

AN OPEN-SOURCE EDUCATIONAL SOFTWARE FOR BASIC PHOTOGRAMMETRIC TASKS

Ilias Kalisperakis, Lazaros Grammatikopoulos, Elli Petsa, George Karras (GR)

Abstract

The current implementation of an educational package for basic photogrammetric operations is outlined. The context of this open-source software (MPT), developed in Matlab, is primarily the introductory course of Photogrammetry. Thus, the scope here is not to show students 'how to do it' but rather to clarify 'what is actually being done' in every step. In this sense, the stress lies mainly on basic photogrammetric adjustments. Students can work with one or two images at a time and perform monoscopic measurements of image points, lines or polylines. Exterior orientation is handled in a variety of ways: space resection with or without camera calibration (with or without estimation of radial lens distortion); linear and non-linear DLT approach (again with or without lens distortion); relative orientation and absolute orientation. Detailed results are presented, including standard error of the adjustment, residuals, covariance matrix of estimated parameters, correlations. Individual observations may be optionally excluded to study their effect on the adjustment. For fully oriented stereo pairs, 3D reconstruction is then possible. The 3D plot may be observed in the program's 3D viewer and exported in DXF format. Besides, 2D projective transformation is also possible, allowing rectification of vector data or resampling of digital images. Other features (e.g. image enhancement tools or self-calibrating bundle adjustment) are already implemented and will soon be incorporated.

1. INTRODUCTION

The new possibilities offered by contemporary digital tools are being readily exploited in education, i.e. for both learning and teaching. This is also true in the field of geomatics, and particularly photogrammetry (and/or remote sensing). Indeed, various tutorials or interactive e-learning environments are now available on the Web (Fluehler et al., 2005). However, the term 'educational' is broad and often used with diverse meanings. In certain cases, for instance, it refers mainly to simple photogrammetric tools which are intended to limit the need for interference by experts. This is the case of 'ARPEUR', a Web-based software which is self-described as a simple and efficient photogrammetric tool for archaeological and architectural applications, i.e. it is essentially addressed to non-specialists using desktop computers (Grussenmeyer and Drap, 2000). In other cases of educational software one meets demonstration tools like the 'Digital Monoplotting Teaching Program', which is mainly addressed to the teaching personnel as an aid in explaining and illustrating particular topics of photogrammetry to the students (Fluehler et al., 2005). And a series of educational tools are, of course, designed in the spirit of 'self-study' or 'self-teaching', i.e. their purpose is to assist students in familiarizing themselves with photogrammetric procedures in parallel to the conventional course. This, for example, is the case of E-FOTO (Coelho, 2004), which is designed as a digital photogrammetric softcopy kit covering most basic phases of a standard photogrammetric workflow. Although the aspect of 'self-teaching' is not the main issue in the software presented in our contribution, a similarity with E-FOTO lies in its 'freedom of software' aspect, namely its accessibility to users who might distribute the software or study its code and even possibly modify it.

In our Departments several standard photogrammetric tools are available (e.g. Z/I SSK, DVP, or EOS Photomodeler, Pictran), through which students may follow and perform all stages of a typical photogrammetric project. However, it is essential that students come to terms with the basic theory and

grasp the fundamental photogrammetric concepts. Commercial software is, of course, intended not for education but rather for routine production, its emphasis lies on the user-friendly means for the creation of a final result rather than on clarifying notions and their actual realization behind each step of a process. In this context – and notwithstanding their other merits – ‘black-box’ aspects of commercial software may, indeed, represent significant obstacles in introductory photogrammetric courses. Interior orientation is an example. If the terminology of a digital photogrammetric workstation was to be taken literally, one might come to regard interior orientation as synonymous with simply ‘clicking’ on fiducials and on the affine transformation button.

Our basic concern focuses here on the introductory course of photogrammetry. In this context, our primary need was to develop an educational tool which would help students not learn ‘how to do it’ but rather realize ‘what is actually being done’. We have therefore concentrated on the fundamental photogrammetric tasks concerning the stereo pair, viewed essentially as a series of least-squares adjustments. Our educational software MPT (Matlab Photogrammetric Toolbox) is intended not mainly for ‘self-teaching’ but for use *in the class*. Its basic mission is to combine with theoretical lecture and directly illustrate, in practical terms, the algorithmic implementation of concepts and processes. This means that students should make their own measurements and obtain their own results, but the source code should also be there for them to see.

