

Importance of Digital Photogrammetry for a complete GIS

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ABSTRACT

Integration of digital photogrammetry applications into Geographic Information System (GIS) databases offers new possibilities for the end-users. This integration allows photogrammetric data collection in a raster/vector based GIS environment. The progress is achieved in stages. These operations are carried out using digital image processing, geocoding, and monoplotted techniques. The process in stereo workstation is more sophisticated and requires specialized hardware and measuring systems. Such systems are available and all existing analytical procedures can be carried out fully integrating with a GIS environment. Interactive and batch processing utilities are provided to convergent image data into topologically structured data sets suitable for spatial analysis in a GIS environment. One of the very promising applications within such an integrated raster/vector environment, is the ability of using multi-temporal change analysis to update raster/vector based GIS.

Digital photogrammetry workstation (DPW) provides the capability of stereoscopic viewing and possibility to do precise 3D measurements. Especially in the GIS environment the demand to display and edit vector formatted 3D data as conveniently as possible becomes important.

In this electronic age managing and distributing data and imagery across an enterprise is a very complex operation. With the family of products designed to eliminate the nightmare of tracking imagery and data across the network. With these products, you have a system that manages geoinaging data (imagery, DTMs, and digitized raster graphics) from acquisition to exploitation to storage to distribution. Since every business is unique, a modular product line provides the tools to manage large amounts of geoinaging data throughout practically any production environment – as well as making it easy to turn a web into an imagery e-commerce site.

INTRODUCTION

We are living in a period of very rapid technological change. In photogrammetry, this is mainly the result of the recent explosion in information technology and is closely correlated with the general development of science and engineering. Looking back over the last few decades in photogrammetry, we can distinguish great developments in several areas. The general development, in particular electronics and computer technology, undoubtedly has opened up new advances in photogrammetry in the areas of instrumentation, methodology, and integration.

The first development in photogrammetry was concerned with the transition from analytical to digital photogrammetry. First applications of this new technique such as digital orthophoto, monoscopic map revision, auto digital elevation models (DEM), and automatic aerial triangulation (AAT) are already operational, and the system development in other areas such as feature extraction is emerging.

The first factor behind the digital revision strategy is growing use of orthophoto as an economical means of having up-to-date map coverage. The immediate problem is how to maintain the base map with limited resources and how to provide an up-to-date map to users. There is a growing need for national base map coverage at larger scales. Traditional techniques cannot meet the demands for timeliness, currency, and

accuracy from the user. The orthophoto and stereo feature extraction can be viable solutions to the map revision problem, as well as fulfill the need for larger scale base maps.

Current mapping systems are generally workstation environment and personal computer (PC) based. The potential of GIS technology is accepted as a critical part of digital mapping system. The graphic displays are both raster and vector, which makes it possible to use orthophotos or stereo image pairs as background. This capability provides a geometrically accurate base for map revision and GIS applications.

Digital photogrammetry is an ideal base for the updating of existing line maps by displaying old vector mapping data over a new orthophoto image. Perhaps the greatest application, however, will be in the use of the raster image – both the aerial photos and satellite imagery– as a layer in the GIS environment.

In this paper, the concept of digital or “softcopy” photogrammetry and its effect on existing mapping and geographic systems are outlined. In order to differentiate digital photogrammetry with previous procedures, the main developments and transitional phases of the art and science of photogrammetry are summarized. Major hardware/software configuration components of a digital workstation are given. A general overview of GIS and its integration with digital photogrammetry, as well as a brief description of softcopy applications such as digital orthophoto, map revision, auto DEM generation, AAT, and stereo feature extraction are discussed. Finally, some general concluding remarks and future prospects of digital photogrammetry and its integration into GIS are provided.

TRANSITION IN PHOTOGRAMMETRY

In general, the invention of photography, airplane, and computer brought about the following phases in photogrammetry (Konecny, 1985):

1. Stereo photogrammetry and analog stereo plotter
2. Analytical photogrammetry
3. Computer-assisted photogrammetry
4. Digital photogrammetry

The first stage of development, known as analog photogrammetry, lasted about 40 years. Aerial survey techniques became a standard procedure in mapping. There was no automation involved in any modern sense. Measurement and drafting were done manually. Classical analog stereo plotters are gradually disappearing from the market and are not being manufactured anymore, although quite a large number of them are still in practical use.

