EVOLUTION OF DIGITAL PHOTOGRAMMETRY AND ITS APPLICATION IN CARIBBEAN COUNTRIES

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ABSTRACT

The chain of developments from analogue photogrammetry through analytical and leading to digital phtogrammetry is reviewed. Major advantages and differences are highlighted with possible application of digital photogrammetry in the Caribbean region.

INTRODUCTION

There appears to be very little understanding about photogrammetry outside the surveying community though it has existed from the middle of the nineteenth century as the science and technology of making reliable measurements and collecting descriptive informations about objects from their photographic image. Analogue photogrammetry can be referred to as the traditional mapping method. With the influence of parallel developments in the computer industry, analytical photogrammetry has developed into a viable and more efficient alternative. The evolution of digital photogrammetry (fig:1) closely followed the acceptance and use of analytical photogrammetry in the mapping organizations. The digital approach is a recent development and hence it is relatively new to the surveying community as well.

The introduction and use of digital photogrammetry in the Caribbean presents many difficult decisions. Most of the Caribbean countries, like the rest of the world, use analogue stereo photogrammetric methods for their topographic mapping. This is being carried out mostly with the assistance of extra regional mapping organizations, except in Trinidad & Tobago, Guyana and Jamaica, where a narrow range of state and private sector facilities are available. The intensity of use of the available facilities is also limited and therefore the expertise in photogrammetry and mapping have had little opportunity for development. This may be attributed to the insufficient appreciation of the links between planning and development, whether physical, economical, social, or integrated and the potential contribution of photogrammetry to such initiatives. The evidence for these observations can be sought in the revision cycles of available maps and the paucity of thematic maps in the region. Nevertheless, there appears to be an increasing awareness of the importance of automated Geographic Information Systems and hence a wider interest in photogrammetric data collection systems.

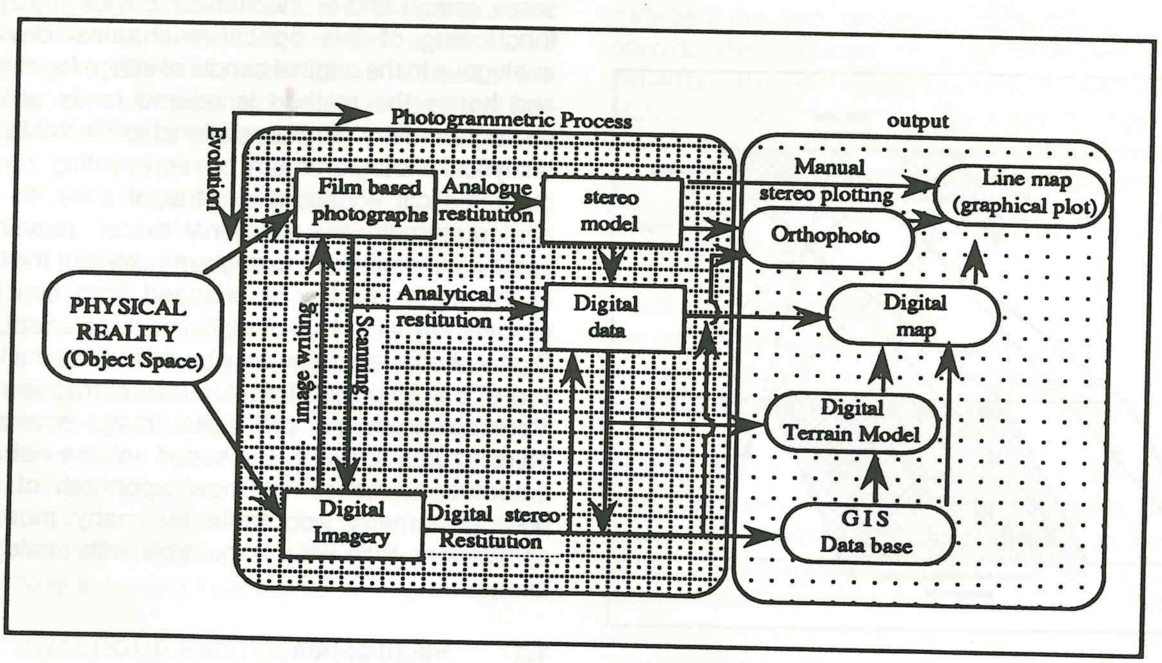

Figure 1 Evolution of Digital Photogrammetry

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Petrie (1990) quite aptly observed that "the analogue stereo plotting instruments which have dominated photogrammetry for the period of over 50 years between the mid-1920s to the beginning of the 1980s have almost disappeared from the market place". Now analytical plotters have taken over the market share, earlier held by analogue instruments. As well, commercial production of digital plotters is expected to increase in the near future [Dowman, 1990]. Countries wishing to acquire or update photogrammetric instrumentation and technology are confronted with the dilemma of choosing an optimum system which is field proven and at the same time appropriate for their needs and financial constraints. Many countries, unlike the Caribbean nations have to contend with the heavy investment already made on analogue instrumentations which have many more years of useful life remaining. They have to decide in addition, whether to write-off their proven work horses of analogue era and invest in expensive computer oriented photogrammetric hardware and know-how, conscious of the shorter life span of computer based equipment. Neither analytical nor digital instrumentation is available in any of the Caribbean countries. The dilemma of the mapping organizations is therefore clear. Configuring an optimum system from diverse technologies and range of instrumentation which will be appropriate to the Caribbean environment would be a challenging task even to the expert in the field. The first step however is to develop an awareness about the state of art and relative merit among alternate technologies.

This paper attempts to meet the need, conscious of the requirement to develop awareness among the producers and the users of the photogrammetric products.

