A SOLUTION FOR THE GENERAL CASE OF THE THREE-IMAGE ORIENTATION

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ABSTRACT:

In an easy solution for three - image orientation, each model coming from two images of a triplet is analyzed and the relative orientation between them computed, by using an exhaustive research of preliminary values of its parameters. This non-conventional approach supplies the orientation of two images, taking into account a priori information among four base solutions. The automatic procedure of orientation wants to skip the manual assessment by using three images, which would allow to solve for the ambiguous solutions. Once each model has been relatively registered, the absolute orientation is computed by using a linear parameterization of this problem.

1. INTRODUCTION

1.1 Orientation procedures in photogrammetry

Orientation procedures play a fundamental role in the object reconstruction process of photogrammetry. Traditionally, the call for stereo-vision leaded to setup a geometric solution based on *interior* and *relative* orientations, which are the pre-requisite for any further task to extract information from a pair of images. The former refers to the determination of 3 intrinsic parameters (principal distance and coordinates of principal point in the camera reference system), the latter to the computation of the baseline vector linking two perspective centres and relative rotation of one image with respect to the other; the number of unknown parameters adds up to 5, which usually follow one of two geometric model, namely the *symmetric* and *asymmetric* one. By introducing the knowledge of ground information (e.g. GCPs) the *absolute* orientation can be computed and the model computed from relative orientation can be transformed into the real world, or to a scaled representation of this such a topographic map. Research on this topic has been attracting the interest of photogrammetrists in the first mid of 20^{th} century (Finsterwalder, 1899; Fourcade, 1926; Kruppa, 1913).
From the 50's to 70's, mathematical fundamentals of *analytical photogrammetry* were established. New formulations of two-image orientation were published (Semple & Kneebone, 1952; Thompson, 1959; Stefanovic, 1973), while the unexplored field of *aerial triangulation* began to be dealt with (Schmid, 1954; Schut, 1955-56).
Two topic aspects have to be focused concerning orientation procedures in photogrammetry up the so called "analytical era":

- the use of analogue imagery and of purely manual measurement for orientation purposes, resulting in the use of a small set of accurate points for computing relative and absolute orientation; this fact limits the problem of blunders to a small number of gross errors (due to wrong labelling, image content misunderstanding and the like) and to a low fraction of small errors.

- orientation problems such as formulated in photogrammetry are non-linear and they are usually solved by a Least Squares approach, after a linearization of equations. In this way, L.S. adjustments can run automatically and more refined treatments (e.g. robust procedures and re-weighted L.S.) can be performed, step by step, always solving linear systems. It is obvious that all methods can start only if the preliminary values of the unknown parameters are known. Aerial blocks feature regular shapes, so that approximations may be easily derived, because the project for data acquisition define these parameters with a sufficient accuracy, or auxiliary measurements are available at the time of data acquisition. But also close-range blocks, up to 70's show configurations, which are very similar to those of aerial photogrammetry, offering the same possibility to solve for approximations.

These statements will result fundamental to comprehend the changes introduced in photogrammetric orientation approaches in the following decades.
Since the 80's a new challenge defied the community of photogrammetrists, given by the possibility of managing and processing digital images by computers. Whether the concept of a totally *digital stereo-plotter* (Sarjakoski, 1981) became in few years a reality, on the other hand automation of all analytical orientation procedures was the topic research issue up to the end of 1900 (for a review see Heipke, 1997).

1.2 Photogrammetry meets Machine Vision

The development of *digital photogrammetry* is parallel to that of *machine* and *robot vision* techniques. Here the problem of object reconstruction is needed for specialized and real-time purposes, such as object recognition, production and quality control, vehicle and robot guidance an so on, not for deriving cartography of however a wider description of the space. This fact limits the number of digital sensors to be used to the minimum: in case of objects lying in a plane, a single image, in case of 3D object a two-image configuration will be adopted, tuning the interest on relative orientation procedure. For this reason, many algorithms have been developed to cope with this task, keeping into account the possibility of solving for any geometric configuration (no approximation needed) and the use

of uncalibrated sensors (cameras and video-cameras). Thus linear methods to solve for relative orientation[1] based on the *essential matrix* (Longuet-Higgins, 1981) and on the *fundamental matrix* (Faugeras *et al.*, 1992), algorithms integrating self camera calibration (Hartley, 1992), applications to motion vision (Weng *et al.*, 1993) and estimation techniques different for classical L.S. have been introduced. A review on this subject can be found in Hartley and Zisserman (2000).
The impact of these solution to photogrammetry was twofold:

