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Digital Mapping Using Entities: A New Concept

Entity-to-entity correspondence allows the use of the wealth of feature information in lieu of or to supplement conventional control in a digital mapping environment.

Abstract: *Generally, the identification of linear features such as roads, railways, etc., can be easier than that of individual points. This is particularly the case with high altitude and satellite imagery and photography. Moreover, well defined linear features can be comparable in precision to point features. However, individual points rather than the wealth of points of linear features have been, so far, used for control. A new concept to utilize such features in lieu of or to supplement conventional control, is presented. The concept is based on entity-to-entity correspondence; an entity being part or the whole of a feature. Points on an "observed" entity need not correspond to points on a "control" entity. The concept has potential in a digital environment. Digital rectification of a satellite imagery and testing the precision of digital maps are example applications. The concept was successfully implemented in analytical absolute orientation of a stereomodel and analytical resection of a photograph.*

Introduction

Aerial and satellite photography and imagery usually contain a number of features such as roads, railways, large buildings, etc. However, such a wealth of information has so far been ignored and individual control points have been solely utilized for relating image points to a ground system of coordinates. This has usually been the case even when identification of individual control points proves to be difficult. We consider as an example the case of a satellite image. The scale of the image is usually too small to clearly and accurately identify individual points. A user, however, attempts to locate points such as intersections of roads on a map and the corresponding points on the image to determine the transformation parameters between image points and map points. Some of the following problems can then be encountered:

- A number of features exist but the number of intersection points is not sufficient for the application.
- The features do not intersect within the bounds of the image dealt with.
- The intersections are not well-defined.
- The intersection points are poorly distributed, which may result in an ill-conditioned solution for the transformation parameters.

A poor solution may consequently be the result, despite the availability of the features themselves and the user's ability to relate the image to the map visually using those same features. (In addition, well-defined linear features were found to possess precision comparable to, or higher than, point features (Masry *et al.*, 1980).

The concept described here uses such features in establishing the relationship between an image and a ground coordinate system in lieu of or to supplement individual control points. The relationship is established mathematically and applied digitally. It may be interesting to note that this mathematical-digital approach is analogous to the analog one in which the photograph is fitted to the map using a Sketchmaster, except, of course, it

Photogrammetric Engineering and Remote Sensing,
Vol. 48, No. 11, November 1981, pp. 1561-1565.
0099-1112/81/4711-1561$02.25/0

can be more precise and utilizes all the information simultaneously.

The concept has several applications, some of which may not be immediately apparent. One of these is digital map revision. Another is the determination of the deviation between two sets of points defining the same features and where there is no one-to-one correspondence between the points of the two sets. An obvious potential of the concept is in its application to digital rectification of satellite imagery.

Research carried out demonstrated that the concept can be successfully used in analytical absolute orientation, analytical resection, and testing of the precision of digital topographic maps. This paper outlines the concept in more detail and discusses briefly how it was implemented in the analytical absolute orientation of a stereomodel and the analytical resection of an aerial photograph.

The Concept

To introduce the concept, some terms must first be defined. An entity is defined here as a set of points describing the whole or part of a feature which can be recognized or interpreted on an image. An entity may be, for example, the edge or the center line of a road, an edge of a building, one rail of a railway track, etc. Entities on the surface of the terrain, as illustrated by Figures 1a and 1b, should obviously be defined in three dimensions and are referred to here as spatial entities.

The image of such entities in the plane of the image, as illustrated in Figure 1c, can be conveniently termed planar entities. Entities can be further classified into sinuous and straight-line entities. (The term sinuous entities, rather than nonlinear entities is used since the term linear entities is sometimes used by cartographers to refer to continuous features and distinguish them from point features.) Sinuous entities obviously require more than two points for their definition. The density of the points depends on the degree of sinuousity and the precision requirements. Defined entities can be obtained from a topographic data base or digitized from a map and are referred to here as control entities. control entities will be used in our case in lieu of conventional control points. Spatial entities can be used, for example, in absolute orientation of a stereomodel and planar entities can be used in digital rectification of an image. At this stage, two points should be emphasized:

- As in the case of conventional individual control, observations are carried out. The observations are adjusted and transformed to the control entities. The difference here is that points on an observed entity need not be of the same density as those of the corresponding control. Moreover, none of the observed points need correspond to the points of the control entity, i.e., point-to-point correspondence is not a requirement.

