AUTOMATIC MAPPING FROM ULTRA-LIGHT UAV IMAGERY

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ABSTRACT:
This paper presents an affordable, fully automated and accurate mapping solutions based on ultra-light UAV imagery, which is commercialized by Pix4D. We show interesting application in the field of UAV mapping, analyse the accuracy of the automated processing on several datasets.
The accuracy highly depends on the ground resolution (flying height) of the input imagery. When chosen appropriately this mapping solution can compete with traditional mapping solutions that capture fewer high-resolution images from airplanes and that rely on highly accurate orientation and positioning sensors on board. Due to the careful integration with recent computer vision techniques, the result is robust and fully automatic and can deal with inaccurate position and orientation information which are typically problematic with traditional techniques.

1. INTRODUCTION

1.1 General Instructions

Fully autonomous, ultra-light Unmanned Aerial Vehicles (UAV's) have recently become commercially available at very reasonable cost for civil applications.
The advantages linked to their small mass (typically around 500 grams) are that they do not represent a real threat for third parties in case of malfunctioning.
In addition, they are very easy and quick to deploy and to retrieve. The drawback of these autonomous platforms certainly lies in the relatively low accuracy of their orientation estimates. In this paper, we show however that such ultra-light UAV's can take reasonably good images with large amount of overlap while covering areas in the order of a few square kilometres per flight.

Since their miniature on-board autopilots cannot deliver extremely precise positioning and orientation of the recorded images, post-processing is key in the generation of geo-referenced ortho images and digital elevation models (DEMs). In this paper we evaluate an automatic image processing pipeline with respect to its accuracy on various datasets.
Our study shows that ultra-light UAV imagery provides a convenient and affordable solution for measuring geographic information with a similar accuracy as larger airborne systems equipped with high-end imaging sensors, IMU and differential GPS devices.

In the frame of this paper, we present results from a flight campaign carried out with various UAV's, as for instance the swinglet CAM, a 500-gram autonomous flying wing produced by the Swiss company senseFly, the Belgian X100, a stable UAV with 2 kg produced by Gatewing or the 2m wingspan, 3.5kg battery powered glider Kahu, Skycam UAV produced in New Zealand). The images of both are geo-tagged after flight and form the input to the automated processing, called Pix4UAV-cloud.

This report demonstrates that the combination of ultra-light UAV imagery and automated processing is possible and yields accurate results, comparable to the ones obtained with traditional photogrammetric systems mounted on airplanes.
The main issue to achieve this is the fact that, due to its low payload ultra-light UAV's yield only imprecise measurements for the location and orientation of the individual images (H. Eisenbeiss and W.Stempfhuber, 2009).

Techniques rooted in computer vision, their fast and scalable implementation and the robust integration into photogrammetric techniques are the main key to circumvent the lack of precise sensor information.
The presented approach opens the door to a wide range of new applications and users which can now access geographic information at an affordable cost and without any knowledge in photogrammetry. The temporal (4-dimensional) analysis of local areas, as for instance the monitoring of reconstruction sites, becomes on one hand affordable because of the reduced cost of the hardware. Expensive helicopters or airplanes are replaced by ultra-light UAV's. The automated processing on the other hand reduces the labour cost substantially and makes such projects, which would normally require a lot of manual intervention using traditional photogrammetry techniques, feasible for the first time.

2. AUTOMATED DATA PROCESSING

2.1 Software Description

The software we use for our experiments was primarily designed for imagery in the visible spectrum. It can process up to 10000 images, is fully automated and with a high accuracy (O. Küng, C.Strecha, A. Beyeler, J-C. Zufferey, D. Floreano, P. Fua, F. Gervaix, 2011). A Geo-referenced ortho mosaic and DSM can be obtained in principle without the

need for ground control points. However, as shown here, more accurate geo-referencing does require Ground Control Points.
The software performs the following steps:

I. The software searches for matching points by analyzing all images. Most well known in computer vision is the SIFT (D.G.Lowe) feature matching. Studies on the performance of such feature descriptors are given in K. Mikolajczyk and C. Schmid (2002). We use here an improved version of the binary descriptors proposed in Strecha et al. (20xx), which are very powerful to match keypoints quickly and accurately.