- solution to the problem of approximations, which are found by applying linear method and then refined by standard photogrammetric equations; ih this case derivation of geometric from algebraic parameters is needed (see Hattory & Myint, 1995; Pan, 1999).

- preliminary gross outlier rejection, integrating high break-down robust techniques (Torr & Murray, 1997).

Several matching techniques were developed to fin homologous points and features. While in photogrammetry orientation equations are prevalently point-based, machine vision techniques also exploit other kinds of constraints, such as lines, surfaces and angles.
Nevertheless object reconstruction from a pair of images suffers from low redundancy, being the control on the extracting of homologous point by matching techniques limited to epipolar constraints. To overcome this drawback, a formulation of the relative orientation of a triplet of images has been established through the so called *trifocal tensor* (also referred to as *trilinear tensor*), introducing a higher redundancy (Spetsakis & Aloimonos, 1990; Hartley, 1994)[2]. A review can be found in Ressl (2000). Application of trifocal tensor to solve for approximations in standard orientation procedures (relative orientation, AT) is very useful, because it allows to deal effectively with large fraction of blunders, such those resulting from automatic extraction of tie points by matching techniques. However as in case of relative orientation, derivation of geometric parameters must be computed.

1.3 Three-image orientation through exhaustive research

In this work, we tried to solve the non-linear problem of three-image orientation based on the classical background of photogrammetry. Solution such as those based on the trifocal tensor could be very useful for stand alone problems such as those of machine vision. When approximate values of geometric orientation parameters of a standard photogrammetric block have to be found, a solution giving this parameterization (or a similar one, e.g. requiring only a 3D transform) would be better. In Mussio & Pozzoli (2003a,b) a solution of relative orientation problem based on exhaustive research of the preliminary values of parameters has been proposed.
Exploring the 3D space with a step of Π/4 is possible to find all the preliminary values of the unknown orientation parameters. This idea want to avoid the linearization of the orientation functions supplying the lack of information about the position and the attitude of an image.

[1] In reality the paper of Thompson (1959), coming from photogrammetry, already proposed a linear method for relative orientation which was similar to that of Longuet-Higgins.

[2] Also in this case (see note 1), formulation of the dependency among three images was already published in photogrammetry by Rinner & Burkhardt (1972).

2. FROM IMAGES TO OBJECT VIA MODEL

The main function of photogrammetry is the transformation of data from the image space to the object space. We can make this transformation in a direct way, with collinearity equations, or in two steps, with the formation of a model and, only in a second time, reconstructing the original object (Kraus, 1993). First of all, we have to take into consideration that:

- an image is not a map;
- at least two images are needed for reconstructing an object.

A relation of roto-traslation with scale variation constitutes the link between the coordinates of the point Q (x,y,z) in an image, and the coordinates of the corresponding point P (X,Y,Z) in the object space. Both reference systems are traditionally Cartesian reference systems, but the same is true, with minor changes, using a different reference system, suitable linked to the previous ones. Let us show the above mentioned relation:

$$\begin{vmatrix} x^\circ \\ y^\circ \\ -c \end{vmatrix}_{ij} = \hat{\lambda}_{ij}\hat{R}_j \left(\begin{vmatrix} \hat{X} \\ \hat{Y} \\ \hat{Z} \end{vmatrix}_i - \begin{vmatrix} \hat{X}_0 \\ \hat{Y}_0 \\ \hat{Z}_0 \end{vmatrix}_j \right) \qquad (1)$$

where x^0, y^0, c = image coordinates and principal distance
$\hat{X}_0, \hat{Y}_0, \hat{Z}_0$ = coordinates of projection center
$\hat{X}, \hat{Y}, \hat{Z}$ = object coordinates
λ = scale factor, variable point by point