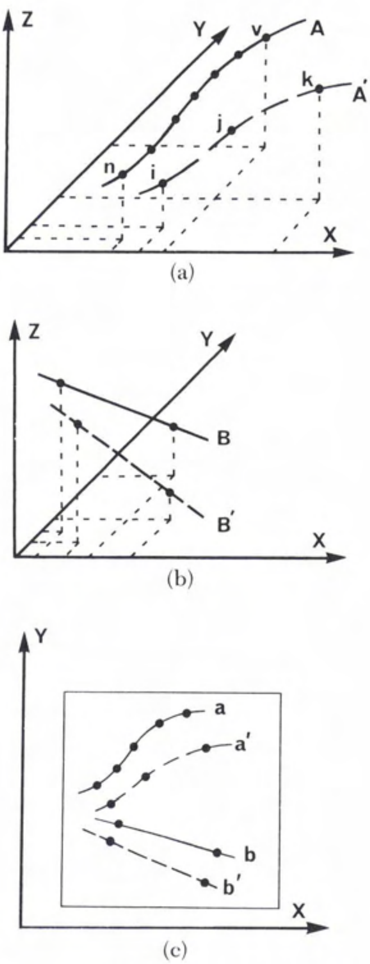

Fig. 1. Illustration of spatial and planar entities. (a) and (b) illustrate two types of spatial entities; entity A in (a) is a sinuous entity described by more than two points; while B of (b) is a straight-line entity described by two points. (c) shows two entities which are similar to A and B of (a) and (b) but are planar.

- The observed points should be within the range of points defining the control entity. The condition is more important in the case of sinuous entities than in the case of straight-line ones. This is illustrated in Figure 1a. Suppose the segment of the control entity, A, to be used is that between points n and v. Observed points such as i, j, and k of the corresponding entity, A', should be within the range (n to v) on the control segment used.

In the following part, spatial entities are dealt with, noting that planar entities are a special case. Suppose (x,y,z) is an observed point on one of the observed entities and that a suitable transformation $T\ (x,y,z)$ has been selected for the application on hand. That is, such a transformation is the one most suitable, practically and theoretically, to transform a point from the observation domain to the control domain. The following equations can then be written:

$$X' = T_1\,(x,y,z) \quad (1a)$$
$$Y' = T_2\,(x,y,z) \quad (1b)$$
$$Z' = T_3\,(x,y,z) \quad (1c)$$

where X', Y', Z' are the transformed coordinates of the observed point (x,y,z) assuming that the transformation allows each of X', Y', and Z' to be expressed as a function of the coordinates (x,y,z).

Suppose also that it is possible to describe a control entity mathematically by a parametric function, viz:

$$X = F_1\,(s) \quad (2a)$$
$$Y = F_2\,(s) \quad (2b)$$
$$Z = F_3\,(s) \quad (2c)$$

The values of the transformation parameters must be such that an observed point, after its transformation, satisfies Equations 2a, 2b, and 2c. Accordingly, from Equations 1 and 2, we have:

$$T_1\,(x,y,z) = F_1\,(S) \quad (3a)$$
$$T_2\,(x,y,z) = F_2\,(S) \quad (3b)$$
$$T_3\,(x,y,z) = F_3\,(S) \quad (3c)$$

The transformation parameters which are sought can be found from Equations 3.

The concept may now be expressed as follows: All observed points are transformed so that, after their transformation, they satisfy the control functions. This allows, therefore, the correspondence to be changed from the conventional point-to-point correspondence to entity-to-entity correspondence.

A more general definition of the concept, but perhaps more complex to implement practically, is as follows: The mathematical functions defining the observed entities are transformed to become identical to the corresponding ones which define the control entities.

Example Applications

The concept has been successfully applied to carry out absolute orientation of a stereomodel, perform analytical space resection of an aerial photograph, and test the precision of digitized planimetric features. A brief description of the first two of these applications and some of the points which may further clarify the concept are given here. Further detail will be presented in future publications.

