INTEGRATION OF DIGITAL PHOTOGRAMMETRY AND RASTER GIS

Kurt Novak
Ohio State University
Department of Geodetic Science and Surveying
1958 Neil Avenue
Columbus, Ohio 43210-1247
614/292-6753

Stephen L. Sperry
ERDAS, Inc.
2801 Buford Highway, Suite 300
Atlanta, Georgia 30329-2137 USA
404/248-9000
Fax: 404/248-9400

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ABSTRACT

This paper investigates the full integration of digital photogrammetric functions in a geographic information system (GIS). Photogrammetry is a very powerful tool that can be used to create accurate data for a GIS. The major obstacle against a wider application as a data capture method is the complicated instrumentation necessary. However, an implementation of photogrammetric mapping and triangulation functions on a workstation in an image analysis environment eliminates the cost of analytical instruments. This makes the system easy to use for non-photogrammetrists and it can be done directly in a data base environment.

The concept of a digital photogrammetric plotter implemented as a software module of an existing GIS is presented. A full range of photogrammetric functions were developed in a workstation environment. They can be used to generate digital elevation models (DEMs) and digital orthophotos from aerial photographs and satellite imagery. These are two important layers of a GIS. The developed software is not limited to digital mapping, but can be used for highly accurate aerial or satellite triangulation. Stereo images are displayed on a workstation screen where points can be selected semi-automatically. This allows analysts to accurately integrate satellite data with digitized aerial photographs in a common system.

INTRODUCTION

Although the geographic information system (GIS) has become a popular tool for many organizations, their implementation is often stalled by the lack of available digital data. Most GIS's are based on vectors (line data) digitized from existing maps. The digitized maps often include error—those transposed from incorrect or out-of-date maps, as well as those occurring during digitizing. Two critical GIS data layers, terrain and land cover, are typically difficult to develop in vector format. Contour maps representing terrain leave many areas blank. Land cover maps generated through manual air photo interpretation methods are time consuming and expensive. These data gaps can be filled by information from a raster GIS.

Information for a raster GIS is mostly derived from satellite sensors or scanned aerial photographs which record spectral information about the surface of the earth. The raster equivalents of vector contours and land cover maps are digital elevation models (DEMs) and digital orthophotos. Digital orthophotos are image-based maps which have been corrected for relief displacement.

In the past, DEMs and orthophotos were derived by manual photogrammetric techniques. Through the development and enhancement of digital photogrammetry, it is possible to derive the information fully automatically from digital imagery. Because of the similarity in data formats between digital photogrammetry and GIS, the DEM and digital orthophoto can be readily used in raster GIS's. Due to recent advances in the integration of raster and vector GIS, the data are also available to vector GIS's.

Digital photogrammetry provides not only current and accurate information for GIS's, but its algorithms are also useful for extracting products from existing GIS data layers. These products include perspective views, slope models, exposition models and contours. This paper describes the development of a digital photogrammetric module in a raster GIS. First, the functions by which digital photogrammetry can enhance the capabilities of automatic information extraction are discussed. This is followed by a discussion of a specific implementation of photogrammetric algorithms in a GIS. The discussion includes descriptions of sensor orientation, image matching, DEM interpolation and digital orthophoto generation. Typical problems that are encountered in these processes are identified along with operator solutions. In the conclusions, future developments and further enhancements of digital photogrammetry are discussed in terms of new photogrammetric image analysis techniques.

DIGITAL PHOTOGRAMMETRY

Photogrammetry has been used for about one hundred years to generate maps from aerial photographs and to compute highly accurate point positions in three dimensions. It is a matured technique for extracting spatial data. The advance of digital sensors have made it possible to use photogrammetry on a computer and apply its algorithms to digital imagery. The use of a computer in photogrammetry is known as a softcopy photogrammetry system. Currently, the most popular techniques are image matching and DEM generation, as well as digital orthophotography.