The second phase of development, known as analytical photogrammetry, began in the 1950's due to the advent of computers. Many analytical techniques were developed and computer-aided- photogrammetry and mapping were designed. The first operational photo triangulation program became available in the late sixties (Ackermann, Brown, Schut, to name a few). Another area of development in this period was the generation of DEM and manual feature extraction. These were also the result of consistent application of computer methods. In these applications, the operator handles the task of measurement with very few computer-assisted operations. It is the data processing that has made photo triangulation, DEM generation, and feature extraction very efficient and reliable techniques.

Perhaps the most important development in this period was the invention of the analytical stereo plotter by Helava (1957). The analytical stereo plotter is essentially an instrument with a built-in digital computer as its main component, which handles the physical and mathematical relationship between object (ground) space and image space. The analytical plotters were introduced into the market during the 1976 International Society of Photogrammetry and Remote Sensing (ISPRS) Congress. Intergraph's InterMap Analytic (IMA), a flexible photogrammetric workstation that combines interactive graphics and an advanced stereo plotter, was introduced in 1986 (Madani, 1986).

The third phase of development, known as computer-assisted photogrammetry, began in the early seventies when electronic plotting tables became available. Computer-assisted photogrammetry has undergone great development by making use of computer technology and graphical data processing.

The early systems were mainframe based and designed by in-house expertise. Digital mapping systems were created on mini computers and were characterized by unstructured formats and internal proprietary formats. The next stage brought computer assisted design (CAD), workstation based systems. These systems had graphic displays that provided on-line graphics for reviewing and editing digitized data. Translators to the most common formats were typical, and database technology began to emerge in digital mapping systems. Interactive graphical workstations were the result of advances in this period. Interactive graphic techniques changed the process of map compilation drastically in terms of flexibility and efficiency in the final output products.

The new phase of transition is known as “softcopy” or digital photogrammetry. By digital photogrammetry, we mean input data are digital images or scanned photographs. Digital photogrammetry has its root in the late sixties when Hobrough (1968) began experimenting with correlation, even though the solutions were analog in nature. For almost 20 years, correlation techniques remained the only noticeable activity in digital photogrammetry. Research efforts in digital photogrammetry have increased tremendously in recent years due to the availability of digital cameras, satellite imagery, high quality scanners, increased computing power, and image processing tools (Sarajkoski, 1981). A digital photogrammetric system should perform not only all the functionalities that as analytical stereo plotter does, but should also automate some processes that are usually performed by operators (Madani, 1991). Two digital photogrammetric workstations were introduced during the XVI ISPRS Congress in Kyoto, 1988.

Since digital photogrammetry is rather new, it is easy to generate a list of problems. In some aspects, the present state can be compared with analog instruments in the thirties or with analytical stereo plotters in the seventies. Most problems arise due to the extremely large size of digital images. An aerial photograph of 23 x 23 centimeters, scanned at 20 micrometers resolution, requires over 200 megabytes of storage. Storage of such a large amount of data is no longer a problem. Hard disks with gigabytes of storage capacity are available in most workstations and personal computers. Fast access and processing of such data is another problem. As an example, local transfer time of a 15-micrometers digitized aerial photo is a few minutes. Transmitting time of this image, through a telephone line, may be a few hours or even days. Creation of multi-resolution of digital images through image pyramids and compression/decompression techniques are some possible solutions to this problem.

NEW DEVELOPMENT IN DIGITAL PHOTOGRAMMETRY

There are a number of important factors that caused this rather rapid development in digital photogrammetry (Dowman, 1991). Some of these factors may be summarized as:

- Availability of ever increasing quantities of digital images from satellite sensors, CCD cameras, and scanners.
- Availability of fast and powerful workstations/computers with many innovative and reliable high-tech peripherals, such as storage devices, true color monitors, fast data transfer, and compression/decompression techniques.
- Integration of all types of data in a unified and comprehensive information system such as GIS.
- Real-time applications such as quality control and robotics.
- Computer-aided design (CAD) and industrial applications.
- Lack of trained and experienced photogrammetric operators and high cost of photogrammetric instruments.