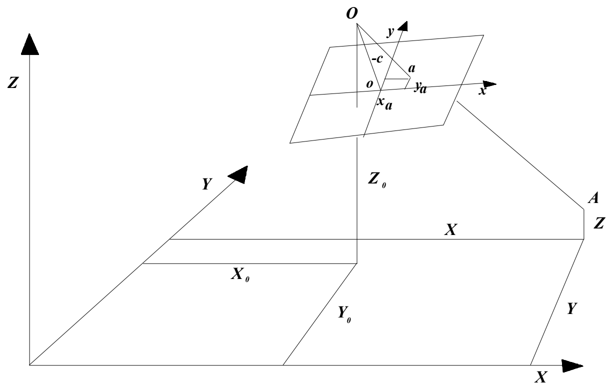


Figure 1. Reference Photogrammetric Systems

3. PROJECTION TRANSFORMATION

The photogrammetric technique is based on a transformation of a perspective (or a couple of perspectives) in a quoted orthogonal projection. In this transformation, we have non-linear equations and, before starting the plotting, we need information about the preliminary value of unknown parameters. Our main aim is to find expressions working with parameters easy to be obtained. We choose a *'two steps'* procedure to orient two images in the 3D space. This procedure does not use the classical collinearity equations (*12 parameters*: X_1, Y_1, Z_1, X_2, Y_2, Z_2 -coordinates of the two projection centers, and ω_1, φ_1, κ_1, ω_2, φ_2, κ_2 -attituded angles of the two sensors), but separates the model formation (Relative Orientation) from the object reconstruction (Absolute Orientation). In this procedure, we define the problem of

Absolute Orientation by means of 7 parameters: t_x, t_y, t_z (shift vector), λ (scale factor), Ω, Φ, K (Cardanic angles). On the contrary, to define the problem of Relative Orientation, we need 5 parameters: φ_1, κ_1, ω_2, φ_2, κ_2 (Symmetric Relative Orientation), or b_y, b_z, ω_2, φ_2, κ_2 (Asymmetric Relative Orientation).

4. MODEL CONSTRUCTION

4.1 Relative Orientation Parameters

Regarding the Relative Orientation, we make an exhaustive research of the preliminary values, solving a linearized problem in all its possible cases. Notice that an exact solution has been found (see par 1.2), but it leads to an equation of order four, which supplies four plausible solutions, as we can easily achieve by repeating a linearized problem via an exhaustive research. In case of Asymmetric Relative Orientation, we have to define b_y, b_z, ω_2, φ_2, κ_2, which are the parameters of position and attitude of the second image, compared to those of the first image. Notice that b_x is already defined in the Absolute Orientation, as the scale factor λ. In case of Symmetric Relative Orientation, we have to define φ_1, κ_1, ω_2, φ_2, κ_2, parameters which represent position and attitude of the two images. Notice that ω_1 is missed because it is already defined in the Absolute Orientation, as the global attitude angle Ω.

4.2 Exhaustive Research

For the Relative Orientation, we should have previous information about the preliminary values of the parameters. It is not always possible to know them, before the plotting. Let us point out that non-conventional photogrammetry implies often camera acquisition without classical surveying measurement. If we consider the classical Symmetric procedure of Relative Orientation, we can make an exhaustive research of all possible preliminary parameters, because we work in a closed group (in the topological sense) of values compared to the rotations in the space.
Notice that in the Asymmetric procedure of Relative Orientation, we have two shift parameters to be searched, but the group of shifting is not a closed one, so we had to use a different way to find the preliminary values. However with the following relations is possible to transform the Symmetric Relative Orientation parameters in the Asymmetric ones, and vice versa:

$$b_x = cos\,\varphi_1\, cos\, k_1 \qquad \varphi_1 = arcsin\, b_z$$
$$b_y = cos\,\varphi_1 sink_1 \qquad k_1 = arctan\frac{b_y}{b_x} \qquad (2,3,4,5,6)$$
$$b_z = sin\varphi_1$$

$$R_2^T(\varpi_2\varphi_2 k_2 | b_x b_z) = R_2^T(\varpi_2\varphi_2 k_2)R_1(\varpi_1\varphi_1 k_1) \qquad (7)$$
$$R_2^T(\varpi_2\varphi_2 k_2) = R_2^T(\varpi_2\varphi_2 k_2 | b_x b_z)R_1^T(\varpi_1\varphi_1 k_1) \qquad (8)$$

