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E-Foto main objective is to diminish the gap that exists nowadays between the teaching of Photogrammetry and Remote Sensing in universities and Research Institutions of developing countries and the high-tech expensive systems that are used under the production environment.

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ABSTRACT

This paper shows our experience at the Rio de Janeiro State University (UERJ), in Brazil, developing and using the E-Foto software, one of the main achievements of the E-Foto project that aims to built-up a software tool for teaching digital photogrammetry and software development, to both graduate and undergraduate students, in the fields of Cartographic and Computer Engineering.
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INTRODUCTION

The E-Foto software is a free and open-source educational digital photogrammetric workstation licensed under the GNU General Public License. During the last 16 years, several graduate and undergraduate students have worked on its development. So, in the academic environment, this project is useful not only for students to learn photogrammetry but also to learn how to develop complex photogrammetric software.

As a photogrammetric educational tool, the E-Foto interface guides the students through an entire photogrammetric work-flow. The software embeds the concept of photogrammetric mapping project. This is a task that requires specific knowledge and skills in the fields of Remote Sensing, Photogrammetry, Geodesy, and Cartography.

The E-Foto software provides tools for all tasks related to a photogrammetric project: project creation; image rectification; interior orientation; exterior orientation; bundle block adjustment for photo-triangulation, image normalization or image re-sampling to epipolar geometry; photogrammetric 3D stereo plotting; automatic extraction of digital elevation models, and ortho-rectification. In addition, our E-Foto project provides software tutorials and a free book on digital photogrammetry to help students with the self teaching and self-learning processes.

As a software development educational tool, we have used its code to teach students how to develop high-quality engineering software. Many students in our University have learned advanced techniques of C++ programming and software development through the E-Foto code, even when they do not have much knowledge about photogrammetry.

All code of E-Foto is available as free software, so computer science students can learn how to carry out a complex piece of software. In fact, students under professor advice have written almost all the code of E-Foto. The E-Foto software and its related didactic materials are being used in the last 10 years for more than 180 countries. The statistics of software downloading and access to the E-Foto home page can be easily gathered from our website (http://www.efoto.eng.uerj.br).

EARLY DEVELOPMENT

E-Foto started as a program developed as a partial requirement of an undergraduate final monograph in the Cartographic Engineering Course at the Military Institute of Engineering of Brazil – IME (Coelho,

2002). As a consequence of this monograph, the author, Luiz Coelho, together with his adviser, Jorge Brito, wrote an ebook aimed at teaching digital photogrammetry. Later, as an improved version, they published a paper book (Coelho and Brito, 2007). This book, in its paper and electronic version, is still used today as a textbook for the teaching of photogrammetry in our courses. These two products, the program and the ebook, were the beginning of the what we call now "The E-Foto Project".

In its very first version, the E-Foto consisted of several programs developed in the C++ language and GUI toolkit QT. Each program dealt with one aspect of the digital photogrammetry process and was linked by a graphical user interface.The only function of this GUI was to call each program from the photogrammetric process. There was no real integration between the programs and no real photogrammetric project as a guide to the user. The user was the only one responsible for controlling all the phases involved in digital photogrammetry processing. Figure 1 shows the first interface of E-Foto.

Figure 1. The first interface of E-Foto.

Since its inception, the e-photo project was conceived as a teaching tool for photogrammetry and should, therefore, be completely open and free. As stated in one of its first publications (Coelho and Brito, 2005):

> The idea behind the E-Foto project was to offer a simple set of software that could help our students understand the principles behind Photogrammetry. Engineers have to comprehend how technologies related to their field of knowledge work, and if they learn it through a self-teaching software, it would be a lot easier to make them understand and extract the maximum amount of information from full-featured commercial systems.

Finally, the authors concluded:

> The final idea is to lead the students to fully understand the principles behind Photogrammetry – reading the e-book, using the software, taking a look at its source code and even modifying it or developing new modules to it.

In order to make the software widely spread, E-Foto has Windows and Linux versions, but the software is developed and tested first on Linux computers. After it has passed all tests on Linux, we make a Windows version. Frequently, this development sequence leads to a more stable version on Linux than on Windows.

DEVELOPMENT AT RIO DE JANEIRO STATE UNIVERSITY

After 2004, professor Brito began to work with professors and students of UERJ, within the graduate program in Geomatics. From its origin to the present, 28 undergraduate students participated in the development of the E-Foto project; 6 of academic masters and 1 of Doctorate. It computes 78 scientific-academical productions, among technical-scientific articles, master's dissertations, scientific undergraduate work, and course completion, both in Cartographic Engineering and in Computer Engineering. The bibliographic production generated by the E-Foto Project includes the book titled "Fotogrametria Digital (2007)", edited at UERJ.

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Each new academic-scientific work brought the improvement of software functions while allowing the student to learn both programming techniques and photogrammetry.

The team has developed new modules, adding new features, and integrating all functions into a single program (Figure 2). Now, a single screen allows the user to control the entire photogrammetric process (Silva et al., 2007). As a methodological basis for software development, we adopt Extreme Programming and Agile Modeling, adapting these practices to the reality of the academic environment (Aguiar and Badolato, 2010).