Because of these key technological advances; cost; labor; and new areas of applications (GIS and CAD), digital photogrammetric systems have been and are being designed. The main idea is to use digital images, scan the model area with a three-dimensional “floating mark” with sub-pixel accuracy. Then use a digital

workstation to compile the required features to form an intelligent description for an information system such as GIS and CAD systems.

The following sections provide some broad information about hardware and software configurations of a high-end digital photogrammetric workstation.

HARDWARE AND SOFTWARE CONFIGURATION

An integrated digital photogrammetry system is defined as hardware/software configuration that produces photogrammetric products from digital imagery using manual and automatic techniques. The output for such systems may include three-dimensional object point coordinates, restructured surfaces, extracted features, and orthophotos.

There are two major differences between a digital photogrammetry workstation (DPW) and an analytical stereoplotter. The first and perhaps the most significant is input data. Most problems arise due to the extremely large size of the digital images. This alone can almost cause the photogrammetric workflow to grind to a halt if the image file is not handled properly. The most efficient way to handle large image files is through smart file formats and image compression techniques.

The second change brought on by the digital photogrammetry system is a potential for automatic measurement and image matching that simply did not exist in the analytical stereoplotter environment. The automatic measurement and image matching techniques are the great value-added components that the new digital technologies bring to photogrammetry (Madani, 1996).

The advent of low cost symmetric multiprocessing computers and very high performance frame buffers allowed us to consider a new solution to the DPW design. The new DPW must satisfy both commercial and government photogrammetry requirements. Furthermore, it should keep pace with the rate at which computer technology is changing.

A DPW system consists of the following components (Madani, 1991):

- Stereo Workstation
- Stereo viewing Device
- Command Selection and XYZ Movement Controller Devices

There are several types of stereo workstations, most of them commercially available, based on different data processing speed, data transfer rates, disk drive storage, graphics and color display capabilities, and other auxiliary devices.

In general, a digital photogrammetry workstation can display imagery in a static (fixed) mode with a moving cursor or in a dynamic (roam) mode with a fixed cursor. In the static mode, the images stay fixed and the cursors move "over" them. The moving cursor mode does not require a very powerful image processing computing power. The images need to be processed only once for an entire window measurement. In the dynamic mode, the cursor is permanently positioned in the center of the display, with the images moving "behind" the cursors. This results in an operation, which is very similar to the analytical stereo plotter. The fixed cursor mode places high demands on the image processor, particularly because fractional pixel pointing is required. The display systems of these workstations are capable of switching from a 60-hz planar mode to a 120-hz non-destructive stereo mode.

The stereo effect may be achieved by an interface to the workstation's monitor by a special viewing device. There are a great variety of stereo technologies to choose from. One of the very popular stereo technologies is to use a passive polarization system. This system consists of a binocular eyepiece and an infrared emitter. The eyepiece has liquid crystal (LC) shutters. A sensor on the eyepiece detects the infrared signals broadcasted by the emitter to switch the LC shutters in exact synchronization with the image fields as the monitor displays them. The active eyepiece is shuttered at 1/120 second providing

stereo by allowing the left eye to view the left image while the right eye is blocked and the right eye to view the right image while the left eye is blocked. Thus each eye only sees its appropriate image.

Mouse, trackball, hand-held controller, or similar devices may be used as input devices for various menu and function selections, such as window manipulation, zoom-in/zoom-out, image rotation, mono/stereo point measurements, and three-dimensional feature extraction.

New DPW Design

Next generation of DPWs must fulfill a basic set of requirements. Some of the main elements of the first generation DPWs were:

- Management of very large images
- Support for very large monitors
- Smooth and continuous roam across the entire image
- Stereo display in a window
- Stereo vector superimposition
- Fully functional data capture during roam

In addition to these fundamental requirements, a number of additional requirements had to be met to satisfy the needs of government organizations. These additional requirements were:

- 16 bit per pixel panchromatic stereo processing
- Bicubic interpolation
- 5x5 convolution filtering
- Automatic convolution filter selection during zoom
- Automatic dynamic range adjustment
- N bit to 8 bit display mapping and gamma correction
- On-the-fly epipolar resampling

On-the-fly epipolar resampling would enable production shops to eliminate the time-consuming batch resampling of images prior to stereo exploitation. The remaining requirements would greatly enhance the quality of the displayed imagery and relieve the operator from the very tedious tasks of image enhancement during exploitation.