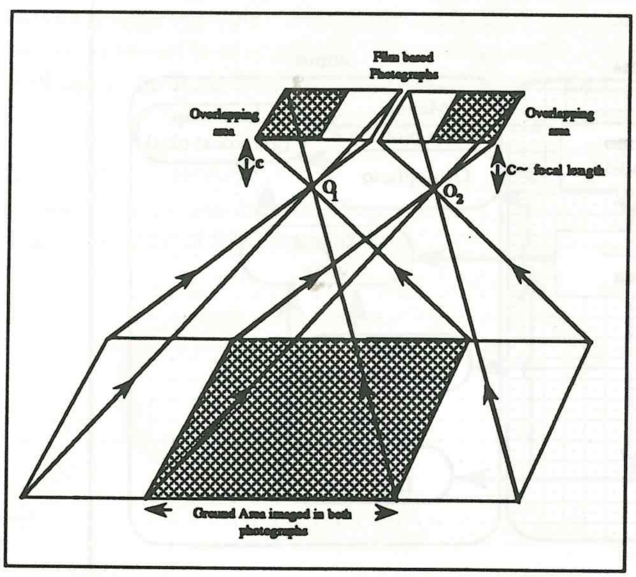

Figure 2 Primary Data Acquisition for Analogue & Analytical Photogrammetry

1.0 BASIC CONCEPTS

Photogrammetry is based on the mathematical relationship between the objects of interest and their images. The image is linked to the object through the set (bundle) of rays reflected from the object and passed through the camera lens to form the image during each exposure (fig:2). A bundle of rays analogous to the original bundle can be reconstructed by replacing the photograph inside the camera and illuminating from behind. If in addition the camera is re-positioned in space as at the time of photography; the reconstructed rays would reach particular points in the object space, ideally of which the image was generated. A further step would be to simultaneously reproject two photographs covering the same area (at least partly) taken from two different camera stations (fig:2), in which case the pair of rays corresponding to the same point in object space should intersect at that point (ideal case). Both metric and descriptive information can be accurately extracted and compiled from this re-projection. In the early days, the imaging process was confined to photography and hence the information extraction process was named as **photogrammetry**. In modern times, the images are formed not only by photography (optics, light and light sensitive film) but also by various sensors and scanners imaging through different electromagnetic corridors like radio (radar), thermal or X-ray wave bands.

In the analogue photogrammetry, the bundle of rays linking the object and its image is re-established through some optical and/or mechanical device (fig:3). The functioning of this optical-mechanical device is analogous to the original bundle of image forming rays and hence the method is refered to as analogue photogrammetry. Similar relationship is established in analytical photogrammetry by representing rays with mathematical equations of straight lines. In digital photogrammetry the functional model remains the same as in analytical photogrammetry but the format of the input imagery is changed from film based pictorial format to that of digital with raster structure. Digital photogrammetry may be defined as the field of three dimensional information extraction from stereoscopic or multiple digital image coverage of objects [Bethel, 1990]. The speed and the viability for automation, makes the new approach of digital photogrammetry adoptable for many more new applications than what is possible with analogue or analytical.

1.1 Rectification

Photogrammetry whether analogue, analytical or digital can be classified into single image rectification and

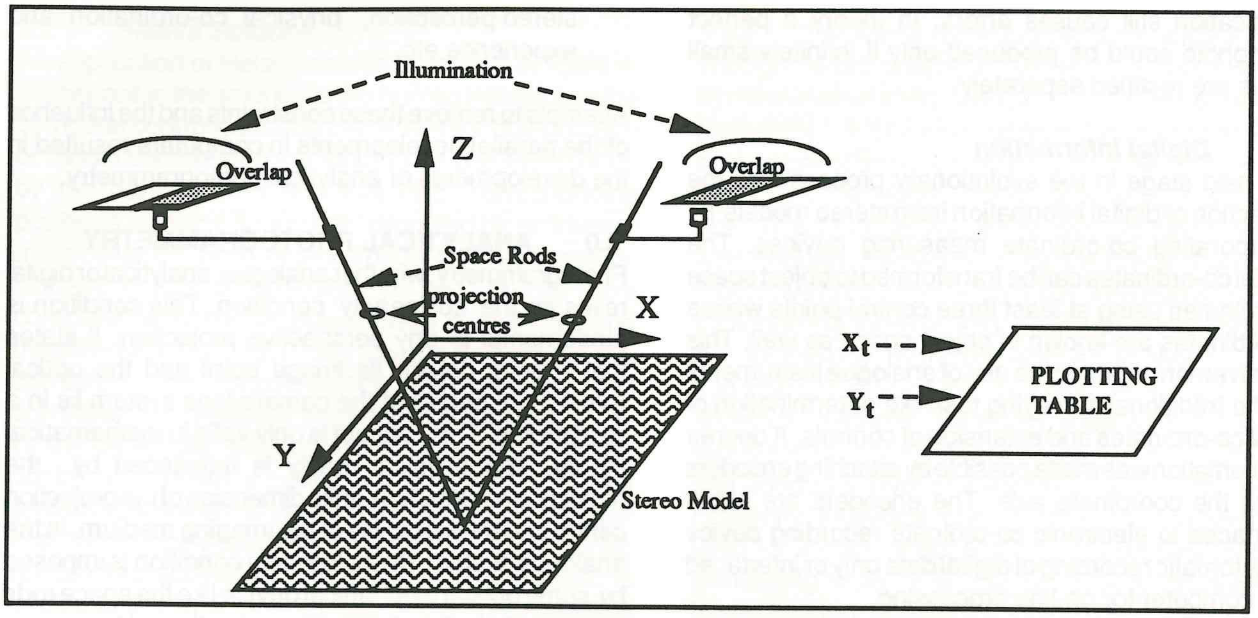

Figure 3 Principle of Analogue (Mechanical) Stereo Plotter

stereo photogrammetry. The latter uses two or more images of the same object space. It is possible by perspective transformation of a single image, to obtain another photographic product with limited characteristics of a map (eg: known scale and free of camera tilt error). This process, called rectification, is fast and economical for applications that do not require height information or high accuacy. The rectification approach is therefore most appropriate when applied to flat object surfaces. However rectification may be applied to very small (differential) areas at a time and at different planes according to the known elevation or depth information. This process has the effect of an orthogonal transformation instead of the perspective transformation as in rectification and hence called 'orthophoto' or 'differential rectification'. Output of the orthophoto process is a photographic product that has positional accuracies of maps.