The convergence of linearization of trigonometric functions is acceptable as far as values lower or near Π/4. Therefore we decided to explore all the admissible values for rotation angles with a step of Π/4, as shown below:

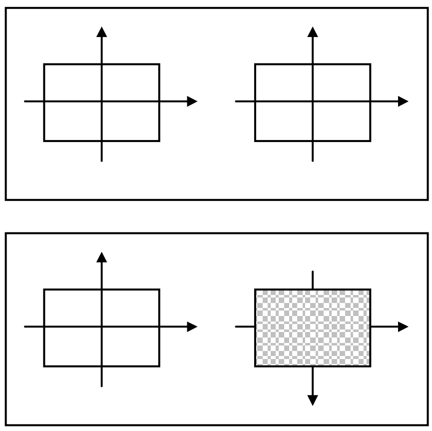
	φ_1	k_1	ω_2	φ_2	k_2
Π/2	∘			∘	
Π/4	•			•	
0	•	•	•	•	•
Π/4	•	•	•	•	•
Π/2	∘	•	•	∘	•
3Π/4		•	•		•
Π		•	•		•
5Π/4		•	•		•
3Π/2		•	•		•
7Π/4		•	•		•

Table 2. Exhaustive Research for Symmetric Relative Orientation parameters

where ∘ $k_1 \equiv 0$ if $\varphi_1 \equiv \pm\Pi/2$ and/or $k_2 \equiv 0$ if $\varphi_2 \equiv \pm\Pi/2$

As known, if the φ angle is around ±Π/2, we can not individuate the k rotation, which is fixed equal to zero. Indeed in the polar zones (we assumed their range in a circle of one degree), the two angles are identical or quasi identical, and this fact produced singularity or ill-conditioning.
The exhaustive research explored $5 \times 8 \times 8 \times 5 \times 8 = 12800$ possible configurations. For each case, a linear system was solved, using the values of this configuration (case), as preliminary values of the parameters of the Symmetric Relative Orientation.
Examples were carried out in all the middle points of the possible configuration. Considering the 5 parameters of the Symmetric Relative Orientation, the angles κ_1, ω_2, κ_2 are defined in a complete rotation (8 configurations), whilst φ_1, φ_2 are defined in a half rotation (5 configurations), which led to the above mentioned 12800 cases.

Each linear system solution gave us the estimate parameters for the Symmetric Relative Orientation. The convergence to admissible values is when σ_0 is small enough. Considering only the distinct solutions, we found four analytical acceptable configurations.



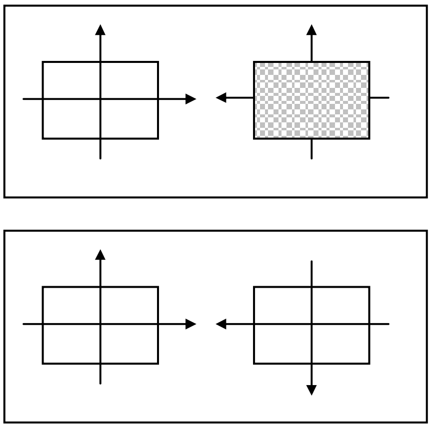


Figure 3. The 4 final possible configurations

These configurations are really different, so it is not so difficult to have information about the initial position of the images, in every specific case. If an operator would select the proper case, it is possible to calculate the estimate parameters for the expected Symmetric Relative Orientation.

5. 3-IMAGE PROCEDURE

In our approach, we choose to use three images to operate the global procedure, in order to eliminate the human decision. Actually to start the Absolute Orientation, we have to select manually one among the founded four configurations. Introducing the third image, we want to bypass the human decision, turning it automatically.
The step of the Model Construction furnishes four admissible solutions, as above said, and produce four distinct models (called A,B,C,D). In case of three partially overlapped images, this step can be repeated two times. Indeed the model 1-2 can be formed by the images 1 and 2, and the model 1-3 can be formed by the images 1 and 3.

