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Research article

Assessment of kite born DEM accuracy for gullies measuring

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Abstract
In Tunisian semi-arid areas, human pressure, torrential rains and low vegetation cover are the essential factors of gully erosion. In these areas, gullies naturally exhibit complex morphologies. Hence they are difficult to measure. This type of erosion, in its most severe form, threatens cultivated lands by the extension of badlands as well as water resources by water reservoir sedimentation. For a long time, the objective of most gully erosion studies was the morphological characterization of the gullies in order to properly understand erosion processes. Gradually, the technological advancement in sensors and platforms for aerial image acquisition made it possible to achieve more detailed mapping of gullies. During the last decade, low altitude aerial platforms have experienced the strongest development in acquiring high-resolution aerial photographs and generating associated digital elevation models (DEMs), in particular with the rise of structure from motion algorithms use in geosciences. Such DEMs meet the need for mapping at the sub-meter scale as well as the capability of studying the gullies in three dimensions. In previous studies, a DEM and the corresponding orthophotography were produced at very high resolution (6.2 cm for the DEM, 3.1 cm for the orthophotography). The 3D reconstruction was performed from overlapping images taken from a consumer grade camera hung down a kite. Such experiments, producing unusual aerial datasets, are poorly reviewed in the literature. Therefore, the objective of this paper is to assess the accuracy of such DEMs obtained from overlapping aerial photographs taken from kite platforms.
Key words: Gully erosion, Kite platforms, High-resolution images, DEM accuracy, Structure From Motion, SfM.

1. Introduction

In Tunisian semi-arid areas, gullies are the typical form of water erosion. Its growth rates and shapes were found to be lithology dependent (El Maaoui et al., 2012; Parkner et al., 2006; Tamene et al., 2006; Thompson et al., 2006). In these areas, gullies naturally exhibit complex morphologies. Hence, they are difficult to measure. Most of the studies on gully erosion aim to estimate the spatial and temporal evolution of gullies. They are consequently descriptive studies dealing with geometry and erosion process than 3D monitoring.

Gradually, the technological advancement in sensors and platforms for aerial image acquisition (Colomina and Molina, 2014), made it possible to achieve more detailed mapping of the gullies. Indeed, lightweight platforms such as UAVs and kite are being the most used to provide high resolution imagery and to generate associated

