# E-FOTO: Development of an Open-Source Educational Digital Photogrammetric Workstation

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*Abstract*—The E-FOTO project aims to develop an educational, digital photogrammetric workstation, under the General Public License (GNU/GPL). E-FOTO software does not intend to overcome commercial software solutions in its field. Its main purpose is to provide a software solution that could be used by anyone who is interested in learning digital photogrammetry. E-FOTO users are offered access to practical software applications of theoretical issues and concepts in the field of Digital Photogrammetry. The project also has an Internet home page from which aerial photographs, camera calibration certificates and other technical data can be downloaded, thus allowing users to fully experience the software. The webpage also provides access to different articles and publications derived from the project development. This paper will report the experiences and results of the development of E-FOTO, which is, to the best of our knowledge, the only academic, GNU/GPL software development initiative for Digital Photogrammetry in the world.

*Keywords-Digital Photogrammetry; Digital Photogrammetric Workstation; Education in Photogrammetry; Open-source code for geospatial applications; Extreme Programming; Agile Methods.*

## I. INTRODUCTION

Photogrammetry is the science that studies methods for reconstructing 3D objects, e.g., Earth's surface, from a set of 2D stereoscopic images. Remote Sensing techniques are typically used for the acquisition of photogrammetric imagery. Currently, it is possible to find a reasonable number of imaging satellites orbiting around the Earth. These devices have achieved spatial resolutions as low as 0.50m per pixel. Airborne remote sensors which use optical devices coupled with Global Navigation Satellite Systems (GNSS) receivers and Inertial Measurement Units (IMU) also play a very important role in topographic mapping activities. Those activities include the production of digital surface models (DSM), the production of ortho-images, and the generation of 3D spatial databases. These products are typically named "cartographic products".

A digital photogrammetric workstation is a set of hardware and software that is able to generate cartographic products. Hardware components include a digital computer and other devices such as topomouses, digitizing tablets and stereoscopic glasses. Some examples of computer software developed for a digital photogrammetric workstation are photogrammetric algorithms for automatic DSM extraction and digital ortho-image rectification.

The cost of a digital photogrammetric workstation ranges from US$ 25,000.00 for educational versions up to US$ 100,000.00 for professional solutions. These prices are too expensive for educational institutions in developing countries.

As a response to such high prices, Coelho Filho [1], proposed the development of a digital photogrammetric softcopy kit for educational purposes. His solution was designed and implemented under the General Public License (GNU/GPL) of the Free-Software Foundation. The kit was named "E-FOTO", which stands for "Educational Digital Photogrammetric Workstation" in Portuguese.

There were many free software solutions for geospatial applications. One could mention POSTGRES, MAPSERVER, GvSIG and GRASS GIS, among others. However a digital photogrammetric workstation with a free GNU/GPL license did not exist yet. In addition to providing users free access to photogrammetric software, a free softcopy kit would allow developers to examine and improve its source code and produce derived projects. Consequently, users would be able to understand photogrammetric algorithms and techniques, while also using their code for various purposes.

It is worth mentioning that the E-FOTO Project was not designed for competition with its commercial counterparts. E-FOTO's main objective is to provide access to Digital Photogrammetry to anyone who is interested in learning about that subject. As a result, E-FOTO users will better understand and practice the theoretical concepts taught in formal classrooms.

A paperback book on Digital Photogrammetry [2] was published parallel to E-FOTO's project development. This book, which is available only in Portuguese, covers most theoretical concepts used for the development of the E-FOTO software. It is currently in its first edition, published

in 2007, even though a provisional e-book version of it had been available since 2002, when the project started.

The development of Photogrammetric software is a complex task. In fact, it involves a multidisciplinary team of professionals with different backgrounds and skills, mostly dealing with Geomatics and Computer Science. In 2004, the project was granted sponsorship by the National Council for Scientific and Technological Development of Brazil (in Portuguese, CNPq), which allowed it to be reallocated to the School of Engineering of The Rio de Janeiro State University. With proper funding, its software development was carried out in a more consistent way. It was supported by both Masters Dissertations and Undergraduate Final projects. In 2008, after having completed all of its modules, the E-FOTO development team started their integration. Finally, in November 2010, the first fully integrated version of E-FOTO was published on the project's website (www.efoto.eng.uerj.br).