1.2 Stereo Photogrammetry

When bundle of rays from two or more photographs of the same object space, but taken from different camera positions are retraced simultaneously; they intersect and a three dimensional (stereo) model of the object space is formed. Precise measurements (including height), interpretations and mapping are possible from the stereo model so formed. This procedure is refered to as 'stereo photogrammetry'. Here again either analogue, analytical or digital photogrammetric methodology can be applied. It may also be noted that height information required for the othophotography are normally extracted from stereo photogrammetry.

2.0 ANALOGUE PHOTOGRAMMETRY

The concept of acquiring data, both metric and descriptive, from photographs, dates back to the eighteenth century even before the invention of aircrafts. In Analogue photogrammetry, a model of the object space is obtained by re-establishing the camera positions of pair of overlapping photographs and genarating an analogue to the bundle of rays that were instrumental in forming the photographic image (eg: by illuminating from behind the photograph end or representing a single ray at a time by a straight rod called space rod). This process is refered to as 'analogue restitution'. Simultanious restitution of two or more photographs of the same object space results in the formation of a three dimensional model surface of the object space at true scale (1:1). The distance between the two projecting cameras is however considerably reduced, in order to obtain a three dimensional model having a reduced but known scale. Metric measurements can be made on this stereo model. The output of traditional analogue process is generaly a graphical representation (line map) of the object space, obtained by tracing features of interest on the stereo model.

Restitution of single photograph (rectification) results in a rectified (free of camera tilt) photograph which may be sufficent in flat areas when less expensive, and / or urgent maps are required.with limited accuracy.

Another photographic product that can be obtained from the analogue process is the orthophoto. The terrain height profile obtained from stereo pairs of aerial photographs are used in the differential rectification of one of the photographs The geometric quality of the orthophoto where height and tilt distortions are corrected is much better than the rectified photo where only the tilt of the camera is rectified. The size of the small segments used as individual units of rectification still causes errors. In theory a perfect orthophoto could be produced only if infinitely small points are rectified separately.

2.1 Digital Information

The next stage in the evolutionary process was the extraction of digital information from stereo models by incorporating co-ordinate measuring devices. The model co-ordinates can be transformed to object space coordinates using at least three control points whose co-ordinates are known in object space as well. This improvement enabled the use of analogue instruments for the traditional surveying task like determination of point co-ordinates and extension of controls. A degree of automation was made possible by attaching encoders along the coordinate axis. The encoders are either interfaced to electronic co-ordinate recording device for automatic recording of digital data only or interfaced to a computer for on-line processing.

2.2 Computer Assisted Photogrammetry (CAP)

The analogue photogrammetric instruments with on-line computer opened up a new subfield called 'Computer Assisted Photogrammetry'. On-line computer can assist the operator in many of the model setting-up routines and photogrammetric outputs. Prime products of computer assisted photogrammetry are the digital maps and digital terrain models. These products are called 'soft copy' products as against the traditional graphical plot called 'hard copy'. The soft copy products are increasingly becoming the standard request from the modern users as well as the standard output of the analytical era. The difficulty in this production line is that the digital data formats are not standardized and hence much time, effort and money are spent on the data format conversions to suit different users.

Analogue instruments can also be interfaced through encoders to Geographic Information System (GIS) and other digital data bases. Photogrammetric methods have been identified and used in many countries as appropriate input devices for data collection and updating for digital data bases, covering large areas.

2.3 Limitations

Analogue photogrammetric systems are characterized by the following limitations:

- The need for heavy instrumentation for stability and accuracy below 10μ (10^{-6}meters) at photo scale,
- The need for precise tooling to reduce errors,
- Effect of instrumental errors in the constructed model
- Instrumental limitations when modelling by analogue means,
- Influence of the operator - subjectivity of his stereo perception, physical co-ordination and experience etc..

Attempts to remove these constraints and the influence of the parallel developments in computers resulted in the developments of analytical photogrammetry.

3.0 ANALYTICAL PHOTOGRAMMETRY

Photogrammetry, whether analogue, analytical or digital relies on the 'collinearity' condition. This condition is fundamental to any perspective projection. It states that a point object, its image point and the optical (projection) center of the camera lens system lie in a straight line. This concept is only valid in mathematical theory. The physical reality is influenced by the atmospheric refraction, finite dimension of the projection centre and the instability of the imaging medium. In the analogue system, the collinearity condition is imposed by some optical mechanical device like the space rods in fig:3 with the inevitable approximations. However in the analytical approach, the collinearity condition and the deviation from ideal condition is mathematically modelled using appropriate functions. Image positions measured on the photo plane in a known co-ordinate system can be transformed mathematically to object space. The complexity of the transformation necessitates the use of a computer.

