TEACHING OF DIGITAL PHOTOGRAMMETRY: THE EXPERIENCE OF THE MILITARY INSTITUTE OF ENGINEERING IN BRAZIL

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ABSTRACT

The Digital Photogrammetry is in the middle stage of development in the world. This technological evolution has been arriving in Brazil, with the returning of teachers who Graduate abroad. It is also worth mentioning the import of several softcopy photogrammetry workstations for cartographic production in Brazil. The acquisition of those workstations makes possible the involvement of the students with digital photogrammetry issues. However, the acquisition of hardware and software do not facilitate the domain of the technology of digital photogrammetry in Brazil. The solutions implemented in the workstations are not available for end users. It appears, then, the need for teaching the concepts of Digital Photogrammetry to both Undergraduate and Masters degree students in Cartographic Engineering.
This work reports the implementation of the discipline named "Digital Photogrammetry" in both Undergraduate and Masters levels, in the Department of Cartographic Engineering of the Military Institute of Engineering. That experience started in 1998.
As a result of the experience mentioned above, the Digital Photogrammetry has started to present its scientific production. For instance, two Masters' Thesis, one final project (undergraduate level) e and two Master's related works are under development. Part of the academic production is being published in national scientific events. Another important result is the increasing of the students' interest for the field of Photogrammetry.
The results obtained up to now show the validity of the approach adopted in the Department of Cartographic Engineering. There are also perspectives for increasing of course loading. A larger integration with related disciplines such as Phototriangulation, Remote Sensing, and Digital Elevation Modeling can be foreseen. It is also worth mentioning the tendency of reduction of the hourly load of the disciplines of Analog and Analytical Photogrammetry, in benefit of Digital Photogrammetry.

1 INTRODUCTION

The technological development occurred in the recent past has brought, as one of its consequences, the development of new techniques for mapping production. The development of Information Science is even more dramatic. Computer is gathering even more importance on the daily life. Map production process or cartographic engineering is not an exemption. It has change dramatically in the past ten years. By quoting Robinson et al (1995) one can say that we are experiencing the third stage of the use of computers for map-making purposes.
Of course the mapping machine (Schenk, 1990) is still ahead in the years to come. However, automation is speeding up the map-making process, starting from flight planning, through map printout. In such a context, photogrammetry is not an exemption. However, it appears as one of map sciences that has evolved more slowly. This fact could be explained by the complexity, ill-posed nature of reconstruction of the object space (3D) from 2D overlapping images and ground control, and for the needing of interactive processing of photogrammetric tasks
The Digital Photogrammetry is in the middle stage of development. This technological evolution has been arriving in Brazil, with the returning of teachers who Graduate abroad. It is also worth mentioning the import of several softcopy photogrammetry workstations for cartographic production in Brazil. The acquisition of those workstations makes possible the involvement of the students with issues of digital photogrammetry. However, the acquisition of hardware and software do not facilitate the domain of the technology of digital photogrammetry in Brazil. The solutions implemented in the workstations are not available for end users. It appears then, the needing for teaching the concepts of Digital Photogrammetry to both Undergraduate and Masters degree students in Cartographic Engineering. That approach was adopted in The Military Institute of Engineering (IME), in Brazil, since 1998. The report of such an experience is presented in the following sections.

2 TEACHING OF PHOTOGRAMMETRY IN BRAZIL

By considering Undergraduate programs in the field of the Geodetic sciences worldwide, one can say that there is a trend to "hyper-specializing" the student in one of the following fields: geodesy, geographic or land information systems, cartography, remote sensing, surveying, or photogrammetry. Hyper-specialization means that the student concentrates his or her Undergraduate program in one of the above mentioned areas of the geodetic sciences.
Generally speaking, the approach adopted in Brazil is slightly different, specially when talking about the Military Institute of Engineering. There we talk about cartographic engineering by means of encompassing all the geodetic sciences and map-making related professionals. In that sense, a cartographic engineer is a professional that has a comprehensive academic background of geodetic and map-making related sciences. The academic life at IME covers more than 3,600 hours of theoretical classes in five years. This explain why we refer to "cartographic engineer" rather than to geodesit, map-maker, cartographer, or even photogrammetrist, when referring to the professional.

