DIGITAL ORTHOPHOTO MAPPING USING A SIMPLE CAMERA

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ABSTRACT

The primary objective of this research has been to develop a simple, accurate and efficient method for producing orthophotos by digital image processing. The system utilizes a 35 mm single lens reflex camera, a rotating-drum type scanning microdensitometer, and an IBM personal computer interfaced with a Professional Graphics Display. The procedure that has been developed includes calibration of both camera and scanning microdensitometer. Numerical image correlation has been employed to produce a digital elevation model.

The system was tested by producing an orthophoto from a stereopair of convergent photos taken of a cylindrical shaped building. The visual appearance of the orthophoto, prepared using resampling and aided by image enhancement, gridding, contouring, and annotating, was excellent. Its accuracy was also evaluated and found to be of high order.

Based upon the results of this research, it is concluded that a simple camera can be used together with digital image processing techniques to produce high quality orthophoto maps.

INTRODUCTION

Handling data in digital form is the trend of photogrammetry. More and more, photogrammetrists prefer digital information, since it offers many advantages, including mass storage, expedient transmission, rapid retrieval, high-speed updating, and the capability to combine with other sources of data Furthermore, both the storage ability and processing speed of a digital computer are increasing continuously, which also lends impetus to the development of digital photogrammetry.

Image processing is an important feature of sophisticated digital photogrammetry. During acquisition, transmission, and retrieval of digital images, many factors could distort the data. Digital image processing can minimize the effects of these distortions and improve the quality of photogrammetric work. Though the human eye is exceedingly acute, it still has some limitations in extracting complete and accurate information from a photographic image. Most of these limitations are due to degradations or distortions of an image. The application of image processing to digital photographic data can minimize these limitations and enable the extraction of more accurate information from images.

The original motive of this research is to develop an efficient photogrammetric reduction method whereby a simple non-metric camera, an existing digitizing scanner, and a personal computer may be used in combination to produce a digital orthophoto. The system presented in this paper performs the reduction process. With this system, orthophotos can be generated from photographs taken by any simple camera. The concept of digital orthophotos is not new; nevertheless, most previous products were limited to those generated from aerial photographs, which employed information from an existing digital elevation model (DEM). This study initiates the use of simple instruments, in the most economical way, to produce digital orthophotos. The results prove that this innovation is highly feasible.

Orthophotos are frequently used in planimetric mapping. An orthophoto map shows all of the planimetric features of a photographed area in great detail. Using digital control systems, unconventional applications are also possible. Vozikis (1983) has described some of these applications. As he states, The Wild Avioplan OR 1, a digitally-controlled orthophoto system with the SORA program package, has been used in producing stereo-orthophotos, rectification of multispectral scanner (MSS) images, architectural and close-range photogrammetry, conservation of sites and monuments, and cartography. The potential for unconventional applications of orthophotos is continually growing.

Non-metric cameras offer the advantages of low cost, light weight, versatility, and ease of operation. The differences in precision between metric and non-metric cameras are smaller than one would expect, and if analytical reduction methods are used, non-metric cameras might be sufficiently accurate for a far wider range of applications than was previously thought. Their use for orthophoto mapping is one possible application that could become practicable.

Through the use of scanning microdensitometers, data from any photo can be converted to digital form and stored on magnetic tape or disk. This data is a set of density values of corresponding gray levels for every picture element (pixel) in the original photo. With rectification, data of an orthophoto having the orthographic positions and corresponding density values of the original pixels can be produced. The photowriter of the microdensitometer may be used to rewrite this data onto unexposed film to produce a digital orthophoto. This concept has been presented by Horton (1978) and modified later by Keating and Boston (1979).

SYSTEM COMPONENTS

The digital orthophoto mapping system developed in this study includes a Canon AE-1 non-metric camera, Optronics P-1700 microdensitometer, and IBM PC/AT micro computer. The descriptions and calibrations needed for these instruments are discussed in the following sections.

NON-METRIC CAMERA

In this research, a Canon AE-1 camera with a Canon FD 50mm f/1.8 standard lens was used, and Kodak 35mm Kodachrome color slide film with ASA 64 was used. Since the camera is not designed for photogrammetric uses, it does not have fiducial marks, and its focal length, principal point, and lens distortion must be determined or calibrated.