In the authors’ view, such an approach has several merits. A series of commands can help students ‘demystify’ what they often perceive either as ‘abstract theory’ or as a simple ‘technicality’. They may experiment with alternative methods and realize differences or similarities. They are directed towards familiarizing themselves with programming and are, thus, encouraged to intervene themselves into the code by making modifications and evaluating them. Furthermore, students also use this environment at different stages of their studies and at correspondingly different levels of understanding. This means that (for instance while preparing their diploma thesis) they may even develop new modules. Based on our experience, we believe indeed that educational software of this type is a necessary intermediate between theoretical teaching and result-oriented practical projects.

2. THE EDUCATIONAL PHOTOGRAMMETRIC SOFTWARE ‘MPT’

Since there is a lack in software of this type, the authors have developed an educational package (which is still being extended) for the basic photogrammetric operations. This open-source software (which is also available in executable form) has been developed in Matlab. For each project, involving several images, measurements and adjustments are all performed in the same windows environment. After the successful completion of every task, detailed results are automatically stored in an ASCII file. In this environment, a student may work with one or two images at a time and measure monoscopically image points, lines and polylines. Image zooming and roaming tools are available (zoom in/out, zoom extends, pan), observations can be corrected, points can be deleted or disabled.

2.1 System of image coordinates

If projective equations are to be applied (2D rectification, DLT), image point coordinates may refer to the system of the digital image. In case the collinearity or the coplanarity equations are used, all image coordinates must refer to the conventional image coordinate system defined by the fiducials. If the image is characterised as digital’ (i.e. coming from a digital camera), this is done automatically by the program. For scanned images (‘analogue’), an affine transformation is performed through the observed fiducials, réseau points or image corners. The presented and stored results include the values for the six coefficients as well as those of the corresponding physical parameters (scale, rotation, two translations, affinity, skewness), image residuals, standard error σ_0 of unit weight and parameter standard errors. All subsequent observations are referred to this image coordinate system.

2.2 Exterior orientation

Exterior orientation may be recovered in a variety of ways, involving both single-image as well as two-image procedures. This allows students to familiarize themselves with different approaches, understand their relation and compare the outcomes.

2.2.1 Single-image approaches

- **Space resection.** For calibrated cameras (known camera constant, principal point and, optionally, radial-symmetric lens distortion), a first possibility to recover the exterior orientation of an image is by simple space resection (collinearity equations) based on sufficient object points of known 3D coordinates. Besides the six parameter values, results include their standard errors (and, optionally, the correlation coefficients), image residuals of ground control points and σ_0 . Selected control points can be excluded from the adjustment, yet the program still displays the deviations in x and y of their back-projection on the image from the original point observation. This possibility – which is available in all adjustments of the program – allows students to see the impact of particular points and, in a wider sense, of the distribution of observed points over the image frame and the role of geometry in an adjustment.

- **Space resection with camera calibration.** For uncalibrated cameras, space resection is extended to allow also a simultaneous camera calibration, provided that a sufficient number of control points are present with adequate extension in depth. Radial lens distortion can be either ignored, given as prior information or included in the adjustment with two unknowns (coefficients k_1 , k_2). A further possibility is to include image affinity as unknown, in the form of two camera constants (c_x , c_y). The results include all information mentioned above. Correlation coefficients allow to evaluate the dependence of the estimated interior orientation values upon those of exterior orientation. Optionally, the radial distortion curve can be calibrated and presented in a diagram, along with the corresponding camera constant.

- **DLT approach.** Provided that the control points have an adequate extension in depth, the option of a DLT approach is also available, whereby image coordinates may refer to the system of the digital image. These 3D–2D projective equations are treated in their non-linear form, after a determination of approximate values by the program using the linear equations. The resulting values for the 11 DLT coefficients are recorded along with their standard errors and the other statistical information. From these coefficients, the program extracts and presents the six conventional parameters of exterior orientation, the three primary parameters of interior orientation and the two affine parameters (affinity and slewness). The standard errors for these parameter values are also given, calculated through error propagation from the 11 DLT parameters. It is noted that initial values from DLT may also be used as approximate values in space resection.

