent that a very large amount of time had been invested for the implementation of GAPS on standard IBM RS 6000 workstation without the very specialised memory requirement of 128Mb on which the Unix version of GAPS has been developed in Southampton.

The restrictions apparently imposed by this hardware requirement could be seen during all the processing stages carried out during the testing of the package tested. Whether it was importing of TIFF files; carrying out the radiometric processing of the images; executing the rectification of the image with or without the use of a DTM, the inherent weakness of the GAPS system is that it appears to be tied to a specific set of hardware resources.

The conclusion reached after all the experience gained through the tests described above is that GAPS really needs to be adapted in such a way that would enable it to be used as a commercial package on a wide range of Unix-based graphics work stations. For this adaption a good knowledge of C programming and Unix as well as of the functions of the GAPS modules will be required. Despite the rather serious restrictions encountered with GAPS, during this project, some positive concluding marks were reached concerning its potential use as it will be seen in Chapter 8.

CHAPTER SEVEN

Chapter 7

Tests Utilising Orthophotographs from Stereo-Pairs for Cadastral Surveys

7.1 Introduction

This chapter deals with the experiments carried out on two orthophotographs produced on an analytically controlled orthophotoprinter on the basis of digital terrain model data obtained from stereo-pairs on an analytical plotter.

The orthophotographs produced by differential rectification from stereopairs is an older and well established alternative to that of monoplotting from digital rectified images. As with all the other techniques tested in this project, once the cadastral data have been identified on the orthophotographs, they can be measured and the resulting data stored in digital form. The high production rates, the tested reliability of the results obtained in other countries and the relatively easy conversion of existing stereoplotters for the production of orthophotographs are all basic points which should cause those concerned with cadastral surveys to consider orthophotography as a very interesting alternative for the generation of cadastral information.

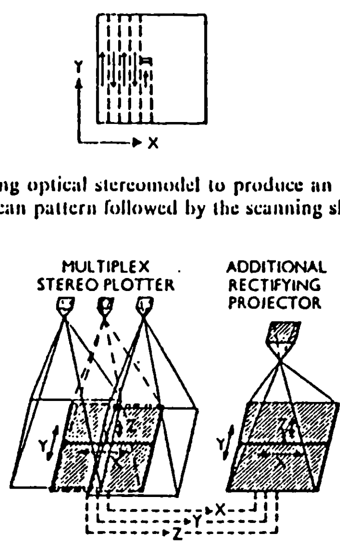
As with the testing of the GAPS monoplotting system, orthophotography has been examined for its suitability for use in Greece. In particular, the practical implementation and the advantages of the whole process up to the point of the extraction of cadastral information in digital form have been considered. Again, the accuracy of the data produced by orthophotographs has been a matter of primary concern. However, the actual testing of the data derived from the orthophotographs was conducted on the basis of its comparison with the coordinate values obtained from the previous tests of stereoplotting which were considered to be of superior accuracy. Hence, the results were based on the relative accuracy of the examined techniques and not from a comparison with data obtained by high accuracy ground survey methods.

7.2 The Production of Orthophotographs in General

The development of modern techniques in photogrammetry such as digital monoplotting from differentially rectified digital photographs has brought monoplotting closer to the plotting from orthophotographs produced from stereopairs. The meshing between the two alternative methods becomes more complicated if, for example, the method of orthophoto production by electronic correlation on stereoplotters is compared to with the method of an orthophoto being produced by digital stereo-correlation on a computer and a subsequent differential rectification of a single photograph in digital form. The first of the above methods would obviously belong to the orthophoto from stereopair approach, whereas the second resembles more to the single photograph rectification approach.

7.3 The Principles of Orthophoto Production from Stereopairs

As in the case of monoplotting from digitally produced orthophotos, a differential rectification process is carried out on the photographic image to produce the equivalent orthophoto from the stereopairs. The basic principle of this differential rectification can be seen in Figure 7.1 where a narrow slit is used for scanning in the model space of the stereoplotter. Light is allowed to pass through this slit, and the intensity of that light is controlled by only one photo of the stereopair. In this manner, the projected photo image is recorded on a photographic film. However, instead of following individual features, as in the case of stereoplotting, measurements are performed by a systematic scanning of the stereomodel in a series of parallel profiles. During the scanning, the measuring mark and its slit is continuously following the model surface so that all the detail visible within the stereomodel is orthogonally projected on the film below.



Slit traversing optical stereomodel to produce an orthophotograph. Raster scan pattern followed by the scanning slit.

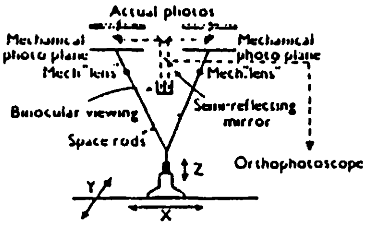
Additional rectifying projector attached to a stereoplotting machine.

Figure 7.1 Principle of differential rectification.

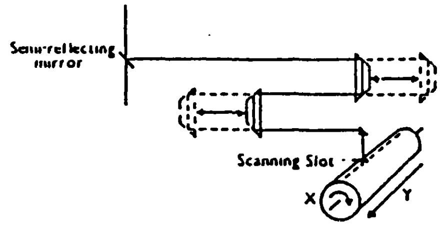
The process just being described, relates to analogue instruments dedicated to the production of orthophotographs. A later approach is the one of an additional rectifying projector, attached on-line to an existing stereoplotter, which duplicates one plotter projector and performs the exposure of the orthophotograph in a similar way to the arrangement described earlier by duplicating the X, Y, Z movements made in the model. An extension of this latter approach is the off-line operation of the orthophoto projector (Petrie, 1977). In this off-line operation, the data obtained from the scanned profiles are stored, most commonly in digital form, and are used in a later stage to control the operation of the additional rectifier projector. The off-line operation has both quality and economic advantages, since in the first case, erroneous data captured during the profiling can be removed prior to the production of the orthophotograph and, in the second, the off-line operation ensures that the rectifier is idle for a minimum period of time and hence reduces the cost of operation.

All of the approaches mentioned up to this point are based on optical projection, and thus retain the limitations of the optical projection stereoplotters, especially the lack of flexibility with respect to the use of aerial photographs with different focal lengths. These limitations can be overcome with the optical and electronic transfer instruments. With the optical transfer instruments (Kennie and Petrie, 1990), the rays of the overlapping photos forming the model are simulated by two mechanical space rods (Figure 7.2). Viewing of the stereomodel is possible with microscopes coupled to these rods which transmit the image of the photograph through separate optical channels to the eyes of the observer. The image from one of these channels can be diverted by the use of a semi-reflecting mirror and transferred optically to produce the orthophotograph during a systematic scanning of the stereomodel, again in a series of parallel profiles. Since there is no projection distance variation corresponding to the variations of the terrain heights, a continuous change in scale is implemented by continuously varying the length of the optical path of the image. Also due to the orthogonal rather than the central projected view, the effects of tilts have also to be rectified by a rotating dove prism. The differentially rectified image is captured on a photographic film sheet wrapped around a drum, which rotates in synchronisation with the scanning movement in the model. The scanning of the model is performed in a similar manner to that of the optical projection instruments (Figure 7.2).

This concept of optical transfer has been adopted by a series of analogue stereoplotters such as the Zeiss Jena Topocart with the Orthophot optical transfer device; the A8 Autograph with the Wild PPO-8 attachment; and the Galileo Stereosimplex with the Orthosimplex device. In a similar manner, optical transfer devices have been utilised in conjunction with analytical plotters such as the OMI AP-C stereoplotter with the OP-C attachment. However, this direct attachment of the orthoprojectors implies an on-line operation which has its relative disadvantages as mentioned before.



Optical transfer with the image of the right-hand photograph in a mechanical projection instrument tapped off or transferred for rectification.



Scale rectification by variation in the optical path length; image rotation to correct for convergence.

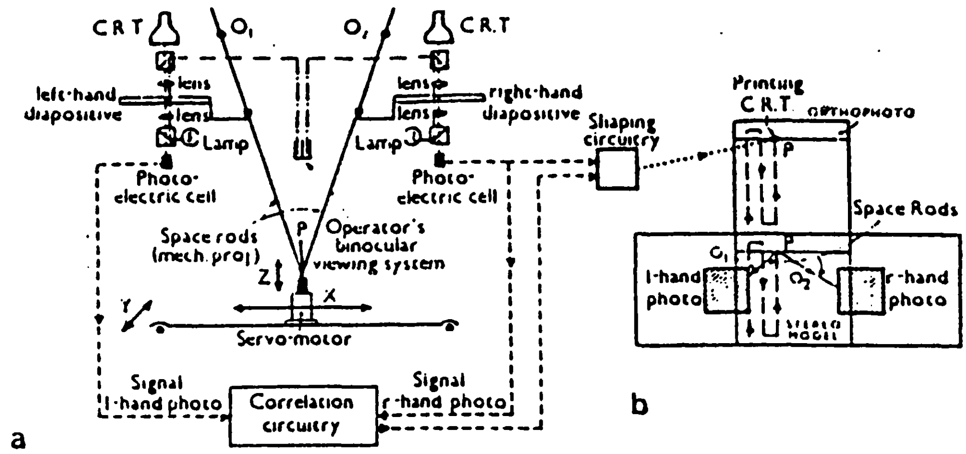
Figure 7.2 Optical transfer principle.

A further development based on the optical transfer devices which combine both the advantages of the off-line mode of operation and those offered by optical transfer is the development of the analytically controlled orthophotoprinters. These devices operate in a very similar way to the optical transfer attachments. However, the necessary scale variations and image rotations for the printing of the orthophoto are implemented by optical elements acting under the control of a digital computer. Examples of these devices are the OMI OP-2 and the Wild Avioplan OR-1, which was actually utilised for the production of the orthophotographs of the two test areas used in this project.

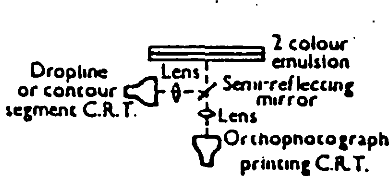
7.3.1 Orthophotographs by Electronic Transfer Devices

Another method for the production of orthophotographs is one utilising electronic transfer instruments. In this method, the scanning of the overlapping areas of the photographs forming the stereopair is made by electronic components.

The correlator as applied to an optical projection type of plotter, replaces the measuring mark with a CRT. On this CRT, a light spot is generated which is projected through the two diapositives, scanning each one of them. The varying intensity of light passing through the diapositives, is detected by photo- electric cells which generate electrical signals that



(a) Correlator as applied in a mechanical projection instrument; (b) raster scan pattern in both the mechanical projection instrument and the orthophoto printing unit located behind the instrument.



Printing CRT for orthophotograph exposure.

Figure 7.3 Principle of electronic transfer.

are compared by the correlation circuitry and related to parallax values. Again, as in the case of optical projection, the whole model is scanned in a raster pattern and the parallax signals in the x-direction, giving a measurement of height, are used to drive a servo motor in Z, so that the CRT is always at the correct height during scanning for the orthophotograph production. In the case of mechanical projection instruments (Figure 7.3), as for example the WILD B8-Stereomat, each diapositive is scanned by a separate CRT. However, the same principle of correlation applies to this case. The production of the actual orthophoto is carried out by a third printing CRT which generates a light output following the pattern of one of the scanning CRTs. This light pattern is modified by the electronic circuitry so that the necessary corrections for the terrain relief and tilts are implemented.

The idea of automatic image matching or correlation was extended to the field of analytical instruments and led to the development of automated systems such as the Bunker-Ramo UNAMACE and the OMI-Bendix AS-II B/C and the later Gestalt Photo Mapper (GPM) (Kennie and Petrie, 1990) which is capable of producing orthophotographs and corresponding dense elevation matrices in parallel.

It should be stated here that the cost of buying and running such automated systems is extremely high and can be justified only for a large mapping programme. A strong and continuous financial support plus experience and careful planning by the operators of the system will be needed in order to carry out the mapping task. These considerations apply to the potential use of these systems in cadastral survey applications and the experience from examples such as that carried out in Colombia (see section 4.2.3.2) reveals the difficult practical implementation of the systems for prolonged periods without the necessary support. The basis on which a cadastral system is organised will also play a decisive role in the implementation of such a mapping system. Cadastres operating on a centralised basis will be the only systems to favour such automation. It will be impossible for a decentralised cadastral system to afford or justify both the number as well as the necessary support of these mapping systems in each individual cadastral office.

