Simultaneous image orientation in GRASS

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Abstract

The current procedure for the creation of othophotos in GRASS allows the orientation and the rectification of a single image at a time. This approach can be troublesome when the final product is a mosaic of orthophotos, since the orientations of the single images are independent and thus usually non coherent. Therefore inconsistencies can be present between parts of the mosaic coming from different images, in particular in the overlapping areas of the orthophotos.

A new procedure has been set up to partially solve this problem by the simultaneous orientation of all the images to be rectified and patched into the mosaic. The procedure uses a new program that performs bundle block adjustment and is fully compatible with GRASS' orthorectification procedure.

Tests show a significant better performance of the new procedure with respect to the traditional one.

1. Introduction

Orthophotos are images of objects in an orthogonal projection rather than a central projection, as usual images are. Unlike common images, orthophotos are compatible with cartography and they can be superimposed to it.

Orthophotos are used when speed or/and cost are critical parameters for cartography production, as it happens in the case of calamity or in the poor regions of the world. The rectification of aerial images is a routine procedure for cartographers and it is usually performed digitally, with the possibility of writing explicit equations for the transformation. Nowadays, the most common environment for the elaboration of cartographic data is a Geographic Information System, therefore the more advanced GIS are able to perform image rectification, usually with some restrictions as to the complexity of the terrain surface and to the attitude of the camera because this allows the adoption of a simplified formulation, thus simpler and faster programs.

Most of the available systems for image rectification can operate on one image at a time, however in practical applications more of one image is needed to cover the investigated area: it is therefore required the union of different orthophotos. This procedure is not typically simple as it is for common cartography, since the images to be joined differ from a geometric and a radiometric point of view. The aim of this work is to solve in part the problem of geometric differences between adjacent orthophotos for the creation of mosaics from geometrically coherent images.

2. Orthophotos

Normal images are central projections of a 3D object into a 2D plane (Fig. 1). These types of projections result in images where the scale changes from point to point: this behavior is incompatible with cartography, where the scale is constant on the whole map.

The process of transforming a central projection into an orthogonal projection is called *rectification*. It is usually performed analytically using the collinearity equations

$$\begin{cases} \xi = c\,\dfrac{r_{11}(X_0 - X_P) + r_{12}(Y_0 - Y_P) + r_{13}(Z_0 - Z_P)}{r_{31}(X_0 - X_P) + r_{32}(Y_0 - Y_P) + r_{33}(Z_0 - Z_P)} + \xi_0 \\ \eta = c\,\dfrac{r_{21}(X_0 - X_P) + r_{22}(Y_0 - Y_P) + r_{23}(Z_0 - Z_P)}{r_{31}(X_0 - X_P) + r_{32}(Y_0 - Y_P) + r_{33}(Z_0 - Z_P)} + \eta_0 \end{cases} \tag{1}$$

which express the collinearity of the point in the object space, the camera principal point and the point on the image, relating the image coordinates ξ and η to the focal length of the camera *c*, the rotation matrix components r_{ij}, the coordinates of the camera principal point (X_0, Y_0, Z_0), the coordinates of the point in the object space (X_P, Y_P, Z_P), and the internal orientation parameters ξ_0 and η_0.

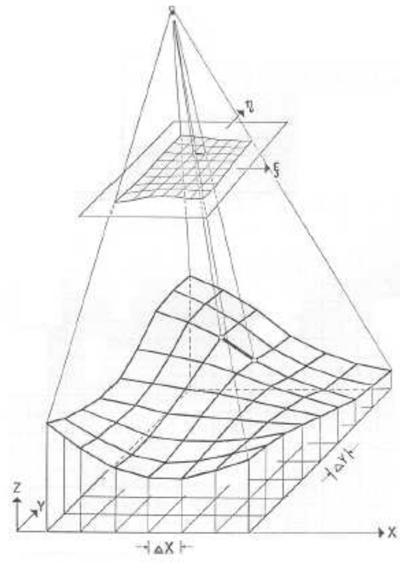

Figure 1 – Central projection of the 3D space into a 2D plane.