- **DLT approach with estimation of radial distortion.** Additionally, it is also possible to estimate radial lens distortion within the DLT adjustment. In this case, however, the current version of the program assumes that the measured image coordinates are already transformed to the conventional image system, to which the distortion polynomial refers.

2.2.2 Two-image approach

Finally, the steps of relative and absolute orientation are also available in the program.

- **Relative orientation.** The coplanarity condition is applied here for the relative orientation of the stereo pair, based on observations of homologue points and the interior orientation data (including lens distortion, if known). In case control points are available, they are also measured and carried

into the adjustment. At this stage, the initial values are introduced by the students. The value for the basis component b_x is fixed to unity. The output includes the values for the five relative orientation parameters, their standard errors, the image residuals and the standard error of unit weight (as seen in Fig. 1).

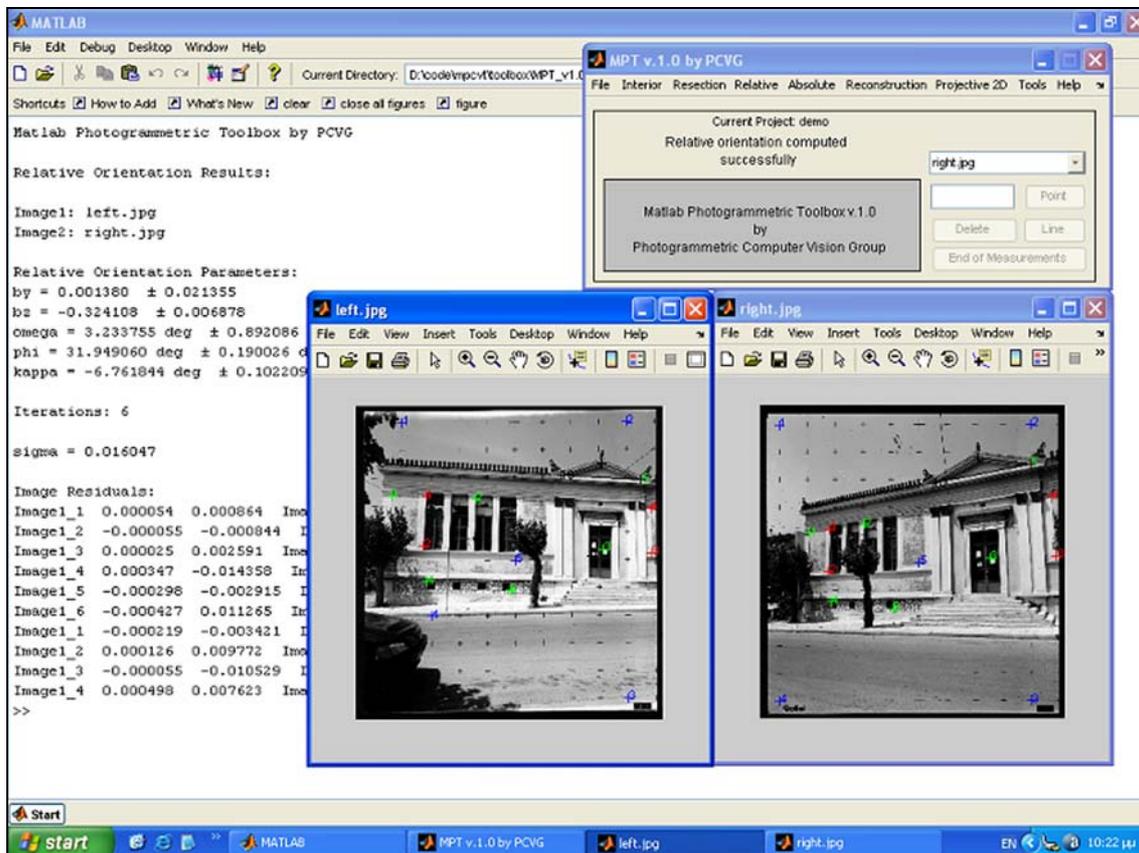


Figure 1. Relative orientation results and measuring environment. Different colours are used for reseau points (blue), tie points (green) and control points (red).

