
DIGITAL MONO-DIFFERENTIAL RESTITUTION OF AIRPHOTOS APPLIED TO PLANIMETRIC MAPPING

Prof. Edson A. Mitishita¹ e Prof. Flávio Felipe Kirchner²

Universidade Federal do Paraná, ¹ Setor de Tecnologia – Departamento de Geociências,

² Setor de Ciências Agrárias – Departamento de Ciências Florestais

e-mail: ¹mitishit@geoc.ufpr.br, ²kirchner@floresta.ufpr.br

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The development of the computer science in the last few years, making available low cost computers with high performance and processing speed, as well as specific softwares that manage vector and raster data, are transforming the ways of preparing and using cartographic products.

Nowadays, with the digital photogrammetric systems it is possible to have a better use of the airphotos in obtaining spatial information, mainly based on low cost equipments and operational facilities.

The development and the employment of techniques that optimize the flow of the productive process, as well as less time and costs spent in finishing the projects, are one of the basic requirements that are required in digital mapping.

Digital mono-differential restitution can be seen as one of the digital mapping techniques that can be applied with great advantages in several engineering segments that require spatial informations.

This paper shows the theoretical, mathematical and operational aspects used in the development of a new procedure of digital Mono-Differential restitution of airphotos, where conventional mathematical procedures of the analytic photogrammetry were associated with a C.A.D.(Computer Aided Design) “MicroStation PC” together with a D.T.M.-digital terrain model.

I INTRODUCTION

The Technology developed in the area of the computer science, with low cost computers with a great capacity of storage of information and processing speed, as well as efficient systems in the area of computer graphics are transforming the forms and use of the cartographic products.

The stereophotogrammetric restitution is now one of the most used techniques in obtaining digital bases in different scales, precisions and types for applications in several engineering segments. Nevertheless, its operation needs highly qualified technicians and high cost photogrammetric equipments.

These needs determine that the photogrammetric mapping is accomplished only by companies specialized in this segment. This way, in several engineering applications, the photogrammetric mapping becomes unviable due to the high cost and time for the accomplishment of the work.

Several segments of Engineering are using digital mappings for the automation of works in Geographic Information Systems. The obtaining of these mappings or the transformation of analog bases in digital bases, it has been showing in many of the applications, that the obtained results don't adapt the user's real needs, mainly with relationship to the cost and time for the execution of the works.

The information systems spatially oriented require mappings oriented for the user's application. Many of the cartographic patterns, such as the precision of the representation, forms data collection, cartographic simbology, types of conventions and projection system should be oriented to the user's application.

In view of these needs for obtaining spatial bases of data oriented to a certain application, it is justified the importance to develop a digital mapping system, where the user is able to accomplish the digital mapping, or possibilities of updating the existent mapping with procedures of easy operation.

Nowadays, it became possible to associate analytic photogrammetric procedures with C.A.D. systems in order to make possible to obtain digital bases by the user, based on digital airphotos “rasterized”, computer equipments of low cost and more flexible photogrammetric operations, if compared with the ones used in stereoplotting.

II DIGITAL MONO-DIFFERENTIAL RESTITUTION

The development of the computer science in making available for the user efficient C.A.D. systems that allow a total integration of digital images and vector files in a same environment, allowed that the technique of Digital Mono-Differential Restitution of airphotos shimmered applications in the areas of engineering.

The Digital Mono-Differential Restitution can be defined as a photogrammetric procedure that facilitates the obtaining of a digital planimetric mapping from the monoscopic digitalization of entities in an airphoto.

Being this technique purely in the analytic domain, it is verified in a general way, that is the application of a group of transformations of coordinates among the spaces of the image and of the surface of the reference model and of the projection surface.

The mathematical theory of the main transformation is based on the proposal presented in (Makarovic,1973), that consists of transforming the photogrammetric coordinates (x_p, y_p) , of points observed in the airphoto, for the local three-dimensional Cartesian geodetic reference (X_L, Y_L, Z_L) , using inverse collinearity equations and of mathematical surface modelling (D.T.M.–“digital terrain model”), as shown in the equation (01).

$$X_L = X_o + (Z_L - Z_o) \frac{m_{11} x_p + m_{21} y_p + m_{31} c}{m_{13} x_p + m_{23} y_p + m_{33} c} \quad (01)$$

$$Y_L = Y_o + (Z_L - Z_o) \frac{m_{12} x_p + m_{22} y_p + m_{32} c}{m_{13} x_p + m_{23} y_p + m_{33} c}$$

For the accomplishment of this transformation, named of “planimetric rectification”, there is a need of parameters of external and interior orientation of the airphoto and a Digital Terrain Model System (D.T.M.), that facilitates the interpolation of the altimetric coordinate (Z_L) as a function of the planimetric coordinates of the point. The final values of the planimetric coordinates are determined, inside of a given precision, by a interactive process, according to figure (01). More details can be found in (Mitishita, 1997).

