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Analytical Generation of Orthophotos from Panoramic Photographs

Employing a digitized panoramic photograph and a DTM, pixels are mapped from the photograph plane to the orthophoto plane.

ABSTRACT: *A procedure for computer assisted generation of orthophotos was developed. An array of map-pixels is defined over the area to be mapped. Restituting the panoramic photography process, the position of each map-pixel is located on the panoramic photograph and in the matrix of the grey-tone values associated with it. An appropriate grey-tone is derived from the matrix and assigned to the respective map-pixel. "Painting" the map with grey tones, pixel by pixel, produces the required orthophoto map. The principal problems related to the above process are discussed and an example illustrating the procedure is presented. The process was primarily designed for panoramic photographs, but it is applicable to frame photographs as well.*

INTRODUCTION

ORTHOPHOTO MAPS are usually produced from frame photographs taken by metric cameras, the production being effected in instruments exclusively designed for that purpose. Parallel with conventional photography, there is a demand for panoramic photography, which excells in resolution and contains a vast amount of detail. Due to its dynamic and geometric features, the panoramic photograph cannot be accommodated by the common orthophoto equipment, i.e., the distortions inherent in the panoramic photograph cannot be compensated by the existing instrumentation. Considering the high image quality of the panoramic photograph, it is more than desirable to attempt using the photographs for orthophoto mapping. Two alternatives may be suggested for solving that problem: (1) Generation of orthophotos in a way similar to the existing procedures, which inevitably leads to problems of designing or modifying the instruments, or (2) generation of orthophotos analytically, replacing the special purpose equipment required in the first case by a suitable algorithm which is effected in such available multi-purpose equipment as a computer and a scanner. The analytical approach offers a high degree of flexibility, allowing the compilation of maps from parts of different photographs. It is applicable to various types of photography and provides a means to generate orthophotos off-line without resorting to any special type of equipment. In addition, the analytical approach is suitable for applying image enhancement techniques to improve the quality of the map. Taking into account these advantages, it seems logical to conclude that the alternative of analytical orthophoto generation is to be preferred.

OUTLINE OF THE PROCEDURE

The common orthophoto process is based on differential rectification, where the photograph is subdivided into a large number of small elements, each element being rectified, uniformly scaled, and projected photographically onto the map plane. It is a process which may be defined as "from the photograph to the map." Contrary to that concept, the proposed algorithm of the analytical orthophoto generation is based on a reversed process, i.e., "from the map to the photograph." The preselected area to be mapped is subdivided into a grid of small

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surface units, usually a grid of squares, each grid square constituting a map-pixel. The orthophoto is generated by attributing to each map-pixel an appropriate grey tone value derived from locating the surface unit on the respective photograph, and subsequently on the digital photograph (matrix of grey-tone values) associated with it and obtained from a microdensitometric scanning. The process outlined above gives rise to several problems:

- Generation of the digital photograph
- Orientation of a single panoramic photograph
- Derivation of elevations
- Restitution of the photography process
- Assigning grey-tone values to map-pixels.

A discussion of these problems is given below.

GENERATION OF THE DIGITAL PHOTOGRAPH

The optical photograph is transformed into digital form by a densitometric scanning. Two problems have to be considered here: selecting the size of the pixels for the scanning procedure and establishing correspondence between the optical and digital photographs.

The size of the pixels and the scanning should conform to the size of the predetermined map-pixels, which in turn depends on the scale of the map being prepared. In addition, the size of the pixels should also comply with the requirement of not affecting the quality of the original photograph. As the digital photograph is the source of the grey-tones assigned to the map-pixels, a relation between the coordinates of the images of the ground points and their locations in the matrix of the grey-tones has to be established. This is accomplished by formulating expressions which convert image coordinates to matrix locations. The formulae are derived from a number of points easily identifiable in the grey-tone matrix. These may be distinctly pronounced details of points marked artificially.

Image coordinates are continuous quantities whereas locations in the grey-tone matrix are discrete values. Hence, to maintain the required accuracy in the final product, the orthophoto map, one has to consider that fact when deciding upon the size of the pixel during the scanning of the photograph.

