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Photogrammetry with UAV's: Quality Assessment of Open-Source Software for Generation of Ortophotos and Digital Surface Models

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Abstract: Nowadays there is an increasing need to keep cartographic information up to date, as well as to obtain topographic information from the terrain as fast as possible. Although presenting high accuracies, classical methods such as aerial photogrammetry or surveying can be expensive and/or time and resource consuming. With the advent of Unmanned Aerial Vehicles (UAV's) a new fast and cheap way of obtaining geographical information has emerged, and it is now possible to make aerial surveys of relatively small areas with consumer grade digital cameras.

One of the main problems related to image acquisition using UAV's is the high amount of pictures taken during the survey, the uncertain geometry between them and the low accuracy of the on-board Global Navigation Satellite System (GNSS) equipment. This fact led to the need of developing innovative algorithms and software packages capable of processing the aerial photography data obtained by UAV's.

There are currently a high number software tools dedicated to processing these pictures. Among them, a highly recommended open-source tool is available, called MicMac and developed at the French institute, IGN. The current study will focus on the use of this open-source tool to assess the quality of the products derived from UAV imaging, comparing the results with other commercially available software's.

The pictures used in the current study were taken at Capelã, Arruda dos Vinhos, and several ground control points and quality control points were coordinated using a GNSS equipment.

We could conclude that the open-source software is capable of processing the data with a good accuracy and generating high quality products. However, the learning curve and the processing time still pose a significant problem when compared with commercial solutions.

1.Introduction

The usage of Unmanned Aerial Vehicles (UAV's) for photogrammetric purposes remotes back to 1979 (Eisenbeiss and Zürich, 2009). Since then, there has been a significant increase in its applications, not only due to the higher availability of platforms, digital cameras and low-cost GNSS receivers, but also because they represent a low-cost alternative to classical aerial photogrammetry systems (Remondino et al., 2011).

These systems, however, have several disadvantages, namely:

- Due to the lightness of UAV equipment, it's sensors are also lightweight and smaller
- The reduced sensor size of the cameras implies the acquisition of a higher number of pictures
- There is a limit on the flight altitude and range, and the flight path of the UAV is unstable
- Due to the low-grade GNSS sensors on-board of UAV's, the georeferencing must be made by recurring to Ground Control Points (GCP's)

These problems result in aerial surveys that yield a very high amount of pictures with a highly irregular geometry, thus making it nearly impossible to tie the images together and restitute them using a traditional approach. This has led to new algorithms and processing approaches to appear, most of them based on the SIFT (Scale Invariant Feature Transform) algorithm (Lowe, 1999) for image matching and tie point generation.

In today's society open-source software is playing an increasingly crucial role, with many academic institutions, research laboratories and even companies recurring to this type ofsolution. This is also true for photogrammetric software and, in particular, one capable of processing images acquired by UAV's.

The most widely used solution, capable of producing high quality professional results, is MicMac[1], a command-line based tool developed at the heart of IGN (*Institute National de L'information Géographique et Forestiére*), initially for traditional photogrammetry and now capable of processing UAV images. This software was the main basis for the work presented here.

The images for this study were acquired in an area in Capelã, Arruda dos Vinhos, where Ground Control Points (GCP's) and Quality Control Points (QCP's) were coordinated using a GNSS receiver.

In order to correctly assess the quality of the product, one needs to compare it with other software solutions. Research has led to three additional tools used in this study: Pix4d[2], Menci APS[3] and AgisoftPhotoscan[4].

The current study aims to present the main results obtained with open-source software, and compare them with what other solutions are capable of generating. For this purpose the two main products generated by UAV imaging, point clouds or Digital Surface Models (DSM) and orthomosaics, are analyzed based on two main criteria: the overall looks of the products (point cloud density, orthomosaic radiometric quality, etc.) and the deviations relative to the coordinates of quality control points.

