

DIGITAL STEREO-ORTHOPHOTOS OF ARCHAEOLOGICAL SITES FROM SMALL FORMAT AERIAL PHOTOGRAPHS

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ABSTRACT:

The digital orthophoto is a valuable tool for representing an object on orthogonal projection at a known scale, due to the relation between its relatively low production cost and the photographic detail representation in its true position. When this orthophoto is accompanied by its mate image, named stereomate, its advantages raises significantly, because the observation can be performed in 3D.

Along the production process of the digital orthophoto the mate image can be produced with a minimum of additional processing. From the DEM, the parallaxes for each image point, and the pixel position for each point of the mate image are computed in a reference coordinate system. Finally a resampling is performed on the mate image in order to complete the image from a visual point of view. That is why we thought to use the stereo-orthophoto to facilitate the study of an archaeological site by archaeologists because the same allows, not only the observation, but also the annotation of thematic observations resulting from field surveys. (directly in orthogonal position when done on the orthophoto)

The practical example on this paper has been done in the old mission town of San Antonio de Mucuña, which was founded in 1620 and abandoned in the early ninety century. The only way to obtain the images over the town, was using small format aerial photographs (SFAP), taken from a small airplane. The SFAP is a reliable tool to interpret archaeological sites

1. INTRODUCTION

In aerial photogrammetry commonly it has been used the 230 x 230 mm. photograph, as standard format for the taking of aerial photographs. In a parallel way, the film formats of 35 mm and 70 mm, known as Small format Aerial Photography (SFAP) also have been used. Nevertheless, these small formats have not been widely accepted for photogrammetric surveys due to the non metric characteristics of those cameras. Its main application has been in the field of photointerpretation.

At present, the digital methods have permitted the determination of the external and internal orientation parameters of the camera in a simple form, expanding the potential of use of the SFAP in photogrammetric surveys in zones of small extension, when comply the following conditions: i) The area is it sufficiently small so that photogrammetric survey using standard format, are not competitive economically. ii) The area is sufficiently large so that a topographical survey is not competitive economically.

This paper shows a procedure used for the generation of digital stereo-orthophoto from SFAP in an archaeological site of difficult access, where is not possible to take standard format photographs to an appropriately scale. This work is part of a cartographic documentation project of this site.

The digital stereo-orthophoto consists of an orthophoto and an associate image or stereomate containing the corresponding parallaxes in order to achieve the stereoscopic vision. The orthophoto and stereomate are produced in digital form. The digital orthophoto is generated from the geometric information of the Digital Terrain Elevation Model (DTEM) of the area, and of the radiometric information of the original image, applying the colinearity equations and resampling procedures to the radiometric values of the original image. The digital stereomate is generated adding the parallaxes to the points image in the digital orthophoto. These parallaxes are calculated from the heights resulting from intersection of the DTEM with the plane of reference, assuming an appropriate relation between photographic base and point height (B/H). The stereo-images are useful in the representation of the planimetric information of the area, and in the photointerpretation of the zone.

2. PROCEDURE

The procedure scheme used for the generation of the stereo-orthophoto is shown in the figure 1. Each stage of the procedure is explained briefly in the next sections.

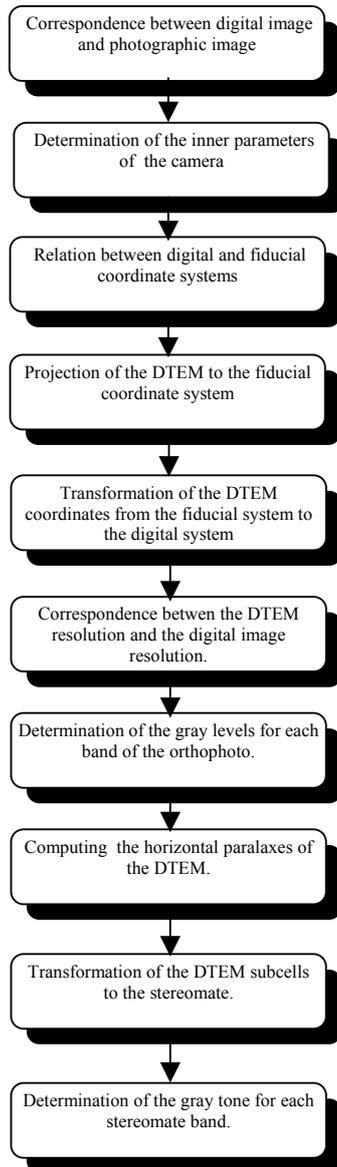


Figure 1. Procedure scheme

2.1 Correspondence between the digital image and photographic image

The relationship between the digital image coordinates and the analogical image is determined from the calibration results of the scanner used. Digital image coordinates are referenced to coordinates system of the scanner, corresponding with its columns and rows. The analogical image coordinates are referenced to an orthogonal axes system (x,y). The relationship between the digital image and photographic image is established through an affine transformation, thus obtaining the coordinates of the control points in the system of photography.