In-line software JPEG image compression and decompression eliminates the need to have the uncompressed images anywhere on the system. Software JPEG compression and decompression allows the system to uncompress the images on the machine only at display time, and only that portion of the image to be displayed. This capability enables operators to store, backup, and transfer over the network images that are approximately 1/4 the size for black and white images or 1/10 the size for color.

In addition, other design goals are necessary to ensure that DPWs can keep pace with the rate at which technology is changing. Among these design goals are:

- Independence from custom hardware
- A single scalable executable
- Hosting on a platform with a large installed software base
- Hosting on a platform with a very high probability of maintaining backward binary compatibility

A careful review of these design goals led us to a symmetric multiprocessing (SMP) architecture. An examination of the workstation market for the late 1990s clearly indicated that the only "open" system supporting SMP that was suitable for technical processing was Windows NT. In addition, the Open Graphics Library (OpenGL) had been ported to the operating system. Thus, the architectural launch pad became:

- Windows NT
- SMP aware software
- Open Graphics Library (OpenGL) for raster and vector operations

Digital photogrammetry software configuration varies from one vendor to another. These systems provide the following capabilities:

- Enhance images for brightness and contrast
- Rotate, flip, and transpose imagery
- Display overview, full resolution, and detail imagery
- Measure fiducials, reseaux, pass points, and control points; manually, semi-automatically, or automatically
- Interior, relative, absolute, and bundle orientation
- Create epipolar stereo models (if necessary) and image pyramids
- Display a digital stereo model for on-Compilation, DEM generation, and three-dimensional feature extraction
- Automatic aerial triangulation, DEM collection and linear feature extraction
- Manual collection of breaklines and other map features
- Graphic updates, while reviewing, roaming, and editing
- Stereo superimposed points, lines, and other map features while roaming
- Several editing options for a quick model set-up

Once interior orientation is performed on an image, its parameters are included in the definition of the pixel's coordinates. This relieves the operator from re-establishing the interior orientation in the case of re-measurement of previously used imagery. Image refinement, such as lens distortion, atmospheric refraction, and other systematic errors may be applied directly to the resampled images. This reduction process leads to a great simplification of the real-time equations.

Automatic measurement of image coordinates of conjugate points for the computation of object coordinates is another task of the digital photogrammetry. This task is referred to as "image matching". Since no unified or well understood theory of human vision exist up to now, a large number of algorithms for image matching have been proposed over the years (Ackermann, 1984, Gruen, 1985, Schenk, 1991, to name a few). The image matching can be accomplished by gray-level correlation, feature-based matching, or a combination of both. As long as good approximations (about few pixels) are available and the gray levels yield enough signals within the correlation windows, traditional correlation methods work well.

Resampling is involved in all geometric manipulations of images, such as rectification, rotation, zooming, and even positioning for subpixel measurements. Digital imagery can be rectified and resampled to normalize images on the fly by using interior and exterior orientation parameters. The generally titled images are projected onto a theoretical plane that is parallel to the model base, facilitating considerably the extraction of operator-specific image information and the matching of features. Different mathematical models, such as nearest-neighbor, bilinear, and cubic convolution are used for resampling. The cubic convolution process provides the best image clarity. Nearest-neighbor and bilinear interpolation can be performed when a quick solution is desired.

DEM extraction is one of the most time-consuming aspects of the map production process. Automating this process can speed the overall map production process by a significant factor. Fortunately, the number of procedures and algorithms has been proposed for automatic DEM generation in batch mode. Today, many photogrammetric and mapping companies use automatic DEM collection software. A regular DEM data of a stereo pair of frame photography can be created in less than two hours with the accuracy of 1/10000 of flying height (Krzystek, 1991). Characteristic features such as break lines, boundary areas, and abrupt changes still are digitized manually. In some DEM packages digitized points can be displayed on the stereo imagery for visual checking and editing. Contour lines can also be generated and superimposed on the stereo display for the visual checking.

In any aerial triangulation process, the image coordinates of all tie, control, and check points appearing on all photographs are measured and then a least squares bundle adjustment is performed. This process ultimately provides exterior orientation parameters for all photographs and three-dimensional coordinates for all measured object points. Until recently, all photo measurement was done manually. Furthermore, the block adjustment was a completely separate step.