Image matching can be classified into different techniques depending upon the features used to detect similarities. The most popular is area-based matching in which a gray value matrix of one image is compared to a gray value window of another image on a pixel by pixel basis. This method is most accurate for measuring image coordinates of well defined points as it gives sub-pixel accuracy. However, this method also requires very good approximations (about 5 pixels) in order to find matches successfully. Other matching techniques are based on features which could be lines or characteristic points of the image. They must first be extracted before the matching can begin. This technique is less accurate, but more robust since correct matches can be found over the whole image area without any approximations.

Other types of image matching, such as binary tree matching, are currently under development and have not been practically implemented in digital photogrammetric systems. The matching of points can take place in image space (on the sensor) or in object space (on the map or on the ground). The relationship between image and object is given by the collinearity (perspective) equations, which form the basis of all photogrammetric point positioning methods. Any point-pair matched in image space can be immediately projected to the ground.

Once in object space, the 3-dimensional points can be used to generate a raster DEM stored in the same format as digital image (a matrix of gray values). Photogrammetry has been involved in the development of DEM interpolation techniques for a long time. Good DEM interpolation techniques allow us to approximate the terrain smooth functions by using reference points. It is very important to smooth reference points derived automatically in order to eliminate wrong matches and reduce noise. Analytical surfaces developed during the DEM interpolation process are represented as a dense grid of elevation points in the GIS. At each location of an elevation pixel, the corresponding gray-value can be found by digital orthophotography. The surface point represented by the DEM pixel is projected into the original image using the perspective relationship between image and ground. The location in the original image is identified and its corresponding gray value is extracted by a resampling technique. Once completed over the whole image, the digital orthophoto is created. This layer fully corresponds to a (digital) map free of any relief displacements.

Digital photogrammetry is heavily involved in the development of feature extraction and image understanding techniques. The digital mapping of linear features such as roads, rivers or rectangular objects such as buildings is of profound importance. Research is currently underway to automatically find these lines, which are usually highly visible in images and supposedly correspond to edges of the real surface. Once lines have been detected and vectorized, artificial intelligence has to be applied to automatically interpret their meaning. Image understanding is a popular discipline which will soon allow us to fully and automatically analyze vector data obtained from the feature extraction. This data can then be integrated into the GIS together with the raster information.

IMPLEMENTATION OF A DIGITAL PHOTOGRAMMETRIC MODULE IN A RASTER GIS

Many of the techniques described in the previous section were implemented in an existing raster GIS to allow the user to acquire spatial data directly in the familiar GIS environment using digitized aerial photographs or satellite imagery. They are collected in a digital photogrammetric module, mainly applied for information extraction for the GIS data base. The functions are comprised of coordinate measurement in the imagery, control data collection, sensor orientation for aerial photos and satellite imagery, image matching, DEM interpolation and orthophotography. The user can densify control point networks by aerial triangulation or satellite triangulation, create a digital elevation model by image matching and DEM interpolation, and consequently derive a digital orthophoto by using the DEM to correct for relief displacements. Figure 1 below shows a flow chart describing all of the functions implemented in this module.