3.1 Image Space Plotters

A comparator connected on-line to a computer system can provide object space co-ordinates from image space measurements in 'near-real-time'. From this discrete point measurements, the on-line computer can be programmed to link related points and thus produce graphical plots. The output can be similar to that of the computer assisted analogue plotters. When a (Vector) plotter is attached to this computer, it can also provide conventional line maps. A range of low cost (<US$ 50,000) and relatively low accuracy (10 - 25μm) analytical plotters based on this principle, are refered to as 'image space plotters' [Petrie, 1990]. The disadvantage in this system is the absence of oriented, parallax free stereo model and hence the absence of on-line contour tracing facility. This category of instruments have wide applications in map revision and are prefered by non photogrammetrist like foresters, agriculturist and planners as input device to their GIS systems, mainly because of its simplicity and low cost. Their popularity, variety and production have been increasing from the late eighties. However, the analytical plotter first proposed by Helava in 1955, was a classical solution, designed to achieve everything an analogue plotter does and more. When initialised (oriented), it presents a error free visual model for subsequent operations.

3.2 Helava Solution

An application of Helava solution is shown in figure 4. Significant in the solution is the human interface to the computer controlled hardware. When the object space or model coordinates are input to an oriented model, by the hand wheels and foot disc, corresponding positions in image space are computed by an inverse transformation from object space to image space. Current image co-ordinates (x_1, y_1), (x_2, y_2) are compared with the computed image coordinates and the difference $(\Delta x_1, \Delta y_1)$, $(\Delta x_2, \Delta y_2)$ are determined and corrected. This transformation, measurement and correction are repeated automatically and frequently (> fifty cycles per second). The system which carries out these functions is called 'real-time -loop' or 'digital projector' which is the vital and expensive component that continuously presents an error free model during human interaction. An adaptation of this system is implemented in almost all top-of-the-line analytical plotters. Low cost instruments like the Adams-MPS2 for small format (< 70mm x 70mm) photography and Cartographic services AP190 for full format (230mm x 230mm) photography have also implemented this real time loop and present a parallax free model during scanning.

3.3 Transition from Analogue to Analytical

Though the principle of analytical plotter was proposed by the middle of 1950s and prototype came out in early sixties, the transition period from the invention to wide spread use of analytical plotter was slow - almost thirty years [Schenk.1988]. The reasons were many. Early operational models had the normal teething problems with frequent hardware, software break-downs and prohibitive price attached to them. Also the users of the analogue era required education and re-training in the new technology. By the mid eighties, analytical plotters had started replacing the analogue stereo plotters and analytical methods are being adopted increasingly, with steep drop in hardware prices, bug free softwares and adequate level of awareness among the users. Presently analytical photogrammetric methods are used for variety of applications, particularly for point positioning tasks. It is also possible to produce film based imagery from digital image (fig:1) such as from charged coupled device (CCD) camera or satellite sensors and the images can be used as input for the analytical restitution.

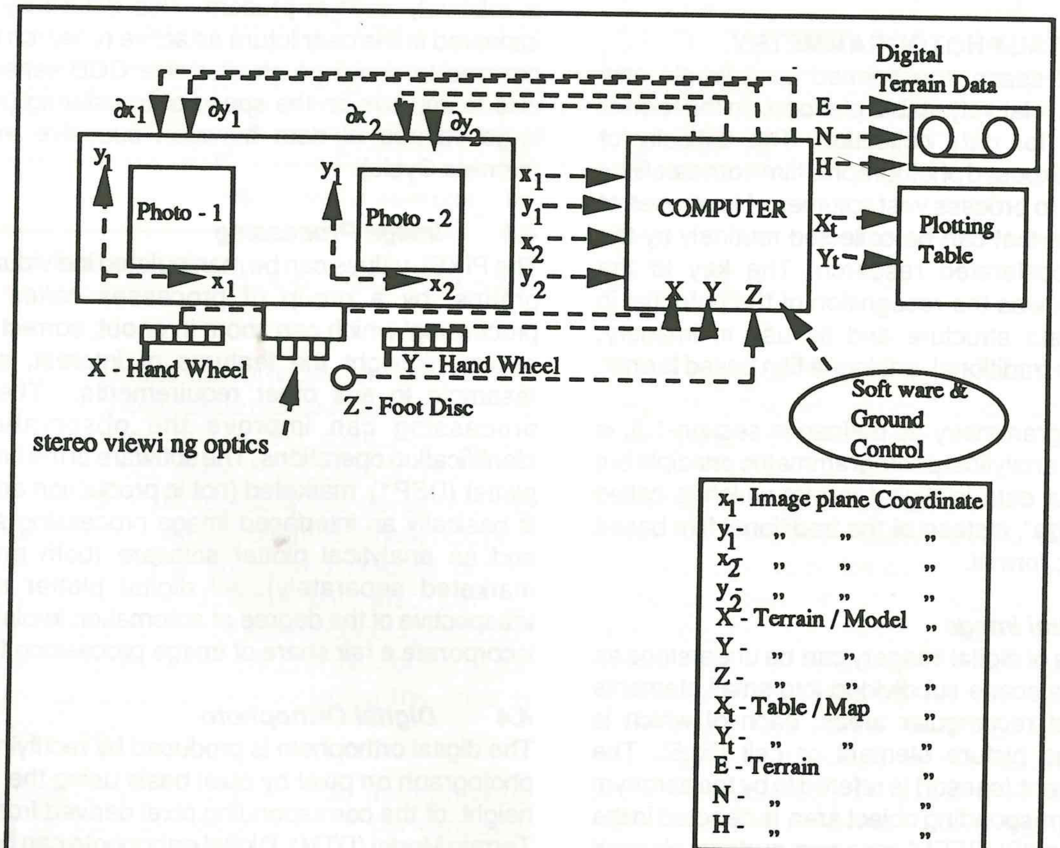

Figure 4 Analytical Plotter -Helava solution
[Modified from Petrie 1990]

3.4 Comparison with analogue

The main advantages of analytical methods over the analogue are:

- overall increase in accuracy, speed and ease of measurement,
- flexibility in the choice of cameras and their positions,
- capability to restitute imageries of non conventional sensors eg: Spot Satellite imaging system,
- facility to model deviations between physical reality and mathematical ideals particularly in photographic data collection,
- direct means of digital data collection,

The deficiencies in the analytical system are mainly:

- the need for skilled human interface and its consequent limitations,
- in automating the system,
- the time-lag between photography and the availability of the images for measurements and hence the limitations in the application, requiring real time processing,
- little room for contrast (radiometric) manipulations within the same imagery,

Digital photogrammetry sought to remedy these areas of deficiencies.