After the convergence, the coordinates in the local geodetic reference are transformed to a cartographic projection system for the elaboration of the vector digital mapping in a C.A.D.–(“computer aided design”) system.

Using C.A.D. systems for obtaining the necessary points for the materialization of the entities and its coordinates in the photogrammetric reference, techniques of vector digitalization can be used that observes analog airphotos in a digitizing tablet or digital airphotos in a “raster” format in the computer video.

In this work, it is used digital airphotos and a C.A.D. system “MicroStation PC” that supplies the software tools, necessary to the management of the digital images, as well as for the creation and management of the vector graphic files of the graphic entities, created from the digitalization of the digital airphotos in the screen.

Suggestions, practical applications and mathematical variations of the model proposed by (Makarovic, 1973), inside of the domain of the conventional analytic photogrammetry can be found in (Dal Poz, 1991, 1993), (Lugnani, 1985), (Masry, 1979) and (Villareal, 1992).

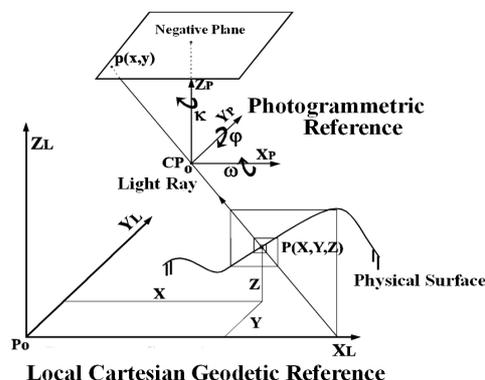


Fig. 1. Convergence by the iterative process

III PHASES OF WORK

The fundamental phases of the work, involved in the Digital Mono-Differential Restitution process of airphotos in raster format, are presented in (Mitishita, 1997). The main ones are:

A. Preparation of the airphotos

The preparation of the airphoto consists of transforming it from analog to digital in raster format. It is recommended a photogrammetric scanner that possesses geometric and real optical resolution compatible with the precision demanded for the elaboration of the digital mapping to be accomplished.

For the application of the analytic photogrammetric procedures, becomes indispensable that the scanned digital image contains the fiducial marks. It is recommended to use the optical resolution of 1000 D.P.I (“dots per inch”), where the smallest discrimination of the image (“pixel”) has a lineal dimension near of 0,025 millimeters. Therefore, the file will result in a size of 82 mbytes.

B. Interior orientation of the airphoto

The interior orientation consists of providing a group of parameters and necessary mathematical transformations to obtain the photocoordinates (x_p, y_p) of points digitalized in the digital airphoto, with the correction of the systematic errors of the image (deformations of the image, lenses distortions and photogrammetric refraction).

C. Approximate spatial orientation of the digital airphoto

Approximate spatial orientation of the airphoto consists of to determine an approximate mathematical model to be used in the transformation of the photogrammetric coordinates (x_p, y_p) in plane coordinates in the local geodetic reference and to accomplish the verification of possible gross errors in the control points. These approximate coordinates are used in the planimetric rectification of the point.

D. Exact spatial orientation of the digital airphoto

Exact spatial orientation of the digital airphoto is considered in this work as the procedure used in the determination of the parameters of external orientation of the airphoto $(\chi, \phi, \omega, X_o, Y_o, Z_o)$.

A. Obtaining of the altimetric information of the area to be monorestituted

As already shown, the use of the equations (01) that implement the “planimetric rectification” in the Digital Mono-Differential Restitution, it is based on the use of a D.T.M. that determines the altimetric coordinate (Z) of the point to be rectified.

Obtaining altimetric information, consists of sampling a group of points with spatial coordinates (X,Y,Z), in a given reference, so that the informative content of the same ones represents the structural behavior of the surface to be monorestituted. These information are necessary for the mathematical modeling of surfaces that can be obtained from several sources of data, see (Mitishita, 1997).