The work presented here was developed in scope of the Geographic Information Project course of the Master in Geographic Engineering of the Faculty of Sciences, University of Lisbon (FCUL).

2. Equipment and Software

2.1 The UAV

The UAV used to carry out the aerial survey was the SenseFly eBee[5] (Figure 1). Which has a Canon IXUS 127[6] camera (Figure 2), already installed in the UAV.

[1]http://logiciels.ign.fr/?-Micmac,3-
[2]https://pix4d.com/
[3]http://www.menci.com/photogrammetry-software/aps-3d-maps-software
[4]http://www.agisoft.com/
[5]https://www.sensefly.com/drones/ebee.html
[6]http://www.canon.pt/For_Home/Product_Finder/Cameras/Digital_Camera/IXUS/IXUS_125_HS/

Some of the main characteristics of the system, according to the manufacturer, are:

- Maximum flight time of 50 minutes (40-90 km/h speed),
- Ground Sampling Distance up to 1.5 cm,
- Absolute horizontal and vertical accuracy using GCP's: 3 cm and 5 cm respectively,
- Absolute horizontal and vertical accuracy without GCP's: 1 m to 5 m

Figure1 – The eBee UAV in flight

Figure2– Close-up of the eBee UAV with camera detail

The UAV is controlled by SenseFly's eMotion software. This software is able to import the flight plan into the UAV (or create one on the fly) for autonomous control, export data for visualization in Google Earth and display real time information regarding the flight.

2.1 Software

Four software's were used for the current study: MicMac, Pix4d, Menci APS and Agisoft.

MicMac is a simple, yet powerful, command line tool, with a steep learning curve. It is composed of several modules, each responsible for a different step in the typical processing chain. It is prepared to process both aerial and terrestrial images.

The three other software's are all similar between them, with some minor differences in added functionality and options. Pix4d, for instance, has an integrated map viewer (using Nokia Maps), capable of displaying the location of relevant survey points (GCP's, projection of the center of the images, etc.), which aids in the georeferencing of the points. On the other hand, Menci APS has a simple integrated Computer Assisted Design tool.

3. Image Acquisition: Field Test Description

The field test took place in Capelã, Arruda dos Vinhos. The survey area was previously defined (Figure 3) and the location of GCP's and QCP's was specified. These points were then coordinated using a typical surveying GNSS equipment. In this case, the Leica GS15 GNSS was used, which presents an horizontal accuracy of 0.8 cm + 0.5 ppm and a vertical accuracy of 1.5 cm + 0.5 ppm, using Real Time Kinematic(RTK) networks, as was the case in this project.

The GCP's consisted of natural points that would be visible in the aerial photo (such as wall edges) and the QCP's consisted of white plastic plates which would contrast with the terrain and could also be identified in the images.

The flight plan consisted of two separate flights, for densification and quality improvement purposes, one in the West-East direction and another in the North-South direction, using a cross-track overlap of 60% and an along-track overlap of 75%. The resulting flight path can be seen in Figure 4, yielding 17 strips in the W-E direction and 14 strips in the N-S direction.

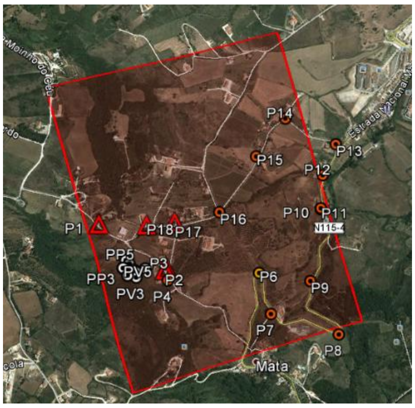

Figure 3 – Survey Area with GCP's and QCP's

Figure 4– Flight tracks of the Survey

4. Processing

All software's follow a typical workflow encountered for the image processing stage of UAV photogrammetry, which is summarized in Figure 5:

- Find tie points between images (typically using a variation of the SIFT algorithm)
- Calculate the internal orientation of the camera, where a subset of the images is used, typically a block in the center of the whole survey area
- Georeference the images by identifying all GCP's in all images in which they appear
- Bundle adjustment (least squares) of the georeferencing. If results are not acceptable, repeat the georeferencing process
- Generate an orthomosaic in order to define the area of interest
- Dense reconstruction of the images, in which the points generated in (1) are densified
- Generation of the orthophotos, the final orthomosaic, and the point cloud

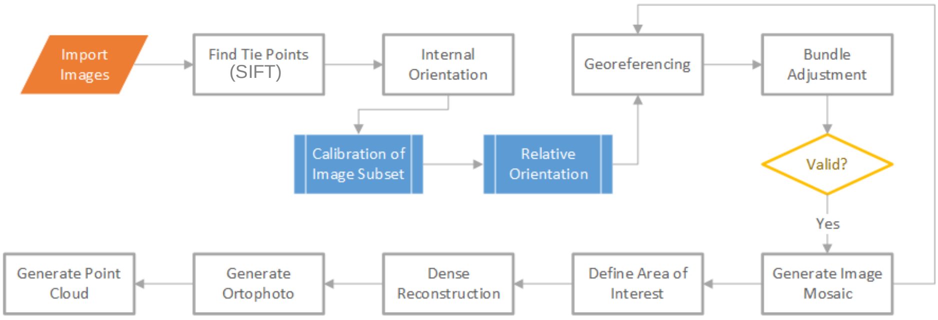

Figure 5 – Typical workflow for UAV photogrammetry processing

Due to the high amount of pictures and the number of tie points to be determined, the processing stage is typically resource and time consuming. Although commercial software's are capable of dealing with this, and in a modern computer this processing is relatively fast, MicMac took much longer to process. Moreover, MicMac was unable to process the whole survey under these processing conditions, with approximately 700 photos. Due to this fact, only a subset of the survey with approximately 150 photos was used for this study. Even so, MicMac took around one day to process, whereas Menci APS (the fastest) took only about four hours, using the same image subset.

The image processing with MicMac was carried out two times, independently and with two independent users and computers for confirmation and validation purposes. The same GCP's were used for all processes, as well as the same image configuration.

5. Results

5.1 Quality Criteria

In order to assess the quality of the generated product, several criterion parameters needed to be defined and analyzed:

1. Visual quality of the orthomosaic:
   a. Brightness uniformity throughout the whole orthomosaic,
   b. Contiguity of the transition areas (e.g. buildings to terrain), sharpness of transition areas,
   c. Unnoticeable transitions in the orthomosaic where individual mosaic areas are joined.
2. Visual quality of the point cloud:
   a. Cloud density,
   b. Edge sharpness.
3. Positional quality of the point cloud.
4. Radiometric quality of the orthomosaic histogram.

5.2 Results and Analysis

The global orthophotos generated by the four software's are presented in Figures 6-9. Overall there are no noticeable differences between them, except in the case of MicMac, where one can observe a darkening of the orthophoto in the North-South direction.