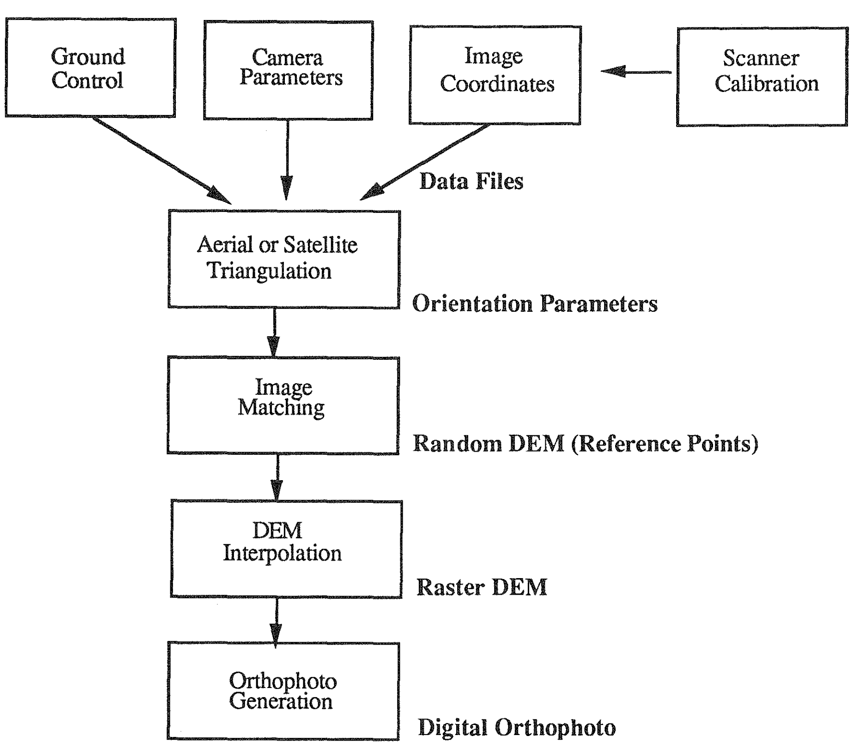

Figure 1: This diagram shows the digital photogrammetric functions integrated in a raster GIS. The boxes indicate the functions and the text to the right state to the data derived at each stage.

In the following sections, the typical application of the photogrammetric module is described.

Image Coordinate Measurement

The first step of data analysis is the preparation of the data files needed for the sensor orientation and as approximations for image matching. Among these data files are a list of ground control points, image coordinates, camera calibration information, and, if available, approximations of the sensor positions and attitudes.

Two windows are used to display a digital stereo image pair on the computer screen in a reduced form. This is necessary as the digital images very large (6000 x 6000 pixels for SPOT imagery and 4000 x 4000 pixels for digitized photographs). A small window can be enlarged to full resolution so that the operator can identify and measure image coordinates to within a pixel, or by using a resampling technique, even to a quarter of a pixel. These measurements are done manually on the screen. At the same time, the operator identifies control points on an existing map. This map must be accurate relative to the digital imagery (e.g., USGS quad sheets at 1:24,000 can be used for SPOT imagery). Otherwise, ground control points must be established by geodetic or terrestrial survey techniques. The split screen simulates the functionality of a stereo comparator to select points in the left and right images of the stereopair. It also allows the user to form a strip of photographs by shifting from one stereopair to the next on the monitor. If aerial photographs are used, the pixel coordinate measurements are transformed into an image coordinate system. This coordinate system is defined in the calibration report by the camera manufacturer, which is available to the user of the aerial photographs. The split screen tool can later be used to edit match points in the images.

The user has an option to check the accuracy of the scanner used for digitizing the aerial photographs. The scanner calibration program was developed to model the distortions of the scanner and to apply corrections to the image coordinates. This is an important procedure because many scanners apply a second projection to digitize the images, in which case additional distortions are unavoidable. These distortions are often larger than 3 pixels.

Sensor Orientation

The sensor orientation is typically done by photogrammetric bundle triangulation. This technique is based on collinearity equations and is widely used in analytical photogrammetry for aerial triangulation. It is a very flexible tool which allows us to solve for the exterior orientation parameters of a photograph (the exposure station and attitude of the camera), to densify the ground points, to derive camera parameters, and to model distortions of the sensor system. The bundle triangulation technique can not only be used for aerial photographs which are modeled by a central perspective geometry, but it can also be modified for satellite sensors. Satellites use separate scan lines that are acquired sequentially. Each of these scan lines has a separate perspective center. Due to its smooth motion in orbit, all perspective centers can be lined up along an analytical function. Therefore, the geometry of the satellite sensors is fundamentally different from aerial photographs, however, it can also be modeled by a modified bundle solution.

Both of these functions were implemented so that the user can compute the orientation parameters of either aerial photographs or satellite scenes. Furthermore, the user can densify points on the ground which were not digitized in the maps network densification. As they are positioned very accurately, they can be used as a reference in separate images. Sensor orientation parameters are important for 3-dimensional positioning of points to create the random DEM, and for digital orthophotography.