5.1 Bridging the models

A 3D S-transformation allows to make the bridging of these models, taking into accounts all the four models obtained according to the admissible solutions founded in the Relative Orientation. The procedure leads to sixteen different small blocks, as it is shown below:

	2A	**2B**	**2C**	**2D**
1A	**1A-2A**	**1A-2B**	**1A-2C**	**1A-2D**
1B	**1B-2A**	**1B-2B**	**1B-2C**	**1B-2D**
1C	**1C-2A**	**1C-2B**	**1C-2C**	**1C-2D**
1D	**1D-2A**	**1D-2B**	**1D-2C**	**1D-2D**

Figure 4. Models Bridging

The majority of these blocks are completely unlikely; indeed the sigma naught of the 3D S-transformation adjustment is enormous. This fact is reasonable because if and only if both models (1-2 and 1-3) are congruent between themselves, the bridging can be carried out successfully.
The set of congruent and incongruent combinations supplies only two small blocks whose sigma naught is satisfying. The two small blocks are originated from two different admissible solutions in each four couple; (this means that) putting in a square table all the sixteen solid structures, the two congruent ones belong always to different rows and columns.
The analysis of the geometry of four admissible solutions recognizes the high regularity of the presented values. As a consequence, the two congruent small blocks present 3D coordinates in two mirror reference frames.

6. OBJECT RECONSTRUCTION

6.1 Absolute Orientation Parameters

Starting from a roto-traslation in the space, a rational alternative to classical Rotation Matrix is the *Rodriguez Matrix*.

$$\mathbf{R} = (\mathbf{I} - \mathbf{S})^{-1}(\mathbf{I} + \mathbf{S}) \qquad (9)$$

where **I** is the *identity matrix* of 3x3 dimensions, and **S** is an emisymmetric matrix defined as follows:

$$\mathbf{S} = \begin{vmatrix} 0 & c & -b \\ -c & 0 & a \\ b & -a & 0 \end{vmatrix} \qquad (10)$$

This *emisymmetric matrix* **S** permits to find the exact solution of the absolute orientation problem, thanks to the solution of a linear system, after a suitable substitution of variables.
After simple substitutions, we obtain a linear solution, showing the direct proportion between the model coordinates $x = x(u°, v°, w°)$ and the object ones $y = y(X, Y, Z)$:

$$y_i = Rx_i = (I - S)^{-1}(I + S)x_i \;\Rightarrow\; (I - S)y_i = (I + S)x_i) \qquad (11)$$

Reorganizing matrices and vectors, in a way which collects in a unique vector the three unknown parameters, coming from the above mentioned emisymmetric matrix, we obtain the following final equation:

$$\begin{vmatrix} 0 & (\hat{Z}_i - w°_{ij}) & -(\hat{Y}_i - v°_{ij}) \\ -(\hat{Z}_i - w°_{ij}) & 0 & -(\hat{X}_i - u°_{ij}) \\ (\hat{Y}_i - v°_{ij}) & -(\hat{X}_i - u°_{ij}) & 0 \end{vmatrix} \begin{vmatrix} \hat{a}_j \\ \hat{b}_j \\ \hat{c}_j \end{vmatrix} + \begin{vmatrix} \hat{X}_i - u°_{ij} \\ \hat{Y}_i - v°_{ij} \\ \hat{Z}_i - w°_{ij} \end{vmatrix} = 0 \qquad (12)$$

6.2 Exact Solution of the Absolute Orientation

In our procedure for the Absolute Orientation, the object reconstruction does not need preliminary parameters, because we can reach the exact solution, by solving the linear system, mentioned in an above paragraph.

6.3 Absolute Orientation with 3-image procedure

If we have to manage two different small blocks in two mirror reference frames, the qualitative comparison with the object coordinates select automatically the congruent configuration. As well known, a 3D S-transformation permits to compare model and object coordinates, transforming the first coordinates in the second ones. The 3D S-transformation can be done in a linear way, in fact the whole procedure terminates with a unique solution, which traces back all the path followed, enhancing the correct choices at the different steps and eliminating the wrong possible alternatives.

