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Use of hybrid Stereopairs in Map Revision

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Conteúdo [esconder]

1. Introduction

The planning, its implementation and the monitoring of physical changes require updated maps and other information provided by aerial surveying. This issue is partially solved by using the revised map of the referred area. Hiring new aerial survey services, on the other hand, implies financial resources, which are not always available from public accounts in local governments at developing countries. In addition, as a result of the dynamics of human activities, maps become outdated over time.

Aerial survey companies are usually hired to revise maps, based on prior (outdated) maps and new information sources, such as recent aerial photographs, satellite images and topographical surveys. Actually, due to the lack of appropriate methodologies to be implemented in the companies, a new aerial survey is carried out, which may render this activity unviable due to the related high costs. The purpose of this work is to research fast and economic methods of map revision.

Technological progress in the fields of information technology and electronics have largely contributed to the development of digital photogrammetric systems and this provides the scientific community worldwide with new and interesting expectations related to the use of automation resources in photogrammetry (Miller et al, 1996; Gruen, 1996; Yoichi, 1996). It is believed that, based on the continual development of these areas, economic and productive

procedures may be implemented in map revision, coupled with geographical information systems, which enables this kind of projects (Al-Garni, 1996).
According to Lugnani (1985), whether by means of conventional techniques or more advanced technological resources, there are two main obstacles in map revision, which are critical: detecting the changes occurred in the object space and preserving ground control. Thus, he proposes certain resources to minimize these great obstacles in map revision. In relation to the detection of changes in the object space the proposal consists in a device, adjustable to analog and analytical plotters, that enables change detection. As regards ground control, he proposes the use of features instead of points.
The proposals suggested by Lugnani (1985) show the concern existing with respect to this endless task, which, in many cases, is more important than making new maps. Therefore, it may be seen that the most significant progress to this date is related to mapping production, that is, the most advanced tools, designed with the aid of new and advanced technologies, which, in turn, are not reflected in map revision.
At present, due to the remarkable technological progress in the field of digital photogrammetry, there are tools to address issues, such as those mentioned by Lugnani (1985). It is in this sense that this work proposes an alternative methodology for map revision based on conventional aerial photography used in the production of current outdated maps, and digital aerial photography (obtained with a Kodak digital camera), aiming at obtaining only the features of interest for map revision, thereby speeding up the process.
Thus, the main purpose of this work is to study an alternative methodology for map revision, both economic and productive. The methodology is based on the integration of information originated at different times, that is, both an outdated aerial survey with the related aerial photographs and recent aerial photographs obtained with a digital camera should be used.

2. Photogrammetric map revision

The interests of map users are multiple since there is a wide range of tasks carried out with the aid of mapping. Coupled with the lack of funds for certain tasks, this results in a constant search for alternative methods of map revision that not always meet the most basic requirements of mapping, falling short in terms of accuracy and efficiency. According to Lugnani (1985), facts of this nature give rise to a wide range of procedures, many of which are not of interest due to the precariousness of the product, the characteristics of the treatment or to inadequacy.
The progress in photogrammetry over the recent years has largely depended on the contributions of information technology since complex mathematical calculations may be programmed with adequate results, mainly in terms of the time saved and the enhanced accuracy in photogrammetric works. As stated by Lugnani (1987), the development of equipment, programs and systematic error modeling techniques has provided a remarkable enhancement of accuracy and reliability of the results obtained in photogrammetry.
Due to the vital importance to the methodology proposed in this work, not only the semantic characteristics of the image, which are aimed at detecting changes, but also the geometric issues in the photogrammetric production of stereoscopic models, in addition to the localization of features of interest, will be analyzed.

3. Methodology

3.1 Hybrid model production

The strategy of combining different data sources for the production of stereoscopic models was first mentioned by Lugnani (1985), who used a hybrid stereoscopic model based on two images obtained with the same conventional photogrammetric camera, where only the date of the flights differed. The main purpose of this work is the production of the hybrid model proposed and should contribute to the development of a new map revision methodology.

The fundamental principle of this work constitutes the use of a hybrid stereoscopic pair consisting of a 23x23-cm scanned aerial photograph, which was used in the map to be revised, and a recent digital aerial photograph.