New advances in digital photogrammetry permit automatic tie point extraction using image-matching techniques to automate the point transfer and the point mensuration procedures. Automatic Aerial Triangulation (AAT) is already in production rather successfully. The AAT solution has reached the accuracy level of a conventional aerial triangulation. It has been proven, that the AAT solution is much more economical than a conventional one. However, like any new products, AAT systems need to be improved to fit increasing demands of the users (Madani, 2001).

In addition, innovative technologies like GPS/INS are more and more challenging the business of aerial triangulation, thus they compete with the next generation of AAT systems. Today, about 40 % of aerial photographs are taken with cameras assisted with GPS systems.

Automatic feature extraction is one of the most difficult tasks in digital photogrammetry. Artificial intelligence and pattern recognition may provide some help to analyze this process. Extraction of linear features and building extraction are somehow automated. An example of this approach might be in the extraction of road networks. Edges can be extracted from the imagery using segmentation operators, and potential road segments are inferred from parallel lines that are separated by an estimate of road width.

INTEGRATION OF DIGITAL PHOTOGRAMMETRY AND GIS

The GIS is a computer system designed to allow users to collect, manage, and analyze volumes of spatially referenced and associated attribute data. There exists a tremendous amount of cartographic and thematic information derived from a variety of sources. The GIS efficiently stores, retrieves, manipulates, analyzes, and displays these data according to user-defined specifications. This cartographic information is usually very static in nature, with most being collected on a single occasion and then archived.

The use of time as another component in GIS has drawn some attention lately. The time component is a must for an effective application of these computer-based techniques beyond the more limited applications of digital mapping and CAD systems. There are three coordinates for space location, time, attribute, and the image; these are the ingredients for an environmental GIS that by the use of information science may answer the needs of global/environment changes of the world.

Digital photogrammetry and remote sensing data also produce a tremendous amount of information. However, these systems usually collect data not just on a single case, but also on multiple dates, allowing the analyst to inventory, and also to monitor. The ability to monitor development through time provides valuable information about the processes at work. Furthermore, remote sensing and photogrammetry often provide valuable information about certain biophysical measurements that could be of significant value in modeling the environment. While photogrammetry has proved to be an economical method for topographic mapping, remote sensing has proved itself to be an effective tool for resource management. Conventional frame aerial photography used in photogrammetry can be characterized as low altitude, analog, and capable of providing stereoscopic viewing while satellite imagery is generally very high altitude and digital such as IKONOS and SPOT. However, photogrammetry and remote sensing are merging. As photogrammetry becomes more digital and the resolution of satellite images improves, the tools developed in each respective discipline can be applied to the other. Both technologies can be effective means to detect manmade or natural changes on the ground on a cyclic basis for map revisions basis.

Procedures of geographic information are feeling the pressures of increased demands of accurate and up to date geographic information for a growing variety of applications. Existing analog approaches to the stereo compilation process for geographic information capture still provide a very powerful means for visualization of topography, and these instruments provide very precise and accurate mechanisms for

geometric mensuration. However, the capture of semantic information about the geographic entities relies on the operator's interpretive skills. While the operator is very good at doing the deductive and heuristic reasoning needed to determine that, for example, the linear feature evident in the image is a railway line rather than a road, the overall collection process is constrained by the reliability and consistency of this approach as well as by the operator intensive nature of it. It is clearly difficult to achieve significant improvements when the process is so heavily dependant on human interpretation.

DIGITAL ORTHOPHOTO AND MONOSCOPIC/STEREOSCOPIC MAP REVISION

The current emphasis is directed toward exploitation of digital orthophotos used in monoscopic revision workstation. The primary source material being considered for a revision program would come from aerial photographs. Satellite images, particularly IKONOS AND SPOT images are being also considered for small-scale map revision.

Because of current commercial hardware and software capabilities, it is now feasible to consider the production and use of digital orthophotos as a cost-effective source for revision of planimetric spatial data. The advantages of monoscopic revision from a digital orthophoto are smaller image data files, less complex processing requirements, and the availability of many hardware and software platforms that support this type of operation.