ORIENTATION OF A SINGLE PANORAMIC PHOTOGRAPH

As stated previously, the optical photograph serves as a medium to establish a relation between the map and the digital photo. The data required for that relation are solved from orienting the photograph utilizing a number of control points. Solving the orientation is based on a dynamic model. Each orientation element is composed of two components, a constant component and a time-related component (linear and angular velocities). It is preferable to solve the orientation of the entire photograph even when parts of it are used, and that despite the fact that any part of the panoramic photograph can be regarded as an individual photograph.

DERIVATION OF ELEVATIONS

Basing the orthophoto generation on the processing of single photographs requires an external source of topographic data. A DTM proved to be advantageous. In the tests reported below, a DTM derived from digitizing contours from existing medium scale maps (1:10 000 and 1:20 000, 5 and 10 metre contour intervals) has been used. Because the accuracy requirements imposed upon the elevations used for orthophoto purposes are "moderate," the topographic information provided by that DTM was rather satisfactory. There is also a possibility to generate a DTM from stereopairs of panoramic photographs for supporting the orthophoto process. Although that possibility is being explored, no final results are available yet.

RESTITUTION OF THE PHOTOGRAPHIC PROCESS

The aim of this stage is to locate points with known ground coordinates X,Y,Z on the photograph and to determine the corresponding x,y coordinates in the image system. The solution of that problem is not as straightforward as it may appear.

Assuming a dynamic model for describing the photographic process, we ascribe to various regions of the photograph different orientation elements. The orientation elements, being time related, can be determined for any particular location on the photograph only when the time element defining that location is known. The time element is represented on the photograph by the y-coordinate, the coordinate along the direction of the panoramic scan, counted from an arbitrarily chosen initial point. It follows that, for transforming the ground values X,Y,Z into image coordinates, it is necessary to use orientation data which are functions of the y-coordinate, that being an unknown quantity which the transformation has to provide. To overcome that difficulty, an iterative solution is devised. After each iteration step, the resulting value of the y-coordinate is utilized for determining improved orientation data related to the processed point, thus permitting the derivation of new values for the x,y image coordinates of that point.

During orthophoto generation the values of the ground coordinates defining the corners of the map-pixels are very close to each other; therefore, each transformed point provides a good initial value of the y-coordinate to start the iterative solution for defining the image coordinates of the neighboring point. In fact, two iterations are sufficient to finally locate a point on the photograph. Only in rare cases, e.g., at the edges of the panoramic photograph, may a third iteration step be required.

ASSIGNING GREY TONES TO MAP-PIXELS

This stage completes the orthophoto generation. A schematic presentation of the procedure is depicted in Figure 1. The surface element obtained from defining a grid over the area being mapped is located on the panoramic photograph. This is accomplished by transforming the X,Y,Z coordinates of its four corners to the image system. The plane coordinates X,Y are preselected quantities, while the elevations, Z, are being derived from the DTM. The resulting image coordinates are transformed subsequently to the system of the digital photograph. As a result, a quadrilateral representing the surface element is defined within the matrix of the grey tones. Generally, that quadrilateral may relate to several pixels, either containing the pixels in their entirety or parts of them. A procedure is now invoked to derive a grey tone value for the quadrilateral considering the respective pixels. Because the quadriiateral is the image of the surface element on the digital photograph, the grey tone so derived is attributed to the surface element and consequently to the map-pixel. A correction is applied to the value of the grey tone to account for the fact that a surface element does not lie in a horizontal plane, whereas a map-pixel does. In those rare cases when the surface element lies in a horizontal plane, the corrections assume zero values.

Proceeding in the above described manner, the map is gradually "painted" with grey tones, pixel by pixel, until the entire orthophoto is generated. At the end of that process the orthophoto is still in a digital form, recorded on a suitable device. A film may be produced from the digital data by means of commercially available equipment.

Testing the Procedure

The photographs used were taken with a panoramic camera with a focal length of 610 mm from a high altitude, so that the scale of the photograph varied from 1:20 000 in the center to 1:40 000 at the edges.