II. Those matching points as well as approximate values of the image position and orientation provided by the UAV autopilot are used in a bundle block adjustment, e.g. (B. Triggs and P. McLauchlan and R. Hartley and A. Fitzgibbon, 2000) and (R. Hartley and A. Zisserman, 2000), to reconstruct the exact position and orientation of the camera for every acquired image (Tang, L. and Heipke, C., 1996).

III. Based on this reconstruction the matching points are verified and their 3D coordinates calculated. The geo-reference system is WGS84, based on GPS measurements from the UAV autopilot during the flight.

IV. Those 3D points are interpolated to form a triangulated irregular network in order to obtain a DEM. At this stage, construction of a dense 3D model, e.g. (D. Scharstein and R. Szeliski, 2002), (C. Strecha and T. Tuytelaars and L. Van Gool, 2003), (C. Strecha and W. von Hansen and L. Van Gool and P. Fua and U. Thoennessen, 2008), (Hirschmüller, 2008), increases the spatial resolution of the triangle structure.

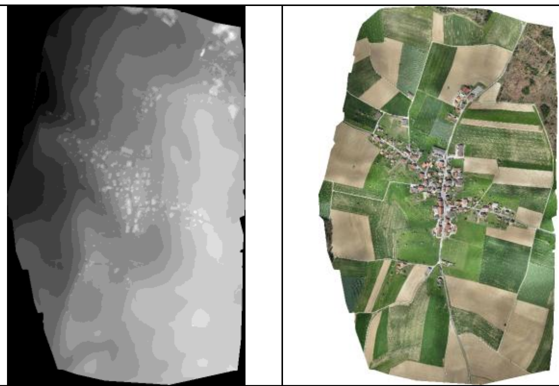
V. This DEM is used to project every image pixel and to calculate the geo-referenced ortho-mosaic (also called true ortho photo) (C. Strecha and L. Van Gool and P. Fua, 2008)

3. ACCURACY

In order to assess the quality and accuracy of this automated process, we consider here several projects that differ with respect to the coverage area, ground resolution, overlap between original images and the number of images.
For all datasets we measured GCPs, which we then used to evaluate the precision of the automated reconstruction.

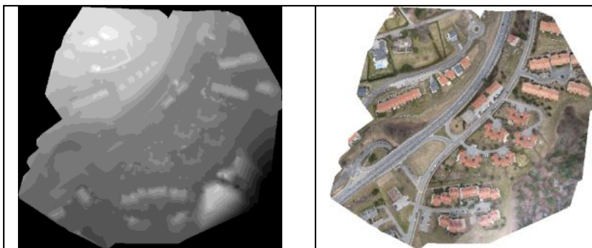
To assess the accuracy, we applied Pix4UAV-cloud to the above datasets. They differ with respect to the ground resolution of the original images, the amount of images and the area they cover. We show in these Figures the resulting ortho-mosaic and DEM for each of the datasets.

In the following Figures, we plot the accuracy results for several test datasets for which we have ground control points available (O. Küng, C. Strecha, A. Beyeler, J-C. Zufferey, D. Floreano, P. Fua, F. Gervaix, 2011). All experiments confirm the expected dependency of the accuracy on the ground resolution of the original images. We can conclude that the accuracy lies between 0.05-0.2m.
However, this accuracy cannot be achieved for all parts of the ortho-mosaic. Some areas might not be very well textured or could contain large discontinuities in depth (for instance near building boundaries or thin tree structures). For those areas the accuracy will be slightly worse.
To evaluate this, more experiments with LiDAR as ground truth are necessary.



