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A PROCEDURE FOR MAP UPDATING USING DIGITAL MONO-PLOTTING AND DTMs

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ABSTRACT

The production and updating of maps of the terrain surface is a procedure that can be done easily by using aerial photographs. In general this procedure needs to use expensive equipment that are not at reach of most offices requiring such maps. The advances in the computer science and the availability of low cost equipment for the digitizing and digital processing of the aerial photographs, open a wide range of applications for the production of cartographic information of the terrain surface by digital means, being one of them the Digital Monoplotting. Digital monoplotting consists in the production of planimetric information of the terrain surface through the direct vectorization on a digital aerial photograph, by using an image display for the digitizing of all the significant features of the terrain, and afterwards performing a analytical transformation on those vectors in order to correct the deformations intrinsic to the aerial photographs.

In the case of non flat terrain, a rigorous transformation has to be performed to the digitized lines (vectors), by using the colinearity equations based on control points of known coordinates and the Digital Terrain Model (DTM) of the terrain. In such a way, deformations due to relief displacement and photograph tilt are corrected, obtaining a map free of deformations, at a known scale and referenced to a terrain coordinate system. In order to know the planimetric position of an image point on the terrain surface, it is necessary to determine the intersection point of the corresponding projective ray with the DTM of the terrain. In general this is an iterative and time-consuming procedure. In this paper an alternative direct solution to this problem is presented, and the requirements of the DTM density and accuracy applied to digital monoplotting are analyzed, with an application example.

1 INTRODUCTION

The updating of spatial data bases is a procedure that can be carried out by using aerial photographs. However, it required the use of sophisticated and expensive equipment, inaccessible to most of the institutions that manage this kind of information. The advances in the computer science and the decreasing cost of the equipment for the digitizing and digital processing of the photographs, open a wide field of application where diverse possibilities for the production of cartographic information surge through digital procedures. One of them is the rigorous digital mono-plotting (DMP), conceived originally in the ITC in 1973 [Radwan and Makarovic, 1980], which consist in producing planimetric information through the direct vectorization of the terrain features on one photographic image, and their rectification utilizing the colinearity equations and a Digital Terrain Model (DTM).

The DTM is generated from sampled points of known planimetric and height position on the terrainl surface and algorithms of interpolation. The planimetric and height position of the sampled points are derived from 3-D photogrammetric terrain models in analogue or digital format, registered in form of X, Y, Z coordinates, or in form of contours. The accuracy of the DTM depends basically of the density and distribution of the sampled points and of the DTM method of interpolation used.

In the rigorous DMP the DTM constitutes the source of basic information since it allows to establish, by means of the equations of colinearity, the correct terrain position of all the points vectorized on the photograph. The height accuracy of the DTM should be within the tolerances that guarantee the planimetric accuracy of the rectified details. In this process, each ray projected from the photography is intersected with the DTM by means of an iterative process,[Doytsher and Hall, 1995] with the purpose of determining the XYZ coordinates of the projected point.

In this article a simple and direct procedure is introduced in order to carry out the rigorous DMP, in which the process of iterative search for the determination of the terrain coordinates of all intersection points (projective ray – DTM) is avoided. Adicionally, is performed an analysis of the accuracy required by the DTM for the rectification of photographic images, generated from digitized contours on existing maps. Finally, is shown an example of DMP in the updating of a mountainous zone, using the proposed procedure and a DTM generated with the introduced criterions.

2 RIGOROUS DIGITAL RECTIFICACION AND DTMs

The digital rectification is a procedure based on the principles of the projective geometry, considering the metric photograph as a central projection of the terrain surface on the photograph negative plane. A central projection system is that in which all the projective rays that originates of the terrain surface, passes through a point or projection center, and are prolonged to intersect the negative plane. If it is required to know the position of a point on the terrain surface having an photographic image, it is necessary to reconstruct the corresponding projective ray, starting from the coordinates of the point image and the projection center; the ray length will be determined by means of the DTM. In the Figure 1, it can be observed that the image point coordinates of p are referenced to the fiducial system (photography system) where the origin is in the projection center O and the projection of their axes x,y passes by the fiducial marks. The vector **l**, defined from the projection center O to the point p in the photography, and the vector **L**, defined from the projection center O to the point P in the terrain, are colineals, this is, **l** is multiple of **L**, i.e.,:

$$\mathbf{l} = k * \mathbf{L} \qquad \text{[Ec. 1]}$$

The mathematical equations represent the projective rays are named colinearity equations, which are expressed as:

$$\begin{bmatrix} x \\ y \\ -c \end{bmatrix} = k^* A^T * \begin{bmatrix} X - X_o \\ Y - Y_o \\ Z - Z_o \end{bmatrix} \qquad \text{[Ec. 2]}$$

where

x, y, -c: image point coordinates referenced to the fiducial system.
c: principal distance of the camera.
X, Y, Z: point coordinates in the terrain system.
X_O, Y_O, Z_O: projection center coordinates O in the terrain system.
k: the scale factor between the vector **l** and the vector **L** for each point.
A(a_1, a_2,..., a_3): rotation matrix for angles ω, ϕ, and κ

Inverting the Ec. 1, are obtained the Ec. 3 and Ec. 4 that allow to compute the point coordinates in the terrain from their image coordinates on the photography.

$$\frac{X - X_o}{Z - Z_o} = \frac{a_1x + a_4y + a_7c}{a_3x + a_6y + a_9c} \qquad \text{[Ec. 3]}$$

$$\frac{Y - Y_o}{Z - Z_o} = \frac{a_2x + a_5y + a_8c}{a_3x + a_6y + a_9c} \qquad \text{[Ec. 4]}$$

For the determination of the coordinates X,Y of a terrain point, it is necessary to know its height Z which can be obtained from the corresponding DTM.

In the digital rigorous rectification, the digitized vectors, are referenced to the digitizer system, for which it is necessary firstly to transform them to the fiducial system by an affine transformation.

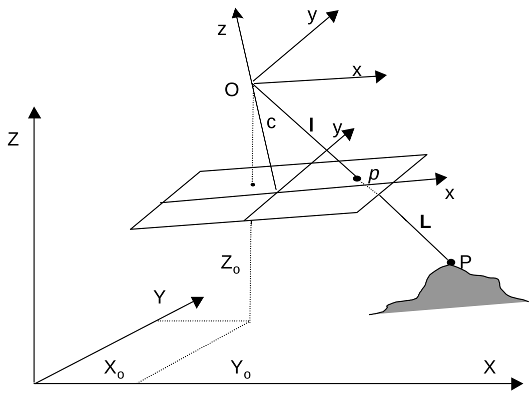

Figure 1. Reconstruction of the projective ray passing through the point image, projection center and terrain point.

3 DTM REQUIREMETS

Any DTM has associated an accuracy value which defines its application range. In the digital rectification, the differences between the DTM and the terrain surface should not introduce relief deformations appreciable on the planimetric representation. The errors in the DTM introduce relief deformation, that could be expressed as:

$$\Delta r = r \frac{\Delta Z}{Z} \qquad \text{Ec. 6}$$

where

Δr : relief displacement.
r : radial distance between image point and nadiral point.
Z : distance between the reference plane and the projection center.
ΔZ : height difference of the object respect to the reference plane.

As the error allowed in the planimetric representation is σ_{xy}= 0.2 mm* Mk, being Mk the scalar module of the map, the maximal relief displacement ΔR should be less or equal to this tolerance. In base to this, it could be established some precision criteria for DTMs, considering the photography scale, plane scale, and flying height.

Table 1 shows the DTM maximal acceptable error Z for map updating. obtained through the Ec. 6, for some photoscales, with a camera principal distance of 150 mm, and considering a radial distance (r) of 100 mm from the nadiral point .