4.0 DIGITAL PHOTOGRAMMETRY

The dawn of space age opened up a whole new frontier and a relatively stable platform, in the form of the satellite, for data collection. The difficulty of transporting exposed photographic film from satellites and the need to process vast volumes of imageries of earth surface, that can be collected routinely by the satellites, accelerated research. The key to the breakthrough was the recognition of the potential in the raster data structure and its use in imagery, instead of the traditional, analogue film based format.

Digital photogrammetry as defined in section-1.0, is based on the analytical photogrammetric principle but with the input data in digital format which is called **"Digital Image"**, instead of the traditional film based photographic format.

4.1 Digital Image

The structure of digital imagery can be understood as a picture or a scene subdivided into small elements composed of rectangular areas, each of which is refered to as picture element or cell (fig:5). The ***pic***ture ***el***ement.(sensor) is refered to by the acronym "PIXEL". Corresponding object area is denoted in the diagram as a "SURFEL" meaning surface element represented by single PIXEL. Sensors aboard an imaging platform record the average reflectance or emmitance received from each SURFEL. An Analogue to Digital Conversion (ADC) device converts the recorded brightness into a integer value using a predetermined grey scale whose range may vary within 0 to 255 which is the largest number that can be represented by a single byte in binary form. These digital values of the pixels are recorded in an ordered sequence of rows and columns so that the relative position of a PIXEL value can be located from its row and column numbers or vice-versa.

4.2 Resolution

The radiometric resolution of a digital image is much greater than that is possible with the film based visual format in which the spectral resolution is constrained by photographic emulsion and the limitations of human eye (about 15 grey levels only can be distinguished by human eye where as 256 grey level are possible in digital images). Extra dimensions are added by the possibility of combining many digital images recorded, within different windows of well defined narrow wave lengths (multi band) and / or at different times (multi temporal). Also the range of sensitivity of the sensors can be extended beyond the visible spectrum. Therefore, digital images have greater potential in providing descriptive information than film based images, but the state-of-art in the resolution of spatial information provided by the intrinsically digital images is relatively poor at present. This deficiency will be improved in the near future as active research is being perused to develope smaller size CCD sensors and also to improve on the speed of transfering (reading) large volume of data between sucesive exposers (camera Cycle).

4.3 Image Processing

The PIXEL values can be manipulated individually or in groups, by a group of processes called 'image processing' which can zoom in or out, correct system errors, highlight the features of interest, scale or resample to suit other requirements. The image processing can improve the observation and identification operations. The software of the first digital plotter (DSP1) marketed (not in production any more) is basically an interfaced image processing software and an analytical plotter software (both previously marketed separately). All digital plotter designs, irrespective of the degree of automation implemented, incorporate a fair share of image processing facilities.

4.4 Digital Orthophoto

The digital orthophoto is produced by rectifying digital photograph on pixel by pixel basis using the average height of the corresponding pixel derived from Digital Terrain Model (DTM). Digital orthophoto can be readily imported into the computer based information systems such as Geographical Information System without the need for digitizing or scanning required to convert the