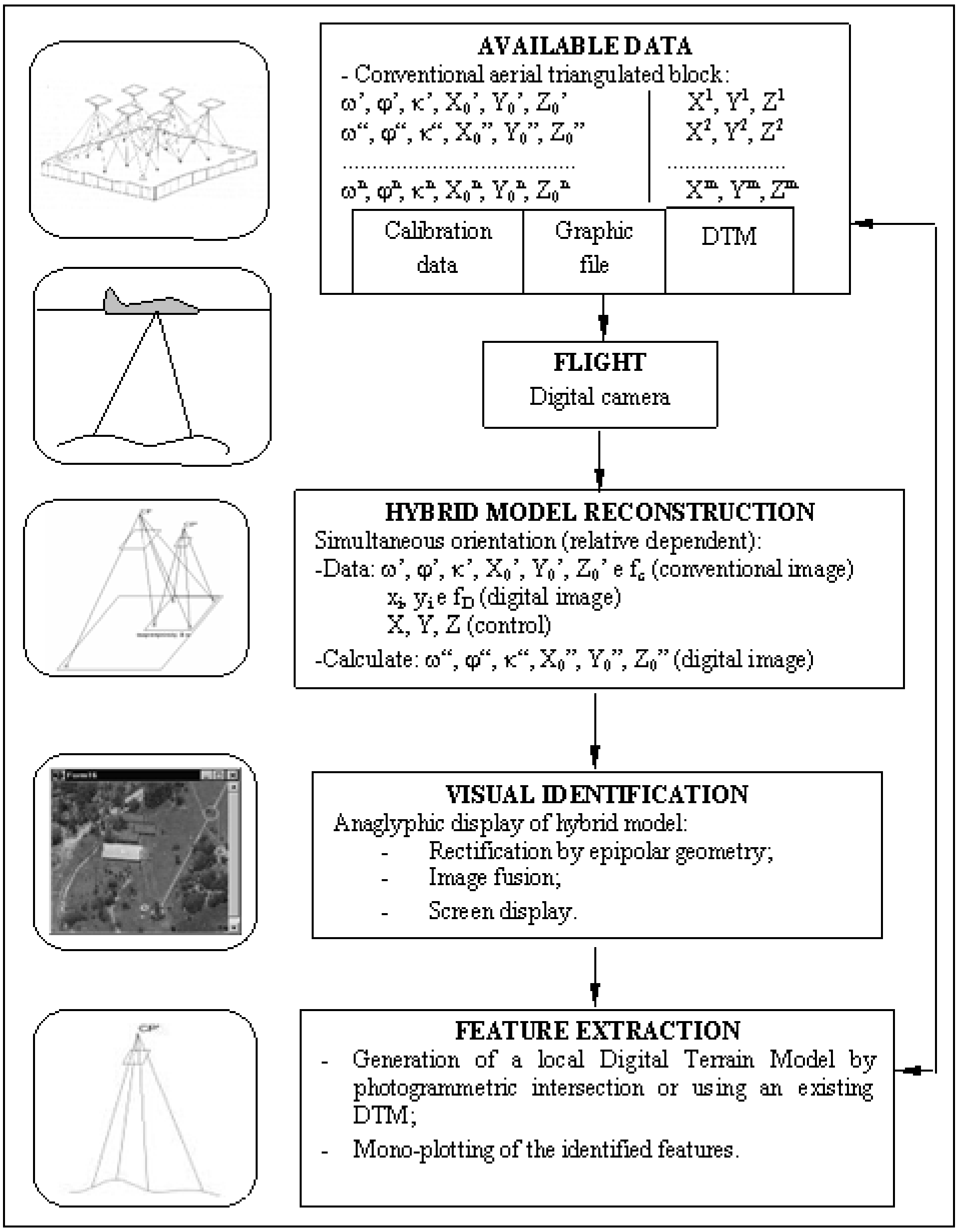

figure 1 : Data flow of the proposed methodology

Digital image has a different geometry than conventional image. Basically, the orientation parameters used in the production of the conventional stereoscopic model, which originated the map to be revised, are known and may be adopted as a requirement for the production of the new model (hybrid). For this purpose, it is necessary to use a relative-dependent orientation algorithm, considering the variations of focal distance between the cameras.