Collinearity equations can be used for different tasks in photogrammetry, depending on which parameters are known and which are unknown. In the case of image rectification the focal length of the camera *c*, the rotation matrix components r_{ij}, the coordinates of the camera principal point (X_0, Y_0, Z_0), and the internal orientation parameters ξ_0 and η_0 are known, and for the center of each pixel of the orthophoto of coordinates (X_P, Y_P, Z_P) in the object space the corresponding image point is located on the image by its coordinates ξ and η.
The color (or gray tone) of the point on the image is assigned to the pixel on the orthophoto. In general the coordinates ξ and η do not correspond to a pixel center on the original image, therefore programs usually operate an interpolation to select the proper color; the most common interpolation methods are the bilinear or the nearest neighbors interpolation, which provide good results with low computational costs.
An example of image rectification is given in figures 2 to 4, showing the original image (fig. 2) the corresponding orthophoto (fig. 3) and its 3D view (fig. 4).

Figure 2 –Aerial image of the town of Trento (courtesy of Provincia Autonoma di Trento).

Figure 3 – Orthophoto from the image of fig. 2.

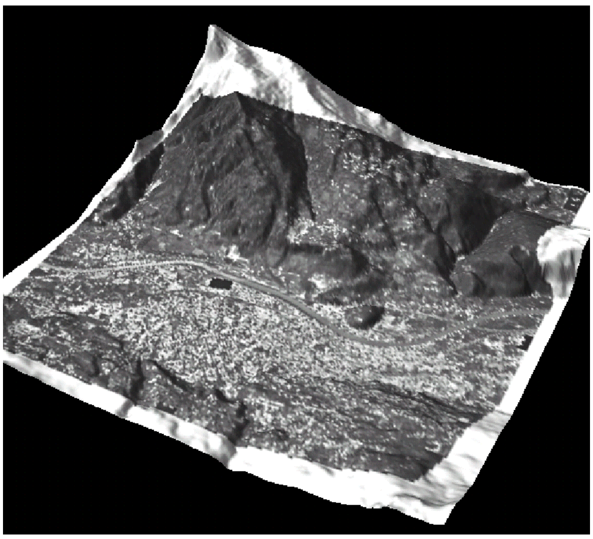

Figure 4 – 3D view of the orthophoto of fig. 3.

3. Orthophoto mosaicing

For practical uses most of the times a single image is not sufficient since the interesting area is larger or because it falls on the boundary of the image: it is therefore necessary to join more orthophotos into a mosaic. Orthophoto joining can lead to inconsistent mosaics due to the lack of coherency from the geometric and radiometric points of views between different images.

Geometric inconsistency (fig. 5) is mostly due to the approximations operated by rectification algorithms to approximations in the determination of the orientation parameters and by the fact that the orientation parameters of different images are evaluated using different ground control points, whose coordinates can have very different precisions.

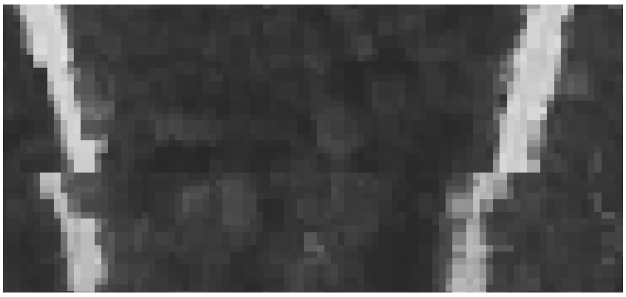

Figure 5 – Geometric inconsistency between two adjacent orthophotos.

Radiometric inconsistency (fig. 6) is caused by non uniform film sensibility, different attitudes during the image taking and different environmental conditions.

