EPIPOLAR IMAGES FOR CLOSE RANGE APPLICATIONS

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ABSTRACT

Digital Photogrammetric Stations (DPS's) have been mainly designed to be used in aerial case issues and barely in close range photogrammetric problems. It is well known that the rotation angles, ω, φ and κ are quite larger in close range in contrast to the aerial case.
When the rotation angles of a stereo pair are larger than certain values, very often, stereo viewing is hardly been established. In cases where stereo viewing is not feasible, useful graphical elements for DTM generation, such as mass points and breaklines cannot be collected. In such circumstances –not having mass points and breaklines-, the commercial software for automatic DTM generation, is generally unable to generate a precise DTM.
The developed non-commercial software, has the ability to use simultaneously more than two epipolar images (a DPS can use just a pair), create the new interior orientation of epipolar images and executes a multi-image matching process. In this paper a technique is presented which explains how more than two epipolar images finally are used in a 3D restitution and multi-image point matching process in a successful way. The epipolar images as well as the matching process have been achieved on a DPS. Statistical tests in a case study close range problem are presented to support the proposed algorithm.

1. INTRODUCTION

Mainly, DPS's have been designed for aerial cases and barely for close range photogrammetric applications. It is well known that in close ranges cases rotations angles are quite larger than in aerial cases. When the rotation angles are larger than certain values, relative orientation and stereo viewing can barely be established in a DPS. These certain critical values are not mentioned by the vendors.

In such cases where stereo viewing is not feasible, the collection of useful graphical elements such as mass points and breaklines is not possible. It is proved that commercial packages developed for automatic DTM generation, cannot create correct, accurate and reliable terrain models if useful graphical data (mass points, breaklines) does not exist. Especially in close range cases, even a representative surface model cannot be created.

The commercial software's inability leads to the development of a technique, where useful modules of a DPS could be used and a new automatic restitution processes is introduced as an external application in order to produce additional data (mass points and breaklines) for correct DTM generation. For example, a DPS can easily and quickly create epipolar images if correct exterior orientation exists. In contrast, a DPS cannot use simultaneously more than two images, either original or epipolar and thus a multi-image matching process is not possible. The home made software is a standalone application that manipulates both original and epipolar images of a photogrammetric project. The application does not have any special requirements of hardware configuration since it does not use stereo-viewing for the collection of conjugate points on the images i.e. monoplotting (e.g. Derenyi & Chen, 1994). In that way a DPS can play the role of the specialized hardware for the production of epipolar images that can be shared to many other non-specialized PCs that run the automatic restitution application for many different photogrammetric projects.

A technique has been developed which can use more than two epipolar images in a 3D restitution and multi-image matching process. It is very important to use more than two images for a global check of matching results and the elimination of gross errors (e.g. Maas, 1996, Shao & Fraser, 1998). The externally created CAD file from the automatic restitution process, can be easily now used as a file which contains all the useful graphical data for the successful execution of the matching process. In addition, the non-commercial package is user friendly and does not demand certain ability for stereo viewing. The points' collection is carried out in just one of the epipolar images (monoplotting), and the conjugate points on the other images are automatically calculated using the least square epipolar image matching tech-

Figure 1. The strategy of the algorithm

Within Figure 1, the following labels appear:

Original image

DPS

Epipolar image

Projective Transformation
(I.O of Epipolar images)
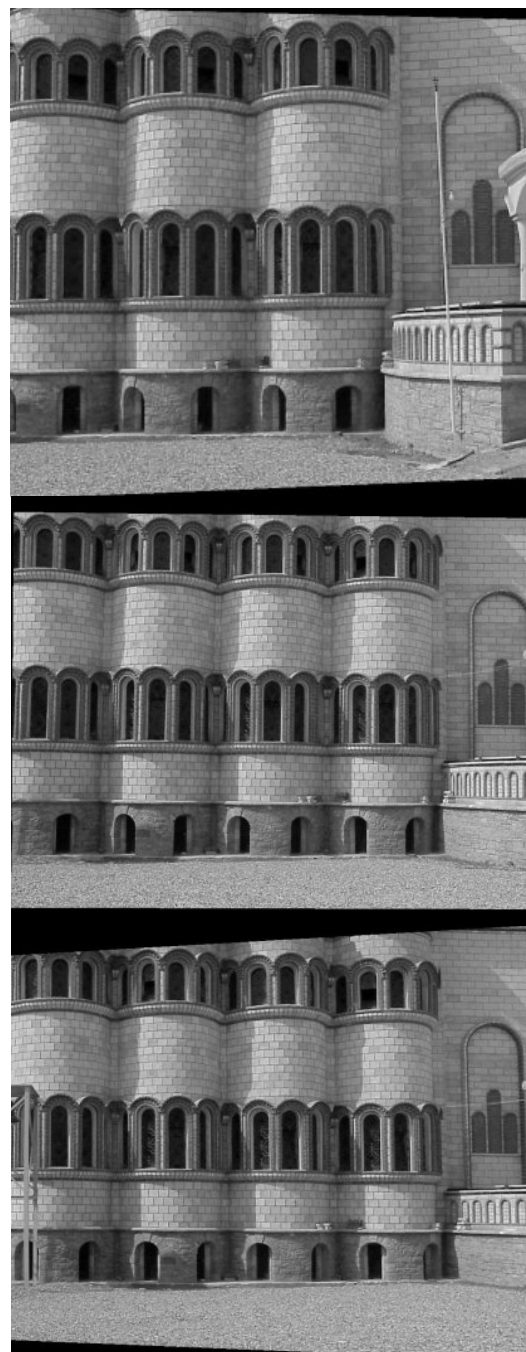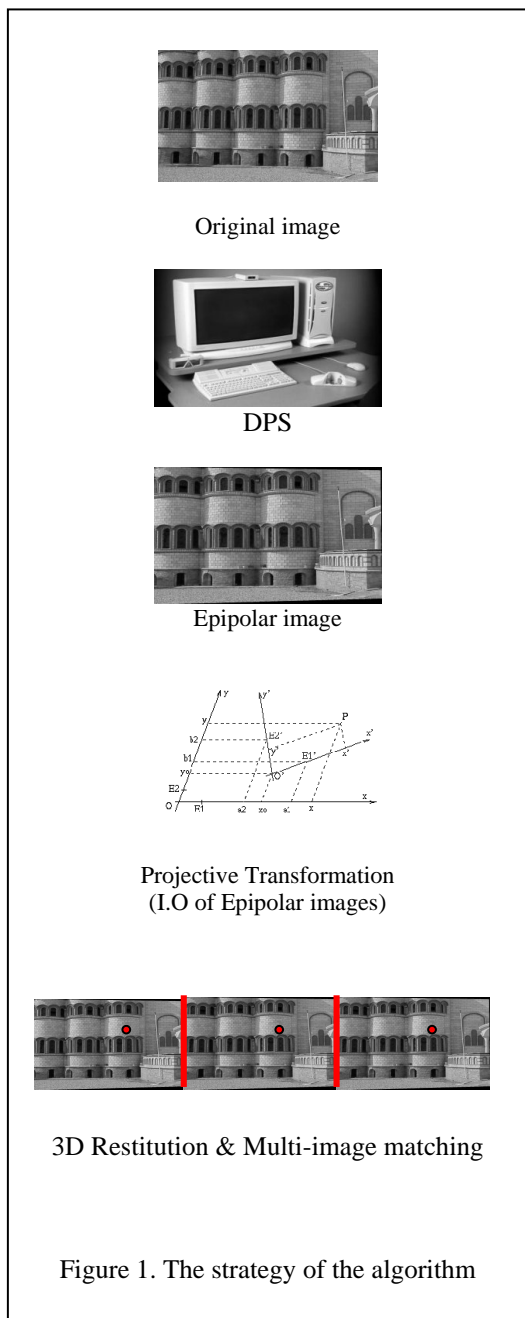
3D Restitution & Multi-image matching

Figure 2. Epipolar image triple created in a DPS

nique (Heipke, 1992). In addition the user observes the correct selection of the conjugate points on the other images, and has also the ability to accept or reject the suggested matched point.

2. EPIPOLAR IMAGES

Normalization of digital images is called the process of:

- their transformation in the normal case or
- the establishment of their relative orientation or
- the y-parallax elimination or
- their transformation in new images where their relative rotation angles are zero or
- their transformation in new images where the scan lines are the epipolar lines
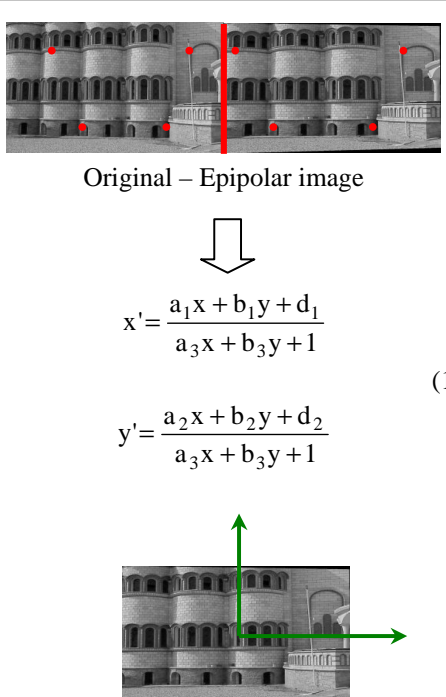
All the above definitions are equivalent but the last one seems to be the most useful because it shows how important is the use of the tool, called epipolar geometry. The new normalized images are parallel to the base of each stereo-pair and their scale is identical.