This article is organized according to the following structure: Section II presents experiences of the E-FOTO team during the development of the aforementioned software; Section III reports the project's benefits; Section IV envisions future work to be done and Section V concludes this paper.

## II. THE E-FOTO DEVELOPMENT EXPERIENCE

E-FOTO's team has dealt with many issues which arose from the development of such a complex system. This section reports E-FOTO's development approaches and experiences.

### A. Academic Work and the development of E-FOTO's Photogrammetric Modules

E-FOTO was originally designed in 2002 as a system composed of eight modules: (a) image rectification, (b) interior orientation, (c) exterior orientation, (d) bundle block adjustment, (e) image normalization, (f) photogrammetric stereoplotting, (g) extraction of digital elevation models and (h) ortho-rectification.

In accordance with free software principles, a free digital photogrammetric workstation should not contain any part of its code based upon proprietary solutions. Thus, it was decided that the project would be developed using free environments such as GCC/G++ (C++) and the Qt graphic user interface for easy multiplatform porting. At first, an interior orientation module was implemented as a proof of concept in 2002.

After E-FOTO was granted sponsorship in 2004, an official schedule was proposed, which aimed to complete the proposed modules in two years, with the possibility of a one year extension. Development effectively began at its new venue, The Rio de Janeiro State University.

Initially, photogrammetric modules were developed as part of undergraduate and graduate students' academic work, often counting on proprietary software, such as Mathcad and Matlab. This step allowed the team to test if algorithms were fully functional and correctly produced desired results. The digital image rectification [3][15][20], exterior orientation [4][22] and bundle block modules [5][22] were developed in

the Mathcad environment. An image ortho-rectification module [8][22] was developed with Matlab.

Some other modules were implemented from the beginning in C++. For example, a digital airborne imagery stereo-visualization and measurement module [7][14][24] was developed and used for stereoplotting and digital elevation model extraction. An image normalization module [6][20] was also developed. Figure 1 shows photogrammetric stereoplotting using E-FOTO.



Figure 1. The photogrametric stereoplotting module.

Modules initially developed with mathematical software were gradually reprogrammed by team members. The first rewritten module was the image rectification module. Next, the stereoplotting module was integrated with an ortho-rectification solution. With the release of these first modules, it was possible to assign students to test the software and write down their impressions about its ease of use. This helped find bugs and adapt E-FOTO's interface so it would be more user-friendly. New modules were built based on these impressions. So, programs for exterior orientation, bundle block adjustment and normalization were developed according to this new philosophy and look and feel while earlier models were adapted to conform to an easier graphic interface. Figure 2 shows the exterior orientation module after the proposed modifications.

In early 2007, the deadline for the creation of the modules was successfully met by the team. However, their integration was not yet desirable. Thus, the need for integration among these modules using techniques of systems analysis became evident. Additionally, another problem arose: in early 2006, Trolltech (Qt's former developer) migrated it from version 3 to version 4. The latter introduced several changes which turned it incompatible with earlier Qt versions. The project's development team decided that porting all modules from Qt3 to Qt4 would be counterproductive at that moment. So, it was decided that all modules would continue to be implemented in Qt3, and then ported as a whole to Qt4.
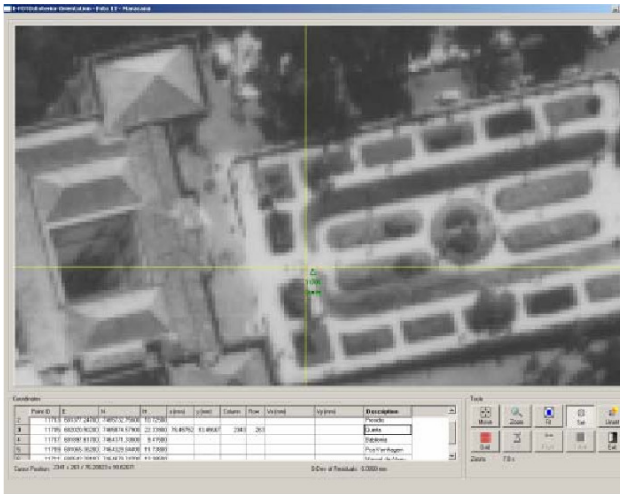
Figure 2.   The exterior orientation module.