2.2 Determination of the internal parameters of photographic camera

From the terrain coordinates of the control points and its coordinates in the photographic image, the internal parameters of camera using the procedure of Linear Direct Transformation (DLT) (Gamal, 2002) are determined. Having the parameters $f_x, f_y, x_0, y_0,$, the coordinates of the control points of the photographic image in the fiducial system are computed.

2.3 Transformation of the DTEM from the terrain system to the fiducial system

The DTEM nodes are projected to the analogical image system by means of the colinearity equations. This is performed in two phases: First, the parameters of transformation between the terrain system and the fiducial system are determined using the control points. Second, with these parameters the coordinates of the nodes DTEM are transformed to the fiducial system.

The representation of a ground point on the negative plane of the image is done by means of the projective line that starts from the point, passing through the projection centre O up to its intersection with this negative plane, as shown in the Figure 2.. The length of the line L is determined from the altimetric information provided by the DTEM. The projective line is represented by the colinearity equations (Eq 1).

$$\begin{bmatrix} x \\ y \\ -c \end{bmatrix} = k * A^T * \begin{bmatrix} X - X_0 \\ Y - Y_0 \\ Z - Z_0 \end{bmatrix} \quad (1)$$

where $x, y, -c$ = image point coordinates referenced in the fiducial system.

c = principal distance of the camera

X, Y, Z = point coordinates in the terrain system

X_0, Y_0, Z_0 = coordinates of projection centre O referenced in the terrain system

k = scale factor between the vector **I** and the vector **L** for each point

A = rotation matrix defined by the angles ω, ϕ and κ around the X, Y and Z, respectively

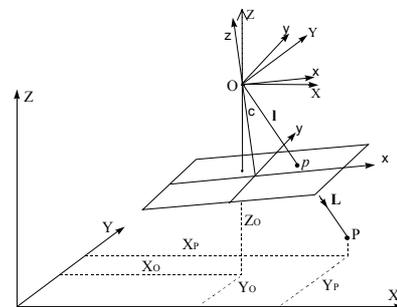


Figure 2. Reconstruction of projective ray

The Eq. 2 can be expressed as the Eq. 2 and 3, where a_{ij} are the matrix elements. The Eq. 3 and 4 are rigorous and not linear in terms of all six parameters unknowns $X_0, Y_0, Z_0, \omega, \varphi, \kappa$.

$$\frac{x}{-c} = \frac{a_{11}(X-X_0) + a_{21}(Y-Y_0) + a_{31}(Z-Z_0)}{a_{13}(X-X_0) + a_{23}(Y-Y_0) + a_{33}(Z-Z_0)} \quad (2)$$

$$\frac{y}{-c} = \frac{a_{12}(X-X_0) + a_{22}(Y-Y_0) + a_{32}(Z-Z_0)}{a_{13}(X-X_0) + a_{23}(Y-Y_0) + a_{33}(Z-Z_0)} \quad (3)$$

2.4 Transformation of the DTEM from the fiducial system to the digital image system

The coordinates of the DETM nodes are transformed from the fiducial system to the digital image system through an affine transformation.

2.5 Correspondence between the DTEM resolution and the digital image

In the stage 2.4, the position of each DTEM cell referenced to the fiducial system, is determined in the digital image system. As the size of the DTEM cells are greater than the pixels of the digital image, the cells must be divided in subcells whose heights are unknown. The geometric correspondence between each subcell of the DTEM and the digital image can be determined in two ways: i) using the colinearity equations or, ii) using a projective transformation. In the first one, it is needed to know the coordinate Z of each subcell, which is given only for the cell nodes of the DTEM. This means that it would be necessary to generate a new DTEM to the resolution of the digital image. This involves a great volume of calculation and information to store. In the second way, it is not needed the coordinate Z of the subcell, since each subcell is projected directly on the digital image, considering each DTEM cell as a plane surface (Figure 3) (Jauregui, 2000).