Because of the type of scanner and the elongated shape of the photograph, it was necessary, for processing reasons, to sub-divide the photograph into 11.5 by 11.5 cm segments; however, the orientation of the photograph was solved prior to the subdivision and referred to the photograph as a whole. The aim of the test was to produce an orthophotomap at a scale 1:10 000 for comparing it with existing line maps at the same scale. In accordance with that, the map-pixels have been selected to be of the dimensions of 1 by 1 metre at true scale, and the densitometric scanning has been performed with a beam of 50 micrometres in diameter with scanning steps of the same magnitude. As a result of the scanning, each photograph segment has been transformed into a matrix which consisted of 3000 by 3000 pixels approximately, with grey tone values varying within the range 0 to 255. To facilitate the processing, the orthophoto has been formed in sections-squares with dimensions 0.5 by 0.5 km each. Compiling the map gradually, square by square, is not only effective from the point of view of the processing, but is also in full agreement with the concept producing a map from parts of different photographs. As already stated, the topographic information for the orthophoto generation has been derived from digitizing medium scale maps (contour interval 5 to 10 m). The DTM was formed as a grid of squares with 20-metre intervals between the grid lines.

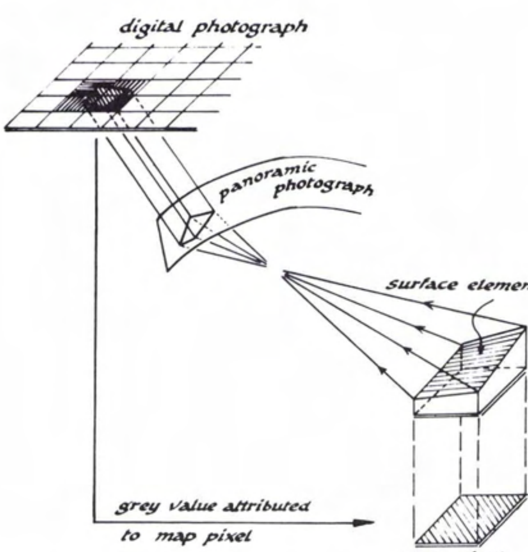

Fig. 1. Outline of the orthophoto generation

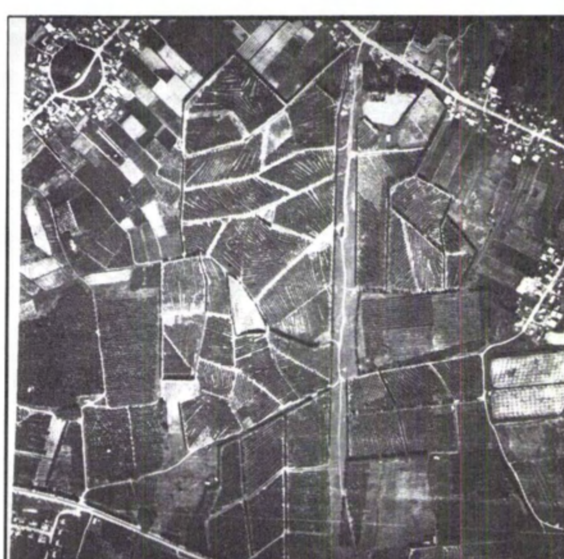

Fig. 2. Sample of an analytically generated orthophoto.

A sample of the generated orthophoto is shown in Figure 2. It represents a total area of 1.5 by 1.5 km.

To check the quality of the product, the orthophoto has been compared with a line map. Control points, road intersections, and buildings, the coordinates of which have been derived from the orthophoto on the one hand and determined from the line map on the other, have been used for estimating the accuracy of the process. The resulting figure obtained from 30 such points (related to the sample on Figure 1) was a standard deviation of 3.5 metres in the ground system. Taking into account that the accuracy of positioning a point on a line map at a scale of 1:10 000 is of the same order of magnitude, it may be concluded that the planimetric accuracy yielded by the above process is satisfactory.

References

Peled, A., 1981. *Analytical Orthophoto Generation from Panoramic Photographs*, D.Sc. Thesis, Technion, Haifa (Hebrew).

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