Field methods were chosen for camera calibration. An array of targets with known relative positions was photographed. Their theoretical image coordinates were computed according to the perfect perspective view. The image coordinates were also measured precisely. Comparing the theoretical and measured coordinates, the elements of interior orientation could be determined. Four small marks were scored on the sides of the camera body frame. The intersections formed between these marks, the sides of the format, and four corners of the frame, were used as the fiducial marks.

The results, lens distortions for four diagonals appeared quite unsymmetrical. Therefore, four sets of polynomial coefficients were determined individually, and radial lens distortion for any image point was a weighted average of its neighboring two diagonal lens distortions, according to the point's location on the photo plane.

MICRODENSITOMETER

A microdensitometer converts film density to digital values (and vice versa if so designed). A Photomation P-1700 Scanning Microdensitometer system made by Optronics International was used. The P-1700 was interfaced with a PDP 11/45 computer and a magnetic tape drive, and offers two independent functional subsystems, "read" and "write". The "read" function converts the photometric density of a transparency pixel to a digital format and stores the information on magnetic tape. The "write" function reverses the process, allowing the recreation of a film based on tape data.

The P-1700 is a rotating drum scanner. In this system, the film is mounted over a square opening in the rotating drum so that it forms a portion of the drum's circumference. The optical systems sense variations in film density, and create a scanning line across the film when the drum is rotated. A reference x-y axis system is used to define the location of any pixel in the scanned imagery. In this system, the x coordinates correspond to <u>row</u> numbers that result from drum rotations, and the y coordinates correspond to <u>column</u> numbers that result from the incremental translations of the source/receiver optics after each drum rotation.

Previous research indicated that the scanner must be calibrated when being used. Researchers have also noted that the scanner introduced greater distortion in the direction of the drum's rotation. However, they evaluated only the read function of the scanner.

In this research, the metric aspects of both the read and write functions of the microdensitometer are evaluated. In the first part, three digital grid image files were written on film. The reseau intersections were measured by the DBA monocomparator. In the second part, a contact printed film from a grid glass plate was scanned to produce a digital image file. Then, this file was "written" onto a piece of unexposed film via the write function. The detailed procedure, the results of this calibration were described by Lo and Huang (1986). and a summary of this calibration are explained in the following paragraph.

Even when generated from the same computer program, different films will show unique distortion patterns. Therefore, these displacement corrections cannot be consistently applied to all films. Moreover, the residuals indicate that distortions for the x (rotation) direction are larger than those for the y (lead screw) direction. Distortions in the rotation direction are more complicated and unpredictable due to variations in rotary speed, and possibly other undetected reasons. These distortions should be considered to be displacements of the pixels when the films are used for other applications.

MICROCOMPUTER IMAGE PROCESSING SYSTEM

In processing the information in this research, an IBM PC/AT microcomputer image processing system was used. This system was interfaced with a magnetic tape drive, and consisted of a twenty megabyte (20M) hard disk drive, a 1.2M floppy disk drive, an 1164k RAM, a Professional Graphics Display (PGD), a monochrome monitor and a printer.

The PGD can show a digital image area comprising 480 rows by 640 columns, with 16 gray levels. The monochrome monitor is used for overseeing input progress. Usually, the operator calls up an image processing program on the monitor and watches the processed image on the PGD simultaneously.

The original software written was compiled using the MicroSoft (MS) FORTRAN compiler linked with a file, FIMAGEIO.LIB, consisting of 28 routines which can be called from source programs. These routines were written by the Environmental Remote Sensing Center at the University of Wisconsin.

DATA ACQUISITION AND PREPROCESSING

The cylindrical part of the Observatory at the University of Wisconsin was the object field of this research. Near the observatory, four ground control stations and two camera stations were established. Also, fifteen discrete points on or near the observatory building were selected for photo control. In addition, nineteen targets were attached to the cylindrical wall of the observatory. The four ground control stations were mainly utilized for redundant observations for bundle adjustment. The two camera stations were set up for taking 35 mm pictures of the observatory.

The depth or range of relief of the Observatory is 10.5 ft. The base line between two camera stations was 21.8 ft. The average distance between cameras and objects was 74.1 ft. These distances permitted the lens to be focussed at infinity while the object still appeared acceptably sharp.