Analytical Absolute Orientation

In absolute orientation, spatial entities such as those of Figures 1a and 1b are utilized. An entity such as A is known with respect to the ground coordinates system and the corresponding entity A' is observed in a stereomodel. The transformation T of Equations 1 is usually taken to be a three-dimensional similarity transformation. The mathematical description of the control entities is as follows: The planimetric coordinates (X,Y) were dealt with separately from the height (Z) coordinate. Cubic spline functions were computed to fit the planimetric coordinates between each two successive points of a nonlinear control entity. The spline equation is of the form

$$Y = C_1X^3 + C_2X^2 + C_3X + C_4 \quad (4)$$

where C_1, C_2, C_3, and C_4 are constants and are functions of the coefficients of the spline functions. These coefficients generally vary from one section to another where each section is described by two points of an entity. The X,Y coordinates give the coordinates of any point along that section of an entity. The X and Y coordinates of a straight-line entity were related by an equation of a straight line, viz:

$$Y = K_1X + K_2 \quad (5)$$

The solution was simplified by grouping the unknowns of the transformation into two groups:

- (i) • Parameters which mainly pertain to the planimetric components and consist of a scale λ, an azimuth rotation κ, and two planimetric shifts X_0,Y_0; and
- (ii) • Another group which describes the vertical components and consists of two tilts ϕ and Ω and one vertical shift Z_0.

Applying such simplifications, Equations 1 can be written as

$$X' = T_1\,(\lambda,\kappa,X_0,x,y) \quad (6a)$$
$$Y' = T_2\,(\lambda,\kappa,Y_0,x,y) \quad (6b)$$
$$Z' = T_3\,(\phi,\Omega,Z_0,z) \quad (6c)$$

It should be noted here that the parameters ϕ and Ω of Equation 6c appear in Equations 6a and 6b but are dealt with as constants when solving for the first group of parameters. Similarly, the parameters of the first group appear in Equation 6c, but are dealth with as constants when solving for the second group of parameters.

Equations 6a and 6b are substituted into Equation 4 to obtain

$$T_2(\bar{X}) = C_1[T_1(\bar{X})]^3 + C_2[T_1(\bar{X})]^2 + C_3[T_1(\bar{X})] + C_4 \quad (7)$$

where $T_2(\bar{X})$ and $T_1(\bar{X})$ denote the transformations of the right-hand side of Equations 6a and 6b for convenience.

Equation 7 was used to solve for the first group of parameters. Further simplification was carried out by using Equation 6c to solve the second group. The Z' coordinate was obtained from the ground height of the nearest two points by interpolation. Thus, the solution was carried out sequentially and iteratively: Solving for one group of parameters, keeping the second set constant, and using for their values those obtained from the last solution, and vice versa. This was repeated until the changes in the values of the unknowns were insignificant.

Application of the concept to absolute orientation and the procedure described above was practically tested. A stereomodel with 12 conventional control points was used in the test. The scale of photography used was 1:5000. The stereomodel contained a number of well-defined man-made features suitable for use as control entities. The model was relatively oriented on an analytical stereoplotter. A total of 32 points was observed on nine entities. Conventional analytical absolute orientation of the model was then performed on the plotter. The selected entities were then digitized in stream mode and the coordinates obtained were taken to describe the control entities. It should be noted that there was no one-to-one correspondence between the points describing the control entities and the 32 points observed after relative orientation. Analytical absolute orientation was once more performed using only the observed points and the control entities, employing a computer program developed for this purpose. The orientation parameters obtained using entities were then compared to those obtained from the plotter using conventional control points. A brief summary of the results is as follows:

- Number of iterations required: three.
- Corrections to parameters after three iterations were: to scale, 0.004; to three shifts, 0.000 m (average); and to rotations, 0.005 secs. (average).
- Differences between values of parameters obtained using conventional control and those obtained using entities were: 0.44 in scale; 0.02 m (average) in shifts; and 10 secs. (average) in rotations.

These results show that using entities in lieu of conventional control can yield good convergence and practically no degradation in the values of the parameters.

Analytical Resection

Analytical resection of an aerial photograph using entities can be readily applied to digital map revision. Semiautomatic detection of changes in a topographic data base requires knowledge of the exterior orientation parameters of a photograph. The method is described in more detail in Masry (1979). This concept has the potential of being used in the change detection stage, and subsequently in the digitization of the updates.