### B.   Migration from Qt3 to Qt4

After Trolltech stopped providing support for its Qt3 framework, in July 2007, E-FOTO developers were forced to start porting its code to Qt4, to continue benefiting from future Qt updates. Initially, it was expected that the conversion could be done without major problems, by using automated migration tools provided by Trolltech. However, due to certain incompatibilities between the two versions, this migration has been very difficult. The main problems experienced throughout the porting process were related to interface and graphic content conversions, since the main resources used for these developments in the previous version, such as bit block transfer (bit-blt), were discontinued. Thus, modules that used these resources, such as the photogrammetric stereoplotting module, had to be more intensely reworked. As a consequence of this migration process, interfaces for currently finished modules had their appearance and functionality slightly changed. Drastic changes were minimized in order to reduce their impact to the end user [12].

One of the most unexpected changes the Qt4 graphics engine brought was the adoption of the Scalable Vector Graphics (SVG) format as the basis for its main graphic elements display system. Even though this format has been widely used in the development of graphics applications, especially as the basis of the widely-used Flash format,  it has a notable disadvantage: it needs some support from the operating system to deliver expected results. This does not pose a problem when using a Windows OS, but when a Linux distribution is used, serious performance issues can be experienced, especially when working with images displayed outside of their standard resolution, i.e. with a different scale factor than 1:1.

Since one of the main goals of the E-FOTO project is to provide an easily portable software, both in terms of operating system and hardware resources, the development team sought alternatives to Qt4's native graphics display system. OpenGL was finally picked as the ultimate solution, both because of its performance, since it was created

specifically for the direct use of the resources present in commercially available graphics cards, and because of its easy integration with most frameworks for developing graphical user interfaces (GUIs). Qt provides support for displaying processed graphics through the OpenGL standard, so the team chose to keep it for other graphical elements (windows, menus, buttons, etc.), thus avoiding the extra effort of adapting the code to redraw those elements. Also, it helped keep the look and feel of the programs similar to their earlier versions [13].

E-FOTO's 1.0 version already had a couple models fully converted to Qt4: interior and exterior orientation modules. Those two were picked not only because they are central to implementing the first stages of the photogrammetric process, but also because they were the ones in which users were not commonly able to work with their own set of data, being limited to examples already provided by the software. The remnant modules are currently being ported from Qt3 to Qt4. Figure 3 shows the results of the interior orientation module migration from the Qt3 to Qt4.
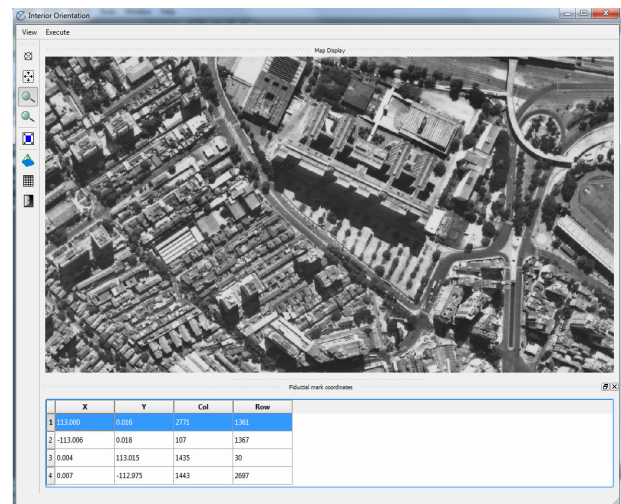


Figure 3.   Interior orientation module after having been  ported to Qt4.

### C.   The Integration of E-FOTO Modules

An important characteristic of the photogrammetric process is its division into smaller, sequential steps. This makes software organization in modules fairly intuitive. Therefore, the implementation of initial versions of E-FOTO followed that modular architecture. But, in these versions, the sequential characteristic of the process was overlooked, and so each module was developed independently of the others, without any concern about data exchange among them. Since it was known that the software would get a major overhaul due to the porting from Qt3 to Qt4, the development team took this opportunity to restructure the entire system architecture, and to offer a solution according to which all modules would be able to communicate through a common language.

This common language was implemented through a specification of the XML (eXtensible Markup Language)

standard created by the project's development team, called E-FOTO Photogrammetric Project, and given the ".epp" file extension [9][10][23]. The choice for this implementation was based upon the extensibility offered by the language and the possibility to view and audit the project without the need to develop complex solutions, since most Internet browsers can understand XML files. To interpret these files, the development team implemented a solution based on the DOM (Document Object Model) approach, and incorporated it in all re-factored modules so that they are able to obtain the information required for their part of the process from a common data source [12][19].