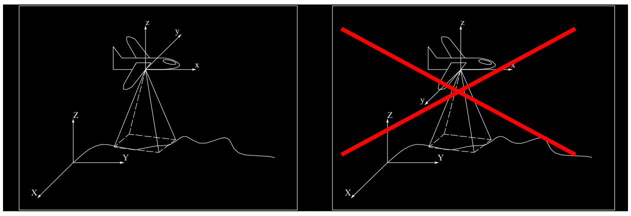


Figure 5. The 2 small blocks obtained after the model bridging (the second one is incongruent)

7. NUMERIC EXPERIMENTS

To verify precision, accuracy and reliability of these techniques, a program in FORTRAN 95 has been implemented and tested. It runs on a Pentium 3 PC, with 933 MHz – 262 Mb / RAM – 30 GB / Hard Disk. The exhaustive research for the Symmetric Relative Orientation works in 4 - 5 seconds, while all others procedures are immediate. In all the examples, we introduced random errors, with standard deviation of 20 µm, as usual in photogrammetry. Here we present an explanation of these programs:

ORPHO_ it converts Cardanic angles in Eulerian angles and vice versa. This is a very large used transformation in close range photogrammetry, because it is essential for the image orientation, when the rotation angles are acquired by surveying measurements.

ORSYM_ it calculates the preliminary values for the Symmetric Relative Orientation. It solves 12800 linear problems, exploring all possible configurations in the space, with a step of Π/4. The same program, choosing one of the four distinct solutions, permits to calculate the preliminary parameters for the Asymmetric Relative Orientation.

ORELA_ it calculates the adjusted parameters of the Asymmetric Relative Orientation, starting from its preliminary ones. If these preliminary values are unknown at the data acquisition, it is possible to get them from the results of the previous program. On the contrary, if they are already known, it is possible to transform the Eulerian angles, more frequently and easily acquired, into the Cardanic ones, by means of ORPHO program.

ORABS_ it calculates the adjusted Absolute Orientation parameters. They are calculated with a simple substitution of variables, which is able to transform the non-linear problem of the Absolute Orientation in a linear one.

Let us summarize the global procedure for the orientation of two images, viewing the flowchart (Figure 6).
With the new procedure, we eliminate any human intervention after the starting inputs. For that reason we unify all the Orientation programs in one called ORTRE. This program can run automatically and is able to find the adjusted parameters of the Absolute Orientation. In the follow flowchart (Figure 7) we want to show how all the global procedure run after the starting inputs of three images.

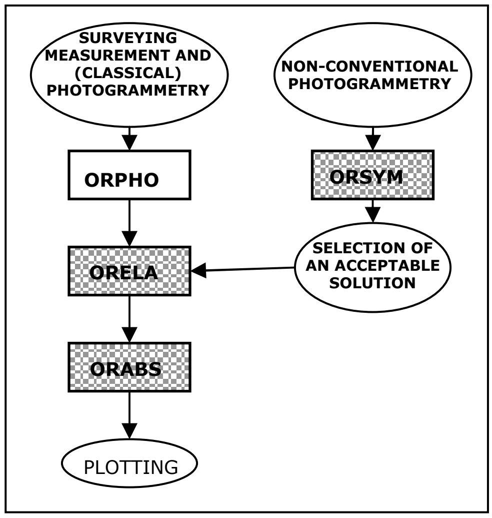


Figure 6. 2-image Orientation – Global Procedure

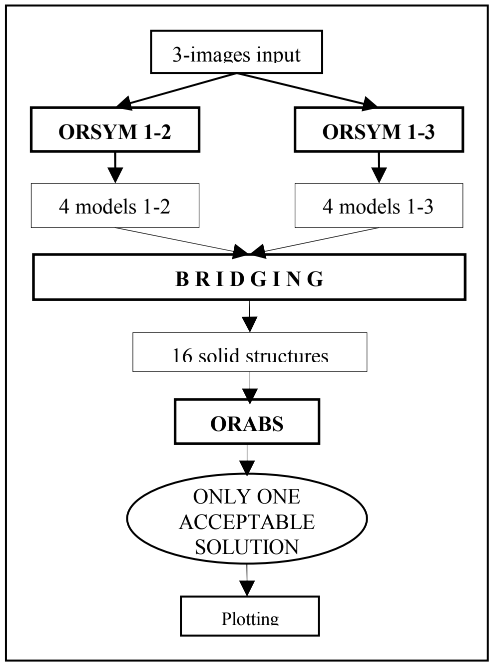


Figure 7. 3-image Orientation – Global Procedure (ORTRE Program)