B. Digitalization of the graphic entities of interest

In this work phase the cartographic entities of interest are digitalized, starting from the digital airphoto already in the screen. The C.A.D. system “MicroStation”, prompts the necessary graphic tools to the production of the digital graphic file in vector form, as well as the management, manipulation and editing of the entities already digitalized.

At the end of the airphoto digitalization, a vector graphic file is obtained in binary format, where all the entities are materialized in the drawing reference.

C. Transformations among references of the space image, object and projection systems

The objective of this phase is the rectification of the vector graphic file obtained with the process of digitalization of the entities.

The graphic file obtained from the planimetric digitalization of the digital airphoto with the program “MicroStation”, has all the entities materialized in a vector digital structure (basically, a group of points with coordinates in the drawing reference in U.O.R.–“unit of resolution”). It can be said that the vector file is in a central projection, because it was “copied” from a digital airphoto in central projection, without any rectification.

What is intended in this phase it is the generation of a second vector file (in orthogonal projection) starting from the first one. For that, the points that define the graphic entities are transformed for a local geodetic reference and later on for the reference of the adopted projection system.

D. Final procedures for the elaboration of the map

The accomplishment of a digital mapping consists, generally, in the elaboration of maps with predefined dimensions of latitude and longitude (systematization). As it is stated, Digital Monorestitution restitutes planimetrically an airphoto and almost always this portion mapped doesn't correspond the defined area of a map.

This phase, named generally of “graphic editing”, consists of grouping the rectified digital files of each airphoto, in only one file and, starting from this, to obtain the maps of the adopted systematization. Also takes place in this phase the correction of the existent imperfections in the rectified entities, such as: closing of polygons, success of breaks of lineal elements and smoothing of curvilinear elements. Also, are placed the existent toponomy, geographic reticulate, of the adopted projection system. At last the, graphic file is added to the legend, and the final planimetric map is obtained.

IV. PHOTOGRAMMETRIC OBSERVATIONS

The program C.A.D. “MicroStation Pc” was used to quantify points observed in the digital airphoto in raster format. The graphic system “MicroStation” to reference a point in its graphic plane (2D digital file plane) of drawing used a reference Cartesian bidimensional destroger, with global origin generally in the center of squared area of 4294967296 UOR (“unit of resolution”).

The drawing plane can be compared as a square matrix of $2^{22} \times 2^{22}$ points, being a point in this matrix the unit of positioning or of denominated resolution of UOR. Inside the program, for the definition of the metric unit of the drawing system, a value of well-known measure is supplied for the smallest lineal distance among two points (UOR).

The graphic system “MicroStation”, working with a raster image, it fastens the same in the plane of drawing in a global, or better way, the whole image has lineal dimensions in terms of units of positioning. This way, the operation of visualization of the image in the screen, in what refers to the magnification and reduction doesn't modify the position of a “pixel” in the image.

When takes place a magnification of the image (“Zoom in”) it becomes possible to observe punctual details (fiducial

marks and photogrammetric artificial points) with larger clarity and precision. This way, the precision of the observation of a planimetric detail in the screen of the computer is basically a function of the stability of the mouse, configuration of the graphic board and of the size of the “pixel.”

Two basic procedures can be considered to be used in the necessary observations to the monorestitution work. In the first, it is admitted that the “cursor” it is parked on top of a position defined as being the point to be observed. In this group the observations such as the fiducial marks, artificial photogrammetric points, pré-signalled points and points defined in the image are founded, such as: house corners, fence and walls corners, etc. In the second, it admits the “cursor” movement in the screen of the computer.

V. ALTIMETRIC INTERPOLATION

The technique of Digital Monorestitution of airphotos needs a system of mathematical modeling of surfaces for the determination of the altimetric coordinate (Z) of the point to be rectified. On the other hand, a system of surface modeling demands mathematical algorithms capable to interpolate the altimetric coordinate inside of the necessary precisions to the rectification of the planimetric coordinates of the point.

E. Plane Triangular Surface

This interpolation procedure is based on a structure of control points in a triangle shape (polyhedric of plane triangular faces).

Adjusting a mean plane passing by the three points that define the triangle, in the triangular face $Z(x,y)$, and the point to be interpolated, contained in this triangle, as shown in the figure 03. The function of interpolation of the altimetric coordinate (Z) can be given by:

$$Z(x, y) = ax + by + d \quad (02)$$

The values of the coefficients of the function (02) are unequivocally obtained with the informations contained in the triangle.