A typical digital orthophoto production system consists of the digitizing, storing, and computing hardware needed to accomplish the differential rectification of scanned aerial photographs. Generally, scanning resolution depends on the intended use of the orthophoto. For softcopy digital orthophotos, a 50-micrometer pixel produces an acceptable image product for many applications. This pixel size produces a rectified image of roughly 15 megabytes of data. A 25-micrometer image quadruples the amount of storage required. When generating hardcopy, a 25-micrometer spot size is desirable because each pixel in the orthophoto is enlarged from photographic scale to final orthophoto scale. The higher resolution maintains better image quality. Scanning time depends on the aperture used; the speed of the scanner, and the number of passes required to digitize the desired colors. Once an image is orthorectified, it can be used as a backdrop for monoscopic map revision and vector editing. The hardcopy orthophoto can be produced by continuous tone plotting of the digital orthophoto file with a film writer. For masacked images, the production of the orthophotos and their subsequent use for map revision and monoplottting provides obvious tangible benefits to mapping agencies.

Conventional analog and analytical plotters have very powerful stereoscopic viewing capabilities that are heavily relied on for image interpretation, feature extraction, DEM generation, and classification, which can reduce the need for the more costly field classification procedures. Digitized feature data are superimposed on the stereo display for visual checking and editing. An efficient feature extraction package should provide many specialized digitizing and editing commands to minimize the operator interaction required to collect or edit feature data. Photogrammetric feature extraction is inherently a highly manual process with thousands of user actions performed during the workday. Therefore, it is necessary to minimize this repetitive interaction, thus increasing the throughput of the system and the consistency of the data produced.

Feature extraction is currently being performed interactively, as no automation tools have yet been fully developed. It is possible to automate linear feature extraction with the operator interaction in difficult areas, outline the boundary of identified area features (water bodies, fields, and others), and extracting building outlines within area identified by the operator. As the technology advances in the area of automation, data storage, and processing, softcopy stereovision could be considered as the primary operational scenario for stereoscopic map revision.

CONCLUDING REMARKS AND FUTURE DEVELOPMENT

This paper has presented the state of new development in digital photogrammetry and its integration into a geographic information system. Recent experiences indicate that there is a great potential for the use of the digital photogrammetric systems, particularly in the areas of automatic aerial triangulation, automatic DEM

collection, feature extraction, and orthophoto generation. Different design concepts are already implemented. This is not unusual considering that computer technology is currently advancing at an incredible pace in terms of higher performance and lower costs. Recent advances in display resolution and digital stereoscopic display are providing visualization and mensuration capabilities that are analogous to the stereo plotter. In addition, the digital domain is better suited to exploit the benefits of image data recorded digitally, such as images acquired from satellites or airborne digital scanner devices. These types of data sources usually provide improved spectral resolution over photographic images, thus providing more data to aid in the semantic information extraction.

The digital domain begins to offer some automated alternatives to the process of capturing and modeling the higher-valued semantic entities required in the geographic information acquisition process. This allows the automation of many photogrammetric tasks that were previously performed by highly trained operators. Digital photogrammetry is expected to open up new areas of applications such as CAD and industrial engineering.

Product integration is another area of concern. Many vendors provide a variety of application packages for mapping and engineering. Digital photogrammetric products are going to be integrated more into other products than before. Due to increasing availability of digital images, accurate scanners, and CCD cameras; digital photogrammetry will be using in mapping, GIS, and non-mapping (CAD) applications.

At present, the interface between geographic information systems and digital imagery systems is functional but weak. Each side suffers from a lack of critical support of a type that could be provided by the other. The GIS has a continuing need for timely, accurate updates of the various spatial data entities, whereas digital photogrammetry and remote sensing systems could benefit from access to highly accurate ancillary information to extract more useful information from the imagery.

As digital photogrammetric systems mature, softcopy exploitation will become less expensive than hardcopy exploitation. Many mapping agencies will benefit from the digital photogrammetric exploitation, particularly when the products required include DEM data, monoscopic map revision, or GIS applications. We ultimately expect from digital photogrammetry that the input be converted to an accurate, intelligent description of the object space that may form the base of an information system, such as a GIS. Finally, merging these two methods, the whole range of geocoded mapping is at our disposal, including the various kinds of thematic/temporal maps, which combine and present thematic/temporal information in a topologically structured fashion on a topographical base.

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