PHOTOGRAPHY AND COMPUTATION

Two kinds of photos were taken in this research. The first was glass plate photography taken by a Wild P-30 phototheodolite at each of ground control stations. The second was slide film taken by the AE-1 camera at camera stations.

Image coordinates of the photo control points and targets on the glass plates were measured using the DBA monocomparator. These photocoordinates were then reduced to the fiducial coordinate system according to the calibrated fiducial coordinates of the P-30 using an affine coordinate transformation.

At each of two camera stations, the AE-1 camera was set up and convergent photos of the observatory building taken. These photos would be scanned for generating orthophotos later. In order for a stereomodel to cover the largest possible area of the building, the cameras were rotated 90° clockwise and two photos with an overlap of over 90% were taken. This also increased the base-depth ratio (it equaled 0.29 in this research) so that parallactic angles between conjugate rays would be increased and, thus, points located more accurately (Wolf, 1983).

Image coordinates of the targets on the slide films were processed using the same procedure as for those on the glass plates. However, the calibrated fiducial coordinates of the AE-1 were used to transform the measured coordinates. The transformed coordinates were then corrected for radial-lens distortion.

The orientation elements of five camera stations (three P-30 stations and two AE-1 stations) and ground coordinates of the photo control points and targets were computed using a bundle adjustment program.

The RMS of discrepancies were 0.059 feet for the X coordinate, 0.079 feet for the Y coordinate, and 0.083 feet for the Z coordinate, respectively, which met expectations.

DIGITIZING OF PHOTOS

A stereopair of two slides (positive exposures) taken by the AE-1 was digitized using the P-1700 microdensitometer. The photos were mounted on the P-1700 with the scanning direction along the fiducial x-axis of each photo. A pixel size of 50 micrometers was used for scanning. Ordinarily, a 35 mm photo with a frame size of 36 mm by 24 mm will be converted to a digitized image having 720 columns by 480 rows. For this research, in order to cover all four fiducials and the four corners of the camera frame, each photo was scanned so as to produce a digitized image having 740 columns by 512 rows. After the scanner coordinates of fiducials were determined, some of the edge area which contained the fiducials was no longer useful. The images were thus reduced to 512 by 512 for convenient processing, generation of a DDM and computation of an orthophoto image as described in the succeeding sections.

GENERATION OF A DIGITAL DEPTH MODEL

The XYZ ground coordinates of a dense network of points throughout a terrestrial photographic area is called a digital depth model (DDM). In terrestrial or close range photogrammetry, the Z coordinate in the DDM is usually considered to be the depth value. A DDM for any particular mapping area rarely exists. Therefore, a DDM must be generated according to the photographic region.

A DDM is necessary for generating an orthophoto. In general, original perspective photos contain image displacements due to tilt and relief. Tilt displacements can be eliminated analytically based upon photo exterior orientation elements, but relief displacements must be rectified differentially, using information specific to the area involved. Therefore, the DDM, an explicit pattern of relief, must be generated in order to eliminate these image displacements in the original photos.

Generating a DDM begins with recognizing control points and matching conjugate points, and proceeds through interpolating data, smoothing, and refining. The more matching points found by image correlation, the better the results of this interpolation will be. However, increasing the number of input points results in slower processing. Since interpolation may operate in several ways, and since the details of a DDM are complex, the decision to use the interpolation method rests on the researcher's judgment about the actual data involved.

The smoothing process weights and averages every value of the DDM grid with its assigned values and those of the surrounding grid points. Data in a two-dimensional grid may be smoothed so that abnormally high or low values are eliminated.

Refining is a procedure used to rearrange a DDM so that its new form has a finer grid and better resolution. Refining is also used to make the scale of a DDM suitable for generating an orthophoto.

To save storage space, the depth values of a final DDM were in binary form, as were the gray values of the digital image. The DDM file could thus be considered as an image file, in which the original depth values have been rescaled from 0 to 255. For example, the depth of the study area ranged from 1.5 to 11.5 feet and was scaled from 0 to 255. The resulting DDM interval was approximately 0.039 feet for each increment of this scale.