A second important point to be mentioned with respect to these automated systems is their applicability to the production of large scale orthophotography which is a primary requirement for cadastral mapping applications. According to Jerie (1977), practical experience has shown that automatic height correlation only seems to work satisfactorily for orthophoto scales smaller than 1:10,000. Poor results might be expected if larger scales are employed.

7.4 Decision Criteria and Cost Modelling for the Selection of Equipment for the Orthophoto Production

The final decision concerning the purchase of equipment should be based on a number of parameters and factors related to cost-effectiveness which are identified as follows (Jerie, 1977).

Product Specifications

1) Scale of photomap
2) Required plan accuracy
3) Required height accuracy (if height information, e.g. contours are produced)
4) Required image quality
5) Colour photography, if required
6) Stereomates, if required
7) One orthophoto for one map sheet if required

Terrain

1) Topographic characteristics

2) Influence of vegetation and man-made objects

Production Organisation

1) Personnel cost per hour

2) Annuity factor to be applied

3) Number of orthophotos to be produced per year

4) Skill of operators

Project Parameters

1) Photo scale

2) Type of camera

3) Forward and side lap

4) Type(s) of equipment to be used

5) Scan width (possibly different for profiling and printing in an off-line mode)

6) Scanning speed (possibly different for profiling and printing in an off-line mode)

7) Availability of contours or DTMs

The testing of orthophotos in this present project was carried out to verify the suitability of orthophotography for cadastral surveys on the basis of the available photogrammetric material, which was common for all the tests and showed the typical peculiarities of the Greek terrain and landscape features. The obtainable results in planimetric accuracy and the amount of detail which could be identified in the orthophotos, were the primary matters of interest.

7.5 The Production of the Two Test Area Orthophotographs

The selection of the particular technique and instrumentation used for the test was influenced by a number of determining factors, being primarily the availability of equipment, the possible accuracy and the cost and time required for the production of orthophotographs as foreseen for cadastral mapping in areas such as Greece. Hence, for the production of these two test orthophotographs, a Wild Avioplan OR-1 analytically controlled orthophotoprinter was used, based on digital profile data obtained from a Wild Aviolyt BC2 analytical plotter. The operations for the production of the orthophotographs were carried out by BKS Surveys in Coleraine, Northern Ireland. The DTM data necessary for the operation of the OR-1 were captured on the Wild BC-2 at Coleraine. The DTM data of the two areas together with the corresponding diapositives were then sent to an associated company of BKS in the USA where an OR-1 unit was available for operation.

7.5.1 Accuracy Considerations for the Test Orthophotos

-The Selection of Orthophoto Scale

The scale selected for the orthophotos to be produced was 1:2,500. The selection of that scale was based partly on cost effectiveness criteria as well as considerations of the accuracy required for the particular type of land. However, the main criteria regarding the selection of the scale revolved primarily around the scale of the available photographs (1:6,000) and the enlargement range of the photogrammetric equipment used to produce the orthophotographs. This enlargement range does not usually exceed a factor of 3x the scale of the original photograph. As already mentioned, the two test sets of photographs, being common to all the photogrammetric techniques examined, cover semi-rural to rural areas in Greece. Most of the examples of the various countries which apply cadastral mapping in this type of area utilise scales not larger than 1:2,000, even when numerical accuracy is needed and numerical stereo-plotting of signalised points is carried out. However, the project test areas had no pre-signalised boundary corners. As mentioned before, the Achaia test area photos reveal boundaries often formed by hedges, tree rows and ditches frequently exceediing a thickness of 3 metres on the ground, while the Corinth area photos showed many unevenly built walls more than 0.5m thick on the ground. Hence, a considerable loss of accuracy and precision between the measurements of the different photogrammetric techniques employed was expected due to uncertainties in pointing during the measurements.

Assuming now a cadastral mapping project based on the extraction of boundary information from linear features of this dimension, a very important consideration for the measuring accuracy of such boundaries is that the intended accuracy is not higher than the accuracy of feature identification (i.e. pointing accuracy). Experience has shown (Visser, 1973) that measuring errors in an aerial survey, approximate closely to those of a field survey for the same features. For the circumstances of the Netherlands, the rmse in planimetry due to measurement were stated to be ±10-25cm for ditches, ±5-10cm for hedges, ±2-5cm for walls. For the cases of features likely to by encountered in the test areas used for this project, an rmse in planimetry of around ±20cm should be more reasonably expected for most of the boundary features. For more dimensionally distinct features (thin walls, pavements, fences, etc), much smaller values of the standard errors would be expected, whereas for thick hedges or rows of trees, higher error values can be expected.

Tests on photogrammetry as applied to cadastral surveys (Visser, 1976) showed that using wide angle photography (23x23, c=15cm) and carrying out numerical plotting on analogue plotters, the maximum rmse in distances is about ±18μm on the film negative. If this value is related to the pointing error values estimated to be ±20cm for the cadastral boundaries of the test areas, then a photoscale as small as 1:11.000 should be sufficient for the accuracy requirements considered. Hence, the scale of the test area photos would be more than enough for the accuracy assumption made above. Considering next the fact that line features are going to be digitised from the orthophoto on a digitiser having a 100μm resolution and an accuracy of not less than 300μm (like the one used during this project), an orthophoto scale of 1:2,500 will give planimetric errors of ±80cm in the ground coordinate system only due to digitising. Hence, the total rmse error in planimetry expected for such an orthophoto should be around ±85cm . These estimated values, being perhaps large if the potential of a numerical stereo-potting is considered, they may be judged to approximate the real conditions to a reasonable extent. Also, if related to distance tolerances such as the established tolerances of the Italian graphical cadastre, they seem to be in quite good agreement.

Based on the above considerations, the decision was taken to produce orthophotos at the scale of 1:2,500 for the test areas.

7.6 The Wild Avioplan OR-1 Orthophoto Unit

As already stated, the Wild Avioplan OR-1 Orthophotoprinter is an analytically controlled orthophotoprinter based on the optical transfer principle. This device is under full computer control and is designed to be operated as an off-line system, unlike the design of other devices built on the same optical transfer principle such as the Zeiss Jena Topocart/Orthophot combination (Figure 7.4).

Using the OR-1, an orthophotograph is produced after a line-by-line scanning of the input photographic image, with the rectification carried out by optical elements which can perform a change of scale, removal of relief displacement and removal of tilt displacement.

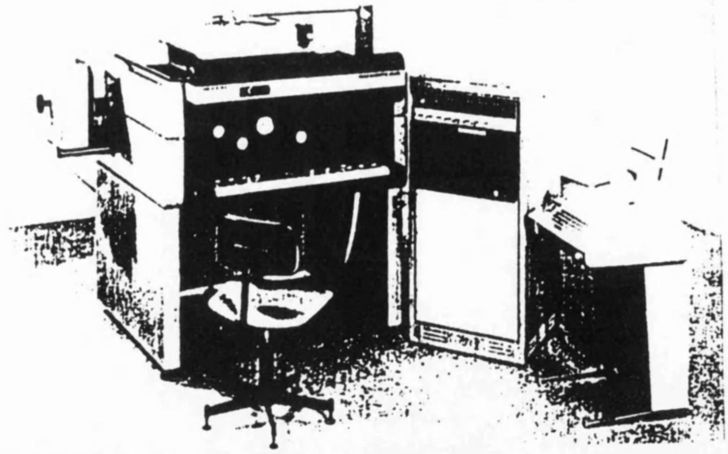


Figure 7.4 Wild Avioplan OR-1 differential rectifier.

After the necessary rectification, each picture element (pixel) to be printed is admitted through a narrow slit to expose an unexposed film sheet which is wrapped around a rotating cylindrical drum. The basic scaling is initially set by the operator using a zoom lens. Since the scale of the image varies with respect to the terrain height variations, further scaling adjustment is implemented continuously to bring all the line elements covering the area into a constant common scale, prior to the exposure of the film. The on-line computer which controls the OR-1, is computing the necessary scaling corrections based on the corresponding DTM data. The scale corrections are applied by a second zoom lens, which is controlled by a digital-to-analogue convertor.

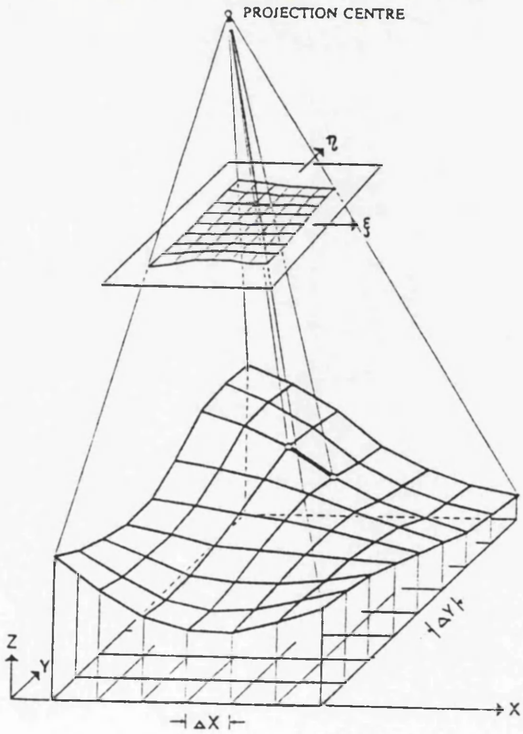


Figure 7.5 Ground and image coordinate relationship.

The geometrical relationship between the coordinates X,Y,Z of any point on the ground surface and the corresponding image coordinates x,y on one of the overlapping photographs can be seen in Figure 7.5, which is actually illustrating the principle of operation of the Wild OR-1.

The X,Y,Z coordinates forming a DTM can be provided by a variety of methods, which can already show the flexibility that the off-line mode of operation can give.

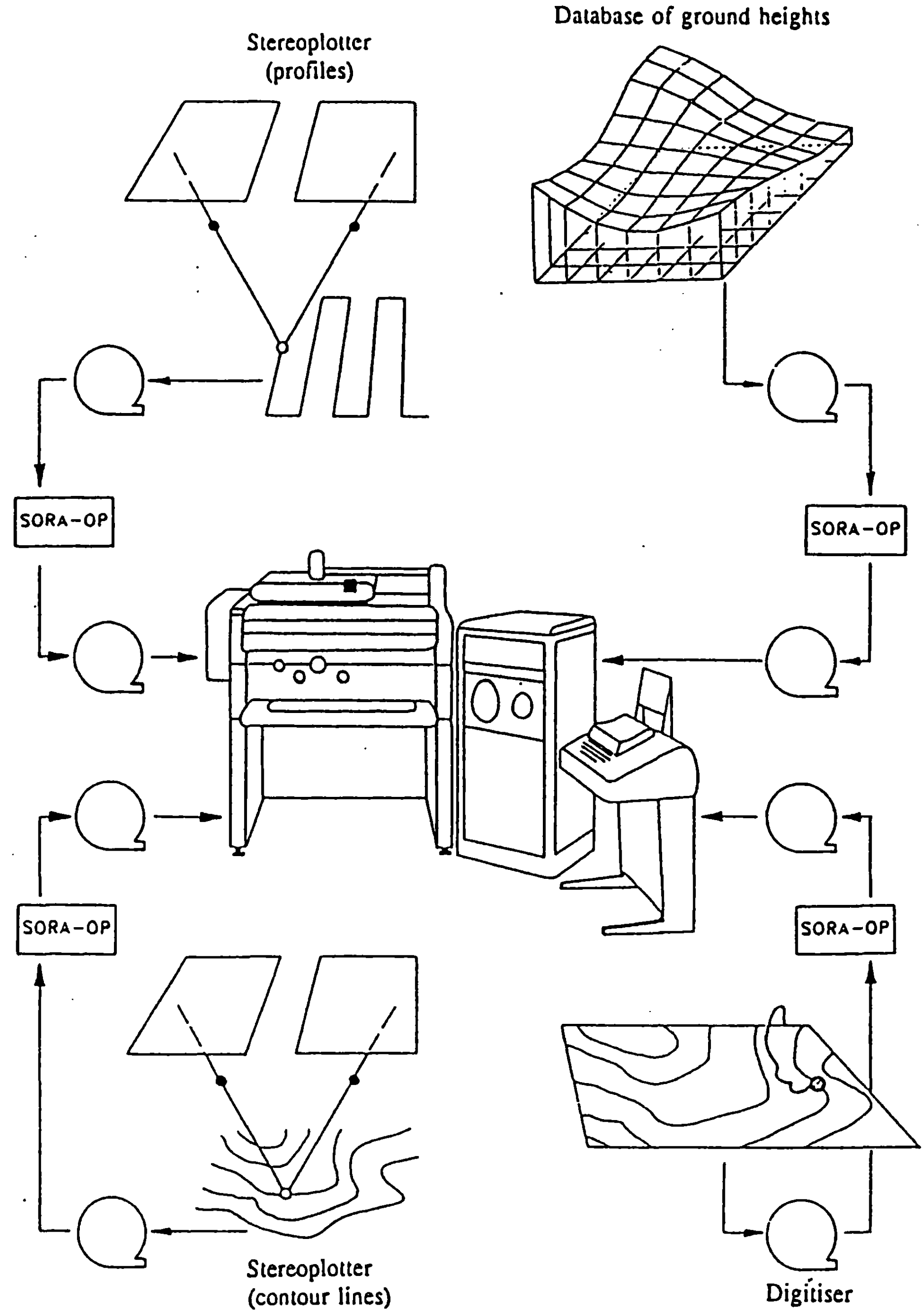


Figure 7.6 Various methods of data capture for differential rectification.