Using the collinearity equation model, two equations (x_c, y_c) may be written for a ground point in the conventional photograph, as shown in the following eq. 1.

$$x_C = f * \frac{m_{11}(X - X_0) + m_{12}(Y - Y_0) + m_{13}(Z - Z_0)}{m_{31}(X - X_0) + m_{32}(Y - Y_0) + m_{33}(Z - Z_0)} \quad (1)$$

$$y_C = f * \frac{m_{21}(X - X_0) + m_{22}(Y - Y_0) + m_{23}(Z - Z_0)}{m_{31}(X - X_0) + m_{32}(Y - Y_0) + m_{33}(Z - Z_0)}$$

where:

- **x_C and y_C are the photo coordinates (coordinates on the image space and in the photogrammetric system of the conventional photograph);**
- **f is the conventional camera constant (calibrated focal length);**
- **m_{ij} are the rotation matrix elements, based on the conventional camera's orientation angles (w, j, k);**
- **X_0, Y_0, Z_0 are the coordinates of the conventional camera's perspective center;**
- **X, Y, Z are the coordinates of a ground point P on the object space and on the established reference system.**

It may be noted that, as the conventional photograph has already been oriented during the production of the stereoscopic model with the two conventional photographs, the rotation matrix elements and the coordinates of the perspective center of that image are already known. The digital image allows, meanwhile, to write two additional equations (x_D, y_D) for the same ground point P, as follows:

$$x_D = f_D * \frac{m'_{11}(X - X'_0) + m'_{12}(Y - Y'_0) + m'_{13}(Z - Z'_0)}{m'_{31}(X - X'_0) + m'_{32}(Y - Y'_0) + m'_{33}(Z - Z'_0)} \quad (2)$$

$$y_D = f_D * \frac{m'_{21}(X - X'_0) + m'_{22}(Y - Y'_0) + m'_{23}(Z - Z'_0)}{m'_{31}(X - X'_0) + m'_{32}(Y - Y'_0) + m'_{33}(Z - Z'_0)}$$

where:

- **x_D and y_D are the image coordinates (P coordinates on the image space and on the digital image photogrammetric system);**
- **f_D is the digital camera constant (calibrated focal distance);**
- **m'_{ij} are the rotation matrix elements, based on the digital camera's orientation angles (w2, j_2, k_2);**
- **X'_0, Y'_0, Z'_0 are the coordinates of the digital camera's perspective center;**
- **X, Y, Z are the coordinates of P on the object space and on the established reference system.**
- **As the actual position and orientation of the conventional camera is already known, which was based on the original aerial triangulation (conventional model), only X'_0, Y'_0, Z'_0, k2, j_2, w_2 should be estimated. Considering that 4 equations may be written for each point, with 6 unknown points in the object space, 24 equations may be written, with 18 unknown (X_1, Y_1, Z_1, ..., X_6, Y_6, Z_6), plus 6 unknown orientation parameters (X'_0, Y'_0, Z'_0, k_2, j_2, w_2), which total 24 unknowns.**

This procedure theoretically resolves the issue of relative-dependent orientation, but a control point or a distance to determine the model scale should still be provided, thus obtaining the relative and absolute orientations simultaneously.

3.2 Change detection

Identifying the features that should be altered in a map revision procedure is an important stage and has become one of the greatest concerns of several researchers. Deemed as one of the critical issues in mapping, detecting changes was the main topic in the research carried out by Lugnani (1985), which became the most significant source of motivation for this work.

The first idea in this work to solve the issue of identifying changes was the production of a hybrid stereoscopic model based on the stereo-image alternator (SIA). Lugnani (1985) used an analytical instrument (Planicomp) with conventional ocular optics in the production of a stereoscopic model, where the images used were obtained with the same photogrammetric camera; therefore, with the same geometry and by adapting a stroboscope that intermitently interrupt observation for each of the images.

The production of the stereoscopic model proposed in this work was tested using a different methodology than Lugnani (1985), that is, by using a digital aerial photograph and part of a digitalized conventional aerial photograph for the production of the model directly by digital means.