The procedure followed to achieve a solution using entities involved the use of spatial entities as well as their planar images. This is illustrated in Figure 2. In the Figure, the planar entity, a, is

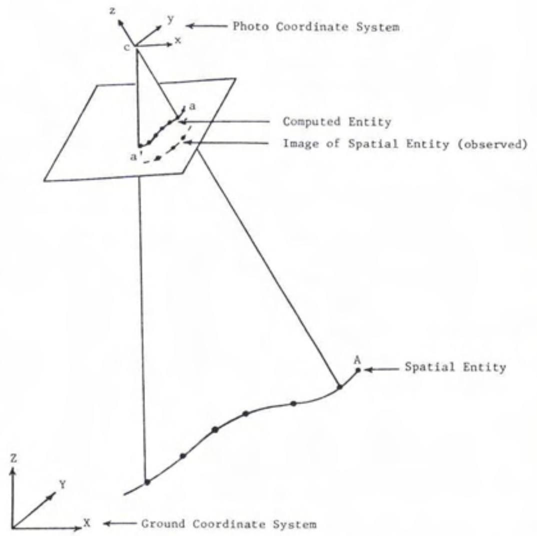

Fig. 2. Illustration of resection of a photograph using entities. The spatial entity A is described by a set of points whose coordinates are known with respect to a ground system of coordinates. The image of A is the planar entity a'. Approximate exterior orientation parameters are used to compute the planar entity a. Entity-to-entity correspondence is utilized to compute projective transformation parameters and corrections to the exterior orientation parameters.

computed using the collinearity equations, approximate values of the exterior orientatin parameters, and the coordinates of the spatial entity, A. The observations consist of photo coordinates of a number of points on the image of the same entity (a' in the Figure). More than one entity is used. Also, the number of observed points on an entity should be, for practical considerations, much less than the number of points defining the spatial entity.

The projective transformation was selected for Equation 1 and applied to the observed points so that they satisfy the functions describing the computed entities. These transformations in full are

$$x' = \frac{k_1x + k_2y + k_3}{k_4x + k_5y + 1} \quad (8a)$$

$$y' = \frac{k_6x + k_7y + k_8}{k_4x + k_5y + 1} \quad (8b)$$

where x, y are the coordinates of an observed point on the photograph, and k_1 to k_8 are the parameters of the transformation. A computed entity, a, was described by cubic spline functions as given in Equation 4. The computed transformations parameters of Equations 8 were then used to compute shifts $\Delta X'$, $\Delta Y'$ of the computed entity a. Such shifts are functions of corrections to the six exterior orientation parameters of the photograph. The corrections are solved for and applied to the exterior orientation parameters, and the procedure is repeated until the corrections to the values of the parameters are insignificant.

Practical tests were carried out using both simulated and actual data. The results indicated that convergence and precision comparable to those obtained using conventional control can be obtained.

Summary and Recommendations

A concept based on entity-to-entity correspondence was presented. The concept allows full use of the wealth of information of features as control. The concept has been practically verified in three applications. The results obtained showed that the precision and convergence are comparable to those derived from conventional control.

The concept of using entities has potential in a number of applications such as digital rectification of satellite imagery, map revision, and resource mapping. Utilizing entities does not exclude the use of any available control points since these can be included in the solution.

A number of organizations are presently carrying out digital topographical mapping. Data bases containing features in digital form will consequently be available in the near future. Some of these digital features can be readily utilized as control entities. Perhaps, at the stage of establishing these data bases, some of the well-defined features can be digitized with their possible future use as control in mind.

Acknowledgments

Research to verify the concept was carried out at U.N.B. first by Mr. S. MacRitchie, at present with McElhanney Surveys. Further work was carried out by Mr. B. Lugnani and Mr. D. Vost. The work carried out by Mr. Lugnani shed the light on many of the problems involved in implementing the concept and paved the way for its use. Mr. Lugnani and Mr. Vost read the manuscript and made fruitful suggestions. The author benefited from discussions with Drs. R. Blais of the University of Calgary and W. Knight of the University of New Brunswick. Mr. V. Oliver's diligence in carrying out the observations used in the tests is gratefully acknowledged.

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(Received 14 November 1980; revised and accepted 17 May 1981)

Forthcoming Articles

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Ismat M. El Hassan, Analytical Techniques for Use with Reconnaissance Frame Photography.

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W. Frobin and *E. Hierholzer*, Calibration and Model Reconstruction in Analytical Close-Range Stereophotogrammetry. Part II: Special Evaluation Procedures for Rasterstereography and Moiré Topography.

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