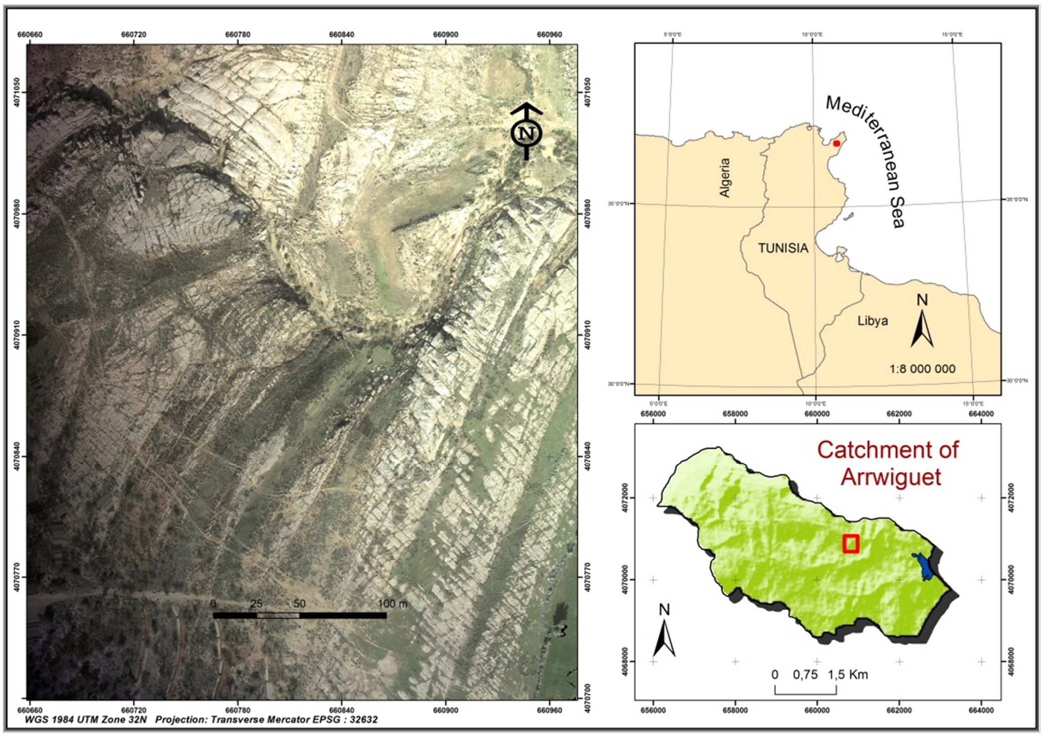

Figure 1: Location of the drainage basin of the Arrwiguet wadi.

digital elevation models (DEMs). Such data allow to precisely understand gully geomorphology (Gimenez et al., 2009; Marzolff and Poesen, 2009; Oleire-Oltmanns et al., 2012), which is commonly facilitated by the rapid progress of structure-from-motion (SfM) algorithms and software which offer significantly easier image processing workflows than traditional aerial photogrammetric techniques (James and Robson, 2012; James and Robson, 2014; (Fonstad et al., 2013)). Unlike field measurements, these indirect measuring techniques allow covering of large study areas with a minimum of time and effort (Martinez-Casasnovas et al., 2004). The accuracy of the 3D reconstruction of the soil topography and gullies geomorphology from overlapping aerial photographs strongly depends on DEM resolution which reflects photographs resolution (Frankl et al., 2013). Historically, blimp and kite were the first platforms that have been used to acquire aerial photographs. Kite aerial photography has been successfully used for a range of topographic applications, such as archaeology (Verhoeven, 2009), geomorphology (Bogacki et al., 2010; Marzolff et al., 2002) and in geosciences (Smith et al., 2009).

In Tunisia, local regulations are the first hindrance to the UAV usage and their development. Additionally, small and affordable UAV often suffer from a lack of autonomy and cannot be deployed under windy conditions, which limits their capacities in terms of both coverage and responsiveness.

In this work, SfM software was used to produce a DEM from high resolution aerial photographs taken by an off-the-shelf camera (Sony NEX-5N) attached to a 10-squaremeter delta kite. The aim of this study is to assess the DEM elevation accuracy obtained by this new photogrammetric technique.

2. Materials and methods

The work presented in this paper has been carried out in the Kamech site and tested in another site located in the drainage basin of the Arrwiguet wadi within the peninsula of Cap Bon, North east Tunisia (figure 1). This 35 ha area is characterized by its Fortuna lithologic formation. The site includes a series of four gullies studied by (El Maaoui et al., 2012). Elevation ranges between 34 m and 107 m. Slopes can locally exceed 100%. Only one flight has been performed on the test site whose characteristics are summed up in Table 1.

Table 1. Data collection information

Site	Fortuna
Date	Jan. 2014, 29
Estimated Beaufort	3-4
Kite used	10 m^2
Flying heights (m)	90, 150
Line length (m)	110, 180
GCP	24
Validation points	176
Images used	612
Surface covered	35 ha

2.1. Image acquisition

During a one day mission on January 29th, 2014, a zone of 35 hectares including fours gullies on the site of Fortuna has been flown over. The flight was carried out with a 10 m2 kite and more than 1500 images were acquired during approximately three hours of flight. The objective was to obtain an orthophotography and a digital elevation model having decimetric accuracy. The flight parameters have been determined according to the desired ground resolution of 5 cm. Image acquisition was carried out using a camera attached to a kite following the method detailed in Feurer et al., 2015. The camera is a Sony NEX-5N, equipped with an 18mm objective and a 23.5 * 15.6 mm sensor. Wind conditions of the acquisition day have led to choose the delta wing of 10 m2. To have a ground pixel of 5 cm, camera had to be placed at an altitude of 190 m. As described with more details in Feurer et al. 2015, flight altitude is controlled by the kite line length. The flight was carried out in two times, with a first pass at half altitude, attained by unrolling 110 m of wire and a second passage to the target resolution with 230 m of wire. Moreover, in order to guarantee a longitudinal recovery of 90% for acquisition, the time interval between two images was set up at 5 seconds. At the end of the flight, images are checked for quality and global multiscopic coverage.