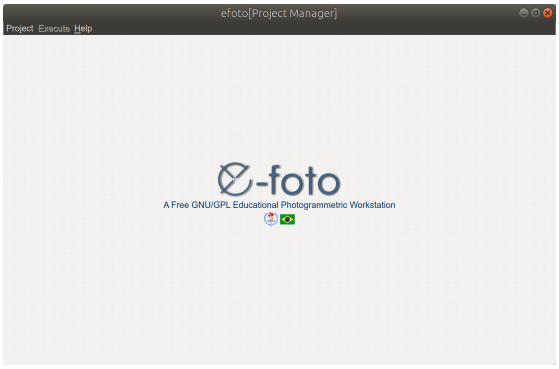

Figure 2. Partial Work-flow. Steps for project initialization.

PHOTOGRAMMETRIC WORKFLOW

This section presents the modules of the photogrammetric workflow. The colored blocks represent software modules from E-Foto. The students implemented these modules as part of their academic work at university. Working with a digital photogrammetric mapping project is a task that requires specific knowledge and skills in the fields of Remote Sensing, Photogrammetry, Geodesy, and Cartography. These courses are part of the curriculum of a cartographic engineer and professional courses from other areas of knowledge related to geosciences.

Project initialization

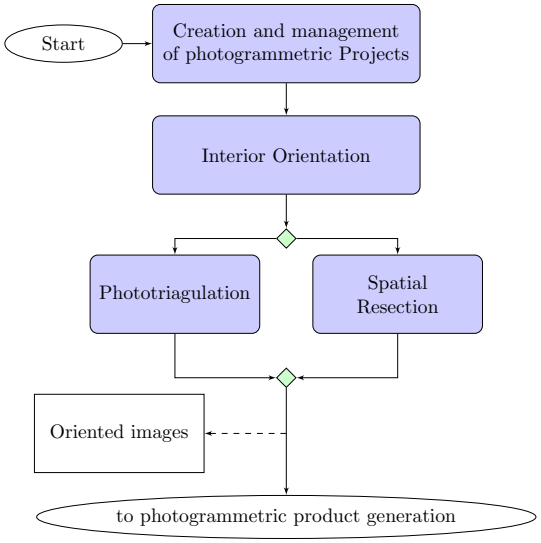

Figure 3. Partial Work-flow. Steps for project initialization.

The first module is the **Project Management** which is responsible for establishing and guarantee the integrity of a digital photogrammetric mapping project.

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The **Interior Orientation** is the process whereby one can recover the digital image's coordinate system reference back to photogrammetric camera's metric coordinate system.

The next step is the **External Orientation**. This is the process that, through control points measured on the ground and points recognizable on images, one can calculate the images' exterior orientation related to the terrain coordinate system.

There are basically two approaches for computation of **phototriangulation**: the adjustment by independent models and the bundle block adjustment procedures. The former method uses a stereo-model as its basic unit of adjustment; the bundle-block adjustment, also known as the multiple spatial resections, on the other hand, considers a light-ray connecting a point in the object-space, the principal point of the camera, and the projection of the point into the image-space, as its essential element for Least-squares adjustment computation. Therefore, a bundle of light rays forms the block of images, which is adjusted in a unique procedure. If a block has only one single image, the bundle-block adjustment procedure is named "**spatial resection**" (Pupim, 2012) (Silveira, 2004).

At the end of these steps, the user gets oriented images ready for the next phase of the photogrammetric work-flow (Bernardo et al., 2005).

Photogrammetric products generation

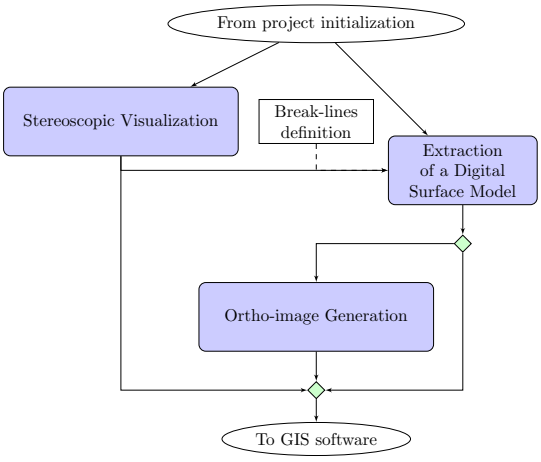

Figure 4. Products Generation.

After we have the parameters of both the interior and exterior orientations of the corresponding images used in the stereo-pair calculated and saved, we can proceed to the generation of photogrammetric products.

The **Stereoplotter Module** performs the three-dimensional photogrammetric restitution of terrain surfaces represented by a stereoscopic model. This operation plots the outline of natural or artificial objects (features) in the stereoscopic model.

When we already have the parameters of the interior and exterior orientations for all images in our project, we can execute the **DSM Extraction module**. In the context of the E-Foto project, a Digital Surface Model (DSM) stands for a cloud of points with ground 3D coordinates automatically computed by digital photogrammetry. The user can also use a break-line file for improvement of the resulting DSM (Silveira et al., 2007).