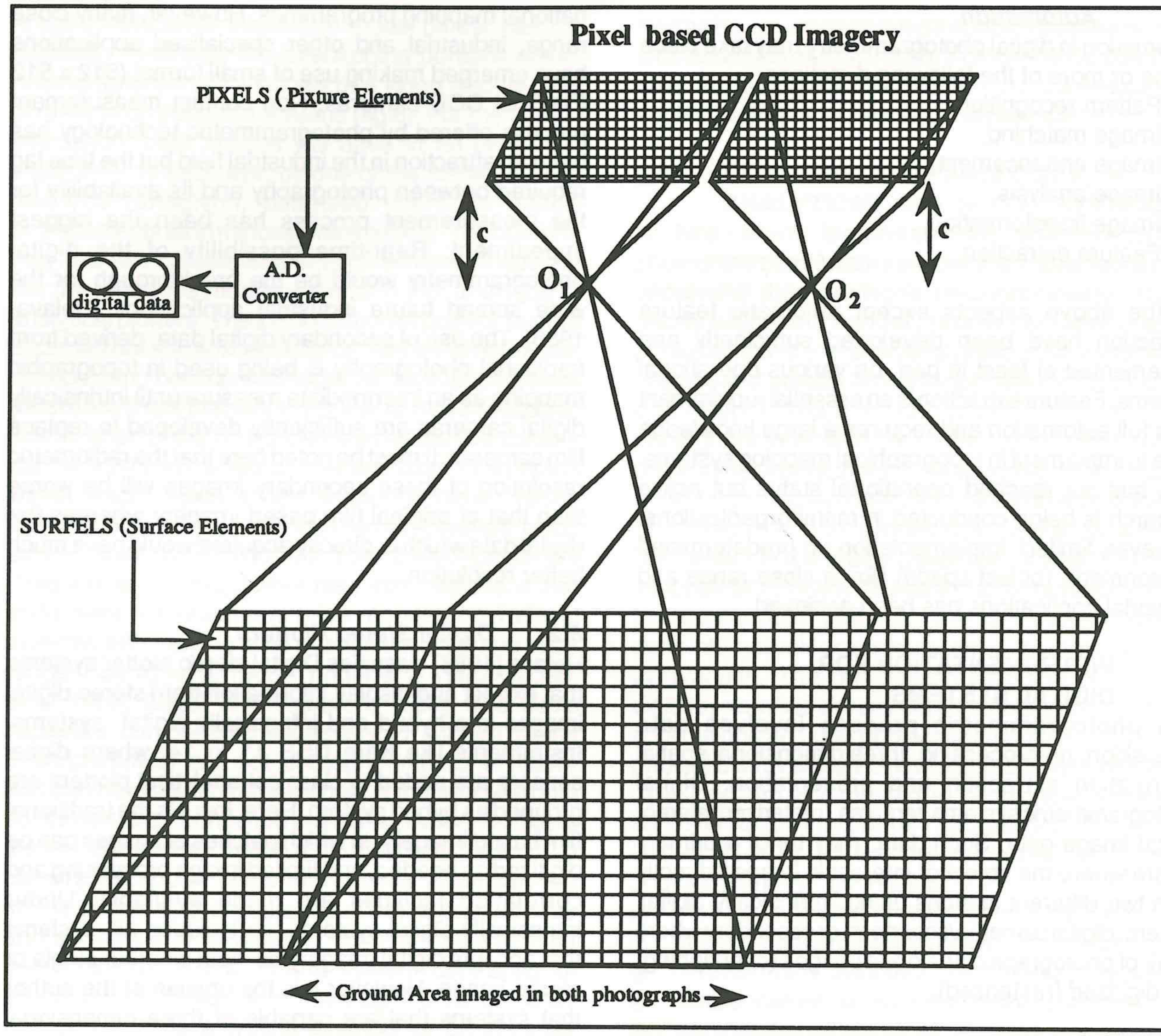

Figure 5 Digital Data Acquisition with a CCD frame Camera

conventional line maps into computer readable format. The digital orthophoto can be manipulated, filtered and classified by image processing softwares for the production of thematic maps. Production of orthophoto from digitized aerial photography has developed and the services are commercially offered by many mapping companies. The digital orthophoto process is fully analytical, hence repeatable and also can be automated. The Automatic digital orthophoto production softwares are being implemented in most of the digital photogrammetric instruments including the ones in lower price range.

The required DTM may be available from previous mapping or can be derived from conventional photogrammetric compilation or automated digital photogrammetric (Stereo Correlation) process. The photogrammetric compilation (conventional or digital) of DTM from each stereo model will require three or four control points whose precise positional information should be known in advance.

The accuracy of an orthophoto is inversely proportional to the size of the individually rectified units. In theory, best accuracy would be achieved when each unit of rectification become point sized. In the traditional orthophoto process (pictorial) which involves major human interface, the selection of rectification unit size has to be a compromise with the time, cost and nature of the terrain. Normal unit size will be in the order of 5 mm x 2 mm. Whereas in the automated digital orthophoto process, pixel size of 0.05 mm x 0.05 mm can be efficiently processed. Hence it can be seen that the achievable accuracy in the digital orthophoto process is far superior to that of the traditional orthophoto.

4.5 Automation

Automation in digital photogrammetry may take place in one or more of the following directions:

- Pattern recognition,
- Image matching,
- Image enhancement,
- Image analysis,
- Image transformation,
- Feature extraction,

All the above aspects except automatic feature extraction have been developed sufficiently and implemented at least in part, on various operational systems. Feature extraction is an essential requirement for a full automation and requires a large knowledge base to implement in topographical mapping systems. This has not reached operational status but active research is being conducted in many organizations. However, limited implementation on predetermined environment (object space) like in close range and industrial applications has been achieved.

5.0 INSTRUMENTATION FOR DIGITAL SYSTEMS

The photogrammetric process involves data acquisition, preprocessing, three dimensional spatial information extraction and presentation. Digital photogrammetric systems requires (rasterized) stereo, digital image data. Such data may be of a primary nature where the object of interest is imaged directly from two different stations using 'intrinsically digital' system (digital cameras/scanners) or secondary where a pair of photographic analogue images (overlapping) are digitized (rasterized).

5.1 Primary Data Acquisition Systems

The acquisition of primary digital data is not sufficiently developed to replace film based aerial photography in national mapping programmes. However, many close range, industrial and other specialised applications have emerged making use of small format (512 x 512 PIXELS) CCD cameras. Non contact measurement process offered by photogrammetric technology has been an attraction in the industrial field but the time lag required between photography and its availability for the measurement process has been the biggest impediment. Real-time possibility of the digital photogrammetry would be the breakthrough for the wide spread future industrial applications [Helava, 1988]. The use of secondary digital data, derived from traditional photography is being used in topographic mapping as an intermediate measure until intrinsically digital cameras are sufficiently developed to replace film cameras. It must be noted here that the radiometric resolution of these secondary images will be worse than that of original film based imagery whereas the digital data which is directly acquired would have much better resolution.

5.2 Digital Stereo Plotters

Helava [1988] classifies Digital stereo plotter systems that extract and display information from stereo digital images into hybrid and intrinsically digital systems. Instruments like Kern DSR 11 to 14, where digital sensors are added to classical analytical plotters are grouped as hybrid system. Here, input is the traditional film based imagery, in which patches of images can be digitized as needed, and limited image processing and correlation facilities are made available. Under intrinsically digital systems, he includes all systems that accepts digital imagery as input whether single or stereo image. However it is the opinion of the author that systems that are capable of three dimensional information extraction be grouped as digital photogrammetric systems and rest could be grouped under image processing systems.