Concerning the general structure of the software, the whole process required one change in relation to the older versions: the addition of another module to the system. Until then, the software contemplated all the stages of the mathematical process, but lacked a module to represent the stage of structuring the photogrammetric project. To solve this problem, a photogrammetric project management module was created, with a set of registration forms [11] and the duties of giving the user an overview of the current state of software and allowing the selection of the next step to be executed. Figure 4 shows the main window of the photo-grammetric project management module.
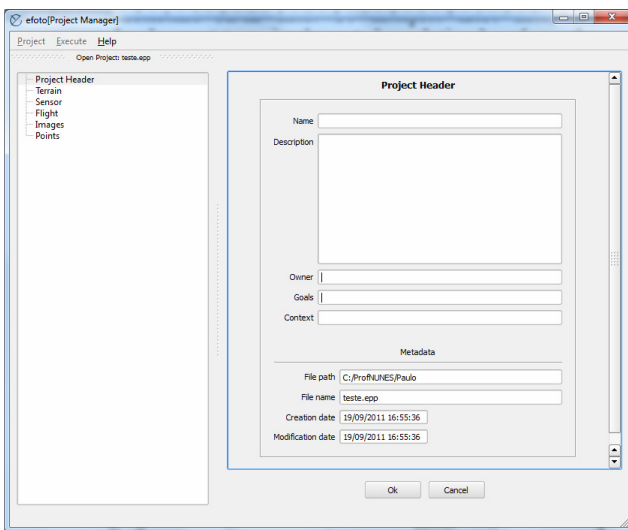


Figure 4. The E-FOTO project management module.

To finish the basic architecture of the system, a "central" manager to the whole system was developed, responsible for memory management and the main control flow. The existence of this manager is what actually characterizes the software's integration, since it is this manager which ensures that the various modules are accessing the same data set, thus keeping the integrity of the project throughout the execution of the software.

## III. LESSONS LEARNED

Due to some of E-FOTO's characteristics, such as the constant presence of a client-like figure in the development team (in this case, the project's lead manager) and the

experimental research scenario in which it is included, the developers decided to try out a different approach to the development process during this new phase of the project's development cycle. After some research, it seemed reasonable to adopt a development process based on the agile methods [17], since their foundations apparently fit very well into the project's context. Out of all the agile methods, the developers chose to adopt the basis of agile modeling [18] and eXtreme Programming [19], mainly due to the fact that some of the developers already had some experience with them.

At first, everything seemed to run smoothly as expected. However, as time passed, the project's own development environment proved itself a big problem to be solved. Since E-FOTO is developed inside a University, with many of its working hands being teachers and students, it became increasingly harder to keep up with XP's so-called "good practices". Everyone had their own schedules, making whole-team meetings very hard; this affected the whole communication effectiveness very badly, since more meetings were needed, costing much more of the developer's time, and not everyone was always to pairing with the latest decisions. This even managed to get worse during exam periods - the teachers needed to design and grade exams, and the students needed to study, effectively slowing down the development to almost a halt. After these periods, the production rate slowly started to rise again, eventually reaching the ideal point, just to be ruined again by another battery of exams. This cycle went on until the first concrete results were achieved - much later than the developers thought they would.

As such, one of the project's greatest lessons learned in the last few years is that developing software in an academic context is very different from the scenario usually found outside the university walls. Sure, enterprise workers also have other things to do, and some of them could even be students or teachers. However, inside the academy these problems present themselves in much higher levels, possibly reaching the point where some of today's more well-known development processes lose much of their effectiveness. The project's development team still tries to apply some of the Agile concepts into their everyday work, but is still trying to find the point where the academic context will present itself not as a problem, but as one of E-FOTO's major advantages in its development process.

Another big lesson that the project's development team learned came from the troubles experienced in the migration from Qt3 to Qt4. As a defensive move to avoid having similar problems in the future, the project received a major architectural overhaul: not only was it to be developed according to the photogrammetric process' modularity, but also following some architecture that could minimize the effects that another framework change could have. The solution found was to follow a scheme based on MVC (Model-View-Controller), where the whole Model and Controller layer were to be developed without the aid of any external libraries/frameworks, isolating these on the View layer. Even then, the communication between the Controller and View layers should be done according to a pure-C++

interface, so that any "low-level-code" changes in the View implementation would not affect the other layers at all.