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Table 1. Maximum acceptable ΔZ error for map updating, using r = 100 mm

Map Scale (Mk)	Tol (m)= 0.2mm*Mk	Photoscale (mb)	Δr =Tol / mb (mm)	Z = c . mb c = 150mm	ΔZ (m)
1:1.000	0.2	1:5.000	0.04	750	0.3
1:2.500	0.5	1:10.000	0.05	1.500	0.8
1:5.000	1.0	1:15.000	0.07	2.250	1.6
1:10.000	2.0	1:25.000	0.08	3.750	3.0
1:25.000	5.0	1:50.000	0.10	7500	7.5

4 DTM GENERATION

The DTM could be derived basically from four data sources: i)Contours, ii)Contours and characteristics lines (as breaklines, peaks, change of slope, points along rivers, etc.), iii)Points sampled from photogrammetric models as grid or representative points, and iv)Points sampled from photogrammetric models and specific characteristics data.

Relying on the data source, the exactness of the DTM may vary considerably. For example, according to Li Zhilin [Li, 1994], the DTM accuracy generated from contours is within 1/3 to 1/5 of the contour interval, depending on the terrain characteristics; when aditional data of specific characteristics, the error is reduced about 40 to 60 percent.

In order to generate the DTM, the data to be used is commonly available in contour maps. The most popular programs used to generate DTM use the raster data model. Some used methods in DTM generation are weighted average interpolation, *Kriging*, and Delaunay triangulation, being the last two the ones giving the best results.

In this paper, the selection of the cell size in order to generate the DTM is based on the Li Zhilin criteria [Li, 1994], which establish :

$$D = \lambda * Ic * \cot\alpha \quad \text{[Ec.7]}$$

where,

D: planimetric interval or cell size
Ic : contour interval
α : angle of maximal terrain tilt.
λ : constant with values between 1.5 and 2.0.

Using this criterion, the DTM accuracy is within 1/3 to 1/5 of the contour interval if the model is generated from contours directly measured on digital photogrammetric models, which coincide with the specifications used in North-América and Europe [Ricardus, 1973]. This accuracy could get worse if the contours are digitased from existing maps.

The table 2 shows the height errors, taking an σ_{DTM} equal to 1/3 of the contour interval (Ic/ 3), where the cell size of the DTM has been determined with the Ec. 7 for a constant value equal to 1.5 and values of α equal to 10° and 30°. If the values of ΔZ on table 1 are compared to the values of σ_{DTM} of the table 2, one could conclude that the accuracy of the DTM derived from contours fulfills the heights requirements.

5 PROPOSED RECTIFICATION METHOD

A form of carrying out the rigorous digital rectification is projecting the points of the photography on the DTM, by means of the Ec. 3 and Ec. 4, through an iterative procedure as follows:

1) Estimate an initial value of Za
2) Calculate the X, Y coordinates for Za
3) Determine the corresponding Z for the X,Y position on the DTM. This implies finding the corresponding cell and to interpolate the Z value.
4) Repeat while │Z of the DTM-Za│>Tolerance
 Za= Za ± Z
 Calculate the X, Y coordinates for Za
5) End

This procedure is laborious and can introduce uncertainties, depending on the terrain shape. Specifically when the projective ray intersect the terrain in more than one point, it could generate several solutions, remaining undefined the point position (Figure 2).

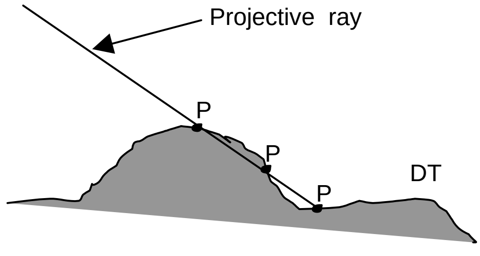

Figure 2: Critical Intersection of projective ray and DTM

Table 2. Height errors (σ_{MET}) in DTM for areas with maximal slope of α =10° and α =30°

Map Scale (mk)	Contour interval Ic (m)	Cell size D (m) α=10°	α=30°	Height error σ_{MET} (m)	Terrain relief displacement ΔR (m)
1:1.000	1	8.5	2.6	0.3	0.22
1:2.500	2	17.0	5.2	0.7	0.45
1:5.000	5	42.5	13.0	1.7	1.11
1:10.000	10	85.1	26.0	3.3	2.22
1:25.000	20	170.1	52.0	6.7	4.45