As can be seen in Figure 7.6, data can be acquired by digitising contours on existing map documents, or from contours and/or a grid of individual points captured digitally during stereoplotting. Other possibilities for acquiring the necessary data are from an existing DTM grid database, or it can be gathered as digital terrain profiles on a stereoplotter. This last alternative was actually the method used to acquire the data for the production of the two test area orthophotos.

The available DTM data are then used to interpolate a rectangular height grid of the appropriate density, for example at 1mm intervals, along the scan lines in the orthophoto. The interpolated grid data are then entered to a Data General Nova mini-computer which acts as the control computer for the OR-1. This computes the exterior orientation parameters of the photograph by the use of collinearity condition equations and a minimum of three orientation points. With the known exterior orientation parameters, the image coordinates (x, y) corresponding to each grid node in the model space (with X, Y, Z coordinates) are computed in an off-line stage. (Figure 7.7).

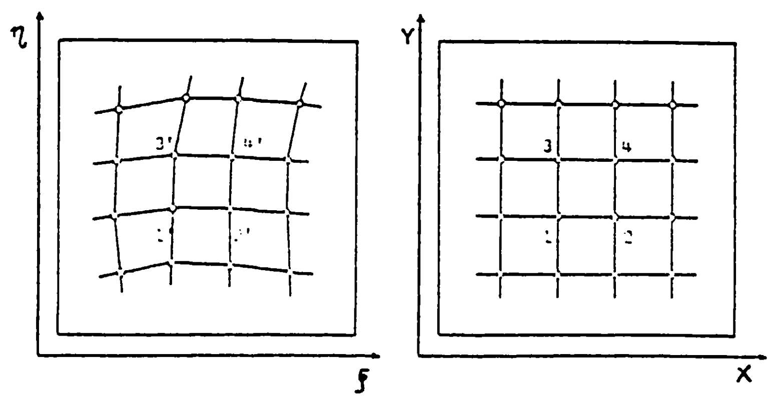


Figure 7.7 Grid in the photograph and in the map.

Thus OR-1 controlling computer is computing the coordinates of the mid point for each pair of successive picture elements (pixels) and accordingly drives the photo-carriage to that point. Similarly, the angle Θ through which the element needs to be rotated to remove the tilt displacement and the amount of the differential scale change M are also computed and the values used to control the settings of the corresponding optical elements in the OR-1 unit.

Overall the Wild Avioplan orthophoto system consists in essence of three units (Vozikis, 1982):

- The projection unit, where the differential rectification is carried out.
- The electronics cabinet. This accommodates a DG Nova process computer, a magnetic tape unit and all the electronic components. The process computer monitors the transformation and controls the projection unit, while the magnetic tape unit inputs the data

required for this.

- The DG 6042 terminal, which allows the operator to communicate with the system.

The photo carriage is an xy-cross slide which is driven by two small DC motors and spindles in the x and y directions. Rotary encoders attached to each spindle provide the actual position of the carriage as a feedback to the controlling computer which can then implement any necessary corrections by the DC motors.

The basic zoom lens unit operated by hand gives a magnification range of 0.33x to 3x which, combined with the original 2x fixed magnification of the optical system, gives a total range of 0.66x to 6x. In parallel with this, as mentioned above, another set of zoom lenses are driven continuously by a servo motor under the control of the computer for the necessary scale corrections. For a black and white orthophotograph (as used in this project), a standard slit width of 0.1mm is used.

The maximum orthophoto size which can be produced is 900 x 750mm (maximum film format 970 x 780mm).

7.6.1 The Acquisition of Digital Data for the Control of the Wild OR-1 Unit

As mentioned before in 7.6, for the generation of the necessary DTM for the production of the test orthophotos, a set of profiles was gathered on a Wild BC-2 analytical plotter. This is an analytical plotter based on the object coordinates primary approach (Petrie, 1990), with a Data General DG30 desktop computer employed as its control computer. The SORA software on the BC-2 can transform the measured data into the data used for the control of OR-1.

7.6.2 The SORA-OP Package

The SORA-OP is the SORA (Software for Off-line Rectification by the Avioplan) program module for the transformation of terrain profile coordinates to the image coordinate system and performs the interpolation of scans in the OR-1 unit as mentioned previously.

SORA-OP consists of the following sub-modules

a) Sub-module 1 for the DTM profile interpolation

b) Sub-module 2 for the terrain to image transformation

c) Sub-module 3 for the control of the OR-1 operations

The submodule 1 can interpolate DTM data from virtually any DTM package. For the sub-module 2, the input sets of data are the inner and outer orientation elements or the inner orientation elements plus coordinates of the control points in both the image and ground coordinate system. If orientation elements are included within the data, the software, as a check, computes the corresponding image coordinates of the control points. If these computed coordinates differ from the given values by more than 0.2mm at the orthophoto scale, a new set of orientation elements is computed by carrying out a space resection, with a view to discarding the point giving the large discrepancy. As soon as the control data for the OR-1 are available, the profile data are transformed into the corresponding points on the image plane and both sets of data are then stored on magnetic tape for the on-line control of the OR-1. The first block of the digital control data consists of an 8-digit header; the scan length and width in mm on the orthophoto; and the x,y coordinates of a minimum of three points to serve as orientation points.

The submodule 3 reads initially the profile data of the two first profiles, computes the coordinates of the first point in the scan and the carriage is driven to this point. At this point, the computer performs an interpolation of the values x_0, y_0 of the midpoint, the values Θ and M of the rotation angle and magnification as stated in Section 7.6 for 99 picture elements. The interpolation is based on the end values (of elements 1 and 2) initially computed. The interpolated and the computed values of x_0, y_0, M and Θ are used to apply the fine individual corrections for each picture element (pixel) by transmitting signals via digital to analogue convertors to the rails, the dove prism and the terrain zoom lens servos. As soon as the centre point of picture element 2 is reached, the same process is repeated for picture elements 2 and 3. At the end of each scan, the drum step is automatically generated, while the profile 3 is read, over-writing profile 1. Profile scan number 2 begins, and this procedure is repeated for the rest of the scans.

Since two consecutive image profiles are always held at a time in the computer, the real-time program can always compute and interpolate the necessary values for the profiles between the two. Hence, the photo carriage always moves along interpolated scans between consecutive recorded profiles. The rectified photoimage based on these profiles is then projected onto the film through the narrow slit.

7.7 Relative Advantages of the Off-Line Production of Orthophotographs for the Project.

The advantages of the off-line operation for the production of orthophotographs are well known (Makarovic, 1973 b). They include the ability to remove and remeasure any profile data which may be doubtful or in error. Whereas in an on-line operation, if an error in the measurement of the profile data takes place, it results in a corresponding error in the orthophotograph, which shows up clearly in the image. Furthermore, a higher production rate can be achieved than in the case of an on-line operation - since a single off-line orthophoto printer can handle the output from several stereoplotting instruments. At the same time, the off-line mode of operation, allows more flexibility, due to the various alternative ways that may be used for the acquisition of DTM data.

On the other hand, a source of planimetric error for the off-line approach will be the exact registration of the input photo to the height information (profile data). Furthermore, a slope correction facility is available mainly in the off-line equipment. The clear advantage offered by this facility, is that gaps and double imaging are avoided. Thus the same planimetric accuracies can be achieved by using larger slit diaphragms resulting in a reduction of the profiling times. Such a facility will obviously be more beneficial to applications in terrain with steep slopes and undulations, being the typical case in Greece.

7.8 Extraction of Cadastral Data from the Test Orthophotographs.

The two orthophoto negatives produced on the OR-1 were then used in the University of Glasgow to produce a set of dimensionally stable diapositives and a set of paperprint orthophotos as contact copies of the original negatives. However film diapositives are difficult to use and any measurements carried out on them will require the use of a special back lit digitising tablet. Since such a back-lit tablet was not available in the Department, the measurement of features for the production of vector map data was carried out on a non back-lit GTCO large format tablet digitiser available in the Department, using the paper print copies of the orthophotos. The problem associated with the production of paperprint orthophotos is that of lack of dimensional stability. However, affine distortion of paper prints can be minimised if a stable resin base is used and these were indeed used in the case of the test orthophotos.

The measurement of the features contained in the orthophotography, was carried out using the MapData digitising software, version 4.77 of which was loaded on to a Viglen 486 PC connected to the GTCO digitiser. MapData uses a two-dimensional affine transformation to fit the document being measured to the ground coordinate system. Such a transformation is necessary to compensate for the affine distortions which as noted above, are likely to occur in paper print orthophotos. So this software was considered to be appropriate for the measurement of the cadastral data. Furthermore, with MapData, the measured point data in the ground coordinate system can be output in an ASCII format which allows the direct acquisition and recording of the ground coordinate values. Hence MapData was considered as appropriate for the extraction of the vector cadastral data from the two orthophotos.

During the photographic process for the production of the paper print orthophotos, attention had been given to the production of high contrast prints which would facilitate the identification of the boundaries and aid a more precise location of the measuring cursor. Indeed, the paper prints produced were very clear and of high contrast. Close detection of the images did not reveal any striping caused by slopes which in fact were not too steep in these test areas. The close inspection of the images also revealed a relatively clear distinction of power lines. However, it was found impossible to detect fences, although their existence was fairly obvious from the grass growing along their sides. It should be noted that it was almost impossible to do so even during high magnification stereo-plotting.

As would be expected, elevated objects such as walls and especially houses, caused considerable displacements towards the corners of the orthophotograph. This phenomenon, as well as the shadows caused by the highly protruding objects, made measurements more difficult to carry out and a lot of estimations had to be made. Buildings for example, were measured at their base and it was impossible to see their fourth corner. However, the interactive measurement with the visual display of the measured data on the colour screen, meant that, using the editing capabilities of MapData, it was possible to ensure that the measured houses were as rectangular as possible. However no particular emphasis should be given to this matter, since the previous experience from the stereoplotting of the same areas had revealed that many of the buildings did not have a rectangular form.

7.8.1 Measuring Data on the Corinth Orthophotograph

Prior to the carrying out of the measurements using the tablet digitiser and MapData, certain initialisation and set-up operations have to be carried out. The initialisation operations set the relation of the ground coordinates to the MapData internal unit range (-32,768 to +32,768 units). This range determines the accuracy up to which the point coordinates can be measured. In order to fit the whole of the orthophotograph area within the internal unit range, an internal unit of 0.03mm (30μm) was selected which is well within the 100μm resolution of the GTCO digitiser being used. With the set-up operation, the orthophotograph is brought into the ground coordinate system with the aid of the available control points. An affine two-dimensional transformation is carried out with MapData if a minimum of three ground control point coordinates are available. The four control points of each of the test areas examined, gave only one redundancy, and the residuals (rmse) obtained were about ±40cm for the Eastings and ±5cm for the Northings. The residuals in Eastings, although within the resolution of the digitiser, were rather high making the assumption once again, as during the stereo-plotting operations, that one of the control points did not have too accurate coordinates.

Measurement of the boundary data started after the setting-up operation. A 16-button cursor was used with the tablet digitiser; for each button, a different command was assigned for a MapData operation. This was found particularly useful and ensured that the need to type in MapData commands as two-letter mnemonics on the keyboard was minimised. Despite this, and in order to speed up the measuring operations, it was decided to discriminate between four main feature categories.

1) Boundaries

2) Estimated / Unidentified boundaries

3) Buildings

4) Roads

With MapData, points of the same segment are assigned a code which is entered manually each time a segment is initialised. This can be of some aid if the data is later edited and structured topologically to form part of a database.