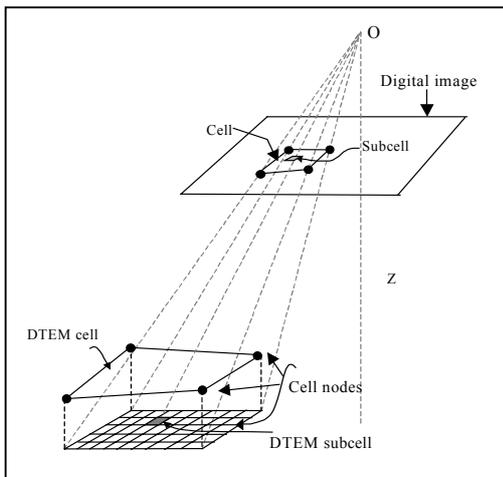


Figure 3. Projection and densification of the DTEM

The projective transformation of each DTEM subcell on the digital image can be expressed in the Eq. 4.

$$\begin{aligned} x_i &= a_0 + a_1 X_i + a_2 Y_i + a_3 X_i Y_i \\ y_i &= b_0 + b_1 X_i + b_2 Y_i + b_3 X_i Y_i \end{aligned} \quad (4)$$

where x_i, y_i = DTEM nodes coordinate referenced to the digital image system
 X_i, Y_i = DTEM nodes coordinate referenced to the terrain system
 $a_0, a_1, a_2, a_3, b_0, b_1, b_2, b_3$ = parameters of the projective transformation.

The parameters of the projective transformation are determined from the coordinates of all four nodes of each DETM cell. Then, the coordinates X_i, Y_i of each subcell node are transformed to the digital image.

2.6 Determination of the grey levels of the color orthophoto bands

The color image is separated into the red, green and blue bands. For each band, the grey tone is assigned to each subcell of the DTEM that has been projected on the digital image in the step 2.5. In general, the DTEM subcells projected on the digital image do not coincide precisely with any pixel. Commonly, it exists a partial overlapping on several pixels. For this reason it is necessary to realize an interpolation of the grey tone, from the pixel values of the digital image covered by the subcell, to obtain the grey value of each subcell. The interpolation methods commonly used are closest neighbour, proportional areas, significant areas among others.

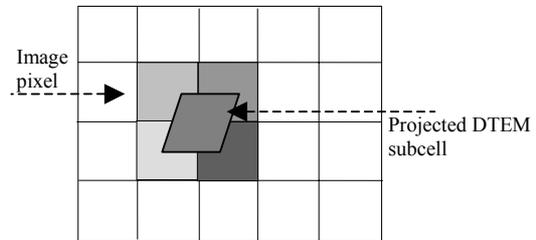


Figure 4. Projection of the DTEM subcell on the digital image

2.7 Determination of the horizontal parallaxes of the DTEM nodes

The horizontal parallaxes of each DTEM node are determined in the terrain system respect to the reference plane. The referenced plane is the one that contains the minimal Z value of DTEM. With these parallaxes and an appropriately photographic base the coordinates of each DTEM node are transformed to the stereomate system, involving only a scale factor along the direction of the X axis in the two systems. The horizontal parallaxes P_x for each DTEM node are determined by the Eq. 5:

$$P_{x_j} = \Delta H_j B / (Z_R - \Delta H_j) \quad (5)$$

where ΔH_j = height difference from each node (H_p) to the reference plane. The reference plane height (H_R) is taken as the lowest DTEM height. Then $\Delta H_j = H_{p_j} - H_R$
 Z_R = relative height flight, determined as the difference between height centre projection Z_0 y H_R .
 B = photographic base of the stereoimagen ($B=Z_R/5$ guarantee an adequate stereoscopic vision)

The coordinates X of each DTEM node in the stereomate system is determined by the Eq. 6:

$$X'_j = X_j + Px_j \quad (6)$$

where X'_j : coordinate in the X' axis of the node j in the stereomate system
 X_j : coordinate in the X axis if the node j in the terrain system
 Px_j : horizontal parallax of the node j

2.8 Transformation of the DTEM subcells to the estereomate.

The position of the DTEM nodes in the terrain system and in the stereomate system allows to determine the parameters of projective transformation between both systems. From them, the position of each DTEM subcell is determined in the stereomate, generating an array with the same number of subcells but of different sizes and forms (Figure 5). Obviously, each deformed subcell has associated the grey tone corresponding pixel in the orthophoto.