As evident, the analysis of the performance of the single programs and of the global procedure was quite heavy. Indeed it needed a long preparation of tools, which permitted to manage files of commands. Furthermore many different levels were prepared in order to collect, save and store the output files for the different steps.

8. CONCLUSION AND FURTHER DEVELOPMENTS

A solution to solve for the problem of object reconstruction from three images not requiring any initial approximations for orientation parameters has been proposed. The procedure is based on the classical two steps approach of photogrammetry, i.e. relative and absolute orientation. All possible combinations of image pair in the triplet are considered and relatively registered by an algorithm running on exhaustive research (Mussio & Pozzoli, 2003a,b). Each pair gives four solutions, among those only the decision of the user would allow to select the proper one. By comparing all sixteen small blocks originated from the tern of images, it is possible to choose the true solution in automatic way. Finally, the object reconstruction is completed by computing absolute orientation, for which a linear parameterization already published in the above mentioned papers is applied.

Advantages of this method are twofold. First of all, the three-image approach is based on a more reliable configuration with respect to simple relative orientation of a pair. This fact will result very important when dealing with image matching algorithms, which are really error prone. Concerning this issue, further developments concerning application of robust technique to reject blunders are expected; in particular we look with great interest to the use of high breakdown point estimators, such as RANSAC (Fischler & Bolles, 1981) and Least Median Squares (Rousseeuw & Leroy, 1987), which are themselves based on the exploration of enough sub-samples randomly extracted from the whole dataset. A possible combination of exhaustive research and random sampling devises to be analyzed in detail, exploring the way proposed by Torr *et al*. (1995).

Secondly, the method is very suitable to provide initial values of the unknowns to solve for machine vision or complex photogrammetric problems (e.g. bundle adjustment, orientation of more then three cameras or video cameras). Being only based on typical parameterization of photogrammetry (symmetric relative orientation and absolute orientation), derived geometric parameters can be easily flow into block adjustments involving several terns of images (see e.g. Niini, 2000), in easier way with respect to methods based on algebraic linear formulations of relative orientation or on the *trifocal tensor*.

Concerning future developments and applications, the use in image sequence analysis seems to be very promising, being the three video camera configuration widely adopted. Especially if the relative positions of cameras is not fixed, the exhaustive research method could upgrade orientations in real time, because the searching space is limited by the knowledge of previous parameters.

Finally integration of self-calibration in this approach would be necessary to extend this use of any kinds of imagery sensor.

9. REFERENCES

References from Journals:

Finsterwalder, S., 1899. Die Geometrischen Grundlagen der Photogrammetrie. *Jahresbericht der Deutschen Mathematiker-Vereinigung*, Vol. 6, Teubner Press, Leipzig (Germany).

Fourcade, H.G., 1926. A new method of aerial surveying. *Trans. of the Royal Society of South Africa*, Vol. 14(1), pp. 93-112.

Hattori, S., and Y. Myint, 1995. Automatic Estimation of Initial Approximations of Parameters for Bundle Adjustment. *PE&RS*, 61(7), pp. 909-915.

Heipke, C., 1997. Automation of Interior, Relative and Absolute Orientation. *ISPRS Journal of Photogr. and R.S.*, no. 52, pp. 1-19.

Kruppa, E., 1913. Zur Ermittlung eines Objektes aus zwei Perspektiven mit inner Orientierung. Sitz.-Ber. Akad. Wiss., Wien, Math. Naturw. Kl. (Abt. IIa 122), pp. 1939-1948.