A second form of finding the terrain coordinates of points vectorized on the photograph, is projecting the DTM grid on the photograph. In this case, firstly the DTM cell where the point belong has to be identified; then through a bilineal interpolation, with the four values of the cell corners, a Z value is assigned, and finally this value of Z is introduced on the Ec. 3 and Ec. 4. In this process, the photo tilt causes additional deformations in the shape of the projected DTM grid, which could result in a more laborious process of searching the correct position in the reference DTM cell.

Another form of solving the problem is by means of the proposed method, which introduces the concept of a digital seudophotograph. A digital seudophotograph is a false photograph whose projection center coincide with that of the photography utilized for the rectification, it has a unitary principal distance (C= 1 m) and its image plane is parallel to the terrain XY plane. In this case the vectorized points and the DTM grid, are projected both onto the seudophotograph. The relationship between an i point of the seudophotograph and their corresponding on the terrain is only of scale, which depend on the height (Zi) derived from the DTM, knowing that the scale Ki = (Zo-Zi)/ C.

In order to elaborate the seudophotograph, the orientation parameters of the digitized photograph are determined utilizing the colinearity equations and with these parameters all the vectorized points of the digital photograph are projected on the seudophotograph. The points of the DTM grid, are also projected on the seudophotograph by means of a unitary rotation matrix, defining a new grid, where each point has associate a Ki scale value (Figure 3).

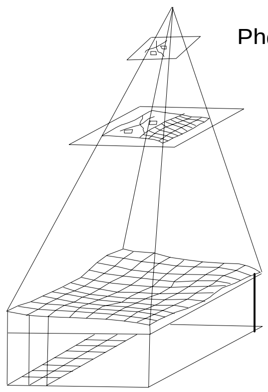

Figure 3. Projection relationships.

In this way, each vectorized point projected from the photograph onto the seudophfotograph is located in the projected grid, and its scale factor is determined by means of a bilinear interpolation, from the values of scale of the cell corners. Once determined the scale factor for each vectorized point projected on the seudophotograph, their coordinates in the terrain system are determined as:

$$X_{terrain} = X_{seudophotograph} * K_i$$

$$Y_{terrain} = Y_{seudophotograph} * K_i$$

$$Z_{terrain} = K_i \qquad \text{[Ec. 7]}$$

The advantages of this method compared to the previous one, are:

a) As straight lines on the photography could be curved on the DTM, it is necessary to densify them by adding intermediate points to the line. In the second method, the projection of these aditional points on the DTM requires to apply the Ec 3 and Ec. 4 to a great quantity of points. In the proposed method, the densification is carried out on the seudophotograph, and their projection is done applying the Ec. 7, which reduces considerably the process of calculation.

b) On the seudophotograph, the deformations of the projected DTM only depend of the relief; while in the second method, the inclination of the photography introduces additional deformations to that grid, making more laborious the identification of the projected.

c) The seudophotograph can be used for the genetration of 3-D views of the vectorized lines.

6 APLICATION

To show the aplication of this method, a montainous area in the state Merida was selected.

The photography of the zone was to a scale of 1:10.000, taken with a camera of normal angle of principal distance 150,48 mm and format 23 cm x 23 cm. The area relief is mountainous, where heights oscillate between

1490 m and 1930 m. above sea level, this generates large relief displacement.

The DTM was generated from a topographical map of the zone at scale 1:10000 with contour interval of 10 m (Figure 4).

Using the Ec. 6 with the values of α= 45°, and contour interval Ic = 10 m, and assuming K= 1.5, the grid size (D) obtained is equal to 15 m; this guarantee a height accuracy of 3 m , which according to the Ec.5, would produce a relief displacement (ΔR) equal of less than 2.0 m (0.2 mm x 10.000 = 2 m).