The overall view of an area that the orthophoto provides, proved to be very beneficial for a better estimation of the positions of boundaries when these were not very clearly identifiable, especially in the case of tree rows or hedges. On the other hand, the lack of stereoscopy and higher magnification meant that measurements necessitated a very cautious and careful location of the digitising cursor. Closed polygons, or points common to multiple segments shared the same coordinate values using the "recall point" (RP) command, thus avoiding duplicate points and hence promoting consistency. Among all the other operations, the estimated measurement of the obscured corners of buildings was found to be the most unfavourable, highly approximating operation.

7.8.2 Measurements on the Achaia Orthophotograph.

A noteworthy remark should be given here concerning the two orthophotos being produced. The orthophotos were not of the same size and, by comparing them with the corresponding photos, it seemed as if they had been produced at a different magnification. However the comparison of known distances both on the orthophotos and on the photographs, immediately confirmed the different scale of the aerial photographs. For the

Achaia area, the photo scale was slightly smaller than 1:6,000, whereas for the Corinth area, the photo scale was closer to 1:5,500.

The process of measuring the data on the Achaia orthophotograph followed the procedure used with the Corinth orthophoto. During the initialisation stage, it was found that the orthophoto had to be placed in a skewed position on the tablet digitiser so that the orientation of the ground coordinate system could be in a close proximity to the x and y directions of the digitising table. During the set-up operation, residuals (rmse), of around ±30cm in Eastings and less than ±4cm in Northings were obtained at the control points.

As has been previously mentioned, the Achaia test area has many boundaries formed by rows of trees or hedges. The lack of a stereoscopic view meant that perhaps a poor estimation of the feature central axis was made. On the other hand, the limited number of buildings made the measurements more straightforward with less need for approximations.

As in the case of the Corinth orthophotograph, the roads were actually measured last and since, in most cases, they coincided with boundary features, they were recorded as duplicate line segments to retain the overall consistency of the data.

Both sets of data from the orthophotos were saved in ASCII file format and were then transferred to the Department's PLOTV2/3 plotting program for the generation of plot files. Remarks with respect to this plot output as well as a comparison between the results and products from the various photogrammetric techniques tested in this project will be given in the next Chapter, 8.

CHAPTER EIGHT

Chapter 8

Evaluation of the Test Results.

8.1 Introduction

In this chapter, an attempt is made to carry out a comparative evaluation of the three photogrammetric techniques tested in this project in terms of relative accuracy and completeness of the measured cadastral detail.

This evaluation was based on a visual comparative analysis of the graphical output obtained from the examined techniques at the two test areas. Also for the comparison in terms of accuracy, of the techniques of orthophotography and of stereoplotting, numerical tests based on the coordinates of the control and a set of check points from each area, had been carried out. For the numerical tests, coordinate values in digital form were used, as obtained from the two photogrammetric techniques mentioned above.

8.1.1 Boundary Identification Checks. Stereoplotting Versus Orthophotography

A visual analysis of the cadastral vector plot for the Corinth test area obtained from stereoplotting showed that just over 200 parcels could be identified in that area. From that analysis it was estimated that, on a parcel unit basis (and not on the basis of their overall length), approximately 6% of the boundaries was assumed as being uncertain either as to whether they were really boundaries or as to what type of boundary they constituted (stereoplotting feature codes 230/220). Much the same figure resulted from the visual inspection of the vector plot produced from the orthophotograph of the same area. This favourable agreement indicated the good potential of the orthophotography for the identification of physical boundaries. However, it should be noted that a high percentage of the identified boundaries in this area were boundaries represented by walls on the ground.

A similar analysis was carried out for the plots of the Achaia test area where approximately 115 individual parcels were identified. For that area, about 15% of the boundaries obtained during stereoplotting were judged to be uncertain as compared to 16% of those obtained from measurements on the orthophoto. This slight increase of uncertainty can be explained as arising from the high percentage of boundaries represented by hedges, fences and rows of trees.

Of course, all the above comparisons might be thought to have small importance without field verification and completion operations. However, they do give a relative comparison of the techniques considering that the same operator carried out the measurements but only after a considerable time gap so that there was a minimum of influence or correlation between the operations.

A remark has to be made here about the measurement of the houses on the orthophotos. The shapes of these plotted houses were fairly irregular and, in many cases, did not match the shapes obtained during stereoplotting despite the great care taken during measurements on the orthophotos. This should be considered as a drawback of orthophotography, and if the recording of houses of regular shape is required, some further editing will be required within a graphics package, which perhaps will mean some loss of absolute accuracy of the corners of the buildings in terms of coordinates.

In general, the individual visual check of all the generated plots verified that there were no blunders and very few omissions and the lines of closed shapes joined up. However, not all the parcels were plotted as closed shapes, indicating that field completion operations should be the only solution for the recording of the missing parcel sides. The very few omissions which were detected comprised one or two houses. Small sheds were not plotted on the orthophotos.

8.1.2 Plots Obtained from Monoplotting

The comparison of the Achaia plot obtained from GAPS showed a close proximity of the plotted features to those obtained from measurements on the corresponding orthophoto, in terms of completeness of identified boundaries. An exception was a small section relating to the northern part of the digital image where the view was of very low contrast and a few parcels could not be identified. The whole vector plot obtained from GAPS did not fit well at all, when placed over the vector plot from stereoplotting. Large displacements occurred exceeding 10m in some cases, especially towards the edges of the area. However, a lot of parcels fit quite well with the plot from stereoplotting, but on a local basis, i.e. individually for every parcel.

A careful examination showed that the displacements were larger along the one axis of the plotted area, indicating a smaller scale of the plotted data along this axis. The plotted detail showed much smaller displacements in the perpendicular to the above axis.

Relating this result to the form of the relief of the Achaia area, it was clear that the scale shrinkage occurred along the direction of slope in the model which was fairly even from the top of area towards the bottom. A better matching of the plot boundaries between the output from the digital image and the stereoplotting occurred around the centre of the area.

The comparison of the graphical vector output from the digitally rectified image produced by GAPS and the orthophoto of the Corinth area showed, as in the case of Achaia, a good consistency in terms of the identified boundaries. There were even a couple of cases where a parcel was identified and measured on the digital image and not on the orthophoto, despite the better quality of the latter image. However, this matter of identification can be considered as a matter of occasional judgment or simply an omission. Again, as in the case of the Achaia test area, the plot obtained from GAPS did not show a good fit over the plots obtained from stereoplotting and the orthophotograph. A large variation of scale was fairly obvious at the locations of high elevation differences with respect to the average elevation of the area. Indeed, a triangular block of parcels located towards the top of the test area having an average height of 65m - a value close to the mean of the height range of the whole area - showed a good fit with the plots obtained from stereoplotting and the orthophotograph. Above and below that block of parcels, two noticeable breaks of slope exist as verified from the contour plots of the area. However, as in the case of the Achaia test area, a better fit of plots can be seen on a local basis at which there is a relatively good matching of boundaries.

8.2 Accuracy Considerations Based on the Superimposition of the Corinth Plots

The superimposition of the plots obtained from orthophotography over the plots obtained from stereoplotting was fairly satisfactory for the cadastral data which were measured by both the above techniques. However, initial efforts to produce plots with the PLOTV2 plotting programme and the Corinth input files from MapData, gave some plots which did not match very well with those obtained from MicroStation and the data obtained from stereoplotting. In particular, it was noticed that the grids of the equivalent plots did not match very well. At that stage, it was believed that the actual scale of the plotted grid was not consistent with the scale of the plotted data. Editing of the scaling parameters of the Corinth.HP file allowed output at the scale of 1:2,000 with a grid at the correct scale. However, the direct superimposition of the plot over that of the same area from MicroStation, did not produce an exact fit. A small difference in the scale of the two superimposed plots was evident, although there was a good fit of parcels at a local basis. The poor fit was especially noticeable towards the south part of the area where it was noted that even the control points did not fit very well.

An initial check was carried out, by computing the distances from the coordinates of the control points as well as scaling off the distances between them on the plots obtained from both techniques. These checks showed that the scaled-off values were in agreement with the distances derived from the coordinate values of the measured data showing that the plots were correct. It should be noted here, that some rather large discrepancies of about 2 metres on the ground, had been noticed between the coordinates of two control points which were plotted as cadastral details between their relative values obtained from stereoplotting and from the corresponding measurements on the orthophotos. These discrepancies were rather surprising considering the relatively much smaller residuals on the control points which were obtained during the set-up (orientation) operations before the measurements on the orthophoto. At that stage, the residuals did not exceed the 0.40m on the ground.

A check of the coordinates of the same control points obtained from the absolute orientation during stereoplotting verified that the residuals in Northings for the two control points located in the south part of the area were about two metres. Similar differences, were obtained for the same control points from their values being measured as cadastral data during stereoplotting. At this stage, it was assumed that the given control point coordinates (obtained by the ground traversing method) were not as inaccurate as was initially believed during stereoplotting, The smaller discrepancies of the given coordinates with the ones from the measurements on the orthophoto, indicated that it was probably a bad identification of a control point during the absolute orientation prior to the stereoplotting, which caused the discrepancies between the two sets of data as became evident on the corresponding plots.

In the following three pages, sample plot overlays of the area of Corinth can be found, as obtained from the three photogrammetric techniques, at 1:2,000 scale. The plot lying on the top comes from digital monoplotting followed by the plot from the orthophotograph and the plot from stereoplotting at the bottom (Figures 8.1, 8.2 and 8.3 respectively). In this sample area, the plot obtained from monoplotting had the best fit as compared to the rest of the Corinth area.

a

Figure 8.1 Monoplotting. Corinth sample area

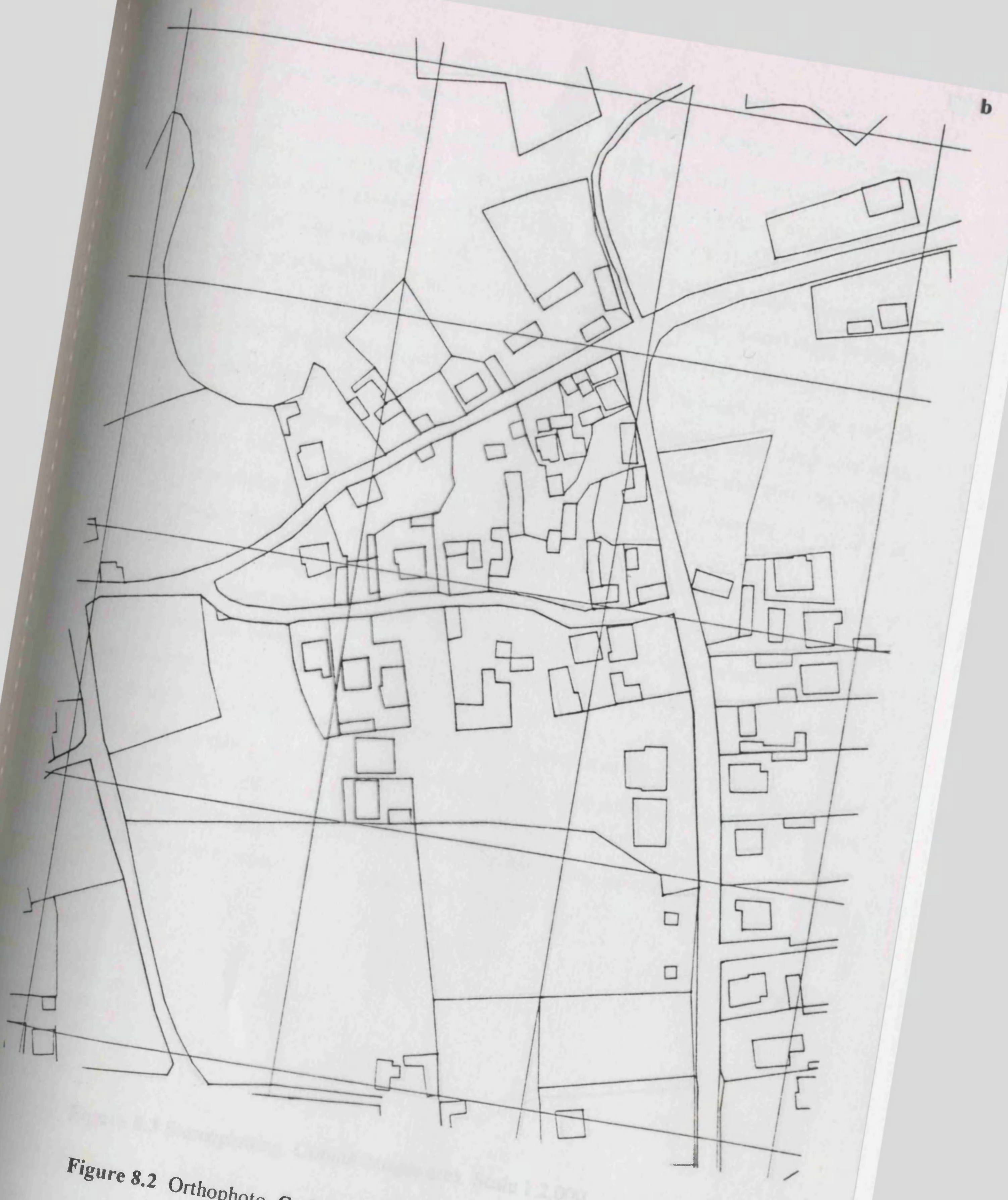


Figure 8.2 Orthophoto. Corinth sample area

Figure 8.3 Stereoplotting. Corinth sample area. Scale 1:2,000

8.2.1 The Superimposition of the Achaia Plots

The same operations were carried out for the plots of Achaia. An initial attempt to generate plots for that area using the PLOTV2 software, was unsuccessful. It was soon found out that the occurrence of negative coordinates in Northings of the Achaia area was the cause of the problem and an alternation in the software enabled the output of the required plot. The visual check of the plots of this area revealed a slight mismatch of the boundaries at a local level. This was not unexpected due to their actual large dimensions (rows of trees, hedges, etc). However, taking an overall view, the Achaia plots showed a good fit of the plotted detail, with a small mismatch towards the south part of the area. The control points on the orthophoto and the plot from stereoplotting, fitted fairly well in the case of Achaia. These control points fitted within ±0.5mm which was also verified by a comparison between the scaled-off and the distances computed from the coordinates of these control points.