3 TEACHING OF DIGITAL PHOTOGRAMMETRY AT IME

3.1 The Military Institute of Engineering (IME)

The IME has strong educational programs in 6 areas of knowledge: (1) Civil engineering; (2) Electrical engineering; (3) Mechanics and Materials; (4) Chemistry; (5) Computing Sciences, and (6) Cartographic engineering. All the programs have both Undergraduate and Graduate (Masters Level). Some of them have also Doctoral programs. Cartographic engineering has both Undergraduate and Master's programs. Both programs are open either to civilians or to people in the military. Graduate programs are offered also to foreign students. The number of students registered in all the programs offered ranges from 1,000 to 1,200 students.
In the Undergraduate Program of Cartographic Engineering, photogrammetry has a total of 360 hours, and is structured into five parts: (1) Basic Photogrammetry (60 hours); (2) Analog photogrammetry (30 hours); (3) Analytical Photogrammetry (75 hours); (4) Digital Photogrammetry (60 hours) and; (5) Close-Range Photogrammetry (45 hours). The Masters program has a total of 600 credit hours, 60 of which are dedicated to the Digital Photogrammetry Course. Students who successfully complete their credits are also required to develop a Dissertation research in their second year of that program.

3.2 The Coursework of Digital Photogrammetry

The "Digital Photogrammetry" matter was included in both Undergraduate and Graduate curricula with a course load of 60 hours, equally distributed between theoretical classes and practical work in laboratory.
The theoretical part of consists of the following subjects: (1) Basic Concepts; (2) Generation of Digital Photogrammetric Images; (3) Interior Orientation; (4) Exterior Orientation; (5) Automatic Mensuration of Points by Cross-correlation; (6) Rectification and Normalization of Digital Photogrammetric Images; (7) Generation of Digital Elevation Models (DEM); and (8) Generation of Digital Ortho-images.
Undergraduate students are required to take both Analog and Analytical Photogrammetry prior to registering for Digital Photogrammetry classes. That procedure facilitates the connection of Digital Photogrammetry with those previously mentioned subjects.
"Basic Concepts" of Digital Photogrammetry start from the main goal of photogrammetry --the reconstruction of the object space from the (overlapping) image space. This unit also goes to the timeline of photogrammetry, and points out the conceptual differences among analog, analytical, and digital photogrammetry. A survey of digital photogrammetric workstations is included. The stereo viewing systems are also discussed.
The "Generation of Digital Photogrammetric Images" unit starts from the concept of digital image, goes to the issues of image resolution, encompasses the concept of Charge-Coupled Devices (CCD), the sampling theorem, and arrives to digitized frame images. The first laboratory exercise is the generation of a stereo-pair of digitized-frame images, by scanning two 9 inches, aerial photographs. Those images will be use in future laboratory exercises, which will be described below.
The "Interior Orientation" unit initially discusses the needing for exchanging between the analog image space, fiducial system and the digitized frame (digital image space) system. The mathematical model for the 2D affine transformation with 6 parameters is reviewed. The implementation of such a model and the discussion of is variance-covariance matrix encompass the second laboratory exercise. That laboratory assignment also requires the students to perform both an

interior and a relative orientation of a pair of digitized-frame images. A digital video-plotter (DVP) workstation is used for that purpose. The solution of the interior orientation implemented by the students is then compared with that which comes from the DVP workstation.

"Exterior Orientation" focuses the space-resection approach as a particular case of the bundle-adjustment solution. That unit also reviews the deduction of the collinearity equations. The laboratory assignment for computation of the exterior orientation parameters of a digitized-frame image completes the job. Similarly to the previous laboratory exercise, the students are asked to implement the space-resection solution (kraus, 1992) for the exterior orientation algorithm of a digitized-frame image. The exterior orientation is also executed in the DVP workstation. The results are then compared.

The "Automatic Mensuration of Points by Cross-correlation" is one of the key units. It teaches the student the fundamentals of automatic point measurement. Initially reviewing of basics of statistics (cross-correlation between two samples) renders the necessary background. The selection of a template and a search-window, respectively, in the base and in the matching images, and strategies for their optimization is emphasized. The concept of image pyramids is also explored as well. The students implement an algorithm of searching for the maximum coefficient of cross-correlation between a template and a search window. The results are compared with those of previously measured points, for verifying the accuracy of the algorithm.