So far, this architecture has proven itself very successful at its job, allowing the developers to meddle with many of the software's "high-level" aspects while keeping the core business intact, such as the addition of different image visualization components. As a bonus, the development of new modules has proven to be very simple, since the modules are now connected to the same model, with the addition of a new controller and user interface to interact with it. Therefore, it can be said that this MVC-based structure is the greatest reason for the success of E-FOTO's integration process.

## IV. BENEFITS OF THE PROJECT

E-FOTO has been tested mainly in Digital Photogrammetry classes, both in the Masters program in Geomatics, and in the undergraduate program of Cartographic Engineering at the Rio de Janeiro State University. It has also been used in many academic institutions over the world. Anyone can access the E-FOTO software by downloading its versions from the E-FOTO´s home page on the Internet [16]. The software runs in both Windows and Linux environments. The following photogrammetric data and training material is also available in the E-FOTO´s home page: (a) a set of three digitized-frame, 9"x9" aerial images; (b) a pdf file containing a photogrammetric camera calibration certificate; (c) a set of twelve ground control point coordinates for photogrammetric processing; (d) a set of seven tutorials about the functionalities of the E-FOTO solutions, and (e) the academic works and the publications generated as a consequence of the E-FOTO development. Another point that is worth mentioning is the statistics about the visits to the E-FOTO´s home page: those statistics show the daily and monthly accesses to the E-FOTO´s Home page. It also has the tracking of the geographical source of the accesses. Figure 5 shows examples of such statistics.
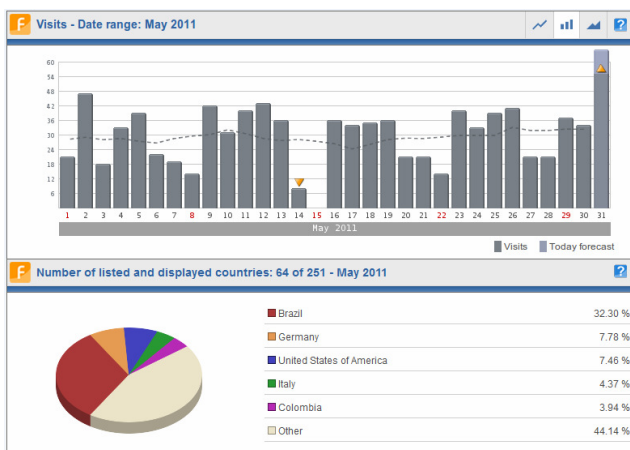


Figure 5.   E-FOTO home page accesses statistics. Source: ShinyStat.

The graphic at the top of Figure 5 shows the visits to the E-FOTO home page in May 2011, with an average of 30

visits.  The pie chart on the bottom of Figure 5 depicts the percentage of  visits to the E-FOTO home page by country in the same period.

## V. FUTURE PLANS

E-FOTO's educational software is being currently used in many different countries, which brings to the development team great responsibility. There is still much work to be done. In fact the team is currently preparing a new integrated version of the software with many improvements. These improvements deal with the correction of systematic effects from earth curvature, lens distortions, and atmospheric refraction. Another improvement is the extension of the E-FOTO´s source code for dealing with optical satellite imagery, through the use of the Rational Polynomial Functions model. The development of the bundle adjustment phototriangulation algorithm is undergoing. Stereoscopic visualization capabilities with either passive or active shutter glasses is another topic of research. The E-FOTO team is also translating the tutorials about the use of the integrated version of the software into English and Spanish.

## VI. CONCLUSIONS

Digital Photogrammetry has manifold applications of potential interest for users of geographical information. In developing countries, such as Brazil, there is a great need of proper formation of new professionals who will work in this field. The  motivation and goal of the E-FOTO project is to make available a GNU/GPL free software platform for education in Digital Photogrammetry. E-FOTO does not intend to replace commercial photogrammetric solutions. However, it does intend to provide a software solution that could be used anytime, anywhere by anybody who is interested in learning about photogrammetric principles. Because of that, E-FOTO could be extremely useful for those people and institutions that cannot afford to acquire digital photogrammetry software solutions, even when purchased for educational purposes.

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