For this project, a DPS photogrammetric software was used to create the epipolar images of an original image triple. Previously, exterior orientation for the triple has been calculated in a bundle adjustment process. Sigma has been calculated at 0.3μm and RMS values for X,Y,Z at 1.2cm, 1.5cm and 1.5cm respectively while maximum residuals for X,Y,Z reached 2.7cm, 2.4cm and 3.2 respectively as well. The three epipolar images are shown in Figure 2, left, central and right from top to bottom. The original images have been acquired with the digital camera Sony Mavica FD81 (image size: 1024x768 - pixel size: 4.7μm).

The epipolar image creation is an essential step in order to perform, in an easy and quick way, the conjugate point collection. It is well known from epipolar geometry that conjugate point localization on the epipolar images is an one dimensional convolution (searching process) along their scanlines.

2.1 Epipolar image interior orientation

In a general approach it is assumed that the epipolar image is a product of a projective transformation of the original one having as projection center, the lens center. Thus, it can be assumed that the fiducials' positions in the epipolar image has been changed by a transformation where the parameters can be calculated if stereo pair relative orientation parameters are known. Unfortunately, the epipolar images are created by DPS and thus it is not possible to know those transformation parameters, which are useful to convert the measurements on the epipolar image to observations on the negative plane.

The calculation of the projective transformation parameters can be achieved using a correlation process for interesting points (high textured points) between the internally oriented original image and the corresponding epipolar. The collection of at least four conjugate points – on the original and epipolar image- is enough to calculate those transformation parameters, while having more than four points an adjustment process can be performed. The test results in the image triple shows that the a-posteriori standard deviation could be lower than a pixel.

A projective transformation (Equation 1) of eight parameters has been used to calculate these parameters and set the interior orientation of each epipolar image.

3. THE ALGORITHM

The automatic determination of conjugate points is achieved with the use of epipolar image matching technique. The innovative aspect about the proposed algorithm is the use of additional constraints in order to minimize the search space along the epipolar lines for conjugate points localization.

In the automatic restitution process only the first point needs to be collected manually on all the epipolar images. After that, the automatic localization point is switched on. The user must define the next interest point just in one of the epipolar images. The algorithm calculates an approximate position of its conjugates taking into account the line segment length and its gradient, as well as the condition that this point should lie on the same scanline. Through a correlation and matching process the exact location of conjugate candidates is found on all the other images. Using these constraints the search area is significantly minimized and normally leads to fast 3D restitution for object reconstruction.

Original – Epipolar image

$$x' = \frac{a_1 x + b_1 y + d_1}{a_3 x + b_3 y + 1}$$

$$y' = \frac{a_2 x + b_2 y + d_2}{a_3 x + b_3 y + 1}$$

(1)

Interior Orientation for each one of the epipolar images has been settled

• Must be common points (at least four)

Figure 3. The strategy for settling epipolar image i.o

Another advantage of the algorithm is the ability to use more than two epipolar images. This can provide not only better accuracy for the calculated ground coordinates but also a blunder check. Conjugate points can be assumed correctly calculated, if the differences in ground coordinates (DX, DY, DZ) between the different pairs of the photogrammetric intersection processes do not exceed a threshold defined value (Tsioukas & Patias, 1999). However the ground coordinates' calculation of every possible pair of conjugate points in all the epipolar image models is a time consuming process. An alternative approach is to eliminate wrong matches (blunders) based on approximate height determination through the x-parallax formula (1).

Figure 4. Example of automatic 3D restitution

On the central image bellow (Figure 4) the user has selected a point on a breakline. More than one possible conjugate points have been found along the epipolar line buffer (3 pixels above and below) on both the left (A,B,C) and right images (F,D,E). Let P_1 be the x-parallax of the previously correctly located point on the breakline (point No.1) of the left-central model. An approximate value of the height for the next collected point (G in the central image) can be expressed by the following equation (Patias, 1991):

$$Z_G = Z_1 + \frac{DP(H-Z)}{P_G} \qquad (1)$$

where P_G is the x-parallax of point G and DP is the parallax difference $P_1 - P_G$. Similarly Z_A, Z_B, Z_C are computed for the left image and Z_F, Z_D, Z_E for the right.