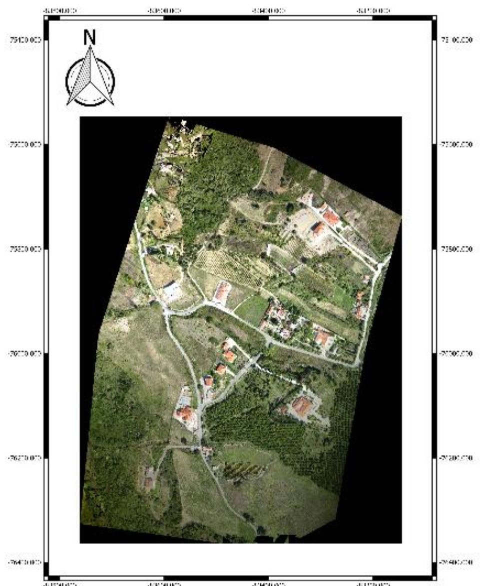

Figure6 – Orthomosaic generated by MicMac

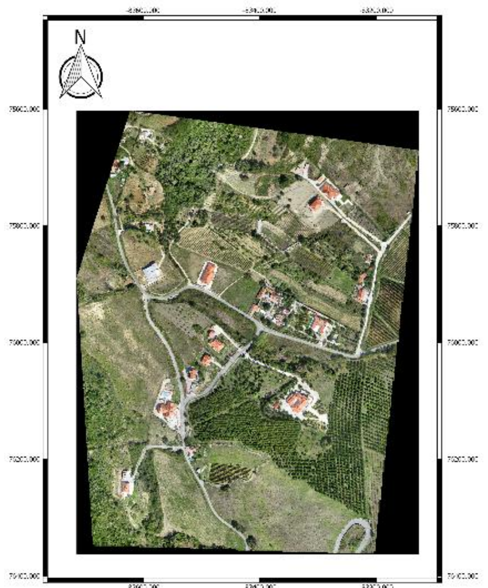

Figure7– Orthomosaic generated by APS

However, if we zoom in on specific regions, some problems are more noticeable.In Figure 10there are noticeable transition areas in the orthomosaic generated by MicMac. In the top image it can be seen that the roofs of the houses suffered a displacement, resulting in the edge of the roof being located on the terrain area. This is not the case for Pix4d software. The bottom image reveals that the frontier between two subsets that form the orthomosaic is clearly visible, with different brightness levels between each mosaic, which is not visible in the orthomosaic generated by Menci APS. In general all tested commercial software do not present the problems described above.

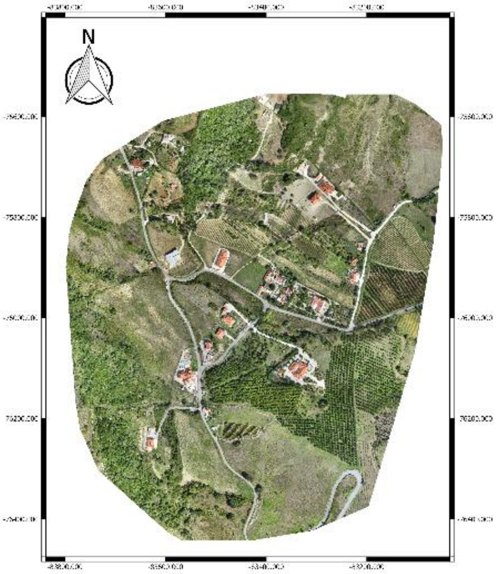

Figure8 – Orthomosaic generated by Pix4d

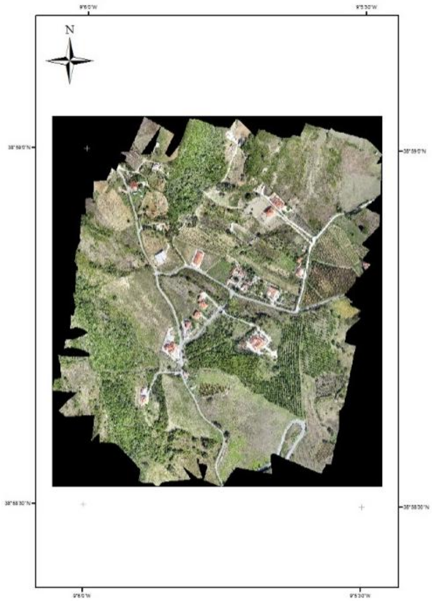

Figure9 – Orthomosaic generated by Agisoft

Figure10 – Ortomosaic details (MicMac)

Figure 11 – Ortomosaic details; Top: Pix4d; Bottom: Menci APS

The point clouds can be viewed in Figures 12 to 15, and a close-up for MicMac and Menci APS cases in Figures 16 and 17 respectively. It is clear that the density of the point cloud generated by MicMac, which was generated after making small changes in some of the default parameters, is significantly higher than other cases. However, the problems detected in the orthomosaic remain in the point cloud, which is expected since they are generated based on the same information.