It is a procedure of altimetric interpolation that presents great advantages with relationship to the time of processing and programming facilities, however it presents disadvantage for not treating the continuity mathematically among the triangles. This procedure presents good results, when applied in a triangulation with small spacing among the control points (larger number of triangles).

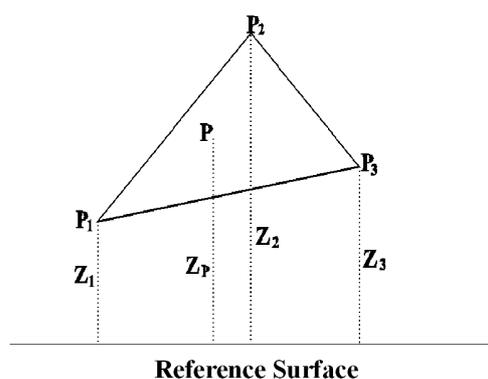


Fig. 3. Triangle and the internal point to be interpolated

F. Continuous triangular surface of 3rd degree

As presented in the interpolation procedure, named of “triangular surface planes”, this procedure starts from a triangulation and the point to be interpolated is inside a triangle. However, it is admitted not to be a plane the internal surface of the triangle and that transition among the adjacent triangles, in the respective points happens in a continuous and harmonious way.

It is considered that the internal surface of the triangular domain can be approached by a bivariate polynomial of 3rd complete degree (03).

$$Z(x,y) = a_1 + a_2x + a_3y + a_4xy + a_5x^2 + a_6y^2 + a_7x^2y + a_8y^2x + a_9y^3 + a_{10}x^3 \quad (03)$$

This polynomial possesses ten (10) coefficients and in this case, they should be determined with the information contained in the triangle. This way, for each vertex of the triangle the following conditions are:

1) Altimetric coordinate Z;

2) Partial derivatives of 1st order:

$$\frac{\partial Z}{\partial x} = a_2 + a_4y + 2a_5x + 2a_7xy + a_8y^2 + 3a_{10}x^2 \quad (04)$$

$$\frac{\partial Z}{\partial y} = a_3 + a_4x + 2a_6y + a_7x^2 + 2a_8xy + 3a_9y^2 \quad (05)$$

3) Partial derivatives of 2nd order:

$$\frac{\partial^2 Z}{\partial x^2} = 2a_5 + 2a_7y + 6a_{10}x \quad (06)$$

$$\frac{\partial^2 Z}{\partial y^2} = 2a_6 + 2a_8x + 6a_9y \quad (07)$$

$$\frac{\partial^2 Z}{\partial xy} = a_4 + 2a_7x + 2a_8y \quad (08)$$

Being these conditions applied for the three vertexes of the triangle, it results a system with eighteen (18) equations for ten (10) parameters, facilitating the determination of the coefficients with adjustment least squares (L.S.Q.).

The subject of this procedure is in the way to be used to predict the partial derivatives in each vertex of the triangle, because the values of the derivatives have great influence in the values of the coefficients of the function $Z(x,y)$, see (Pettinati, 1983).

For the partial determination of the derivatives in each point of the triangle, in this work it was used the partial derivatives of a quadratic surface, being:

$$Z(x,y) = a_1 + a_2x + a_3y + a_4xy + a_5x^2 + a_6y^2 \quad (09)$$

The quadratic surface is determined by least squares adjustment in an area of restricted domain, defined by the vertex and its nine (9) closer points. The partial calculation of those derivatives can be given by:

$$\frac{\partial Z}{\partial x} = a_2 + a_4y + 2a_5x \quad (10)$$

$$\frac{\partial Z}{\partial y} = a_3 + a_4x + 2a_6y \quad (11)$$

$$\frac{\partial^2 Z}{\partial x^2} = 2a_5 \quad (12)$$

$$\frac{\partial^2 Z}{\partial y^2} = 2a_6 \quad (13)$$

$$\frac{\partial^2 Z}{\partial xy} = a_4 \quad (14)$$

x_v e y_v planimetric coordinates of the triangle vertex.

Being adjusted a quadratic for each vertex of the triangle, and being admitted the quadratic derivatives as being the same ones as the polynomial of 3rd degree, we have the necessary information for the determination of the coefficients of the interpolation function by least squares adjustment.