2.2. Field surveying

In order to validate the elevation data estimated by the photogrammetric method, topographic data were collected with a TOPCON-GR3 differential GPS RTK. The manufacturer's specifications give an accuracy of 1 cm and 1.5 cm, for both planimetric and altimetric accuracy respectively. However, field measurements carried out on fixed points showed a standard deviation of the error which falls within 3cm for both planimetric and altimetric estimations. They were 24 ground control points (GCP) and 176 check points well distributed on the site having been measured. The choice of GCPs has been done a posteriori on kite images. They have been chosen on rocks to ensure that they do not change and so identified unambiguously both on field and images. For each selected point, two types of image prints were established: one in A4 format to identify the point surroundings on the ground (full picture of the zone) and one in A3 format at full image resolution to precisely positioning the point on the rock.

*2.3. Data pro*cessing

Three-dimensional information is computed from 2D images following four steps: (I) identification of key points and their matching in the different images, (ii) estimation of camera orientations and positions as well as its internal geometry by an iterative bundle block adjustement, (iii) dense matching at the pixel scale for the calculation of elevation and individual orthophotos and (iv) mosaicking of individual orthophotographies with radiometric equalization.

Several fully automated softwares are available, which present a good solution for many applications. Compared to conventional photogrammetric techniques, they show shortages on measuring accuracy (Pierrot Deseilligny and Clery, 2011; Rosnell and Honkavaara, 2012; Stöcker et al., 2015). APERO/MICMAC software (Pierrot-Deseilligny and Paparoditis, 2006; Pierrot-Deseilligny and Clery, 2011) was used in this study. It is an open-source tool which constitutes a complete photogrammetric data processing pipeline based on rigid equations of photogrammetry. It is dedicated to research applications, and allows better control on precision and more reliable results (Georgantas et al., 2012; Pierrot Deseilligny and Clery, 2011; Stöcker et al., 2015).

The typical Micmac pipeline is close to those of SfM algorithms. Automatic tie points extraction and matching is performed first by the Tapioca tool, which uses SIFT (Vedaldi, 2011) based on (Lowe, 2004). 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.