Detecting changes using the SIA system is affected by the high frequency in which the images are displayed on the computer screen, without satisfactory results. On the other hands, the change detection method proposed in this work consists basically in an anaglyphic visualization of the hybrid digital stereoscopic model. This method, of stereoscopic display, is well known in the field of photogrammetry and was extensively used in analog optical plotters for stereoscopic plotting.

A colored digital image may be formed by red (R), green (G) and blue (B) channels, allowing to separate the channels in three different images. Based on that principle, the idea was to form an image using the red (R) channel of one of the images and the fusion of the other two channels (G and B) of the other image. This procedure is equivalent to the application of a red filter in one of the images and a cyan filter on the other, based on the principle of stereoscopic modeling by the conventional anaglyphic method.

The main problems detected during the referred procedure are the geometrical differences between the digital and the digitalized conventional images, as well as the distortions caused by different image orientations. This problem may be minimized by rectifying and resampling the images to be used.

3.3 Feature extraction

3.3.1 Direct digitalization

A monoplotting procedure to collect planimetric coordinates directly on the digital image may be used as a rapid alternative to determine the position of a recent feature. For that purpose, the exterior orientation procedure may be carried out as just a spatial resection in the digital image and a scale factor.

3.3.2 Photogrammetric plotting

The advantage of working with a hybrid stereoscopic model is a more reliable and faster visual change detection. On the other hand, if a feature to be extracted, appearing on the digital image, does not appear in the conventional image, photogrammetric intersection can not be used to determine the coordinates of the feature points in the object space, since they may not be located in the image space of the conventional image.

To solve this drawback, the procedure of photogrammetric intersection is applied to determine points appearing on both images forming a local DTM (Digital Terrain Model) in the vicinity of the feature to be extracted by mono-plotting. The test described in section 4.2.2 shows that this procedure works properly.

Photogrammetric intersection is used to estimate three-dimensional X, Y and Z coordinates in the object space based on the two-dimensional coordinates extracted in two different images that will be dealt with in this section as conventional and digital images.

The transformation of coordinates, from object space to image space, may be carried out by similarity transformation by means of the eq. 3.

$$\begin{bmatrix} x_i \\ y_i \\ f \end{bmatrix} = \frac{1}{\lambda} \cdot \begin{bmatrix} m_{11} & m_{12} & m_{13} \\ m_{21} & m_{22} & m_{23} \\ m_{31} & m_{32} & m_{33} \end{bmatrix} \cdot \begin{bmatrix} X - X_0 \\ Y - Y_0 \\ Z - Z_0 \end{bmatrix} \quad (3)$$

where:

- **l is an arbitrary scale factor;**

Reverse transformation passes from the coordinates measured in the image space on the image to the coordinates in the object space as shown in eq. 4.

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \lambda \cdot \begin{bmatrix} m_{11} & m_{21} & m_{31} \\ m_{12} & m_{22} & m_{32} \\ m_{13} & m_{23} & m_{33} \end{bmatrix} \cdot \begin{bmatrix} x_i \\ y_i \\ f \end{bmatrix} + \begin{bmatrix} X_0 \\ Y_0 \\ Z_0 \end{bmatrix} \quad (4)$$

Once the interior and exterior orientation parameters of the referred two images are known, three-dimensional coordinates in the object space may be calculated, using photogrammetric intersection.

Based on the current methodology proposed, two rectified images are used in the production of a stereoscopic model for the purpose of visually detecting the changes occurred over a certain period. By the rectification of those images, the camera's orientation angles w, j and k are eliminated, which results in a considerable simplification in the mathematical model. The rotation matrix will be equal to the identity matrix.

The use of rectified images is recommended, because a better stereoscopic visualisation is enabled, since vertical paralax are minimized, provided that the same GSD where used in both images with a previous resampling.

When the position of a point (x_i and y_i in the image) is known in only one of the aerial photographs and its exterior orientation parameters, as well as its approximate elevation, Z_i, the planimetric coordinates of the point (X_i,Y_i) may be determined by the mono-plotting procedure.

