KITE-BORNE PHOTOGRAMMETRY FOR DECIMETRIC 3D MAPPING OF SEVERAL SQUARE KILOMETRES AREAS

D. Feurer[1], M. A. El Maaoui[2], O. Planchon[1], M. R. Boussema[2], M. Pierrot-Deseilligny[3]

[1]IRD, UMR LISAH (INRA-IRD-SupAgro), F-34060 Montpellier, France, denis.feurer@ird.fr
[2]Université de Tunis El Manar, ENIT, Laboratoire de Télédétection et SIRS, Tunisie
[3]IGN/ENSG/DIAS et IGN/SR/LOEMI, Université Paris-Est, 94165 Saint-Mandé cedex, France

ABSTRACT

This paper presents a new methodology for the calculation of a digital elevation model (DEM) and the corresponding orthophotography at very high resolution (20 cm for the DEM, 10 cm for the orthophotography) on a large surface (more than 3 km^2). Image acquisition was done with an off-the-shelf camera (Sony NEX-5N) attached to a delta kite. Developing the most accessible methodology being one of the goals of this study, the overall cost of the apparatus is limited to less than 1500 euros. This method has been developed to form an alternative with acquisitions from small Unmanned Aerial Vehicles (UAV). In particular, kite as payload carrier is seen as being complementary to lightweight multicopters, which are increasingly used for remote sensing applications [1, 2]. Kite is of a strong interest when the use of radio-controlled and motorized systems is hampered by local regulation and/or when too strong winds keep these lightweight devices on ground.

***Index Terms*—** Aerial imagery, Digital elevation models, UAV, Kite, Photogrammetry, Structure from Motion, Frugal innovation, Micmac

1. INTRODUCTION

With the development of UAVs and structure from motion (SfM) algorithms, very high resolution mapping has become accessible to most people. However, in a lot of countries, usage of UAVs is strictly controlled and local regulations are the first hindrance to its development. As Colomina and Molina state, "Let them fly and they will create a market"[2]. Additionally, small and affordable UAV often suffer from a lack of autonomy and cannot be deployed under windy conditions, which limits their capabilities both in terms of coverage and responsiveness. In other words, current affordable technology does not cover exhaustively spatio-temporal scales and domains of very high resolution cartography. There is hence still a need for flexible and affordable very high resolution 3D mapping solutions of large areas.

Limitations presented above led us to investigate the potential of a method based on kite-borne aerial imagery. Kite is historically one the the first platforms with hot-air balloons that have been use to acquire aerial imagery. Kite aerial photography has even met a fairly good success in the field of archaeology (see for instance [3]) and has been used in geosciences (e.g [4]). However, existing literature does not takes full advantage of the recent advances of photogrammetric and SfM software, that now allow for the processing of big data sets. The aim of the work presented hereafter is hence to propose a method that (i) refines existing principles of kite aerial photography and (ii) make good use of the huge power of recent SfM algorithms. Moreover, using affordable equipment, we thus propose a frugal innovation answer to the need of very high resolution mapping of several square kilometers areas.

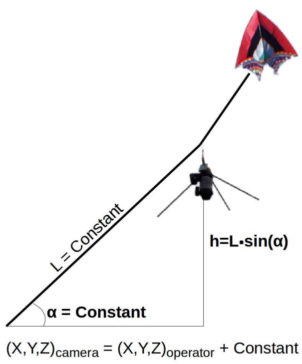
2. MATERIAL AND METHODS

2.1. Material

Criteria driving the material choice were cost, robustness, easy set up and in-flight reliability. For the platform, framed delta kite were used. They have been chosen within a large variety of kites because of their flight qualities (stability and high flight angles), easy mount with no need of adjustment, and fair payload. In this study, two delta kites, one of 4 m^2 and another one of 10 m^2 have been used. The line is a thin and light 200-lb Dyneema line. Low weight and thin kite line allows for better, more robust and constant flight characteristics. The line is graduated every 10 meters on the first 100 meters and then every 50 meters with a simple colour/thickness coding system. The rig is simply a tripod hung down a long line forming a pendulum. The long line ensures low-frequency movements of the rig around the vertical. The camera was chosen to meet a compromise between weight, image quality and geometry, and cost. The best compromise found at the time of the experiment was the SONY NEX-5N, which allows to take 16Mpix images with fixed focal and disabled image stabilizer. A GentLED-Auto intervallometer has been used to trigger automatically the camera at given time intervals. Two autonomous QSTARZ BT1400S GPS logger were used, one attached onto the camera and the second on the kite operator. This positional information is gathered in order to develop and refine the acquisition protocol at first and then check its operational application.