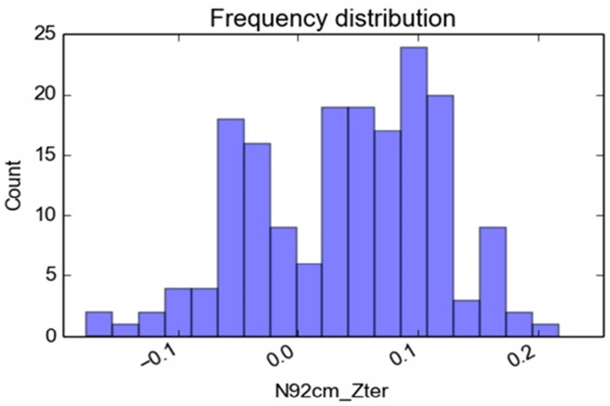

Figure 2: Estimated altitude error distribution

3. Results and discussion

The calculation of the digital surface model and of the orthophotography covering the zone of more than 35 ha was carried out starting from 612 images (figure 3). The data processing sequence described above was carried out on a cluster whose operating system is Rocks 6.1. A single node equipped with a 32 core processor and 120 Go of RAM was used. The first two steps (key points detection and matching, and camera position estimation, performed by Tapioca and Tapas) were carried out on 1300 images at full resolution in order to achieve the best possible results for image orientations and positions as welle as the camera internal parameters taking into account the lens distortion. Automatic calculation of homologous points on the images using Tapioca, took a little bit more than 6 hours, whereas Tapas required 7.22 days of calculation. It is the longest step in terms of calculation time, depending on the number of homologous points, used for the compensation and corresponding to huge matrix computations. This step is also the most consuming in RAM. Thereafter, the compensation of heterogeneous measurements between the homologous points and ground control point (GCPs) had taken almost 7 hours of calculation. Finally, the calculation of the digital surface model and image orthorectification were carried out in a little more than 17 hours. MICMAC automatically determines the full resolution of the orthophotography and the digital surface model as well as the Z accuracy. In our case, the planimetric and altimetric accuracy are 6.2 cm and 3.1 cm for both digital surface model (DSM) and orthophotography, respectively.