The "Image Rectification and Normalization" unit discusses the concepts of rectification without including relief displacement issues. There the key idea is image resampling, by means of generating a vertical, central perspective, digitized-frame image. Theoretical issues of image resampling for epipolar geometry (Cho et al., 1993) are detailed discussed in theoretical classes.

Two approaches are used for teaching the "Generation of Digital Elevation Models (DEM)" unit. The former is the space intersection solution (Kraus, 1992), which employs the collinearity equations and the parameters of the exterior orientation of both images of a stereo-pair. The second strategy for terrain extraction is through the use of the parallax equation (Kreiling, 1989). The automatic measurement of grid points by cross-correlation is the basis for such a laboratory exercise. Ground control points are used to compare height generated by the implementation with ground truth. Like previous lab assignments, the students are also required to generate a DEM in the Digital Video plotter. The DVP workstation is useful to point out the blunders or the mismatches in automatic cross-correlation. Manual measurement in those points corrects the mismatches, and points out the practical problems occurred in automatic terrain extraction.

"Generation of Digital Ortho-images" is the last unit in the course. The bottom-up method (Mayr and Heipke, 1988) is detailed discussed in theoretical classes.

The syllabus described above, although comprehensive, does not cover all the issues in the field of digital photogrammetry. The practical teaching experience shows that it is necessary to include an unit on digital photriangulation. It is equally important to address some advanced topics in automatic feature extraction, iamge compression and reconstruction, strategies for automatic DEM extraction, occlusion detection, epipolar resampling, practical exercises of digital ortho-image generation, and so forth. These concepts could be explored in a separate course for Graduate students.

3.3 Laboratory Exercises

Practical exercises allow the students to implement the solutions presented theoretically. The MathCad™ Professional Educational software available in the laboratory of photogrammetry and image processing is used to verify the results found in the implementations with those that come from the softcopy workstation. The MathCad package is a fourth generation programming language, through which the students easily implement and interact with their solutions.

The laboratory of photogrammetry of IME has one Digital Video Plotter (DVP)™, and one scanner Sharp™ JX-610, with 600 DPI optical resolution, for supporting of lab assignments. Those equipment are used in the execution of the following practical assignments: (1) digitized frame image generation by scanning of aerial photographs; (2) execution of both interior, relative, and absolute orientations; (3) point mensuration by cross-correlation of digital imagery; (4) image rectification; and (5) generation of DEM's.

Some of the "black-box" solutions implemented in the photogrammetric workstation are also assigned to the students, for the implementation of their own solutions. To illustrate the approach followed in the digital photogrammetry course at the IME, the solution developed by Agusto and Brito (1999) for the computation of the space resection algorithm is summarized below

The space resection solution is a non-linear mathematical model, which solution requires good initial approximations for the sensor attitude angles (ϕ, ω, and κ), as well as the coordinates of the perspective center (X0, Y0, Z0). A function was designed for that purpose, using the resources offered by the MathCad™ package. Figure 1 shows that function, named fLo(Xo). On can observe in figure 1 that the coordinates in the analog image space (ξ and η) , respectively, are given by the collinearity equations (Kraus, 1992). These equations are also implemented as functions of the calibrated focal distance, the coordinates of the perspective center, and the coordinates of at least four ground control control points, in both analog image space and in the object space (terrain). Their implementation is straightforward. See figure 1.

$$
fLo(Xo) := \left| \begin{array}{l} \text{for } i \in 0..n-1 \\ \quad \left| \begin{array}{l} Lo_{2 \cdot i} \leftarrow \xi(\xi o, c, \phi, \omega, \kappa, X, Y, Z, Xo, Yo, Zo, i) \\ Lo_{2 \cdot i+1} \leftarrow \eta(\eta o, c, \phi, \omega, \kappa, X, Y, Z, Xo, Yo, Zo, i) \end{array} \right. \\ Lo \end{array} \right.
$$

Figure 1. Computation of the initial approximations for the space resection solution.