It is a mathematical procedure that presents excellent results in the altimetric interpolation of points, however it presents disadvantages in relation to the procedures presented previously as operational facilities and time of processing. More details in (Mitishita,1997).

VI RESULTS

Trying to show, in this work, the precisions obtained with this new methodology of Digital Monorestitution of airphotos, the results of one of the accomplished experiments is presented. Detailed results can be found in (Mitishita,1997).

Using an airphoto in the scale of 1/8000, thirty eight points were observed. Its planimetric coordinates were determined with the procedure of Monorestitution and by conventional photogrammetric procedures (orientation of the models in an analytic stereoplotter Wild BC 03). For the mathematical definition of the relief of the area an irregular net of points was used with interval among points of 15 meters.

Comparing the geodetic coordinates determined with the monorestitution and the ones obtained with the conventional fotogrammetry, it was obtained the averages of the absolute discrepancies the values of 0,235 meters for the coordinates X and 0,262 meters for the coordinates Y and its standard deviations, respectively the values 0,150 and 0,174 meters, as shown in table 01.

Using the standard error, the confidence level of $\pm \sigma$ or more the less a standard deviation, which corresponds a probability of 68,27% of the mean to be in this interval.

This way, the standard error of the discrepancies is respectively $\pm 0,150$ meters for coordinate X and $\pm 0,174$ meters for coordinate Y or 68,27% of the tested points are inside of these intervals.

Being admitted the precision of a digital photogrammetric mapping in function of the mean scale of the airphoto and of the maximum tolerable error in the positioning of the measure mark (stereoscopic floating point) in an analytic photogrammetric system, the value of 0,050 mm. Taken the value of the mean scale of the airphoto the value of 1/8000, the acceptable error in the planimetric digital mapping the value of $\pm 0,40$ meters. We verified then that the monorestitution procedure, reached in more than 68,27% of the points tested values of precisions above the limits of acceptable errors for the scale of work.

N° Point	DX(m)	DY(m)	No. Point	DX(m)	DY(m)	No. Point	DX(m)	DY(m)
300	0.231	0.445	301	0.252	0.204	302	0.025	0.200
303	0.342	0.429	304	0.180	0.124	305	0.085	0.252
306	0.008	0.516	307	0.365	0.170	308	0.227	0.007
309	0.139	0.268	310	0.005	0.144	311	0.318	0.139
312	0.270	0.095	313	0.033	0.572	314	0.212	0.224
315	0.539	0.094	316	0.418	0.033	317	0.273	0.311
318	0.066	0.091	319	0.295	0.135	320	0.435	0.339
321	0.170	0.189	322	0.206	0.602	323	0.382	0.274
324	0.175	0.336	325	0.210	0.342	326	0.008	0.159
327	0.353	0.238	328	0.232	0.136	329	0.112	0.090
330	0.264	0.500	331	0.515	0.008	332	0.067	0.388
333	0.396	0.315	334	0.241	0.553	335	0.009	0.640
336	0.410	0.333	337	0.453	0.065			
Mean values			DX (m) = 0.235			DY (m) = 0.262		
Standard error			DX (m) = $\pm 0,150$			DY (m) = $\pm 0,174$		

Table 1 - Absolute value of the discrepancies obtained

VII CONCLUSIONS

The results obtained in the accomplished experiments, it is verified that the procedure of Digital Monorestitution, developed in this work, it can be applied perfectly in rural planimetric mapping, using digital airphotos in the scale that facilitates the visualization of the entities to be mapped, as well as the necessary precision of the representation.

For the obtaining of compatible values with the stereophotogrammetric restitution the need of points that define the shape of the relief in fact, to provide the altimetric determination mathematically, inside of the necessary precision for the exact planimetric rectification of the point monoscopically observed.

The monorestitution procedure developed in this work, is applied mainly for digital planimetric mapping of existent natural and artificial entities in the terrestrial surface that don't present great heights in relation to surface of the land.

The difficulty of photo interpretation of certain photo identifiable details in the monoscopic image can be considered as the largest disadvantage that the procedure presents in relation to the stereoscopic technique. On the other hand, an enormous advantage is had as to means of operationalization of the process, because need of sharpness of stereoscopic vision is not necessary. The stereoscopic sharpness demands that only a highly qualified photogrammetrist accomplish the stereoscopic restitution.

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