A further check was carried out by generating two plots of the test areas at a scale of 1:2,500 on a transparent base material. These plots were overlaid on the relevant orthophoto paper prints and also on the equivalent positive film transparencies. In the case of Corinth, the mismatch between the plots and the relevant orthophotos was only just noticeable.

Sample plots of the central part of Achaia, obtained from the three techniques, can be seen as an overlay at the following three pages in the same order as with the sample plots of Corinth (Figures 8.4, 8.5, 8.6).

The complete plots of the Corinth and Achaia areas, as obtained from the three photogrammetric techniques, can be found in Appendix A.

a

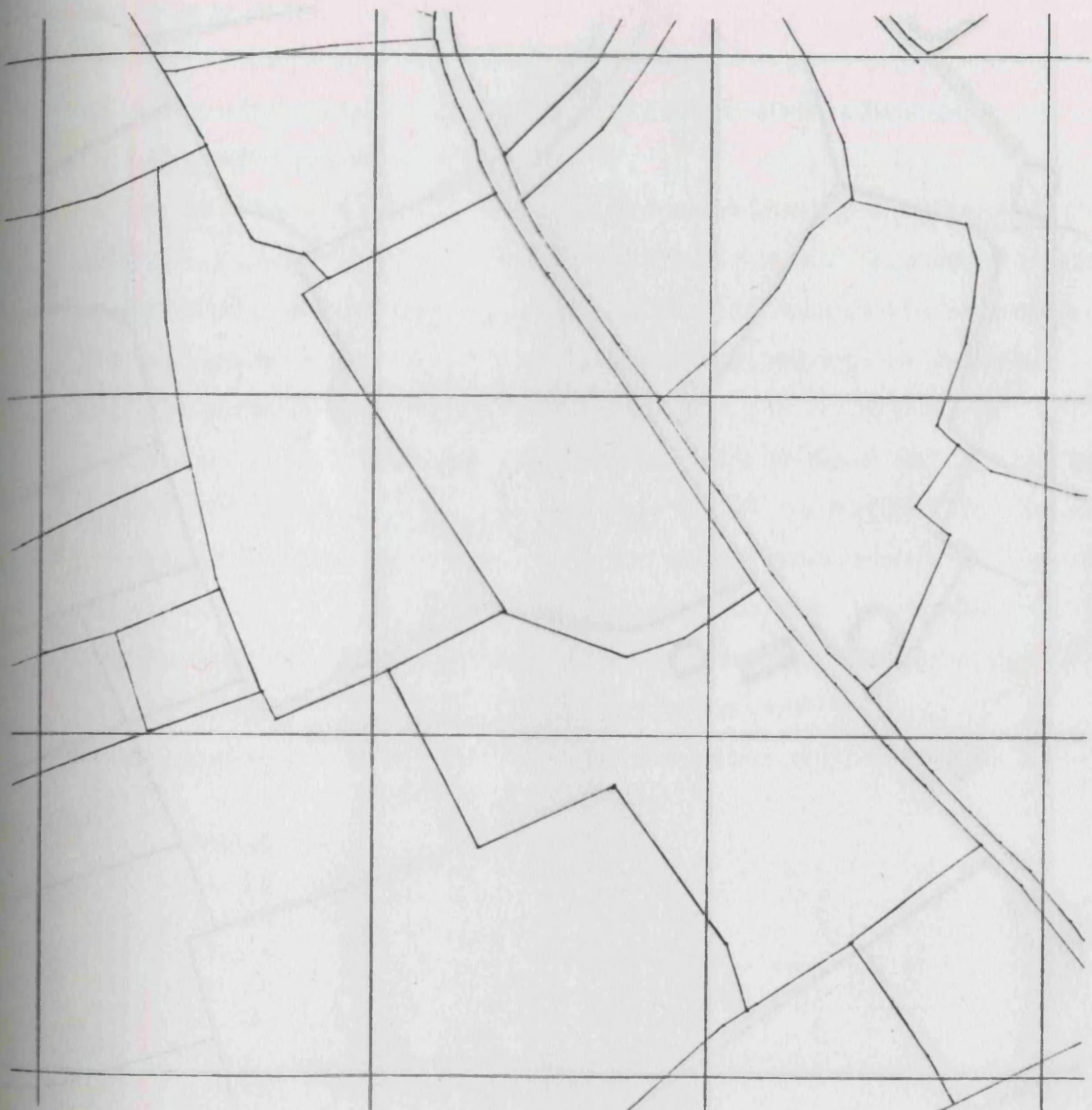


Figure 8.4 Monoplotting. Achaia sample area

Figure 8.5 Orthophoto. Achaia sample area

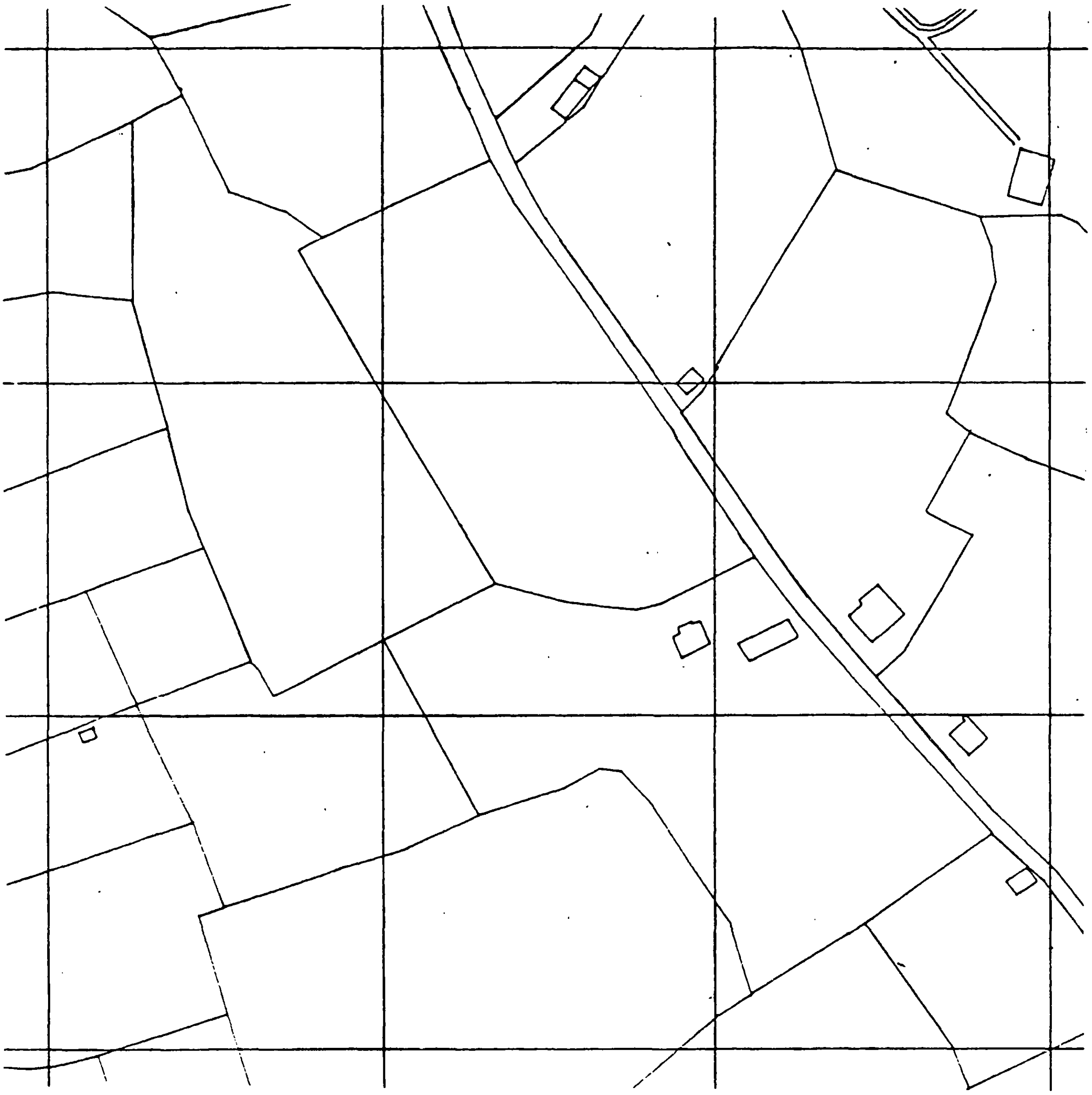


Figure 8.6 Stereoplotting. Achaia sample area. Scale 1.2,000

Having obtained these graphical results, it was decided to carry out a further test, this time based on the actual coordinate values from both the stereoplotting data and the data from the orthophotos.

8.3 A Numerical Comparison Between Check Points Present on Both the Stereoplotting and the Orthophotography

In order to obtain a better comparison of the results from the two photogrammetric techniques, a check was made based on points obtained from both the stereoplotting and the orthophotographs. Twenty well distributed check points were used for each test area. The check points were of various cadastral feature types, although for the Corinth test area, these points were predominantly wall junctions.

The coordinates of the check points were available in digital form for the two photogrammetric techniques examined. From both RPLOT and MapData, data files had been obtained in ASCII readable format, so it was possible to read directly from these the coordinate values of the check points. However, the task of searching out the corresponding values from the files of the stereoplotting and orthophotography, was a very time consuming and tedious task which was carried out on a word processor.

The coordinates of the check points from both sets of data are listed in Table 8.1.

	Stereoplotting		Orthophoto	
1,	-7341.629,	17838.672,	-7341.070,	17836.910
2,	-7357.197,	17688.835,	-7357.300,	17687.900
3,	-7492.001,	17682.532,	-7491.160,	17681.660
4,	-7458.220,	17604.867,	-7457.830,	17604.650
5,	-7607.383,	17546.815,	-7605.490,	17547.650
6,	-7442.211,	17537.232,	-7440.940,	17536.940
7,	-7178.436,	17589.123,	-7179.400,	17587.550
8,	-7648.633,	17438.567,	-7649.410,	17437.100
9,	-7367.083,	17437.894,	-7366.690,	17437.190
10,	-7419.876,	17288.636,	-7418.980,	17289.020
11,	-7203.555,	17369.516,	-7204.000,	17369.570
12,	-7547.486,	17214.087,	-7546.300,	17215.460
13,	-7422.106,	17384.201,	-7421.890,	17384.780
14,	-7443.946,	17153.319,	-7443.760,	17153.540
15,	-7535.276,	17100.772,	-7533.700,	17101.130
16,	-7170.021,	17277.208,	-7171.270,	17276.630
17,	-7367.268,	17045.977,	-7366.990,	17047.250
18,	-7592.853,	17034.888,	-7592.560,	17035.130
19,	-7639.960,	17058.090,	-7638.820,	17058.260
20,	-7167.130,	17043.650,	-7167.400,	17043.260

Table 8.1 Corinth check points coordinates (in metres).

With the two sets of coordinates available for each area, the error vectors of the points and the rmse values were computed using a small program which was available in the Department, and the results were verified by manual calculation.