GENERATION OF ORTHOPHOTOS

Initially, each pixel in an orthophoto will not have any gray value, and the dimension of the orthophoto image is assumed to be the same as that of its DDM. The row/column coordinates of the DDM image can be used to compute X and Y ground coordinates by applying coefficients of the two-dimensional conformal transformation. The pixel value of this image is multiplied by a scale factor and added to the datum depth to obtain the Z coordinate.

The space object of any pixel may be hidden in the original photos; its XYZ ground coordinates and collinearity equations can be used to check whether it appears in the original photos. If the object is not hidden in an original photo, its ground coordinates may be transformed into rectified image coordinates using the calibrated focal length and orientation elements of the camera station, then applying the collinearity equations. Rectified coordinates are theoretical photocoordinates which contain no displacements or errors.

The rectified image coordinates are then modified, in order, according to radial lens distortion, principal point offsets, and fiducial marks. Principal point offsets, coefficients of lens distortion polynomial curves, and coefficients of a two-dimensional affine transformation from the fiducial-axis system to the measured comparator system are used in this modification. The modified image coordinates are now considered as the original measured comparator photocoordinates.

Using the coefficients of a two-dimensional affine transformation, one may change modified image coordinates into scanner coordinates for one of the two original slides, while allowing for scanner distortion. The comparator coordinates and scanner coordinates of photo control points are used to calculate these coefficients.

At this stage, a grid point in the desired orthophoto image has been made to correspond to a certain point in the scanned image. Though this point may not be precisely located at a grid point in the scanned image, its neighboring pixels can still be identified. The density values of these pixels can be extracted, using a resampling technique, and transferred to the grid point in the orthophoto image.

RESAMPLING

As mentioned before, the input scanned image and the output orthophoto image are respectively defined on two evenly spaced grids. Though geometric transformation can be used to relate these two grids, the transformed grid of the output image is generally not in accord with the grid of the input image. The gray values of pixels on the orthophoto grid are obtained by interpolation, using the neighboring pixels on the distorted input grid. This process is called resampling.

Three resampling procedures, nearest neighbor, bilinear interpolation, bicubic interpolation, have all been tested in this research. Since bicubic interpolation gives the best image quality, it has therefore been used throughout to generate the output orthophoto images.

IMAGE ENHANCEMENT

An image is often degraded during the digitizing and resampling processes; the resultant image may be blurred by various irrelevant features. Enhancement methods aim to overcome these impairments and to emphasize features of interest. While a number of enhancement approaches may be applied, including contrast, color, and edge, only contrast enhancement is employed for this study.

Contrast enhancement can increase the contrast between features in an image so that pertinent information can be distinguished much more easily. In this research, most density values of the orthophoto image range from 65 to 165. If this digital image data is written onto film, the whole film will appear too homogeneous for most objects to be recognized. A simple linear stretch can be used to expand the range 65 to 165 uniformly over a full range of gray values (0 to 255).

GRIDDING, CONTOURING, AND ANNOTATING

Superimposing a rectilinear grid, contour markings, and annotations on an orthophoto makes reading and interpretation of the image faster and easier. A grid for an image can be made using one of two simple methods. In the first, a pixel with a specific gray value, G_g, is inserted after every tenth pixel (or a multiple of ten) in every row, and a line with the gray value G_g is inserted after every ten rows. In the second method, every tenth pixel in every row is replaced by a pixel with the gray value G_g; and every tenth row is replaced by a line with the gray value G_g. The former method will preserve the original pixels but will change the map's scale, while the latter preserves the scale but loses some pixels. Since pre-serving the scale is more important than preserving the pixels in an orthophoto image, the pixel replacement method is used herein.

A digital orthophoto can be contoured by using its corresponding DDM image. As mentioned before, the DDM contains the depth values for every pixel in the orthophoto image, so that pixels at any predicted depth can be found. A simple way of contouring is to change the pixels in the orthophoto to a specific gray value, G_c. This method maintains the original scale but alters some pixels in the output orthophoto.

A library of symbols, letters or characters in digital form should be established in order to annotate a digital map. After this library has been generated, the necessary figures can be copied onto the digital orthophoto image. This research utilizes certain letters as shown in the final orthophoto map, with grids, contours, a given scale, and a brief legend, shown in Fig. 1. Additional advantages realized from using image processing techniques are increased speed, and the potential efficiency with which the orthophoto image can be updated, should that be desired.