In order to assess the positional quality of the data, the QCP's were identified in the point cloud (Figure 18)and the approximate coordinates of their center were obtained. These coordinates were then compared with the ones obtained with the GNSS equipment and the resulting Root Mean Square (RMS) was determined. The summary of the results are presented in Table 1.

For this study, the main measure used for the analysis was the altitude, due to the fact that values in the X-Y position can contain errors due to the uncertainty in determining the center of the plate. From the table below one can conclude that MicMac presented the best results, with an accuracy in altimetry of only 5 cm in one of the iterations.

On the other hand, Pix4d presents the lowest accuracy. However, it is suspected that this is a result of a poor ground control point identification by the user, and a second iteration should yield better results.

Figure12 – Point cloud generated by MicMac

Figure13 – Point cloud generated by APS

Figure14 – Point cloud generated by Pix4d

Figure15 – Point cloud generated by Agisoft

Figure16 – Point cloud detail (MicMac)

Figure17– Point cloud detail (Menci APS)

Figure 18 – Example of identification of a QCP (plastic plate) on the point cloud

Table 1 – Root Mean Square (RMS) of the deviations between observed values and ground truth

Software	RMS_x (cm)	RMS_y(cm)	RMS_z(cm)
MicMac (First Process)	4.7	5.5	8.1
MicMac (Second Process)	5.0	9.9	5.2
Pix4d	10.8	11.4	23.2
Menci APS	10.1	9.6	8.4
Agisoft	4.2	4.6	9.0

Finally, the radiometric quality of the orthomosaic was analyzed by viewing the histogram, which revealed a good balance for all software's. The contrast values for MicMac, however, are slightly darkened (Figure 19) when compared with the results for APS (Figure 20).

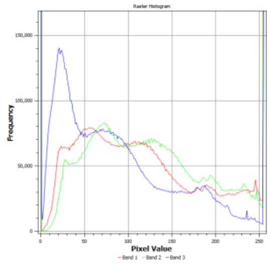

Figure 19 – MicMac orthophoto histogram.

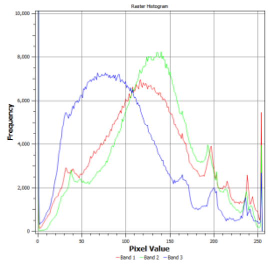

Figure 20 – Point cloud generated by APS

6. Conclusions

Unmanned Aerial Vehicles are playing an increasingly important role in the acquisition of geospatial information for several purposes. However, due to the reduced sensor sizes of these equipment, the accuracy of results may not be as high as traditional aerial photogrammetry. This leads to the need of analyzing different software solutions to find the expected accuracies and quality of the derived products in order to choose the best solution to fit the needs. In the current study an open-source software was compared to other commercial solutions.

Two main products are derived from UAV surveys: orthomosaics and point clouds. To assess the quality of the products among all tested software, these were compared based on three main criteria: the visual quality of the orthophoto, the visual quality of the point cloud and the positional quality of the final products.

It could be concluded that MicMac is capable of producing professional results which are comparable with products generated by commercial solutions. However, the orthophoto still presents some unwanted artefacts in transition areas. Furthermore, the radiometric balance of the orthomosaic is slightly worse than what could be viewed in the results of commercial software. Nevertheless, the resulting point cloud was the densest among the results, and the positional quality was the most accurate.

MicMac also has the disadvantage of being difficult to master and requiring a much longer processing time, but the tweaking of several parameters of MicMac should yield slightly better results in what the orthomosaic is concerned.

Overall, MicMac proved to be highly capable of generating derived products from UAV imaging. With the significantly lower costs associated with UAV surveys, and the high quality of the derived products, this is a technique which proves to be useful for several applications, and a most certain viable alternative to traditional techniques.

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