- **Absolute orientation.** If control points are available, a 3D similarity transformation is applied for the absolute orientation of the model, producing an output structured similarly as before. From these relative and absolute orientation results, the exterior orientations of the two images are finally calculated and recorded.

2.3 Model reconstruction

Thus, from all above alternative procedures the final result is the exterior orientation of the image pair and – in case it was not known beforehand – its interior orientation. For a fully oriented stereo pair, 3D object reconstruction is then possible with space intersection. In case no control points are available, the step of absolute orientation is skipped, and reconstruction may proceed in the system of the left image with an arbitrary scale. For each intersected point the standard errors of its 3D coordinates are shown. Thus, corresponding points, lines and polylines measured on the images are reconstructed in 3D.

The resulting 3D plot may be observed and manipulated in the 3D viewer of the program, but also exported in DXF format for further processing. This concludes the currently available functions of MPT as regards the stereo pair.

2.4 Image rectification

Finally, our program also has the possibility for projective transformations of images of 2D objects. The process evolves as before, with measurement of control points (which may optionally be disabled) and presentation of results. After the eight projective coefficients have been determined, rectification can proceed in two modes. On the one hand, it is possible to collect lines and/or polylines and then rectify this vector data to an orthogonal projection. Additionally, the program also allows a digital resampling of rectified images, whereby the student needs to select their pixel size according to the required scale of the final product.

3. INTRODUCTION OF FURTHER FEATURES IN THE SOFTWARE

Several further features are already implemented or under implementation and will soon be introduced into the environment of MPT. These include:

Orientation and reconstruction

- Unified solution of two overlapping images (bundle adjustment of stereo pairs), both with and without control points. If control points are available, self-calibration will also be provided.
- Multi-image bundle adjustment, with and without control points. In both cases, the possibility for full self-calibration will be provided.
- Introduction of linear algorithms for the automatic estimation of initial values for relative orientation of a stereo pair, but also for multi-image adjustments.

Radiometric processing of digital images

- Basic radiometric transformations of images (brightness and contrast, histogram equalization etc.)
- Application of digital filters for image smoothing or enhancement.
- Tools for automatic extraction of image edges and interest points.
- Automatic detection of homologue points by digital image correlation.

Geometric transformations of digital images

- Resampling of epipolar images, whereby it will also be possible to use complementary colours for stereoscopic viewing with the 'anaglyph' method.
- Generation of orthoimages.
- Digital 'unwrapping' of developable surfaces.

4. CONCLUSION

Following earlier attempts for creating simple photogrammetric tools (Glykos et al., 1999), an educational software (MPT) has been developed, which is essentially intended for use in the class of introductory courses in photogrammetry. Up to now our weight has been put mainly on the basic photogrammetric adjustments, yet the intended future features will widen its field considerably. Its purpose is to bridge theory with practice in one and the same environment, by allowing students to perform themselves basic photogrammetric tasks, while the full code is at their disposal to study. In this sense, students are in fact able to analyse and understand the mechanism behind the visible consequences of every manual measurement or every choice they make. They are, thus, encouraged to attempt interventions into an existing source code and, eventually, develop their own variations or even modules. Indeed, this program has provided the starting point for certain students who later, in their diploma theses, dealt with topics as those mentioned above.

We hope that this program, which will soon be freely available on the website of the Department of Surveying of the Technological Educational Institute of Athens (TEI-A), may be of use to other educational institutions as well.

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Authors:

^{1,2} Ilias Kalisperakis, PhD Student (ilias_k@central.ntua.gr)

^{1,2} Lazaros Grammatikopoulos, PhD Student (lazaros@central.ntua.gr)

¹ Elli Petsa, Professor (petsa@teiath.gr)

² George Karras, Associate Professor (gkarras@central.ntua.gr)

¹ Dept. of Surveying, Technological Educational Institute of Athens (TEI-A), GR-12210 Athens, Greece

² Dept. of Surveying, National Technical University of Athens (NTUA), GR-15780 Athens, Greece.