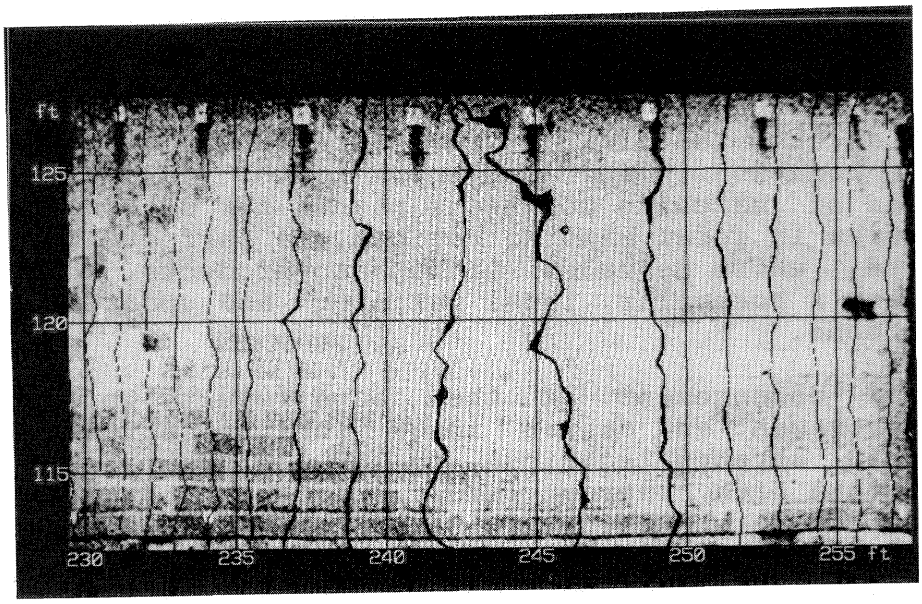

Figure 1 Resulting Orthophoto Map.

CONCLUSIONS

Based upon the results and experiences concerning each stage of this research, several conclusions can be drawn, as follows:

1) The results have demonstrated that digital orthophoto techniques can be applied to photographs taken with a simple camera. Utilizing such a camera has provided considerable convenience for operations, including photography, digitizing, displaying, and image processing. Its frame (24 mm by 36 mm) is so small that much existing electronic equipment can accept and process its images without difficulty.

2) As demonstrated in this research, convergent terrestrial photos can be used. Procedures for generating orthophotos from oblique, panoramic, or any other kind of photos would also be similar to those described herein.

3) In order to successfully recognize photo control points and match conjugate points through digital image correlation, the shape of the targets and their distribution must be considered. In this research, a circular white board with a smaller black circle painted on it served as the best target for the purpose of image correlation. In areas that were difficult to correlate, dense targets gave better results, while for areas more easily correlated, evenly spaced targets were suitable for matching conjugate points.

4) The resolution and accuracy of a DDM strongly influence the quality of an orthophoto produced digitally. Since both the orthophoto and its corresponding DDM are images with the same dimensions, every pixel must correspond to an exact depth value in the DDM so that the pixel's gray value can be extracted from an accurate location in the original photo. However, due to difficulties of matching conjugate points for discontinuous or sharp features in local mapping regions, a perfect DDM cannot be generated, which degrades orthophoto products. To overcome this problem, a posterior local refining and updating of the DDM can be done.

5) Contrast enhancement of the image results in impressive quality improvement and easier image interpretation. Using a simple linear stretch technique, a low contrast image can be enhanced into a high contrast image, and thus most objects can be recognized very easily. This not only avoids the awkward contrast refinement of film in a darkroom, but also may compensate for the discrepancies between two pictures of the same scene taken at different times.

6) Grid lines, contours, and letters can be precisely and quickly added to an image through the use of image processing techniques. An orthophoto image can thus be refined and updated efficiently.

7) The accuracy of the results here involved a planimetric RMS error of 0.054 ft, and a depth RMS error of 0.148 ft, respectively, on the ground for a map scale of 1:152.4 with a contour interval of 1 ft. This amount of precision shows that this system may be most efficiently applied in planimetric mapping for flat terrain or for a regularly-shaped object.

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