2.2. Image acquisition

The image acquisition protocol lies on the following hypothesis : with a very stable kite as payload carrier, the camera remains stationary relatively to the kite operator. As a consequence, the "flight plan" is directly the translation of the operator's movement. Then, knowing the kite flight angle, flight altitude is controlled by line length, as showed in figure 1(a). A comparable approach is used by [5], with less constraints on the acquisition protocol due to the low altitudes.



(a) Acquisition geometry

(b) Camera, tripod, intervallometer and GPS

Fig. 1. Material used for image acquisition.

In the case of the method described in this paper, whose aim is to seamlessly acquire images on relatively wide areas, flight angle stability has to be carefully investigated and its mean value properly estimated. Calibration of the flight angle for each kite is hence the first step of the method. For each kite, several flights - with different wind conditions and line lengths - are done, all of them with camera and operator positions GPS-logged. These logs are then used to compute flight angles. Moreover during this step, the ideal wind window for each kite is verified.

The second step is preparation of image acquisition in field. A minimal scouting is needed, at least with very high resolution satellite images freely provided online or through virtual globe software, and preferably if possible, directly on site. According to mapping needs (ground resolution, targeted area) flight parameters are determined. The first parameter is flight altitude, which is converted to line length for a given kite. Then, given an approximate walking speed, the maximal triggering interval allowing for a 80-90% along-track overlap is determined. Finally the kite operator route necessary to obtain a full multiscopic coverage is planned. High resolution satellite imagery printed with a known scale (so as to be able to use a ketch) is prepared.

Thirdly the acquisition itself. When possible the day is chosen with the most favourable wind : medium strength, orientation allowing for stable conditions and easiest acquisition according to local topography. Depending on the actual wind strength, the appropriate kite is chosen. Kite, with several tens of meters of line, is sent. A direct check of flight conditions (kite and wind stability) is done while the payload is prepared. The payload - pendulum, rig with camera, intervalometer and GPS shown on figure 1(b) - is fixed to the line and started. Then the pre-determined length of line is sent so that the camera is positioned at the right altitude. The determined route is followed. When possible the route is mostly perpendicular to the wind and followed downwind from track to track. This allows for the most stable kite - and hence camera - position.

2.3. Additional field work and image processing

For absolute spatial referencing, target or ground features visible in images are used. Their positions are surveyed with DGPS. At the end of the flight, images are checked for quality and global coverage. A screen displaying GPS time is pictured with the camera in order to be able to synchronize pictures and in-flight GPS measurements. A special care is taken to keep camera settings unchanged and a set of images dedicated to camera calibration is acquired.

Image processing was done with Micmac [6], an open-source software developed at the French national geographic institute. The typical Micmac pipeline is close to those of SfM algorithms. Automatic tie points extraction and matching is performed by the tool Tapioca, which uses SIFT. Then camera calibration and alignment is done by Apero or Tapas. Coordinates of ground control points and/or camera positions are used to orientate the model into a cartographic coordinate system. Finally, dense matching and individual orthophotos are computed by Malt, the orthomosaïc being assembled by the tool Tawny.

2.4. Test Sites and Data

The work presented in this paper has been developed and tested in two test sites located in the semi-arid region of Cap-bon, Tunisia, both in the drainage basin of the Lebna wadi. The 20 ha area site of Fortuna is located in the Fortuna lithologic formation. The site encompasses a series of four ravines studied by El Maaoui et al. [7]. Elevation ranges between 100 m and 160 m. The Kamech test site is a small cultivated experimental catchment of 2.63 km^2 whose outlet is a small reservoir. Detailed description can be found in [8, 9]. Elevation ranges between 80 and 100 m. Slopes can locally exceed 100%.

Except from the flights that have been used to characterise the two kites, three flights have been done, two on the Kamech test site and one on the Fortuna test site. Characteristics of these flights are summed up in the table 1.

Site	Kamech	Fortuna
Date	Sep. 2013, 18 & 19	Jan. 2014, 29
Estimated Beaufort	4	3-4
Kite used	10 m^2	10 m^2
Flying heights (m)	120, 300, 500	90, 150
Line length (m)	150, 360, 600	110, 180
GCP	8*	24
Validation points	469*	176
Images used	752	612
Surface covered	318 ha	2x24 ha**

*for this test site, Ground Control Points (GCP) and validation points were concentrated around the lake
**two coverages have been done in one flight

Table 1. Data collection information by site

Site	Kamech	Fortuna
Mean (m)	+0.13	+0.04
Standard deviation (m)	0.37	0.07
Sample size	469	176
Pixel size (m)	*0.20*	*0.05*