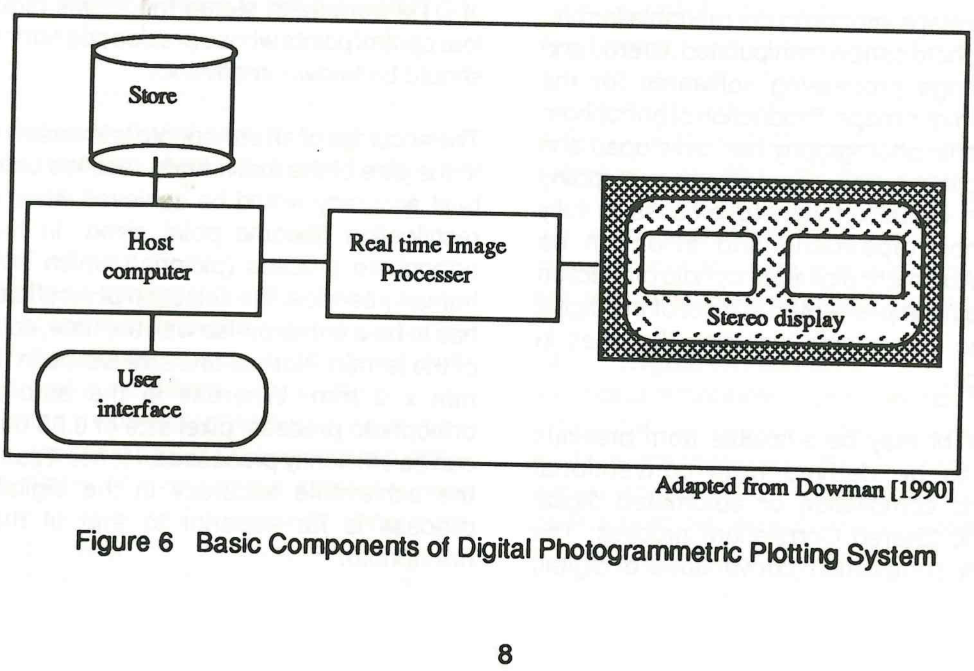

Figure 6 Basic Components of Digital Photogrammetric Plotting System

A basic, functional interactive digital plotter has the capability to display the overlapping portions of two photographs on two windows of a video display (split screen) or on separate screens (fig:6). For the human interaction, both images will have to be presented separately to each eye, by one of the stereo viewing methods (anaglyph, polarised filters, or optical arrangements as in mirror stereoscopes). The operator may use two cursors one in each window to operate like the reference (floating) marks in the analogue or analytical plotters. The identification of point or feature is carried out stereoscopically by the human interface, manipulating both cursors together as a floating mark (reference mark that would appear to move in space). The location of the pixels identified by the two cursors can be easily extracted as row and column numbers within each digital image frame [Schenk, 1988]. Development of a simple inexpensive system along similar lines was reported from Laval University [Gagnon, et al 1990]. Other research institutions and instrument manufacturers have reported operational systems with varying level of sophistication and price range [Koenig, et al 1988, Trinder,et al 1990, Cogan, et al 1988, Euget and Vigneron, 1988]. The basic hardware components necessary to support digital photogrammety are not photogrammetric in nature and can be obtained off-the-shelf. A modern personal computer can be converted to a digital photogrammetric station by adding suitable components like CCD camera, computer chips and boards necessary for image processing and display. They are accessible and affordable to developing countries as well. The new industrial measurement system consisting of precision theodolites with integrated CCD cameras and computer is a typical example of off-the-shelf purchasable systems.

At the cheaper end of the market, a system with capabilities to acquire, process, and to output 512 pixels x 512 pixels size imageries may cost less than an analytical or analogue system with the same capabilities. The Desktop Mapping System from R-Wel Inc.(USA) and Digital Video plotter from Leica are typical examples of digital photogrammetric systems costing below ten thousand United State Dollars (US$10,000). The cost will increase steeply as the volume of data increases and sophistication of required human interface, image processing and manipulation level increases. Many of the operational real time measuring systems are currently functioning in interactive mode only. Surprisingly the cost of softwares required for automation with limited keyboard interaction is expected to be less than the hardware cost of providing human interface (with image display) facilities to match the optical quality commonly available in photogrammetric instruments.

Normally, accuracy of image space measurements is a function (normaly a fraction) of the PIXEL size (area covered by single picture element in object space) and sophistication of the software implemented.

6.0 COMPARISON OF ANALOGUE, ANALYTICAL AND DIGITAL SYSTEMS

It has been demonstrated that analytical photogrammetry is more accurate and eventually more successful than analogue photogrammetry. This is mainly because of the use of image coordinates as the prime component in analytical photogrammetry, which has allowed greater flexibility for corrections of image deformation than it was possible in analogue photogrammetry with its model coordinates as the prime measured quantity. This advantage is maintained in digital photogrammetry with additional possibilities of corrections and processing of the radiometric component of the imaging process as well. The major variation or flexibility of digital photogrammetry lies in the identification process. The identification can be done interactively or automatically without any operator intervention. The on-line and real-time potential of digital system has already attracted many non traditional applications and non photogrammetrist as users. The present disadvantage of lower spatial resolution in the digital system is expected to be rectified soon with improvements in the primary data acquisition systems. Gruen [1988] listed the benefits of digital photogrammetry as follows:

- no high precision optical-mechanical parts
- robust measurement system; no wear and tear
- no instrument calibration or manual image handling
- stable images ie. no deformation over time
- combination of automatic and operator controlled processing
- high degree of interactivity
- data acquisition, processing, editing, storage and administration in a single system
- on-line and real-time capabilities

Table:1 below summaries the comparison of important features among the analogue, analytical and digital photogrammetric processes.