The plotting model proposed by Makarovic (1973), uses the elvation Z_i interpolated from a DTM (digital terrain model) generated from contours of the map to be revised, computing coordinates Xi and Yi, by means of inverse collinearity model. (eq. 5)

$$X = \frac{m_{11} \cdot x_i + m_{12} \cdot y_i + m_{13} \cdot f}{m_{31} \cdot x_i + m_{32} \cdot y_i + m_{33} \cdot f} \cdot (Z_i - Z_0) + X_0 \quad (5)$$

$$Y = \frac{m_{21} \cdot x_i + m_{22} \cdot y_i + m_{23} \cdot f}{m_{31} \cdot x_i + m_{32} \cdot y_i + m_{33} \cdot f} \cdot (Z_i - Z_0) + Y_0$$

where:

- **x_i and y_i are the image coordinates of a point to be projected to the object space;**
- **Z_i is the approximate elevation of P in the object space (the best value will be determined trough an iterative process).**

The images used in this work were rectified, eliminating the camera's orientation angles. Thus, the rotation matrix is equal to the identity matrix, so eq. 5 may be written as follows:

$$X = \frac{x_i}{f} \cdot (Z_i - Z_0) + X_0$$
$$Y = \frac{y_i}{f} \cdot (Z_i - Z_0) + Y_0 \quad (6)$$

It may be noted that Z_i is interactively obtained by interpolation. According to Makarovic (1973), an initial elevation Z_i is estimated (Z_1), and the initial X and Y coordinates are calculated (X_1 and Y_1). Based on X_1 and Y_1 coordinates, a new elevation, Z_2, may be interpolated, based on which X_2 and Y_2 may be calculated. This procedure should be repeated until the increments in X and Y are within a predefined tolerance.
The methodology proposed in this work is completed with the implementation of mono-plotting where the approximated elevation (Z_1) is estimated based on the interpolation of elevations surrounding the feature of interest to be extracted.
According to Makarovic (1973), several mathematical models may be used to interpolate the elevation of a point of interest. One of the simplest procedures that may be used in this task is a planar triangulation by approximating the interior of each triangular face to an average plane, which passes through the points defining the triangle and the point to be interpolated. The function of elevation interpolation (Z_p) in this case results from the following eq. 7.

$$Z_{p(x,y)} = ax + by + d \quad (7)$$

Where:

- **Z_p= the interpolated elevation;**
- **x and y are the planimetric coordinates of P;**
- **a, b and d are the parameters calculated on the basis of the elevation of the points defining the mid-plane.**

This procedure presents suitable results when it is applied to an interpolation with short distances between the points defining the triangle. The advantage of a flat surface assumption is the reduction in the computational cost of the process and the easy of implementation.

4. Tests

4.1 Change detection based on an anaglyphic stereoscopic model

The MRS program (Map Revision System) was developed using C++ language in a Borland Builder environment for current map revision, using several procedures previously described by Hasegawa and Camargo (1998), Oliveira et al. (1999), Tommaselli and Nobrega (1997). Thus, the tests were based on the principle that several data are already known, such as the exterior orientation parameters of the conventional image and the camera calibration parameters.
Once the conventional and digital aerial photographs were entered, the following steps were carried out:

- **-Conventional image:**
    - **-Interior orientation**
    - **-Clipping of the area of interest (consistently with the digital image)**
    - **-Rectification and resampling**
    - **-Screen display.**

- **-Digital image:**
    - **-Interior orientation**
    - **-Relative-dependent orientation**
    - **-Rectification and resampling**
    - **-Screen display.**

figure 2 : Rectified conventional and digital images

With the two rectified images displayed on the screen, as shown in Fig. 02, the anaglyphic model may be constructed. This is done by selecting the 'anaglyphic model' option in the 'Tools' menu and marking a point in the conventional image, as well as its homologous point in the digital image with the extraction cursor. Thus, with the anaglyphic model displayed on the screen the new features may be identified, as shown in Fig. 3. It is worth mentioning that the identified features are best displayed on the screen than in a hardcopy.

figure 3 : Change detection using an anaglyphic model

As previously discussed, stereoscopic visualization is even possible in this case, but it is not the most important issue, since the main purpose is to simply identify the new feature, as shown in Fig. 2. In this Fig., the new feature appears highlighted in red, whereas its components in green and blue do not appear in the conventional image.