The computation of the design matrix fA(Xo) requires the computation of the partial derivatives of the collinearity equations with respect to the parameters of the space resection solution (X0, Y0, Z0, ϕ, ω, and κ). This task may require some programming effort, if implemented in traditional languages, like "C" or Pascal. However, it is easily implemented in the MathCad package. Figure 2 illustrates that implementation, which is self-explanatory.

The computation of the vector of adjusted parameters is an iteractive procedure, where the previous solution is used as input for the next iteration, until the specified tolerance is achieved. Figure 3 shows the least-squares adjustment of the mathematical model.

$$
fA(Xo) := \left| \begin{array}{l} \text{for } i \in 0..n-1 \\ \quad \left| \begin{array}{l} A_{2 \cdot i,0} \leftarrow \frac{d}{dXo}\xi(\xi o, c, \phi, \omega, \kappa, X, Y, Z, Xo, Yo, Zo, i) \\ A_{2 \cdot i,1} \leftarrow \frac{d}{dYo}\xi(\xi o, c, \phi, \omega, \kappa, X, Y, Z, Xo, Yo, Zo, i) \\ A_{2 \cdot i,2} \leftarrow \frac{d}{dZo}\xi(\xi o, c, \phi, \omega, \kappa, X, Y, Z, Xo, Yo, Zo, i) \\ A_{2 \cdot i,3} \leftarrow \frac{d}{d\phi}\xi(\xi o, c, \phi, \omega, \kappa, X, Y, Z, Xo, Yo, Zo, i) \\ A_{2 \cdot i,4} \leftarrow \frac{d}{d\omega}\xi(\xi o, c, \phi, \omega, \kappa, X, Y, Z, Xo, Yo, Zo, i) \\ A_{2 \cdot i,5} \leftarrow \frac{d}{d\kappa}\xi(\xi o, c, \phi, \omega, \kappa, X, Y, Z, Xo, Yo, Zo, i) \\ \ldots \\ A_{2 \cdot i+1,5} \leftarrow \frac{d}{d\kappa}\eta(\eta o, c, \phi, \omega, \kappa, X, Y, Z, Xo, Yo, Zo, i) \end{array} \right. \\ A \end{array} \right.
$$

Figure 2. Computation of the Design Matrix for the Least-Squares Solution.

$$
fXa := \left| \begin{array}{l} \text{while } dm > Tol \\ \quad \left| \begin{array}{l} Xo \leftarrow Xa \\ Lo \leftarrow fLo(Xo) \\ A \leftarrow fA(Xo) \\ X \leftarrow -\left(A^T \cdot P \cdot A\right)^{-1} \cdot A^T \cdot P \cdot (Lo - Lb) \\ Xa \leftarrow Xo + X \\ \text{for } j \in 0..5 \\ \quad d_j \leftarrow \left| Xa_j - Xo_j \right| \\ dm \leftarrow \max(d) \end{array} \right. \\ V \leftarrow A \cdot X + Lo - Lb \\ S \leftarrow \text{stack}(Xa, V) \\ S \end{array} \right.
$$

Figure 3. Computation of the Vector of adjusted parameters for the Least-Squares Solution.

3.4 Selected Bibliography

Since the syllabus of the digital photogrammetry course is comprehensive, no single text-book covers the whole contents of the course. A number of references were selected and used. For example, the Addendum to the Manual of photogrammetry (ASPRS, 1997) is one of the base texts. Kraus' books (1992, 1997) are also key texts. The Ohio State University publications were also extremely valuable. See for example Novak (1990), Schenk (1990), and Cho et al (1992).

The Dissertation research developed by Brito (1997) also contributed in many aspects. The algorithms and summaries of many concepts found in Kreiling (1989) are very useful tools.

4 CONCLUSIONS

The implementation of the digital photogrammetry course has brought to the cartographic engineering department of IME an important achievement: the increasing of the students' interest for the field of photogrammetry. Digital photogrammetry has also started to show its scientific production. For instance, two Masters' thesis, one final project (undergraduate level) e and two Master's related works are undergone development. Part of the academic production is being published in national scientific events.
The key idea of this paper is to point out some of the practical experiences in teaching digital photogrammetry in the cartographic engineering department of IME, in the past two years. We hope that our experiences be helpful to other academic environments, specially in developing countries like ours. We are also opened for exchanging ideas, and sharing our experiences.

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