8.3.1 Corinth Check Points

For the Corinth test area, an rmse value of m_{pl}= ±1.30m in planimetry was obtained. This rmse value is equivalent to 0.5mm at the 1:2,500 scale of the orthophoto. The corresponding error values (m_x, m_y) in x and y were ±0.89 and ±0.87 metres respectively, which are equivalent approximately to 0.35mm on the orthophoto. These values can be considered to be much as expected, assuming the accuracy of the digitiser which might be expected to be of m_{pl}= ±0.3mm. The vector diagram of the check points of the test area of Corinth can be seen in Figure 8.7.

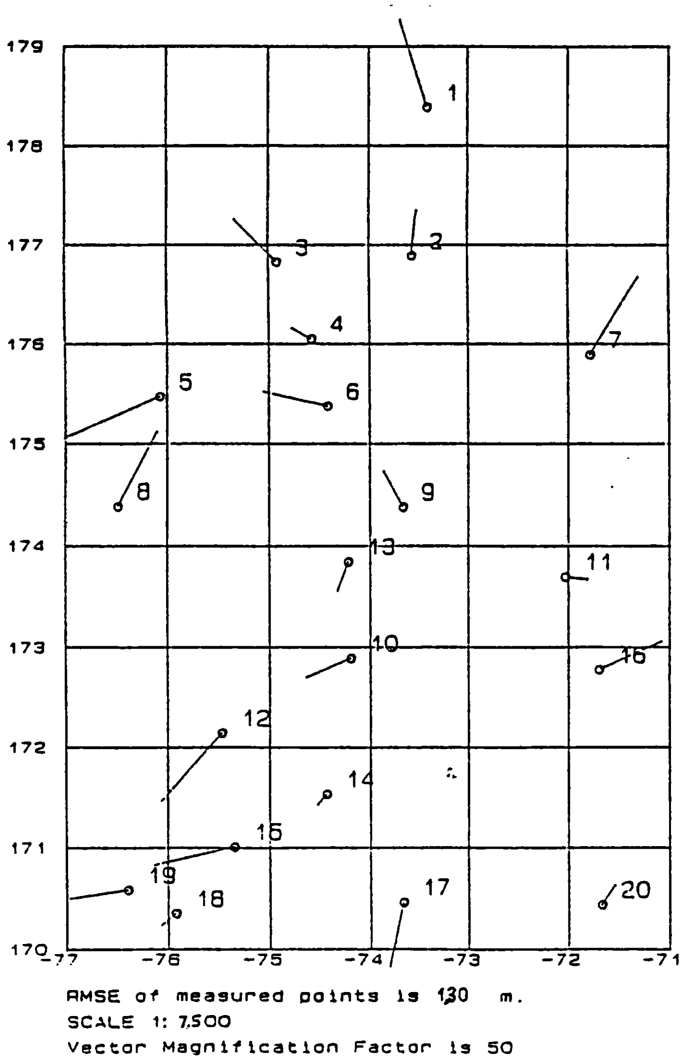


Figure 8.7 Corinth, check points. Error vectors.

A visual check of the plotted error vectors showed a relatively random distribution of the errors, with the vectors having a tendency to increase towards the edges of the area. Their orientation appeared to be, for the majority of them, towards the centre-east part of the plot. The examination of the position of the error vectors on the photograph from which the orthophoto was derived, verified that the vectors had the tendency to orient towards the centre of the photograph. Such a result is in agreement with results obtained from other testing of orthophotos (Krauss, 1993) on a basis of known coordinates of signalised check points and an illustrative example is given in Figure 8.8.

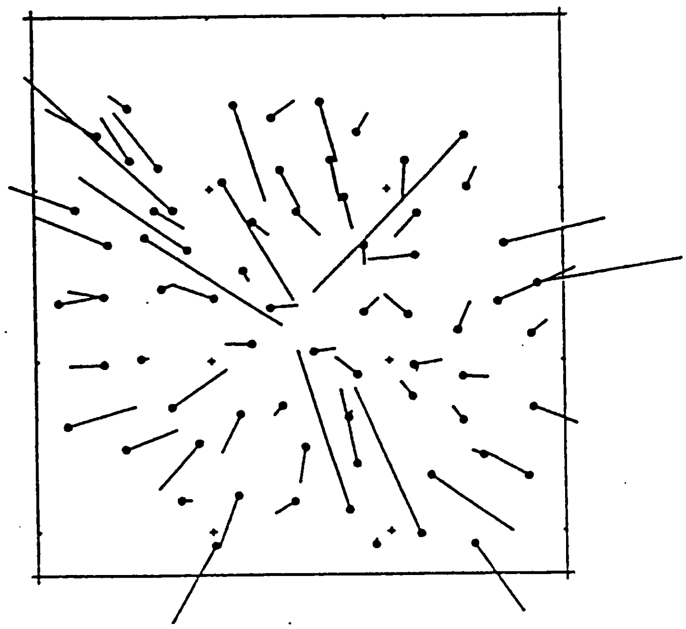


Figure 8.8 Planimetric errors in orthophotos.

8.3.2 Achaia Check Points

A similar check has been carried out for the Achaia test area using 20 check points, the coordinates of which are listed in Table 8.2.

The comparison of the coordinate values of the Achaia 20 check points gave rmse values of m_x= ±0.66m, m_y= ±0.74m for x and y coordinates respectively and m_{pl}= ±1.00m for the planimetry. These values relate to about 0.26, 0.29 and 0.40mm at the scale of the orthophotography. These results were considerably better than the ones obtained for the Corinth area. However the ±0.4mm rmse in planimetry is again slightly high as compared to the ±0.3mm accuracy rmse that can be achieved with the GTCO digitiser, which was used in the tests. For this specific area, despite the smaller rmse values which were obtained as compared with the Corinth area, it was expected that some higher rmse values could result due to the nature of the boundary features. Indeed, the majority of the check points were boundary corner points measured at rows of trees, hedges or ditches. On the other hand, these somewhat superior results, have to be balanced with the fact that for the Corinth area, there were larger discrepancies at the control points between the two methods. However, the error vector diagram of the Achaia check points as seen in Figure 8.9, showed that the vectors had the tendency to align with the vertical axis of the plotted area, indicating some affinity of the errors.

	Stereoplotting		Orthophoto	
1,	21918.302,	-5259.882,	21918.800,	-5261.330
2,	22148.187,	-5234.782,	22148.720,	-5235.530
3,	22343.966,	-5132.581,	22343.570,	-5134.190
4,	22058.772,	-5354.217,	22058.990,	-5354.930
5,	22476.453,	-5521.471,	22475.930,	-5521.850
6,	22210.877,	-5472.085,	22211.630,	-5472.830
7,	22280.495,	-5559.221,	22280.690,	-5559.650
8,	21917.091,	-5521.874,	21917.660,	-5521.820
9,	21990.293,	-5753.152,	21989.720,	-5753.420
10,	21927.846,	-5728.052,	21929.150,	-5728.610
11,	22174.081,	-5660.382,	22174.970,	-5660.900
12,	22477.515,	-5630.918,	22476.440,	-5631.320
13,	22312.027,	-5752.184,	22312.160,	-5752.910
14,	22142.598,	-5832.037,	22142.810,	-5832.800
15,	22382.418,	-5835.774,	22382.480,	-5836.100
16,	22525.839,	-5891.402,	22525.640,	-5891.870
17,	22685.160,	-5786.607,	22684.070,	-5786.330
18,	22829.627,	-5839.337,	22829.240,	-5838.950
19,	22333.091,	-5232.559,	22332.110,	-5233.340
20,	22317.570,	-5963.086,	22318.250,	-5964.020

Table 8.2 Achaia check point coordinates (in metres).

The resulting correlation of the error vectors, should not be related to possible large errors in the given control point coordinates. For both the stereoplotting and orthophoto production and measurements, the same control data have been used, and hence any differences in accuracy is relative between these two methods. However, as in the case of Corinth, poor identification of the control points during the process of absolute orientation in one of the methods tested, could have caused the introduction of systematic errors in the measured data. On the other hand, the MapData package performs an affine transformation based on the minimum of 3 control points being measured, in order to compensate for any affinity between the two directions of the measured document besides which, systematic errors in orthophotos are not something normal (El Niweiri, 1988). Thus the possibility of distortion of the paper print orthophoto occurring after the initial set up (orientation) operations was carried out, had to be considered.

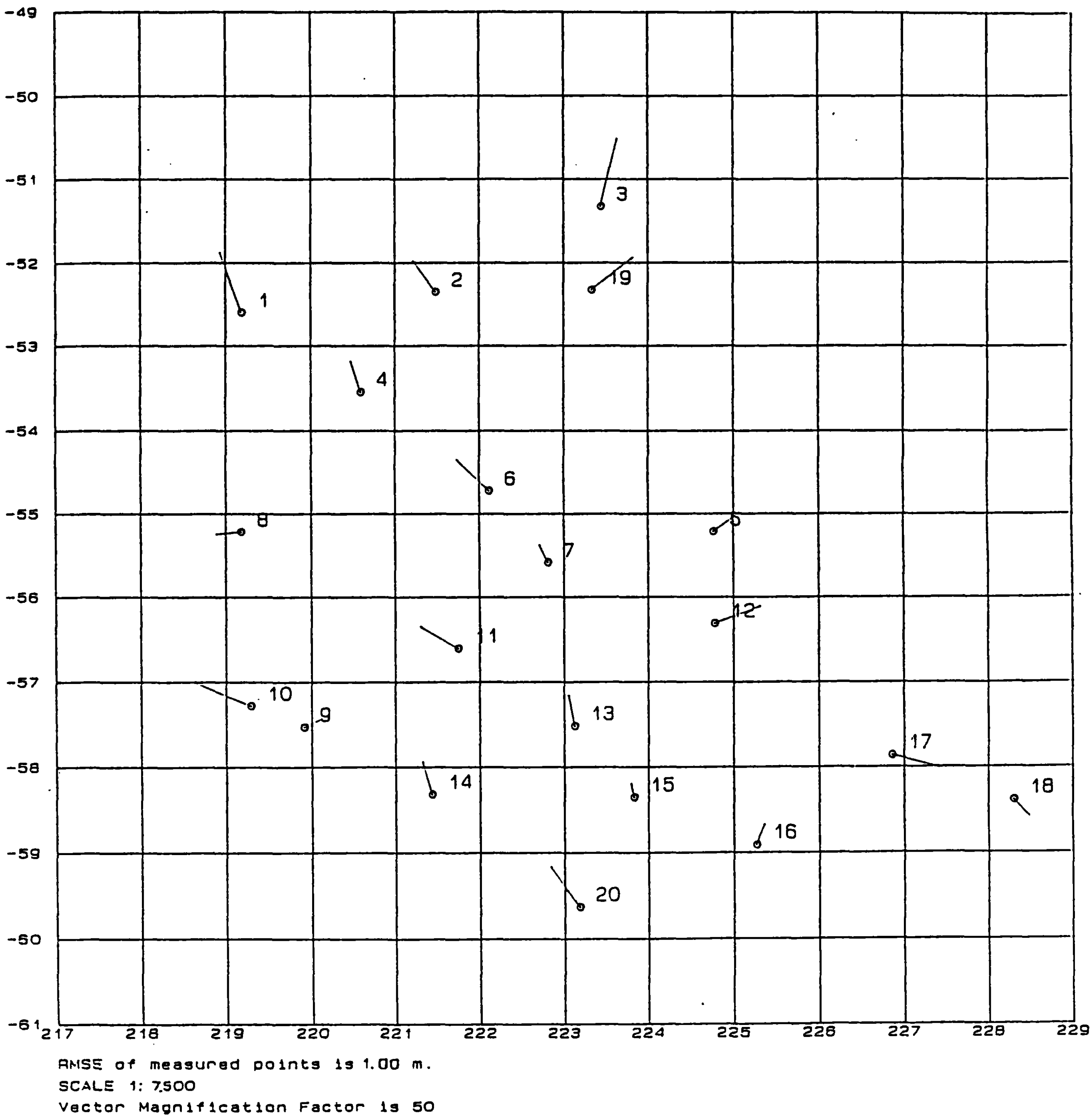


Figure 8.9 Achaia, error vectors on check points.

8.3.3 Checks for Orthophoto Deformations During Measurements

In order to verify the influence of distortions of the orthophotograph on the results, the four control points available for the area of Achaia, had also been measured as data points at the end of the measuring operations. Hence, the residuals and rmse values between coordinates of the control points measured at the end, and the ones computed at the beginning of the operations were calculated. The ±0.85m rmse obtained and the orientation of the vectors (Figure 8.10), approximated to a considerable extent the magnitude of the rmse and the orientation of the check point error vectors of the same area.