Once the feature is identified, the 'extract features' option from the system's tool menu by opening the window for feature extraction with the following options: 'End feature,' 'New Feature,' and 'End Vectorization.' Once the features of interest are extracted, the file should be completed and saved by selecting the 'Save Vectorization' option in the 'File' menu. Thus, the file is saved in a DXF format that may be imported from any CAD system.

4.2 Map revision using the proposed methodology

4.2.1 Direct digitalization on the digital image

In addition to the possibility of identifying and extracting new features, it is necessary to ensure its geometric accuracy since they will be part of a mapping produced under the standards of cartography and aerial survey, according to the national map Standards.

The first experiments were performed using direct feature digitizing over the rectified images, but, as expected, the results were affected by relief displacement. Therefore, these procedure can be used only for flat terrain, as should be expected.

An alternative that may render this technique interesting is a subsequent processing, rectifying the errors resulting from the relief displacement, based on a DTM generated by the contours existing in the map under revision.

4.2.2 Mono-plotting of interest features

The results of the tests carried out based on the digitalization of the features directly on the rectified digital image are largely affected by the relief displacement when conducting a revision of or mapping an uneven area. Additionally, only the planimetric coordinates are estimated based on the digital image.

Based on the methodology proposed in this work, the planimetric coordinates of the points defining the features to be plotted are estimated by means of a mono-plotting process, as described in section 3.3.2. A pair of digital images (0310-scanned and DCP311-digital) were oriented with a relative-dependent orientation, but including also five control points, and some experiments were carried out.

The points were homogeneously distributed in order to provide adequate geometric configuration on the digital image, since they were used as control. Natural features found in this area were choosen, since no signalized points were used either as control or for checking. This points were surveyed with a GPS Trimble Receiver (4600), using the cinematic method.

For this test, the coordinates of certain points representing new features and, therefore, only appearing in the digital image, were estimated in the object space, based on the mono-plotting model.

Fig. 4 shows the feature defined by points 5, 6 and 7, which planimetric coordinates were estimated using the proposed approach.

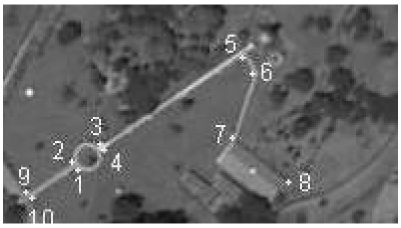

figure 4 : Detail of the feature defined by points 5, 6 and 7.

To proceed with the mono-plotting of these points, it is necessary to determine an elevation for each point appearing in both images (scanned and digital). By applying the methodology proposed in section 3.3.2, a triangle was defined by tree points (2, P1 and 8) as shown in Fig. 04, which appear on the two rectified images, thus allowing to calculate its 3D coordinates by photogrammetric intersection. Table 1 shows the ground coordinates calculated by photogrammetric intersection.

Points	E (m)	N (m)	h (m)
2	457958,917	7553614,618	440,553
P1	457889,504	7553471,127	443,634
8	457817,079	7553545,882	440,458

By applying the planar interpolation model, shown in eq. 10, the parameters defining the triangle used to determine the approximate elevation of each point to be plotted were calculated. Based on the average elevation (h), shown in Table 1, as the initial approximate elevation of the points to be plotted (5, 6 and 7), the interactive mono-plotting model was applied. After the third iteration, the results shown in Table 2 were obtained.

Points	E (m)	N (m)	h (m)
5	457892,896	7553483,111	443,343

6	457877,588	7553490,382	442,914
7	457866,982	7553539,549	441,362

Points 5, 6 and 7 are ground control points, which allows to calculate the differences between the coordinates estimated by mono-plotting and the related coordinates determined on the ground by GPS, as shown in Table 3.

Points	dE (m)	dN (m)	dh (m)
5	0,099	0,031	0,151
6	-0,088	0,149	-0,246
7	-0,117	-0,225	-1,039

Based on the results shown in Table 3, it may be noted that the coordinates were accurately determined since they meet the accuracy requirements of the Brazilian Cartographic Standards for Class A maps at a 1:5000 scale, that is, 1.06 m for E and N directions, and 1.67 m for elevations.