Table 2. DEM error statistics

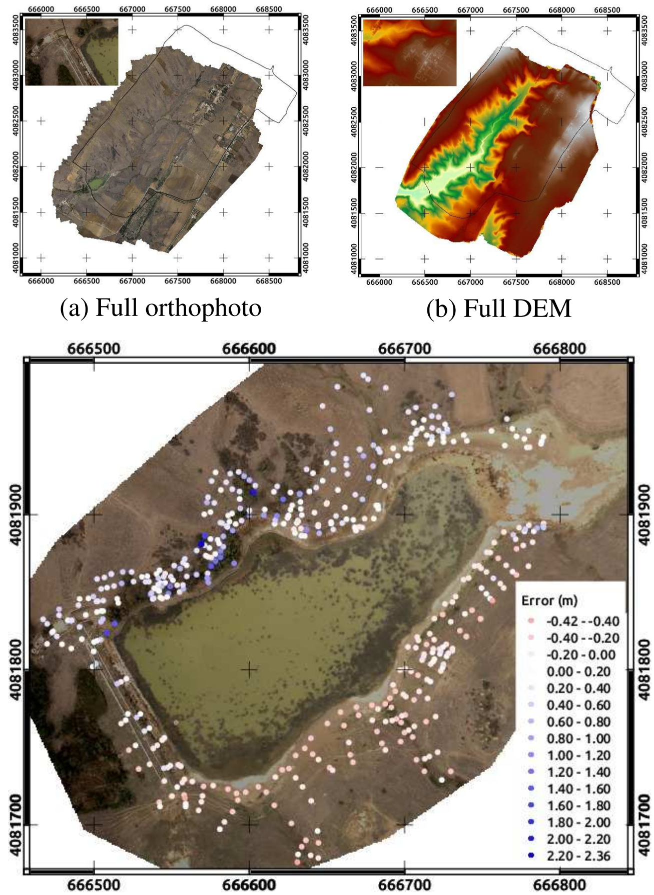
3. RESULTS AND DISCUSSION

For both sites, more than a thousand images have been collected in less than four hours. A noticeable point with kite aerial photography - compared to more widespread UAV-based acquisition - is the huge autonomy of such a platform. In our case, with a 64Go SD card and a five-second triggering interval, the limiting factor was camera power, hampering flights longer than four hours.

Orthophotos and DEM of both test sites have been produced (figures 2 and 3, (a) and (b)), covering respectively 318 ha and 48 ha (see table 1). Micmac determines automatically the optimal ground sampling distance of the produced DEM. For the Kamech test site, the DEM has a 20 cm ground sampling distance ; for the Fortuna test site, the DEM has a 5 cm ground sampling distance. Statistics of DEM error is summed up in the table 2. Bias is of the order of magnitude of the ground sampling distance. Vertical precision falls within a pixel.

Non-random spatial patterns of the errors (figures 2(c) and 3(b)) suggest that some parameters are still mis-estimated. In particular, a doming effect on the Fortuna test site might be attributed to residual lens distortion effects.

Experiments conduced on two test sites showed the feasibility and the repeatability of the method and the quality of the results. However, the method has some limitations. Firstly, the route followed by kite operator must be clear and open. On the fortuna test site though, we managed to walk through a sparse wood, thanks to the high flight angle of the kite. Another limitation is the computing time and memory resources necessary to photogrammetric processing of hundreds of images. Finally there are still some operations with a high human or financial cost : GCP survey needs expensive GPS equipment ; images selection requires manual inspection.



(a) Full orthophoto (b) Full DEM

(c) DEM error distribution

Fig. 2. Kamech test site results

4. CONCLUSION

Within this study, we have (i) provided a method for image acquisition over several kilometre square areas by kite aerial photography and (ii) assessed the quality of DEM obtained with such a method. Within three or four hours of field work, and with very affordable imaging equipment, it is possible to gather hundred of images suitable for photogrammetric processing. Open-source software can handle such large data sets. Outputs are cartographic and topographic information with decimetric resolution and better than decimetric altimetric precision. More generally, even with kite-borne acquisition, expectable altimetric accuracy is of the order of magni-