Image Matching

The image matching techniques implemented are following the area-based approach. To minimize the need of approximations, an image pyramid is created by reducing the original image four times by a factor of two. At the lowest resolution, a square grid is established in the left image and matched to the right one. Once this grid has been found, its points are projected to the next higher level of the pyramid (higher resolution) until the match points finally appear in the full resolution image. This first, coarse grid can be edited on the split screen monitor so that the user can correct wrong matches. These wrong matches typically occur in areas of low contrast such as lakes or desert areas. Afterwards, a densification is performed to obtain a dense set of reference points in the images. For example, in SPOT scenes points can be matched as close as every third pixel.

Two area-based matching techniques are applied: cross correlation and least squares matching. Cross correlation finds corresponding image points at an accuracy of one pixel. It is a very robust technique which locates the points without very precise approximations. For the densification, least squares matching is used. This technique yields an accuracy of a tenth of a pixel in the image.

Once these sets of corresponding points are available and have been edited, an intersection is computed to project the image coordinates into object space by virtue of the known orientation parameters of the two images. In object space they form a random DEM of reference points which can be used to interpolate a grid DEM, or they can be connected by triangles using a TIN structure.

DEM Interpolation

This procedure transforms the spatial random points to a regular raster format. It can also filter elevations to eliminate wrong matches. The algorithm implemented is based on the summation of surfaces, which creates a smooth, analytical surface over the whole interpolation area. Wrong matches stick out of the surface as spikes. These areas and other noise are filtered at this stage to fit the surface to the reference points in the best way. The surface of this algorithm also covers areas with or without sparse reference points. As a result, we obtain the raster DEM that directly forms the elevation layer of the GIS. It is georeferenced and can be created in any selectable map projection supported by the GIS.

Digital Orthophoto Generation

Once a DEM is available, the relief displacement of the original images can be corrected by applying the surface elevations to this image. Basically, any DEM pixel is projected back into the original image where we can resample a gray value. This gray value is placed in the corresponding DEM pixel location in the orthophoto plane. The relief corrected image is georeferenced to the map projection as the DEM. As there is no relief displacement, this image can be directly overlaid with vector data without showing any off-sets. This is a typical problem of regular geocoded images that were not relief corrected.

Although the procedure of creating orthophotos and DEMs was described in a sequential form, the digital photogrammetric module is very flexible. The user can enter the flow chart (figure 1) at any stage if the appropriate information is available. The user can also combine data from different sources. For example, if the major objective is to create highly accurate digital orthophotos at a high resolution, they should be produced from large-scale aerial photographs. The DEM used to correct relief displacements need not be very accurate in this case. Actually, it can be derived from satellite imagery, such as SPOT Panchromatic stereopairs. The DEM would still have a vertical accuracy of 10 - 15 meters, which hardly effects the planimetric accuracy of the final orthophotos. Thus, the user can create the raster DEM using SPOT imagery and then apply it to aerial photos for relief correction. The orientation parameters must be derived from both sensors.

GENERAL PROBLEMS OF IMPLEMENTATION

Conclusions

The integration of digital photogrammetry and raster GIS is a very important enhancement of the way in which information is acquired for geographic information systems. Currently, the techniques to automatically derive digital elevation models and digital orthophotos in raster format are operational in the ERDAS GIS package. Many enhancements of this system can be envisioned. For example, it would be useful to use a real, 3-dimensional monitor to view image pairs as stereo-models, in which the operator could trace lines in space with a 3-dimensional cursor. The automatic interpretation of raster data is of critical importance for combining raster and vector GIS's. Therefore, feature extraction algorithms are being developed which will permit the user to automatically find lines in the images, and even interpret them as objects on the ground such as, roads, rivers or buildings.

Another enhancement to speed up digital mapping is automatic line following in the digital images. For this procedure, the operator would select the starting point of a linear feature, such as a road or a river, and the function would automatically trace this line as long as it is unambiguous.

In the future there will be many new developments in automatic data acquisition for geographic information systems. Software vendors have recognized the importance of integrating photogrammetric functions in a GIS and are working on modules similar to the one described here. Ultimately, this information extraction technology will also enhance the importance of satellite sensors and digital aerial cameras for small-scale mapping and geographic data bases, as well as for civil engineering applications.