Longuet–Higgins, H. C, 1981. A computer algorithm for reconstructing a scene from two projections. *Nature*, 293(10), pp. 133-135.

Pan, H.-P, 1999. A Direct Closed-Form Solution to General Relative Orientation of Two Stereo Views. *Digital Signal Processing*, Vol. 9(3), Academic Press, pp. 195-211.

Sarjakoski, T., 1981. Concept of a completely digital stereoplotter", The Photogrammetric Journal of Finland, no. 2, pp. 95-100.

Schmid, H., 1954. An analytical treatment of the orientation of a photogrammetric camera. *Photogr. Eng.*, Vol. 20, pp. 765-781.

Schut, G., 1955-56. Analytical aerial triangulation and comparison between it and instrumental aerial triangulation. *Photogrammetria*, Vol. 12, pp. 311-318.

Stefanovic, P., 1973. Relative Orientation – a new approach. *ITC Journal*, pp. 417-448.

Thompson, E.H., 1959. A rational algebraic formulation of the problem of the relative orientation. *Photogrammetric Record*, 3(14), pp. 152-159.

Torr, P.H.S., and D.W. Murray, 1997. The Development and Comparison of Robust Methods for Estimating the Fundamental Matrix. Int. Journal of Computer Vision, no. 24(3), pp. 271-300.

References from Books:

Hartley, R.I., and A. Zisserman, 2000. Multiple View Geometry in Computer Vision. Cambridge University Press.

Rinner, K., and R. Burkhardt, 1972. Photogrammetrie. In Handbuch der Vemessungskunde (Hsgb. Jordan, Eggert, Kneissel), Vol. 3 a/3, Metzlersche Verlagbuchhandlung, pp. 2286-.

Rousseeuw, P.J., and A.M. Leroy, 1987. *Robust Regression and Outliers Detection*. John Wiley, New York.

Semple, J.K., and G.T. Kneebone, 1952. *Algebraic Projective Geometry*. Oxford Science.

Weng, J., Huang, T.S., and N. Ahuja, 1993. *Motion and Structures from Image Sequences*. Springer-Verlag, Berlin, 1993.

References from Other Literature:

Faugeras, O.D., Luong, Q.T., and S.J. Maybank, 1992. Camera self-calibration: Theory and experiments. In Proc. of European Conf. on Computer Vision '92, pp. 321-334.

Fischler, M.A., and R.C. Bolles, 1981. Random Sample Consensus: A Paradigm for Model Fitting with Applications to Image Analysis and Automated Cartography, Comm. of the Ass. for Computing Machinery, no. 24, pp.381-395.

Hartley, R.I., 1992. Estimation of relative camera position for uncalibrated cameras. In Proc. of European Conf. on Computer Vision '92, pp. 579-587.

Hartley, R.I., 1994. Lines and Points in Three Views – a Unified Approach. In Proc. of "Image Understanding Workshop.", Monterey, California, pp. 1009-1016.

Kraus, K., 1993. *Photogrammetry*. Vol. 1, 2, Dümmler Verlag, Bonn.

Mussio, L., and A. Pozzoli, 2003a. Non-Linear Problems of Analytical Photogrammetry, *IAPRS*, Vol. 34, Part 6/W11, pp210-215.

Mussio, L., and A. Pozzoli, 2003b. Quick Solutions particularly in Close Range Photogrammetry, *IAPRS*, Vol. 34, Part 6/W12, pp. 273-278.

Niini, I., 2000. Comparison of the projective block adjustment method versus the bundle method. *IAPRS*, Vol. 33, Part B3, pp. 643-650.

Ressl, C., 2000. An introduction to the relative orientation using the trifocal tensor. *IAPRS*, Vol. 33, Part B3, pp.769-776.

Spetsakis, M.E., and J. Aloimonos, 1990. A Unified Theory of Structure from Motion. In Proc. of "Image Understanding Workshop.", Pittsburg, Pennsylvania, pp. 271-283.

Torr, P.H.S., Zisserman, A., and S. Maybank, 1995. Robust Detection of Degeneracy. In Proc. of 5th Int. Conf. on Computer Vision, Boston (MA), pp. 1037-1044.