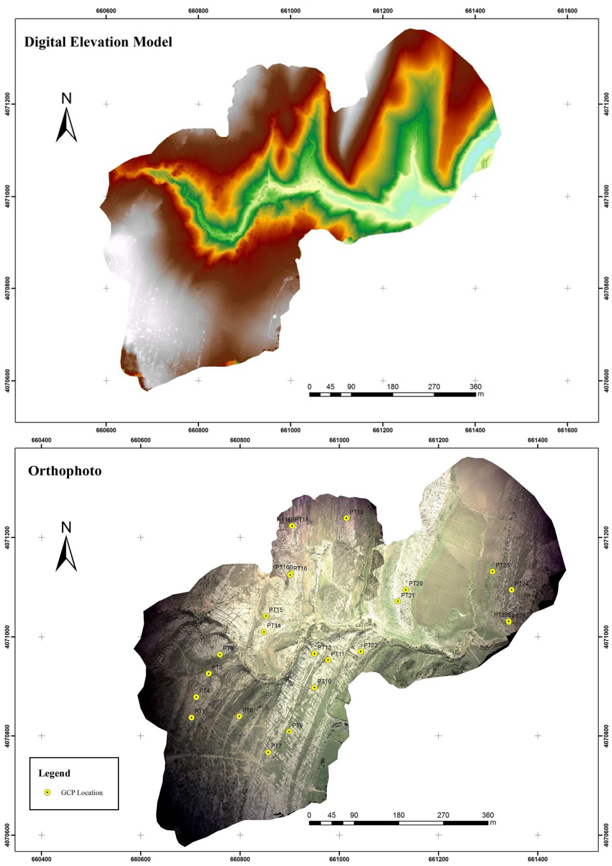

Figure 3: Fortuna test site results

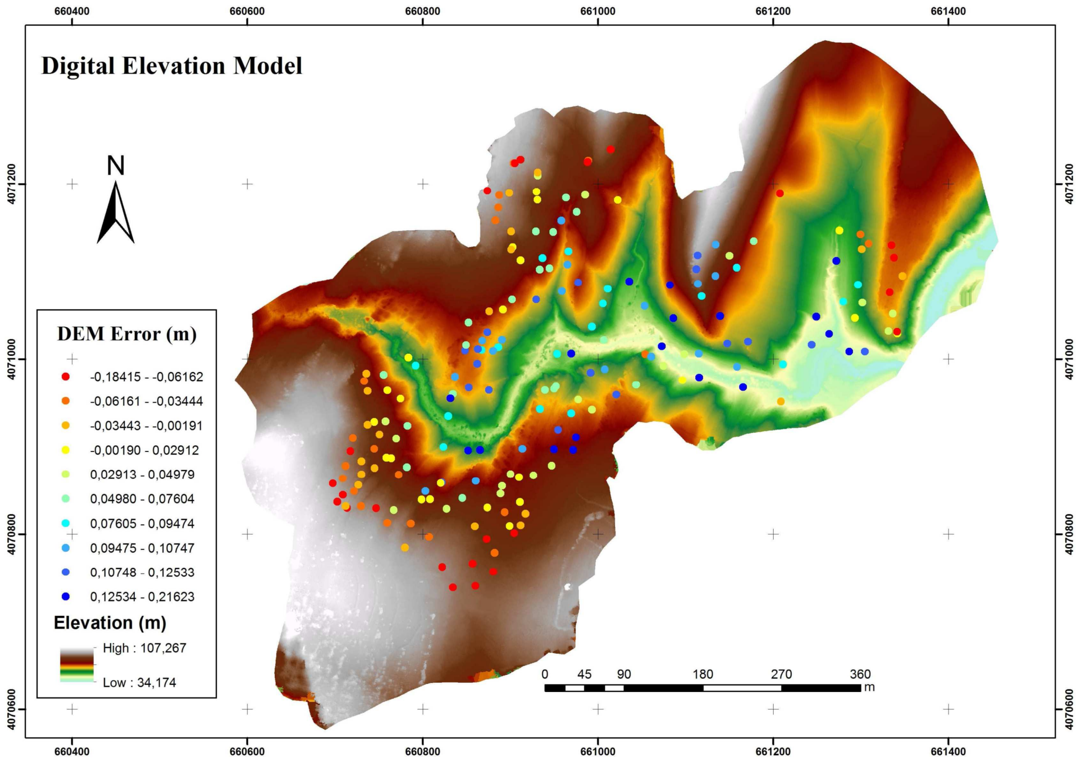

Figure 4: DEM error distribution

After bundle adjustment and compensation between homologous points and (GCPs), the residuals of GPCs and validation points were used to assess the results accuracy and the absolute orientation. Here, all the points (control and validation) were considered separately and the mean square errors (RMSEs) were calculated.

Firstly, we started with a quantitative assessment of the topographic data produced by photogrammetric method in comparison with the ground data (validation and check-points). The altimetric error of restitution is estimated by calculating the difference between values of the altitude restored by photogrammetry and measured by differential GPS RTK respectively. We evaluated the DEM altimetric quality by calculating the average error of altitude and the standard deviation as shown by Table 2 and figure 3. Secondly, we calculated the altimetric residual errors by comparing the measured positions of all the points (GCPs and validation) with their positions traced on the orthophotography and DEM (figure 2 and Table 2).

Moreover, the altitude estimation errors were determined by the difference in DSM altitude and ground altitude, with negative errors indicating an underestimation of altitude and positive errors associated with an overestimation (figure 4). Non-random spatial patterns of the errors (figures 4) suggest that some parameters are still miss-estimated. In particular, a doming effect on the Fortuna test site might be attributed to residual lens distortion effects, such as the ones studied by James and Robson (2014). Since the camera is a consumer grade digital camera, it is necessary to estimate its distortion model accurately when it is used for measurement to avoid the doming effect.

Table 2. Error statistics

Site	Fortuna
Mean (m)	+0.04
Standard deviation (m)	+0.07
Sample size	176
Pixel size (m)	0.062

4. Conclusion

In this study we assessed the accuracy of the topography altimetric restitution of a strongly gullied zone covering 35 hectares. High-resolution aerial photography are taken by kite platform. DEM accuracy assessment shows the utility of this remote sensing technique to estimate the topography altitude with a precision which answers the gullying problems (monitoring and quantifying volumetric soil loss). Stereo photographs should allow stereoscopic interpretation of gully morphology and erosion processes. They can be employed for digital photogrammetric analysis and production of DEMs. This opens the way to a better soil loss volume quantification. But we need to investigate photogrammetric fundamentals prerequisites for any metric reconstruction from images such as camera calibration, image orientation and measurement. In the case of kite-borne acquisition, the altimetric accuracy is found to be approximately of the pixel size and the precision better than the ground sampling distance. Aerial kite photography provided excellent alternatives to more traditional techniques in monitoring and calculating gully erosion rates and volumes. In this respect, structure from motion software for images, acquired by consumer grade digital camera, processing could be considered as an advantageous alternative to conventional aerial photography processing. The method affordably increases photo resolution and improves flexibility, rapidity and site specificity in very fine detail.

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