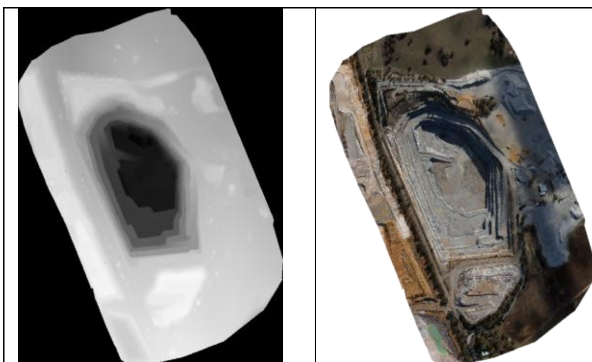
	X[m]	Y[m]	Z[m]
RMS	0.11	0.99	0.23
σ	0.064	0.062	0.127

senseFly dataset, 523 images, 20 GCPs



	X[m]	Y[m]	Z[m]
RMS	0.027	0.029	0.270
σ	0.020	0.020	0.015

senseFly dataset, 73 images, 12 GCPs



	X[m]	Y[m]	Z[m]
RMS	0.086	0.074	0.053
σ	0.040	0.061	0.053

Gatewing x100 dataset, 416 images , 11 GCPs

4. NIR-RGB INTEGRATION

Because of the limited payload of ultra-light UAV's it is sometimes not possible to put all sensors simultaneously on board. Here we show the application of RGB-NIR data capture where two flights have been performed: one with a camera in the visible spectrum and one with a NIR camera. Both flights captured images from a small area at the same day.

4.1 Acquisition Sessions

Imagery was collected over six swamps on the Woronora and Newnes Plateaus. Imagery was collected between 10am and 3pm to minimise shadow impact on the imagery. A total of twelve sets of imagery were collected in both RGB and NIR spectra. Image sets from 150-900 single photos were collected in each flight depending on shrub swamp size and wind conditions. Images were collected at 2.2sec intervals in flight lines with >80% forward overlap. Imagery was collected at approximately 300ft above ground level and camera location and attitude at time of image capture were recorded on board throughout the flight. Imagery was collected in RAW (.ARW file) format and converted to JPG format prior to photogrammetric processing using Pix4D workflow.

4.2 Combined Processing of Visible and NIR Imagery

To process this kind of data we applied to Pix4D processing to all images, RGB and NIR images. As a results all camera centres are obtaind and the ortho-image can be computed from the RGB and NIR imagery. Both of which are now in the same coordinate system.

Figure 1 shows the results of combining two datasets, RGB and NIR into a single reconstruction. Both, RGB and NIR are in the same coordinate system by taking matches between the two modalities into account. It is therefore possible to create a 4-band ortho image, even though the data has been acquired by two different flights.