Although, more control points measured both at the beginning and at the end of the operations would have been needed in order to obtain a more solid answer, it was believed that the measured coordinate data have been considerably affected by distortions of the orthophoto after the initial orientation (set-up) operations. Such a belief can have a reasonable basis since the measurement of all the cadastral data on the orthophoto took place over a long period of time. Hence, despite the affine transformation carried out during the set-up operation with MapData, some subsequent distortions of the paperprint orthophotos could well have occurred, thus introducing systematic errors into the data of the Achaia area. This might also have occurred for the Corinth area which however, due to the errors in the data from stereoplotting, were not so obvious from the vectors obtained.

In order to give a basis to the assumption made above, a similar check was performed for the control points of the Corinth area, which have also been measured at the end of the operations. As in the case of Achaia, the error vectors of the control points, followed the same pattern of the vectors of the check points (Figure 8.11). Also, their rmse value was of approximately the same magnitude (±1.31m). Although again this is of small comparative value, the close similarity of the errors of the repeatedly measured control points, with the errors of the check points give some basis to the assumption made about the introduction of systematic errors due to the distortion of the orthophoto occurring after the initial set-up procedures.

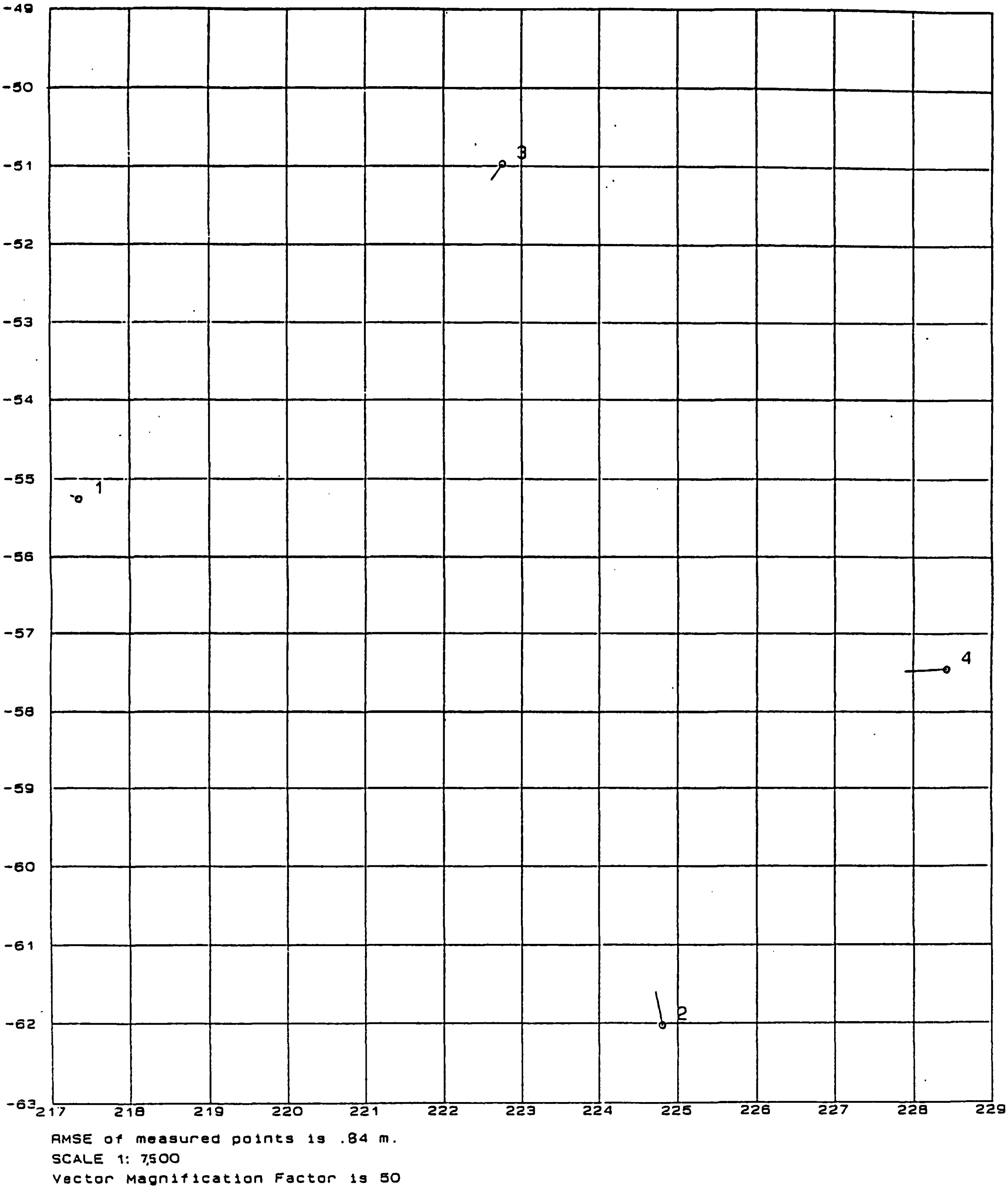


Figure 8.10 Achaia - Control point vectors.

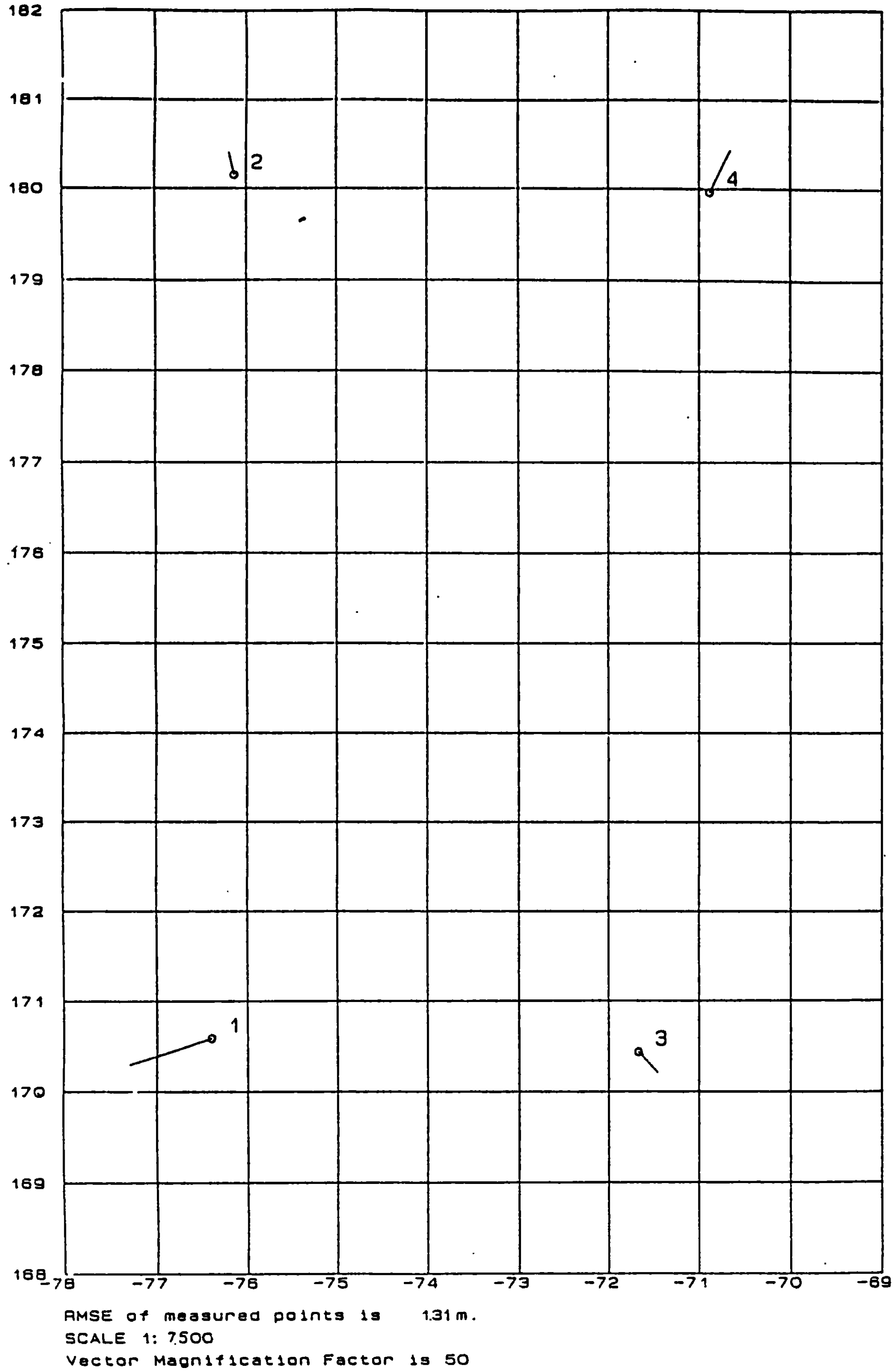


Figure 8.11 Corinth control point vectors.

8.4 Remarks on the Accuracy Results

From the discussion above, a number of error sources such as poor control point identification or the deformation of the orthophotos during measurements, appeared to have caused the introduction of errors in the data obtained both from stereoplotting and from measurements on the orthophoto. Considering this fact, the rmse values of ±1.00m and ±1.30m obtained from the comparison of the check point coordinates were not too large although (especially those of Corinth) they exceeded considerably the obtainable accuracies of the tablet digitiser and the values as expected with the assumptions made in 7.5.1. The plots of Achaia obtained from stereoplotting and orthophoto showed a good overall fit with the exception of some local boundaries, formed by thick and dense rows of trees or hedges, exceeding in some cases a thickness of 5m. The plots from Corinth, showed some overall mismatch between them, but the actual plot obtained from the orthophoto proved to be more accurate than the one from stereoplotting due to poor control point identification in the latter technique. However, the results of both techniques showed a good agreement of parcel boundaries on a local basis, which should be of major importance for graphical cadastral surveys. If the accuracy of the absolute coordinates of a parcel is of secondary importance, then any computed distance or area for a parcel unit will have much smaller residuals than the average residuals in the coordinate values obtained for the check points of the test areas

The overall accuracy can be improved for the measurements made on the orthophoto, if some measures are taken to compensate for orthophoto deformations. First of all, measurements might be carried out on a stable base diapositive of the orthophoto using a back lit digitiser. On the other hand, if measurements on control points are carried out frequently during the plotting operation and new affine transformations are performed each time, it should be possible to ensure that errors due to deformations will be minimised considerably, although some increase of the operational time will also occur.

With respect to the digital monoplotting without the use of a DTM, this should be considered as inappropriate for cadastral surveys in non-flat areas or these areas with non-constant slope. The plot obtained from monoplotting of the Achaia area which is predominantly one having a constant slope, indicated that only a small consideration can be given to this technique in this type of areas at a local basis, as a complementary method, if some omissions are identified and only at such flat rural areas, which will be a rather rare situation in cases like Greece. If a program such as GAPS could be made to work efficiently in conjunction with a DTM, then this could improve the accuracy greatly and would have the distinct advantage of being suitable to be implemented in district offices in a distributed cadastral system.

Concluding, the need for accurate ground control with enough redundancies should be emphasised. The fact that only 4 control points were available per model, gave rise to the possibility that a considerable amount of error could be introduced in the data either if its given coordinates have errors, or because of a simple misidentification. The cost in terms of time and money to establish some more redundant control points, e.g. by aerial triangulation, will be small when compared to the additional cost for corrections over a badly plotted area.

Also, if the control points are to be used for the production of orthophotos, careful selection of the topographic detail used for control purposes has to be made, if premarking of control points is not used. Points located on the tops of buildings or at their obscured side on the photographs will inevitably cause bad identification both at the stage of production of the orthophoto, but also at the stage of vector digitising of the cadastral data and will introduce errors within the data. Points like these described above, were used during these tests, which most probably have been one of the factors causing the rather large residuals encountered both on the control points and the check points between stereoplotting and orthophotography.