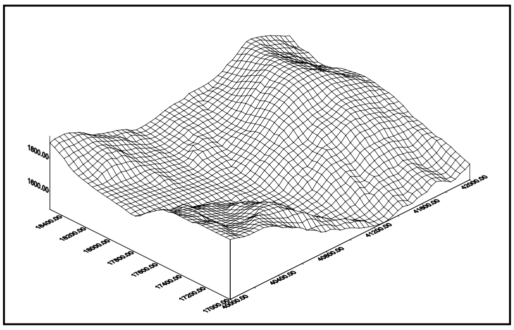

Figure 4. Perspective DTM view of example area.

The DTM of the area was generated using the *Kriging* interpolation method, its evaluation was realized comparing the height difference between the sampled points and points interpolated from the derived DTM grid. The results are shown in table 3.

Table 3: DTM evaluation

Number of sampled points: 48561

No.Points $\sigma_z \geq$ Ic/3	% $\sigma_z \geq$ Ic / 3	No.points $\sigma_z \geq$ Ic/2	% $\sigma_z \geq$ Ic / 2
675	1.39	73	0.15

RMS = 1.051 m

The aerial photograph was scanned with an optical resolution of 600 dpi. Its image is shown in figure 5. The digital image was displayed on a monitor, and the most important planimetric features to be updated were digitized, using a commercial software.

Figure 5. Aerial photograph of selected area.

Figure 6 shows the vectorized features on the digital image of figure 5. The lines are referenced in the scanner coordinate system.

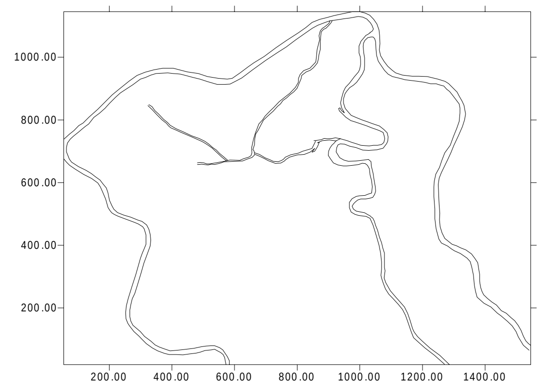

Figure 6. Vectorized lines.

By using computer programs, the vectorized lines were first transformed from scanner coordinates to fiducial coordinates, then using 8 control points and the parameter Ec. 3 and Ec. 4, were determined. From this parameters, the seudophotograph was constructed using a principal distance C= 1 m, and finally, the terrain coordinates of the points were computed using Ec. 7. The result of the rectification performed in this way, is shown in figure 7.

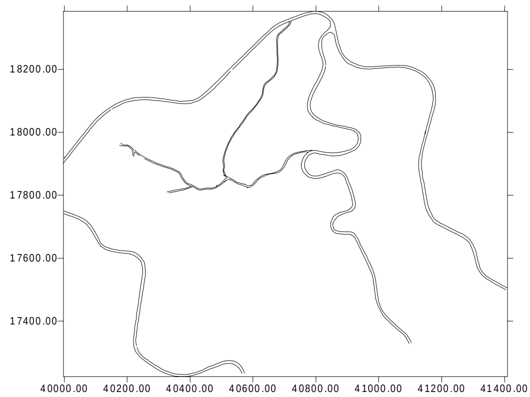

Figure 7. Results of digital rectification.

7 CONCLUSIONS

The proposed method represent a valid alternative for the updating of maps and spatial data bases on any kind of terrain surface. It has a potential use for map updating at small scale from satellite images. The method is fast and easy to use. It does not require of expensive equipment.

In this method, the direct solution to the determination of the intersection point between the projective ray and the DTM is more efficient than in the iterative one. Also it has the advantage that undefined intersection points due to terrain shape are avoided.

This method can be combined with the display on the monitor of anaglyph images, this allows for stereoscopic vision, making the digitalization process a lot easier. In

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this case the lines have to be vectorized on one photograph, what can be done if the color used for the feature vectorization is red or blue.

8 REFERENCES

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