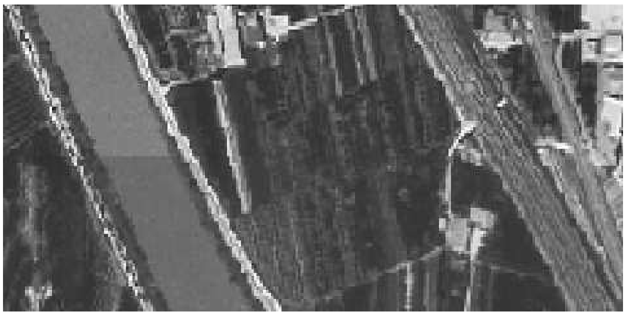

Figure 6 – Radiometric inconsistency between two adjacent orthophotos.

Radiometric inconsistency can be reduced by modifying the color histogram of the images to make them match so that the transition between one image to another is unnoticeable.

The reduction of geometric inconsistency can be obtained by implementing an algorithm that uses the collinearity equations without approximations, but this leads to high computational costs, while the orientation inconsistency can be reduced by the simultaneous evaluation of the orientation parameters of all the images used in the mosaic.

This paper presents the implementation of a procedure for the simultaneous evaluation of the orientation parameters of images using the bundle block adjustment approach. The procedure is integrated in the usual image orthorectification procedure of the GRASS GIS.

4. Bundle block adjustment

In the bundle block adjustment approach the system of equations (1) is solved in one step for all the images and all the point involved. Usually more ground control points coordinates than those needed to solve a system of equations like (1) are provided and a least square estimation is carried out. Equations (1) are not linear and must be linearized. Moreover, approximate values for the unknown parameters must be provided.

An original procedure for the determination of the approximate values of the orientation parameters has been implemented. This procedure is based on the similarity of the triangles in fig. 7.

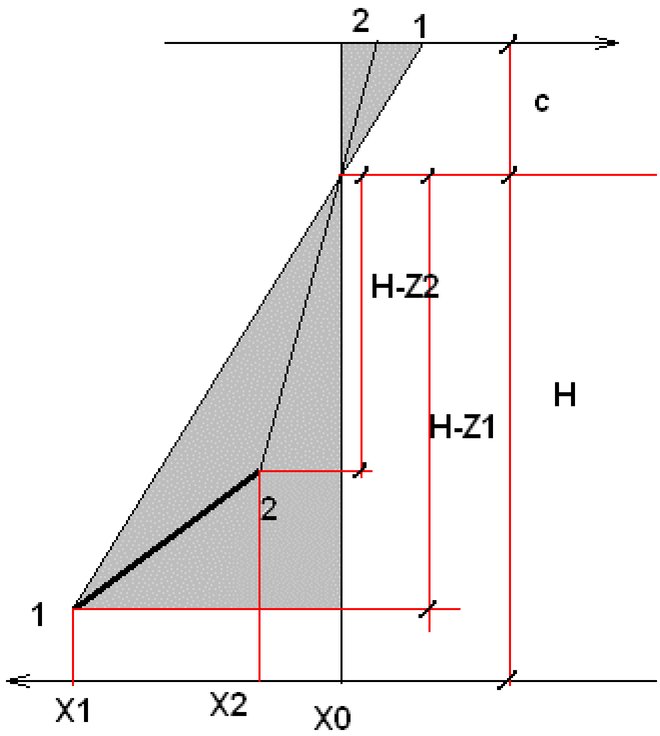

Figure 7 – Triangles used for the determination of the approximate orientation parameters.

For each point couple it is possible to write the following relations

$$\begin{cases} H = Z_1 + \left|\dfrac{X_1 - X_0}{x_1 - x_0}\right| \cdot c \\ H = Z_2 + \left|\dfrac{X_2 - X_0}{x_2 - x_0}\right| \cdot c \end{cases} \qquad \begin{cases} H = Z_1 + \left|\dfrac{Y_1 - Y_0}{y_1 - y_0}\right| \cdot c \\ H = Z_2 + \left|\dfrac{Y_2 - Y_0}{y_2 - y_0}\right| \cdot c \end{cases}$$