A second experiment, considering a worse geometric configuration of points surrounding the interest feature, was then performed (Fig. 5). The aim of this experiment was the restitution of the rectangle defined by points 15, 16, 17 and 18, as seen in Fig. 5. The 3D coordinates of points P2, P3 e 19, appearing both in the scanned aerial image and in the digital image were computed by photogrammetric intersection. A fitting plane, passing trough these points was then calculated. The image coordinates of points 15, 16, 17 and 18 were measured only in the digital image, since they do not appear in the scanned photograph and its 3D ground coordinates were computed by the proposed monoplotting procedure. In Table 4 the discrepancies between the coordinates computed using the hybrid model and the field truth, measured with GPS receivers, are presented.

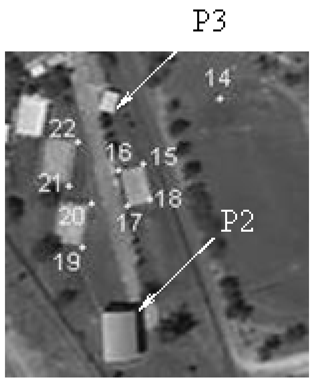

figure 5 : Details of points used in the second experiment.

Point	dE (m)	dN (m)	dh (m)
15	0,314	-0,830	7,398
16	0,208	-0,580	4,955

17	0,179	-0,723	5,206
18	0,485	-1,133	7,824

The results presented in Table 4 show that planimetric coordinates are confident with the required accuracy even in this unfavorable configuration but the interpolated elevations presented high systematic errors, most likely due to the distance between the points defining the triangle and the terrain slope and the non-metric nature of the digital camera.

5. Conclusions and recommendations

A new technique to detect changes is shown in this paper based on the construction of an anaglyphic stereoscopic model, where the G and B channels of the rectified conventional aerial photograph are fused with the R channel of the rectified digital aerial photograph. This anaglyphic model highlights in red the new features to be plotted with adequate results.

Photogrammetric techniques have been, and still are, widely used in mapping, but this is not the case of map revision. Thus, this was one of the main reasons that fostered this work.

The initial proposal of this work was to integrate several data sources to create a methodology that provides reliable low-cost map revision. Such a low cost is largely obtained by using already existing material and information and also by implementing easy procedures that save time in the execution of the referred tasks.

It is difficult to show data that enable concrete analysis, mainly reflected in Fig.s, as well as in economic terms since, in addition to the countless variables that are part of the procedure, the tests described in this work represent certain costs that may be hardly estimated due to the scientific nature of the research.

However, as shown in Table 5, the ground survey and aerial triangulation procedures represent approximately 20% of the cost of a conventional aerial survey, since those procedures would be minimized by using the proposed methodology. Additionally, localized restituition is recommended, that is, only related to the new features. It is, therefore, not necessary to fly over and plot the entire area, thus significantly increasing productivity.

STAGES	COST (%)
Flight	10
Ground Survey	18
Aerial Triangulation	2
Stereo Plotting	35
Field Checking	5
Map Editing	30
TOTAL	100

The fact that one point related to a new feature appeared in only one of the images (digital image) requires a method to estimate its three-dimensional position in the object space, without the need to know its position in the conventional aerial photograph. This may be solved by using a mono-plotting model, as discussed in section 3.3.2, establishing the 3D coordinates of a point based on the image coordinates and its interpolated elevation in the object space through a DTM (Digital Terrain Model). The test carried out in this work was based on the application of a mono-plotting model, without the need of using an local DTM of the whole area, which considerably decreases computational efforts.

As it may be noted in section 4.2.2, three points were determined by photogrammetric intersection near the identified features, as if they were part of a DTM, which enabled the mono-plotting of the referred features and with satisfactory results as regards accuracy.

It is believed that the proposed methodology as described in this work may be customized according to the needs of any application, enabling new research, for example, by using satellite images.

Finally, this methodology may provide improved working conditions in the map revision processes, reducing time and therefore costs.

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