CHAPTER NINE

Chapter 9

CONCLUSIONS AND RECOMMENDATIONS

9.1 Introduction

Even today, sixty years after its first use, many cadastral surveyors still find it difficult to accept photogrammetry as a solution to some of their problems, considering it either as irrelevant to cadastral surveys or as an unacceptable competitor against ground survey methods. However, having a look at the many examples from various countries summarised in Chapter 4, it becomes obvious that photogrammetric techniques have been tested and adopted widely according to the specific needs of the cadastral systems in these countries. The types of photogrammetric techniques that have been employed on cadastral applications range from the most simple, cheap and easily applied techniques up to the most technologically sophisticated, which does not necessarily mean that they are ideal for implementation in every country. Looking at those examples of the techniques which have been applied, it can be seen that photogrammetry has managed to provide a good solution to many cadastral survey needs, provided that the appropriate technique is selected with respect to the specific needs of the cadastral system; that is according to whether it was numerical or graphical; whether its structure was centralised or decentralised; the type of terrain to be surveyed; the available resources, etc.

Greece is one of the few countries, at least in Europe, considering the establishment of a new cadastral system. The existing land registration system, being a registration of deeds, operates on a decentralised basis and, until recently, cadastral plans were not kept in the registries or by the owners of the land. Considering the existing registration system, the fact that the terrain of Greece is predominantly mountainous and the limited economic resources, the establishment of a new cadastral system over the whole extent of the country can be more safely satisfied via a graphical cadastre.

However, the decision for the use of a graphical cadastre can be debated, considering the opportunity that a completely new cadastral survey offers. The problem of integrating older, often inconsistent data obtained by different techniques and at different accuracies, simply does not exist. The existence of survey regulations is of primary importance and especially their relation to the overall legislation of the cadastral system. If cadastral data are needed also to form the basis for the reconstruction of lost or disputed boundaries, then the accuracy with which such a reconstruction can be performed should be catered for in the legislation. Most probably, a graphical photogrammetric survey will be insufficient for the production of data accurate enough for boundary reconstruction.

9.2 The Potential Use of Photogrammetry to Cadastral Surveys in Greece

However, apart from the matter of the cost and the available resources necessary for the adoption of a more accurate but also more expensive technique, some other influencing factors have to be balanced. These include the use and value of the land, especially in the rural and mountainous areas, in conjunction with the fact that, very often, physical features form the boundaries. On top of these factors, the pre-marking of boundary corners will, in the opinion of the present author, be hard to implement successfully in Greece. Based on these considerations, the adoption of a high accuracy numerical photogrammetric technique used in conjunction with signalised boundary points to serve demanding tolerances, as for example those successfully set in Switzerland, will have little or no practical value in Greece.

On the other hand, the developments in computer technology have changed the traditional concepts about the storage, retrieval and manipulation of cadastral information. The advantages provided by this technology for the maintenance and manipulation of such data is steadily increasing the potential for the more efficient management of information in integrated cadastral and land information systems. The requirement of these systems for data in digital form has had its impact on photogrammetry, which evolved initially as a graphical method. Similar pressures have come from other users of photogrammetric data, e.g. from the civil engineering industry and its requirements for data suitable for entry to CAD systems. Hence photogrammetric techniques have been adapted accordingly to produce digital data for cadastral surveys, whether these are based on numerical or graphical accuracy in standards.

The test material utilised in this project may be regarded as fairly typical for rural and semi-rural areas in Greece with respect to the cadastral data requirements, the relief and the type of boundaries. Thus the photogrammetric techniques tested in this project gave results which are interesting in terms of their possible adoption for cadastral surveys of these areas in Greece.

9.2.1 The Suitability of Stereoplotting

The digital encoding of analogue stereoplotters, as used during the tests, proved to be a worthwhile conversion which suited the needs of cadastral surveys for data in digital form.

Stereoplotting is probably the only recommended solution for plotting of highly elevated or steeply situated boundaries and it has proved its ability worldwide for plotting over large areas. The integration of the stereoplotters with an encoding system such as RPLOT verified the functionality of this type of system, the gains in operational times and the ability to handle the data successfully in a large number of separate information layers being quite notable. However, it should also be noted that the operational times increase greatly if data are classified into a very large number of feature types, as was done during the stereoplotting stage of this project. If the information required in multiple layers and for multiple purposes can be extracted, structured and edited as an off-line operation, considerable savings in time and costs could be expected over the procedure of carrying out these operations during stereo-plotting. However, in any case, stereoplotting showed its superiority when carrying out the identification of features such as fences, as compared with the execution of this task on the hard copy orthophoto or the rectified digital image. The integrity of the data and the minimal need for editing proved the functionality of the system.

Although the need for editing of the captured data captured was limited, the MicroStation PC graphics package proved to be a useful tool for editing. On the other hand, the transfer and editing of the measured data in MicroStation had the disadvantage of losing the feature coding information and the restriction of operating within the available "Levels". If the captured cadastral data have to be transferred into a digital data base, then the feature codes will have to be reassigned. In any case, MicroStation PC 4 can offer a friendly environment for editing which will probably be much simpler and more efficient than working directly within the more complex environment of a database system. This should be so at least for the initial stage of data manipulation concerning the corrections for gross errors and omissions. The successful merging of data files in the tests, proved that MicroStation is a handy tool for such operations prior to the entry of data in an LIS.

The accuracy obtainable from stereoplotting should be high. Capture of the data in digital form considerably increases the accuracy of the output which is limited mainly due to lack of point signalisation. The rather high residuals obtained from the observation of the control points during the tests is a point to look at. Unfortunately there was only one redundant control point for each model to allow an estimation of the errors which were present or the possible misidentification of the points. However, the provision of accurate ground control points to meet the obtainable accuracy of the technique is a complete necessity, especially considering the needs of a cadastre with data in digital form. The existing control being established for the needs of graphical stereoplotting for topographic mapping, might suffice for that particular use. Rmse's of ±0.30cm on the ground relate to just the plottable accuracy even at the 1:1,000 plotting scale. Ground survey techniques, should be able to produce control at higher accuracies to satisfy the requirements of digital stereoplotting.

9.2.2 The Suitability of Analytical Rectification and Monoplotting

Despite the considerable efforts made, the experiments with GAPS showed that the system being tested, was inappropriate for production use, at least as it stands. This was due both to the hardware restrictions of the package and to the fact that it turned out to be "research" type software rather than a fully tested and bug-free software package suitable for production use. However, provided that such a system could be developed further and functioned properly on a wide variety of computer platforms and gave satisfactory results in terms of accuracy, then the system would look to be quite promising for a possible application in Greece in those relatively flat rural areas that do not require high accuracy standards of mapping. However, even such an implementation should be seen more as being complementary to another more accurate technique. The need for an operator with no special knowledge in photogrammetry and its potential implementation on a readily available and inexpensive computer, make this technique very interesting for a decentralised cadastral system. Regional cadastral offices could make much use of such a system for the updating or completion of their data on a local basis, if another survey technique is not feasible. The monoplotting on a digital rectified image without the use of a DTM, proved to be unacceptable for cadastral surveys in the terrain types likely to be encountered over much of Greece. However, again at a local level, the plotting of small blocks of parcels might be feasible, but only if the area is flat and has enough redundant control points. Since no DTM is required, it then becomes an attractive solution for these few applications that it may serve. However, if accurate terrain model data was available, then the accuracy of the data produced by the monoplotting method would be drastically improved and it could then be employed much more widely, especially in decentralised regional offices.

9.2.3 The Suitability of Orthophotographs

The last photogrammetric technique tested was the hard copy orthophotographs obtained by differential rectification from stereopairs. This is an older and tested alternative than the rectification of a single photographic image in digital form. Although orthophotos are graphical documents, measurements of the cadastral data which are identified on the image, can give the desired digital output. Experience has shown (Visser, 1977) that digitising data on the orthophotos, can be done in about half of the time needed for scribing, if line maps are going to be produced in that way. The tests in this project, verified that orthophotos measured by the use of a fairly simple map digitising software package such as MapData, can give high production rates. Although the actual production of the orthophotos was a separate photogrammetric operation and since the feature classification was limited to a few classes, the time needed for the measurement of the cadastral data, was only a fraction of the corresponding operational time incurred during stereoplotting. Again, as in the case of digital monoplotting, much less knowledge of photogrammetry would be needed for the operator at the stage of measurements. If the orthophotographs were produced at a central facility, the actual measurement and digitising operations could still be carried out in local or regional offices.

Despite the influence of sources of error to a higher extent than was expected, the residuals obtained at the check points were fairly small, especially for Achaia, which is a relatively flatter area. However, even if errors were limited to the measuring errors on the digitiser, and despite the relatively large scale of the orthophotographs involved, the conclusion given by other photogrammetrists and again verified in this project, is that orthophotographs are very beneficial for regional planning, but perhaps of less benefit for land ownership protection. In particular, the intrinsic weakness of the orthophoto, that of radial displacements of highly elevated objects, has to be borne in mind.

More specifically, the use of orthophotographs for cadastral mapping in urban or sub-urban areas should be avoided, since quite apart from the residual relief displacements and obscured boundaries, the higher value of land in these areas would justify the use of stereoplotting. Secondly, the specification of the photographic material and the required control points should be redefined. Photographs obtained with normal angle lenses but at higher flying height to retain the same scale while reducing the relief displacements will improve the obtainable planimetric accuracies of the orthophotos, especially, if the control data (DTM) for their rectification is obtained from stereopairs of shorter focal length. However, such a combination of photographs will only apply to off-line orthophoto production. In terms of control points, these should be properly marked points on the ground or at least well defined physical features at that level. Points at the tops of buildings especially at the corners of their obscured sides will inevitably cause bad identification and introduce errors within the measured data.

The actual production of the orthophotos should benefit from the relatively small cost of analytically controlled orthophotoprinters as compared to the cost of fully automated systems for the production of orthophotos or stereo-orthophotos. Furthermore if stereoplotters which can be converted for orthophoto production (e.g. Topocart), exist, then the investment of money will be further reduced. The traditional orthophotography, although not benefiting from the more modern improvements of computers and image processing concerning the manipulation of image in digital form, avoids the requirement for huge memory space for the wholly digital images. On the other hand, the possibility of digital output from hard-copy orthophotos for input into the digital data base forming the basis of an LIS and the quick production rates, could make it very beneficial for application in cadastral surveys in Greece. However, there must be some considerable reservation for the applicability of orthophotography in very steep areas which is not a rare case in Greece. Orthophotos in these areas, whether or not lateral correction has been used for their production, will probably show gaps and overprojections of the image and the only answer then, at least as far as photogrammetry is concerned, will be the use of stereoplotting machines.

9.3 Recommendations

Despite the conclusions which were reached after the tests of this project, some <u>more tests</u> will be of great interest to the authorities wishing to establish a new cadastral system in Greece. The tests, first of all should be carried out over a larger area than the area covered by a single stereomodel. This would allow the factors of operational time and cost, for the execution of the cadastral work to be estimated for the whole extent of the application using the selected photogrammetric technique. In order to obtain a better comparative evaluation in terms of accuracy of the examined photogrammetric techniques, the need to employ experienced photogrammetrists as well as accurate and clearly identifiable ground control of many redundancies should be emphasised.

Furthermore, the need for <u>field completion</u> operations are considered of vital importance. These could give a better estimation of further ground survey operations that will be necessary. Also, if possible, field completion operations may show the areas of the country that will have a low coverage in terms of cadastral data, if photogrammetry is applied without boundary pre-marking. Moreover, the feasibility of adopting of boundary corner pre-marking has to be evaluated, at least for those areas requiring boundary measurements at the highest possible accuracy level that photogrammetry can give.

The need to develop <u>analytical rectification and monoplotting</u> into a more reliable technique is also recommended. This technique could be then evaluated properly for cadastral applications at least for some remote areas of the country.

9.4 Epilogue

As an end to this thesis, it is noted that this research work has benefited the author greatly in that it has enabled him to enhance considerably his knowledge and experience of photogrammetry applied to cadastral mapping and also of various computer-based photogrammetric methods giving digital data output for use in digital mapping and other similar applications.

Finally, the author believes that the knowledge and experience acquired from this research work will be of great usefulness to his future professional career as a topographic scientist or surveying engineer in Greece.

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CADASTRAL MAP
SCALE 1:2000

CORINTH
STEREOPLOTTING

c:\dgn\acor.dgn Oct. 13, 1993 19:21:18

CADASTRAL MAP ACHAIA
SCALE 1:2,000 ORTHOPHOTOGRAPH

CADASTRAL MAP
SCALE 1:2,000

ACHAIA
STEREOPLOTTING

c:\dgn\oa.dgn Dec. 4, 1993 17:48:34

CADASTRAL MAP
SCALE 1:2,000

CORINTH
MONOPLOTTING (NO DTM)

CADASTRAL MAP
SCALE 1:2,000

ACHAIA
MONOPLOTTING (NO DTM)

CADASTRAL MAP
SCALE 1:2,000

CORINTH
ORTHOPHOTOGRAPH