setting

$$\Delta Z = Z_2 - Z_1$$
$$\Delta x_1 = x_1 - x_0$$
$$\Delta y_1 = y_1 - y_0$$

These lead to

$$\begin{cases} X_0 = \dfrac{1}{\Delta x_1 - \Delta x_2}\left[\dfrac{\Delta Z \cdot \Delta x_1 \cdot \Delta x_2}{c} - (\Delta x_2 \cdot X_1 - \Delta x_1 \cdot X_2)\right] \\ Y_0 = \dfrac{1}{\Delta y_1 - \Delta y_2}\left[\dfrac{\Delta Z \cdot \Delta y_1 \cdot \Delta y_2}{c} - (\Delta y_2 \cdot Y_1 - \Delta y_1 \cdot Y_2)\right] \\ Z_0 = Z_1 + \left|\dfrac{X_1 - X_0}{\Delta x_1}\right| \cdot c \end{cases}$$

These equations are used to evaluate the coordinates of the camera principal point (X_0, Y_0, Z_0), while the attitude angles are all set to zero since this is reasonable for most of the images.
This equations system shows two singularities for aligned points and for points close to the origin of the image reference system. Infact, for aligned points the terms Δx_1-Δx_2 and/or Δy_1-Δy_2 vanish therefore X_0 and/or Y_0 tend to infinite. For points close to the origin of the image reference system the term Δx_1 vanishes, therefore Z_0 tends to infinite. Using the law of the propagation of the errors it is possible to estimate how the alignment of the points affects the approximation of the coordinates: for example if $\Delta x_1-\Delta x_2=10^{-1}$ m then $\sigma^2_{X0}=10^{-2}$ m^2, i.e. $\sigma_{X0}=10^{-1}$ m, while if $\Delta x_1-\Delta x_2=10^{-2}$ m then $\sigma^2_{X0}=4\ 10^8$ m^2, i.e. $\sigma_{X0}=2\ 10^4$ m. For points close to the image reference system's origin, if $\Delta x_1= 10^{-1}$ m then $\sigma^2_{Z0}=1$ m^2, i.e. $\sigma_{Z0}=1$ m, while if $\Delta x_1=10^{-2}$ m then $\sigma^2_{Z0}=10^4$ m^2, i.e. $\sigma_{Z0}=10^2$ m.

5. Implementation

The bundle block adjustment procedure has been implemented in a program that is compatible with GRASS, in the sense that its output is the same of the `i.points` GRASS module and it can be used as input for the `i.orthophoto` module.
The program reads from an auxiliary file (FOTO_PNTS.dat) the maximum number of images and points used.
Image coordinates are read from a file (C_OMOLOG.dat) that carries a record for each point, indicating the number of the point, the indexes of the images the point is visible on and its coordinates on each image. Ground coordinates are read from (INPUT.dat) along with the focal length of the camera and the orientation parameters. To each parameter in this file a flag is associated, indicating if the parameter is constrained, i.e. its values is known and not to be evaluated: it is possible in this way to pass to the program known (constrained) or approximate (not constrained) values.

6. Tests

Tests have been carried out to check if the simultaneous image orientation gives more coherent orthophotos and in which situation the gain is more relevant.
As reference situations against which the results are matched, two approaches to image orientation are used: in the first case each image is oriented as to create a single orthophoto without taking into account the sequent patching, following the standard guidelines for the choice of the ground control points, i.e. selecting points in the peripheral areas of the image. The second approach uses the same ground control points (tie points) for different images in the overlapping areas (fig. 8): this should give a better consistency of the orthophoto to be patched.

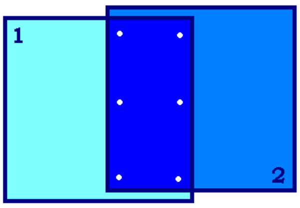

Figure 8 – Tie points for overlapping images.

The tests have been carried out for aerial images of a part the Adige valley around the city of Trento. Since the critical factor for image rectification is slope and its variation, a map of the slope has been created using the `r.slope.aspect` GRASS module.