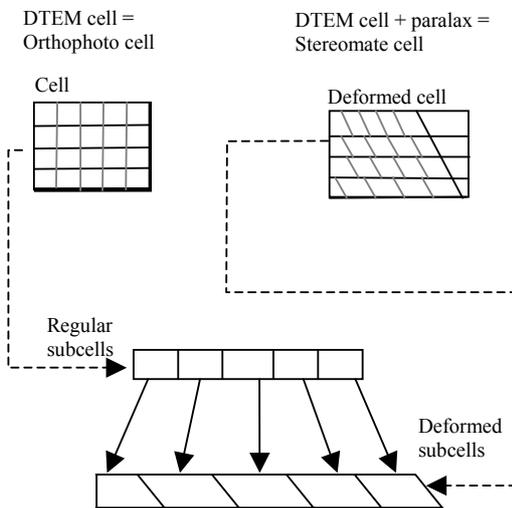


Figure 5. Correspondence between DTEM and stereomate.

2.9 Determination of the grey levels of the stereomate color bands

The stereomate imagen is created from the digital orthophoto radiometric values. There is a geometric variation between the orthophoto and the stereomate number of pixels, due to a

deformation of the stereomate subcell width.. Therefore, to generate the stereomate image, it is necessary to have an array of pixels to the same resolution as those of the ortofoto. It happens then, that in a row of the stereomate the number of pixels is different than in its corresponding row in the ortofoto, see figure 6. Then, a correspondence is established between the stereomate cells and the stereomate image pixels, in order to assign the respective tone.

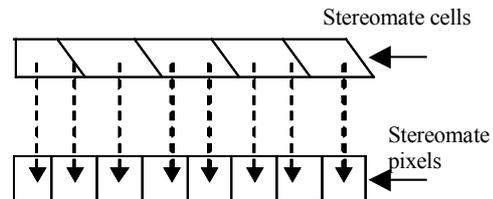


Figure. 6. Linear interpolation of the stereomate pixels

2. APPLICATION

The procedure was used on the ancient town of San Antonio of Mucuño, located in the State Merida, Venezuela, of mountainous relief. The SFAP are selected by two reasons: i) a budget reduced to realize the survey of the zone, disabling the photogrammetric survey in standard format, and ii) a topographic survey of the area, made six years behind, allowed to compare it with the survey obtained through aerial photography using SFAP.

From the beginning, it was considered to take the photographs, having the control points previously marked on the area. Nineteen ground control points were measured, which were used as control points for the restitution of the aerial photographs. These points were signalled on the ground with two white concentric circles before the flight. The result is that the points appear as white circles clearly defined in the photography.

It was used an Hasselblad 553 camera (format 70 mm) with an lens of $f = 40$ mm, mounted in a special support coupled to the baggage porthole of a Cessna 182 plane. Over the area were realized three flight passes, with heights between 8000 and 10000 feet above the sea level.

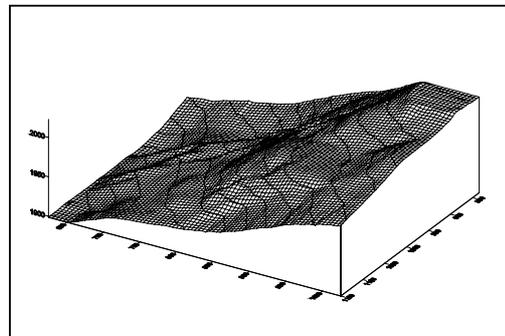


Figure 7. DTEM perspective view of application area

The photographic scale is 1:30000. The area is the average heights ranging between 1200 m and 2000 m above sea level, generating large relief displacements. The DETM was generated from the photogrammetric restitution, with contour intervals of 2 m (Figure 7). The size grid was 2 m. The aerial photography was scanned with an optical resolution of 1200 dpi.

The results of the affine transformation, performed to determine the parameters of correspondence between the digital image (rows and columns) and the photographic image (system of photography in millimeters) are shown in the Table 1. The internal camera parameters obtained through DLT are shown in the Table 2.

Table 1. Affine transformation from digital image to photographic image

Control points	Digital image system (pixels)		Analogic image system (mm)	
	x	y	x	y
1	0	0	-47.280	47.020
2	4460	0	94.550	0.0
3	4460	4436	94.550	94.040
4	0	4436	0.0	94.040

$a_0 = 1486.78895787$, $a_1 = 34.06663634$, $a_3 = -7.90508804$,
 $b_0 = -1478.63191356$, $b_1 = 13.03227868$, $b_2 = 55.03313438$

Table 2. Internal camera parameters obtained by DLT

f_x (mm)	f_y (mm)	Skew	X_0 (mm)	Y_0 (mm)
39,66	40,65	0.91062	0.05283	0.27962

The orientation parameters determined using the coordinates of all seven control points in both fiducial system and terrain system and the Eq 3 and 4, are shown in the Table 3. From these parameters, the DETM nodes were projected on the photographic image using the Eq. 3 and 4, obtaining the rectified image show in the Fig. 13. The stereomate corresponding is presented in the Fig. 12. Finally, the Figure 11 is an anaglyph made with both images.