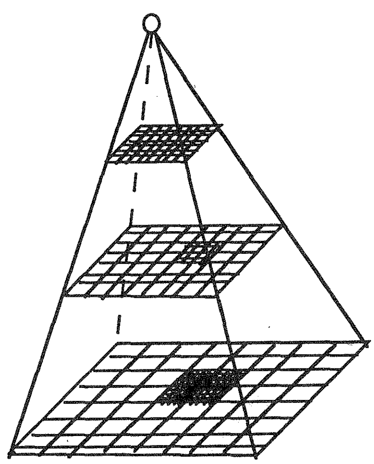

Figure 2

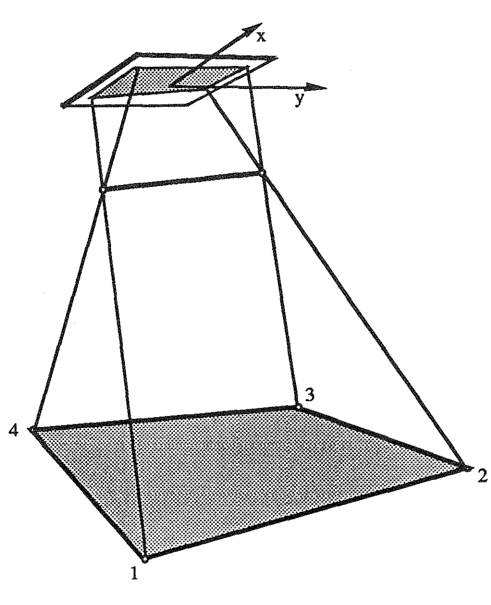

Figure 3

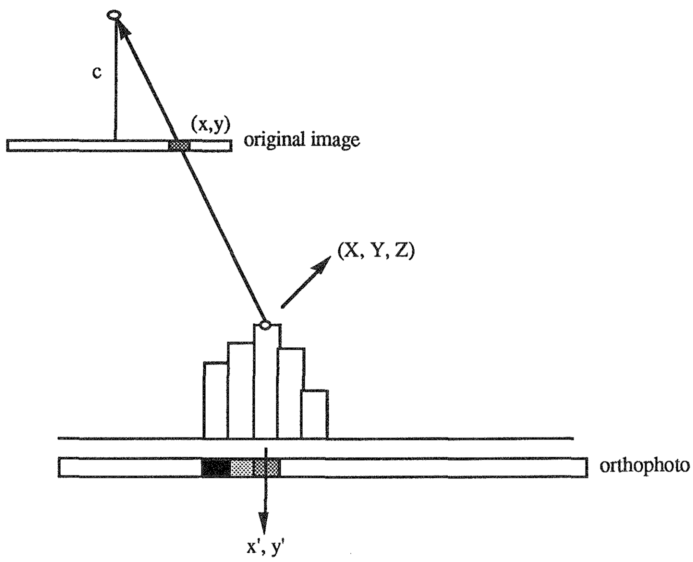

Figure 4

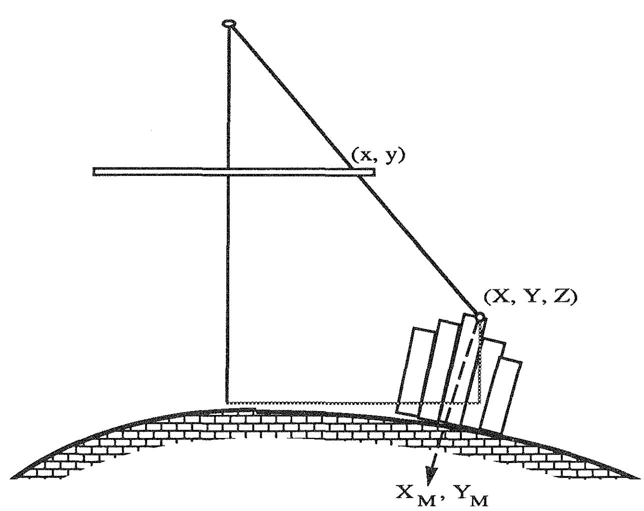

Figure 5