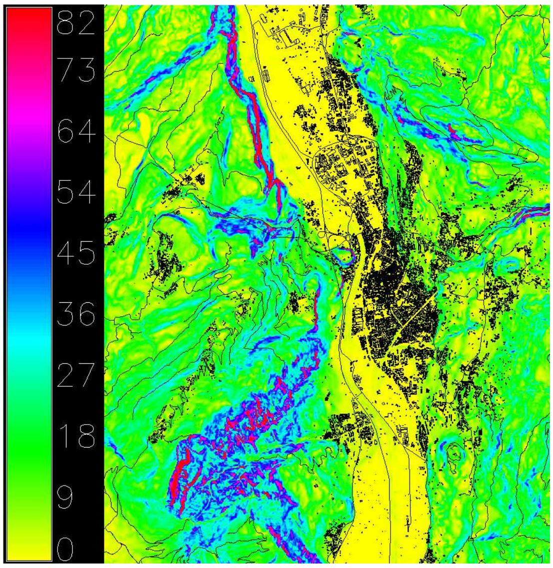

Figure 9 – Slope map [degrees] for the Adige valley near Trento, vector roads and settlements have been superimposed.

Four points showing different situations with respect to slope have been selected as test points (figures 10-12): the first one is located on a very slanting slope, the second one on a variation of the slope angle, the third one on the bottom of the valley with no slope, the fourth and last one on a mild slanting area on the east side of the Adige valley.