By comparing the height estimation of every possible point on each pair model, trashing out of the wrong matching points is achieved. The remaining points are conjugates to the manually collected point on the central image and they are drawn on each image window. The user is finally prompt to accept or reject the algorithm's suggestion. In case a point does not find a match, the user may manually collect its conjugate on the other images.

3.1 Useful hints for algorithm success

In the next few lines, some useful information for the successful algorithm execution is presented.

- The object's high color texture is an essential condition for the success of correlation and matching process.
- Small line segments drawn manually in the first image, give better approximate values for conjugate points in the other images. If line length is large then the position of the conjugate point may not lie in the region of the calculated approximate value.

- The user has the ability to collect manually the point in cases where point matching fails.

Finally, the software exports a 3D DXF file of all the collected graphic elements. This is very useful basically for two reasons:

- a 3D restitution of the presented object is a real digital CAD product
- a 3D DXF that constitutes the CAD file with breaklines and mass points.

4. EXPERIMENTAL RESULTS

Experimental test took place in a new built church. Figure 4 presents the results for DTM as produced by a DPS matching software without any helpful information such as breaklines or mass points. As it can be seen, results are extremely bad in contrast with the ones presented in Figure 5, where additional information was used. The cylindrical surfaces are described with adequate fidelity whereas only few points were incorrectly calculated.
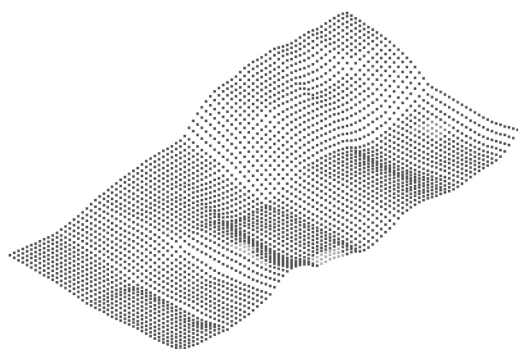
Figure 4. DTM generated without any additional data (breaklines, masspoints)
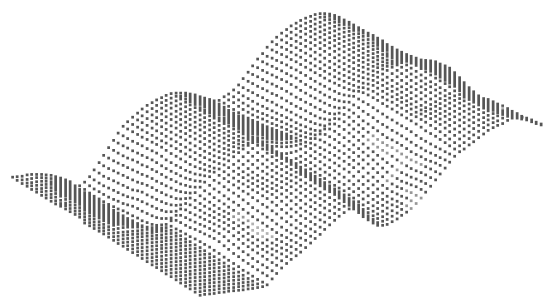
Figure 5. DTM generated when in matching process additional data have been used

The selected surface occupies an area of 32 m^2 and DTM grid width has been selected at 10cm. The estimated internal height precision has been calculated approximately to 1cm in both cases. However this criterion does not include any ground truth and does not represent the actual accuracy of the surface model as well. Additionally, in Table 1 values for minimum and maximum calculated height are presented. In the ground coordinate system it is known that objects height is in the range of 0m to 1m approximately. This leads to the conclusion that results coming from the DTM which was generated without any additional data (Figure 4) is very bad and does not represent the reality. In contrast, when additional data are used (Figure 5), the created surface model is very close to the real object.

	Minimum height (m)	Maximum height (m)
Case 0 (Reality)	~ 0	~ 1
Case 1 (Figure 4)	-1.17	0.13
Case 2 (Figure 5)	-0.05	0.94

Table 1. DTM statistics

5. CONCLUSIONS

The proposed technique has been developed to run either as a standalone application for automatic 3D restitution for close range applications or as a parallel and complementary process of a typical strategy that is used in the majority of photogrammetric applications in the DPS.

The developed technique has many advantages that are analyzed below:

- It can use simultaneously more than two images in a monoplotting process. This process demands the collection of a point in just one image. A two step process, crosscorrelation and matching, automatically collects the conjugate point and calculates its 3D coordinates. It is a more useful and productive for non-experts or for those who are not familiar to stereo viewing.

- Due to the fact that a third image is used, an automatic blunder detection can be performed.
- It avoids blunders created by repeating patterns on the object. Except from the epipolar constrain that is used, additional conditions are taken into account. In the automatic restitution module, the length and the gradient of the sketched line in the first image is used as additional constrains, as they should have similar values to the other epipolar images.
- It does not need special hardware. Thus it gives the ability to distribute much of the DPS tasks to other supporting PCs.

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