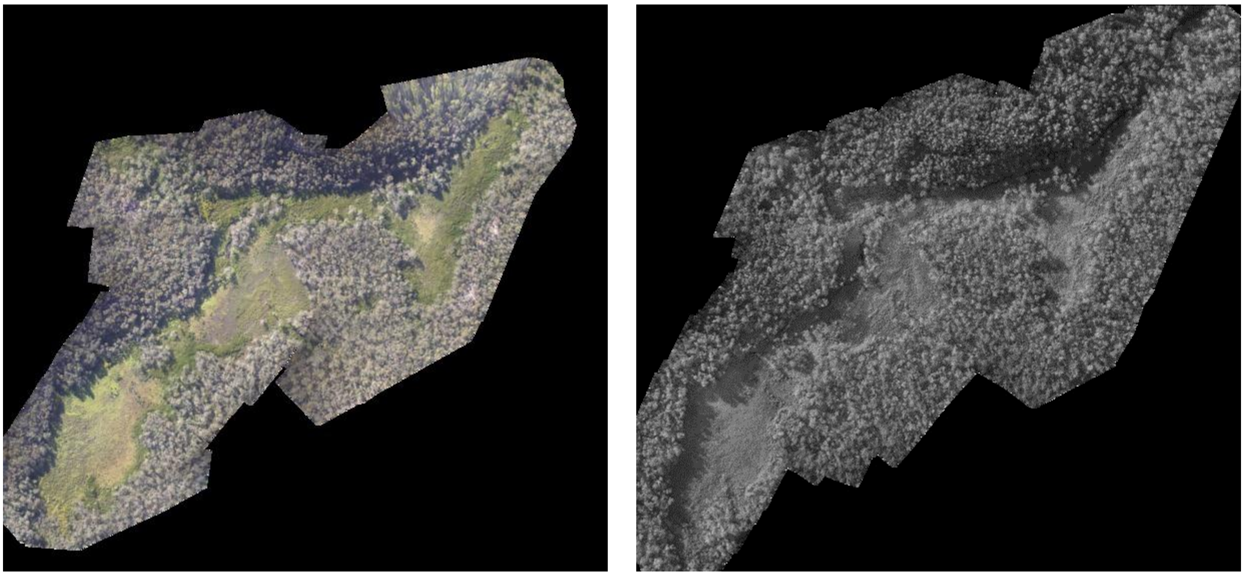


Figure 1: Ortho images for the visible (top) and the NIR spectrum (bottom) that have been obtained by combining both datasets into a single reconstruction.

5. SPATIO-TEMPORAL MODELLING

One further interesting application of UAV base image capture is the temporal modelling. It is very convenient and not expensive to capture the same, local area every day, week of month. Such data make it possible to look at change detection in rapidly changing environments (as for instance open mines) or building sites.

In Figure 2 We show the results of a building site. Similar so the visible NIR modelling in the last section we have put the images from all times into the same coordinate system by matching them not only within time, but also between different time instances.

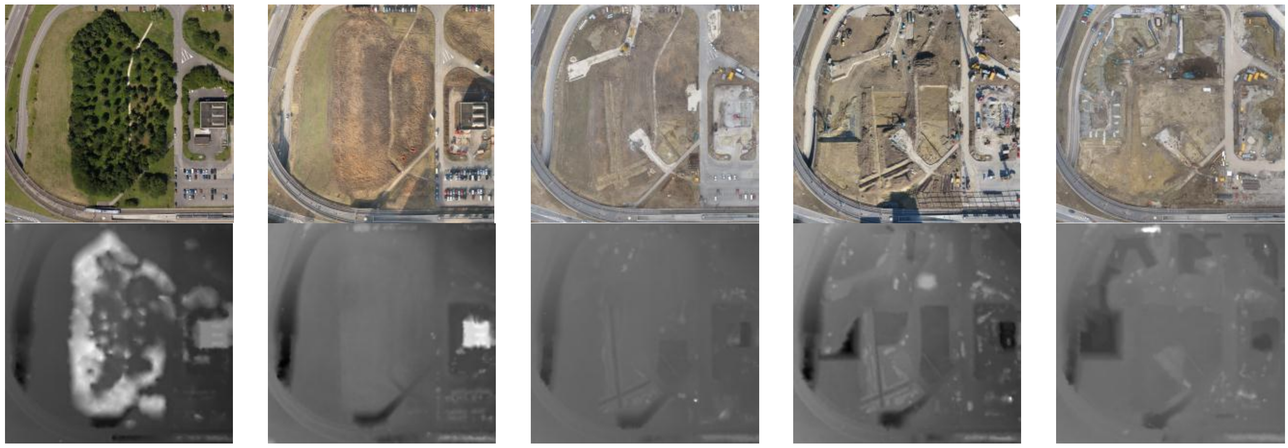


Figure 2. Teporal modelling of a building site. Each of the 5 individual ortho images and DSM models are computed from about 80 UAV images. Matching has been perfomred also between images from a different time such that all models are in exacly the same coordinate system.

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