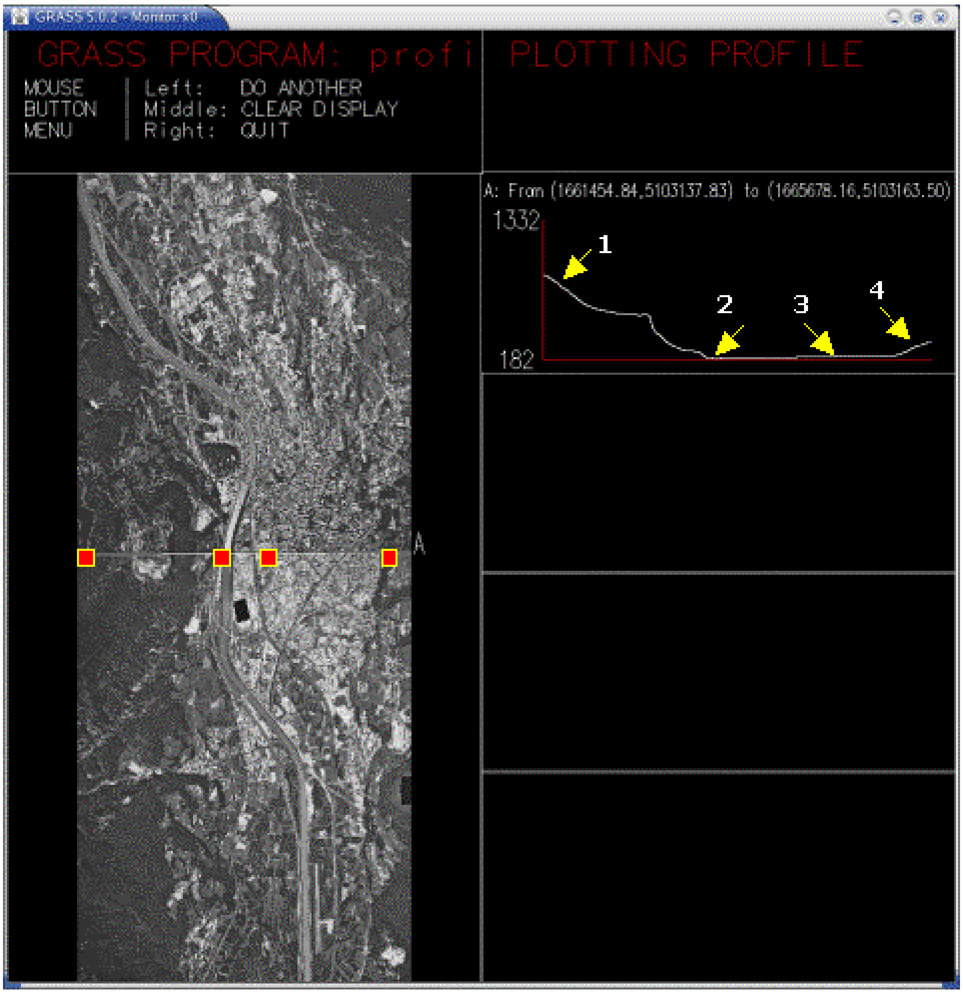

Figure 10 – Test points on the seam line between two orthophotos.

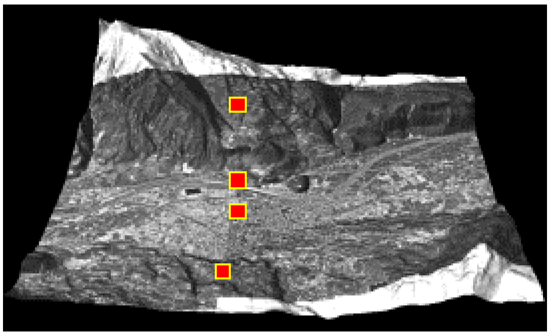

Figure 11 – Test points on 3D view.

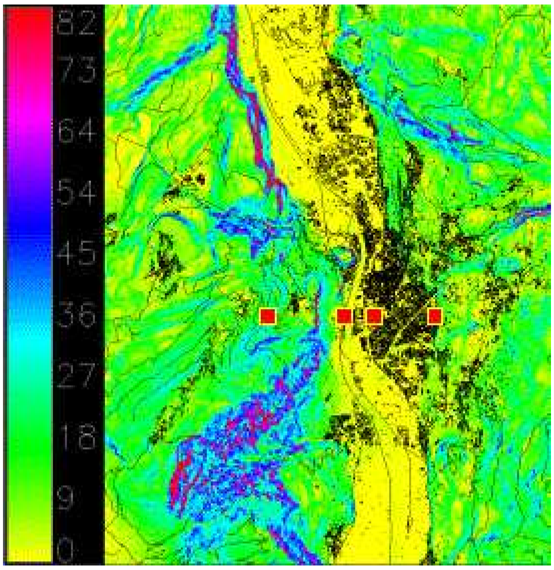

Figure 12 – Test points on the slope map.

For each test point the distance of two corresponding points (such as road or building sides) in two different orthophotos on the seam line has been measured for the tree approaches to the evaluation of the orientation parameters. The results are shown in table 1, where with the red color the worst results are highlighted, while the green color indicates the best results.

Mean shift [m]	Traditional approach	Tie points approach	Simultaneous orientation
Test Area 1 (very slanting slope)	4.10	4.70	2.80
Test Area 2 (variation of slope angle)	1.40	2.40	1.30
Test Area 3 (plane)	1.30	2.30	1.00
Test Area 4 (mild slope)	2.10	2.95	2.85

Table 1 – Distance between corresponding points on the seam line between two orthophotos.

The resolution of the orthophotos is of one meter, therefore shifts of this order of magnitude reach the intrinsic precision limit of the measurement on the images. In the first three test areas the simultaneous orientation of the images provides the best results, while for the fourth test area the naïve approach apparently performs best: this is probably due to the approximations of the rectification algorithm, which are somehow compensated by the inconsistency of the orientation parameters.
The use of tie points can lead to good results only when the overlapping area is relevant.

7. Conclusions

The new procedure, that uses a bundle block adjustment approach for the simultaneous orientation of the images to be patched after their rectification, allows a significant advance with regard to the continuity between adjacent orthophots. While the tests of the previous paragraph have been carried out with two images, the procedure is ready for the use with an arbitrary number of images, with the limit set by the hardware capability.

8. Bibliography

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