An ortho-image is an image in an orthogonal perspective, when the projective rays are parallel and the viewpoint is at the infinite. The **Ortho-rectification module** uses the method of differential rectification for generating an ortho-image. Such a method requires a DSM model, from which it is possible to generate its corresponding ortho-image (Oliveira, 2004).

At the end of these steps, the user can export the E-Foto products to other GIS software, like Quantum GIS, for example.

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SOFTWARE ADOPTION

Thanks to the availability of software and educational material on the Internet, the E-Foto project has achieved international visibility, allowing its use in the teaching-learning process of photogrammetry in any part of the world. The statistics of visits and access to the didactic content of the project can be visualized in its own page, as shown in Figure 5. These numbers correspond to nearly 34,000 page views and 16,000 visitors.

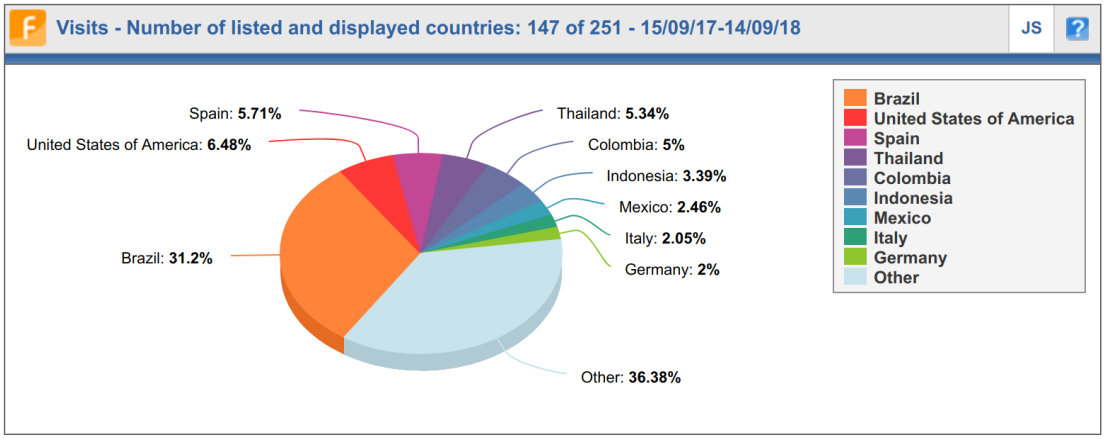

Figure 5. visitors by country, last 12 months.

We can also use the amount of software downloads as an indicator of its adoption by the community. Figure 6 shows the software downloads from our repository at Sourceforge from the last 12 months. Nearly 10,000 users downloaded our software during the last year, Linux and Windows versions included.

	Country	Android	Linux	Macintosh	Unknown	Windows	Total
1.	Brazil	7	143	13	30	2,400	2,593
2.	Thailand	0	2	15	0	1,034	1,051
3.	Colombia	2	5	0	0	675	682
4.	Spain	2	90	6	0	449	547
5.	United States	14	77	13	88	195	387
6.	Indonesia	7	7	1	0	360	375
7.	Peru	0	0	0	0	308	308
8.	Bolivia	39	2	0	0	233	274
9.	Germany	2	64	4	63	133	266
10.	Croatia	0	228	0	0	23	251

Figure 6. Downloads by country, last 12 months. (source: Sourceforge.)

The reliability and quality of E-Foto have led us to win the second prize in **Computer Assisted Teaching CONtest** (CATCON) in 2016 (Brito et al., 2016). CATCON is the name of a software competition organized by the International Society for Photogrammetry and Remote Sensing (ISPRS). The main purpose of the contest is to promote the development and dissemination of software designed and used specifically for computer-aided learning. The E-Foto project had already won the third place award in 2012 with an older version of the software (Aguiar et al., 2012). This demonstrates the international recognition and the relevance of the project.

E-Foto was recently selected by the **GISGeography** site of free software classification for GIS, as one of the 13 best open source remote sensing software (http://gisgeography.com/ open-source-remote-sensing-software-packages/).

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CONCLUSION

Since 2002, we develop E-Foto at the State University of Rio de Janeiro. During these years, thousands of students around the world have learned photogrammetry and software development by working with E-Foto. The development of the E-Foto Project has contributed a lot to the training of the professionals who work with photogrammetry.

The last years, we have worked mainly on regular maintenance of the code, without launching new versions of E-Foto. Brazil has been in recession for two years (2015-2016) and, even now, we have economic and political problems that affected our University. The impacts of this crisis are the slow down of our activity on development. We have had to postpone several improvements because we are a small team of developers and testers with almost no funding.

We continue to evolve the software, correcting any bugs and planning improvements. We want the e-photo to work in the future not only with aerial photos, but also with drone and close range images (Ribeiro et al., 2014). The e-photo today is a reality built with a lot of work over the years. The challenge remains, but the results obtained outweigh any effort.

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