7.0 APPLICATIONS IN THE CARIBBEAN REGION

Introduction of a new technology in any environment has to be gradual and cautious. It is also necessary to perform critical analysis of cost benefit, backup and servicing facilities. Automation is usually related to unemployment and hence can be a sensitive issue. All these factors will have negative contribution and assume pioneering proposition when application of front end of technology, such as the digital photogrammetry, is involved as against field proven

	Feature	Analogue Photogrammetry	Analytical Photogrammetry	Digital Photogrammetry
1.	Primary Data	Black/White or Colour Photographs	Black/White or Colour Photographs	Digital Image (single or multi band)
2.	Measured quantity	Model X,Y,Z, Coordinates	Photo x,y coordinates	Scene brightness values (radiance)
3.	Measuring instrument	Analogue-Stero Plotter	Analytical Plotter/ Comparator or Digtizer	Digital camera/Sensor/ Raster Scanner
4.	Hardware	Optical-Mechanical	Computer controlled Optical-Mechanical/ encoded optical mechanical	Computer with raster display
5.	Measurement mode	Manual	Manual	Automatic
6.	Evaluation of geometric information	Inversion of geometric stero model to object surface by optical-mechanical arrangement or computer assistance	Inversion of geometric camera model to object space is carried out by mathematical modelling	Similar to analytical photogrammetry
7.	Evaluation of radiometric data	Not feasible	Not feasible	Filtering and enhancement is possible Inversion of pixel radiance to object radiance can be modelled
8.	Evaluation of semantic data	Visual	Visual/with graphics/overlay	Visual automatic

Table 1 Comparison of major features of Analogue, Analytical and Digital Photogrametry.

[modified from Wrobel.1991]

technology. On the contrary, one has to introduce the changes at the earliest opportunity in order to maximise the benifits of technological advancements.

7.1 *Topographic and Thematic Mapping*

In the case of application of digital methods to topographic mapping, it can be said that the digital technology is still in the infancy. It has a great potential but is not developed, especially in the state-of-art of intrinsically digital cameras and automation. The state-of art presently available can be assessed as satisfactory for thematic mapping and map revision in image map format (Digital Orthophoto). Unfortunately the speed and automation provided by the digital technology has not attracted its fair share of the production market. The reason may be the unrealistically low importance attached to the need for thematic maps and the belief of it as a spin-off from topographic mapping.

Use of speed, automation and real-time capabilities of digital photogrammetry would be a useful asset to an emergency disaster (eg: hurricane, flood or earthquake) management system in caribbean countries. Here too, it would be cost effective to estabilish a centralised facility for the entire Caribbean. Fast access (near real-time) to satellite data is also necessary.

A few manufacturers are marketing interactive, digital, topographical plotters from the late eighties. They cost more than US$350,000 and are faster by a factor of three. The accuracy of their output products is lower than that of analytical methods at present. This is mainly due to the nature of the available primary data. The data input at present is derived from scanning (digitizing) aerial photographs and intrinsically digital, satellite imagery. Satellite data (Eg: stereo imagery from French SPOT satellite) can be used to produce small scale maps (scale factor of 250,000 or less), from these digital plotters.

Large land areas like Guyana would benefit by adopting digital technology for their small scale topographical and thematic mapping from SPOT satellite imagery.

Even here it will be beneficial to hire than rather acquire, instrumentation until continuous digital mapping demands can be assured.

7.2 GIS Input

When the technology and its spatial resolution of intrinsically digital data acquisition system improves further and the cost of hardware required to handle large volume of data decreases, it can be expected that digital photogrammetry would become the prime tool for spatial information collection. Presently digital images acquired from satellites are used to extract planimetric data (without height information) using remote sensing techniques. Application of digital photogrammetric techniques for such tasks will provide height information as well as better spatial accuracy. Development and maintenance of country wide three dimensional digital data bases for Geographic Information Systems within realistic time frame and known accuracy would soon be possible through the implementation of such systems that are already available in the market (eg: Kern Digital Stereo Plotter-DSP1, Matra Traster T10N Digital Stereo Plotter, Intergraph Image Station, LEICA Digital Video Plotter and Desktop Mapping System from R. Well Inc. USA).

7.3 Close Range and Industrial

The use of digital photogrammetric methods for close range (object distance < 300m) and industrial the volume applications is more promising. CCD cameras available off-the-shelf can provide the primary data directly in digital form. The volume of data can be as small as two 512x512 PIXELS and thus negating expensive hardware requirements to handle the large volume of data. The complexity in automation (pattern recognition, image matching/correlation, image analysis and feature extraction) can be eased if the prior knowledge of the scene (object space) is made available. Therefore it can be seen that it would be possible, with little investment, to introduce applications, based on hardware components that are already available in-house. A modern personal computer can be converted to a digital photogrammetric station by adding suitable software and components like CCD camera, computer chips and boards necessary for image processing and display. The new industrial measurement system consisting of precision theodolites with integrated CCD cameras and computer is a typical example of digital photogrammetric systems, available off-the-shelf.

Even in small to medium industrial production plants, quality control of production lines or assembly plants can be automated by a system of CCD cameras interfaced to a computer for on-line collection of data, processing and display of the results. Collecting data from different parts of an industrial plant and electronic transmission to a centralized processing and monitoring location is another possibility.

8.0 CONCLUSIONS

It is clear that the development of digital photogrammetry has widened the scope of photogrammetric applications. But it has not developed as a cost effective alternative for topographic mapping applications in which analogue and analytical methods are presently used. This status may change sooner than expected if the trend set by the computer industry in recent years continues. The automation and the real time capabilities would be attractive enough reasons to foresee the increase in applications at appropriate levels in developing countries too.

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