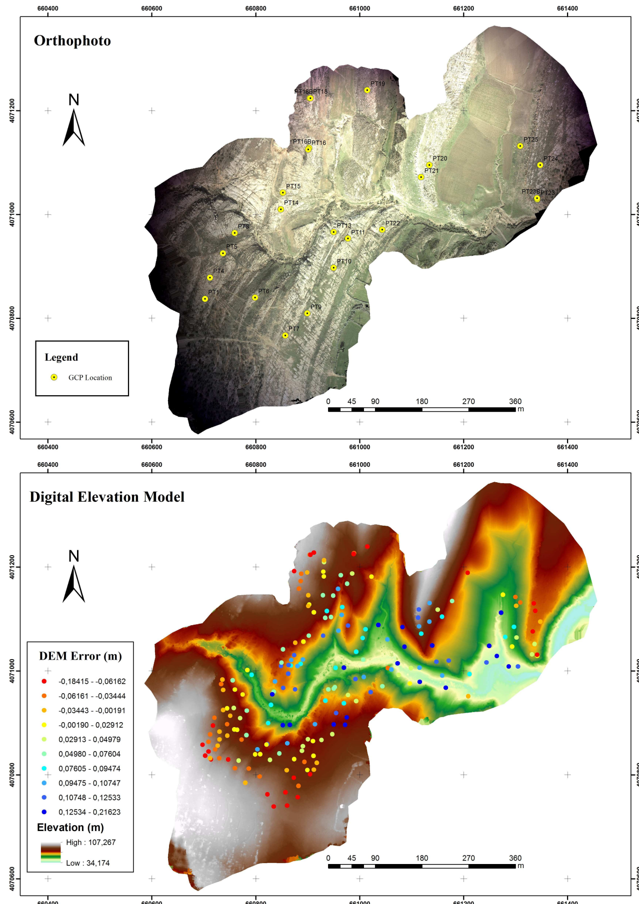


Fig. 3. Fortuna test site results

tude of the pixel size and precision is better than the ground sampling distance.

Capable of high precision topography estimation and wide area coverage, the method presented herein forms, with the ones based on small UAV acquisitions, a solid alternative for kilometre scale mapping. Moreover, examples of such large area coverages with small UAV are very few in literature, which may indicate that kites are more suited than small UAV to map relatively wide areas at decimetric or centimetric resolution. This seems particularly true in contexts where windy conditions are frequent or in countries where regulation concerning UAV is very strict.

Next advances are probably to be done both on the processing and the field work. For the field work, cost of GCP survey has to be decreased, either by using less expensive equipment, either by developing acquisition strategies that limit the need for GCP. For image processing, main progresses may concern the development of automatic images selection as well as more efficient algorithms for image orientation (camera alignment). This may be achieved in particular through optimisation and decimation of the tie points dataset.

5. REFERENCES

[1] Francesco Nex and Fabio Remondino, "UAV for 3D mapping applications: a review," *Applied Geomatics*, vol. 6, no. 1, pp. 1–15, 2014.

[2] Ismael Colomina and Pere Molina, "Unmanned aerial systems for photogrammetry and remote sensing: A review," *ISPRS Journal of Photogrammetry and Remote Sensing*, vol. 92, no. 100, pp. 79 – 97, 2014.

[3] Geert J. J. Verhoeven, "Providing an Archaeological Bird's-eye View - an Overall Picture of Ground-based Means to Execute Low-altitude Aerial Photography (LAAP) in Archaeology," *Archaeological Prospection*, vol. 16, no. 4, pp. 233–249, Oct-Dec 2009.

[4] Mike J. Smith, Jim Chandler, and James Rose, "High spatial resolution data acquisition for the geosciences: kite aerial photography," *Earth Surface Processes and Landforms*, vol. 34, no. 1, pp. 155–161, Jan 2009.

[5] Mitch Bryson, Matthew Johnson-Roberson, Richard J. Murphy, and Daniel Bongiorno, "Kite Aerial Photography for Low-Cost, Ultra-high Spatial Resolution Multi-Spectral Mapping of Intertidal Landscapes," *PLOS ONE*, vol. 8, no. 9, Sep. 19 2013.

[6] Marc Pierrot-Deseilligny and Nicolas Paparoditis, "A multiresolution and optimization-based image matching approach: An application to surface reconstruction from spot5-hrs stereo imagery," in *IAPRS vol XXXVI-1/W41, ISPRS Workshop On Topographic Mapping From Space (With Special Emphasis on Small Satellites)*, Ankara, Turkey, February 2006.

[7] Mohamed Amine El Maaoui, Mennoubi Sfar Felfoul, Mohamed Rached Boussema, and Mohamed Habib Snane, "Sediment yield from irregularly shaped gullies located on the fortuna lithologic formation in semi-arid area of tunisia," *CATENA*, vol. 93, pp. 97 – 104, 2012.

[8] Insaf Mekki, Jean Albergel, Netij Ben Mechlia, and Marc Voltz, "Assessment of overland flow variation and blue water production in a farmed semi-arid water harvesting catchment," *Physics and Chemistry of the Earth, Parts A/B/C*, vol. 31, no. 17, pp. 1048 – 1061, 2006.

[9] Damien Raclot and Jean Albergel, "Runoff and water erosion modelling using WEPP on a Mediterranean cultivated catchment," *Physics and Chemistry of the Earth*, vol. 31, pp. 1038–1047, 2006.