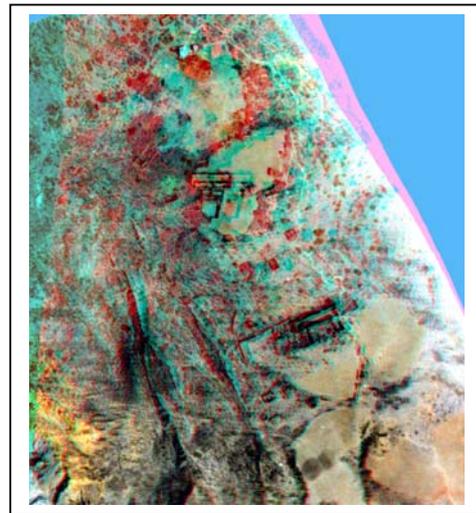


Figure 11. Digital anaglyph of the site.

Table 3. Coordinates of control points in fiducial system after colinearity transformation

Control points	Fiducial system		Terrain system			Discrepances	
	x (mm)	y (mm)	X (m)	Y (m)	Z (m)	Δx (mm)	Δy (mm)
1	7.50	15.39	881.34	930.02	2009.9	0.07	0.01
2	16.40	20.11	943.61	1004.70	2011.6	-0.02	0.01
3	25.70	11.58	1063.26	967.77	1992.1	0.02	0.03
4	21.24	5.19	1048.58	893.89	1982.7	0.02	0.02
5	17.84	-1.82	1049.99	817.40	1959.5	-0.03	-0.06
6	10.37	-12.33	1027.52	681.16	1924.1	0.04	0.02
7	13.59	2.86	986.96	844.17	1976.3	-0.02	0.02

RMSEX = ± 0.037 mm, RMSEY = ± 0.027 mm

Exterior orientation values

$X_0 = 897.422$ m ± 0.011 m

$Y_0 = 739.531$ m ± 0.011 m

$Z_0 = 2393.797$ m ± 0.002 m

$\kappa = 0.395029647942704$ rad ± 0.000040 rad

$\phi = 0.05.931734883602581$ rad ± 0.000059 rad

$\omega = 0.07.045014123448921$ rad ± 0.000011 rad

$$\text{Rotation matrix } A = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} = \begin{bmatrix} 0.92337454 & -0.37741467 & 0.07026816 \\ 0.38142073 & 0.92268157 & -0.05636445 \\ -0.04356237 & 0.07884723 & 0.99593445 \end{bmatrix}$$



Figure 12. Digital Stereomate

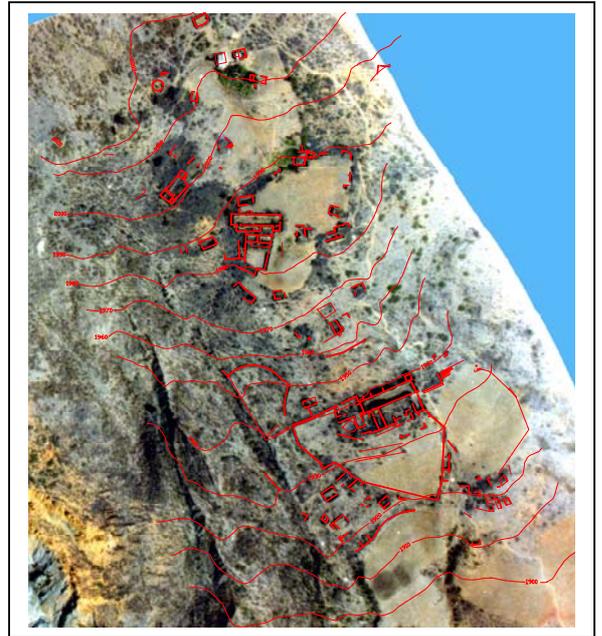


Figure 13. Digital orthophoto with restitution superimposed

Conclusions

The photogrammetric flight realized over Mucuño, though made in experimental form, and therefore without having major guarantee of success, contributed providing a lot of information on the general characteristics of the area, as well as from the methodological point of view. It can be stated that the aerial photography of small format constitutes a valuable instrument for the surveys of archaeological sites..

The stereo-ortofoto allows for three-dimensional observation of an area in study. Annotations can be made directly on the ortofoto as if it was a very detailed map of the area.

This procedure was realized in an area of mountainous relief, producing satisfactory results which shows the potential of use.

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