

High-Res Digital Surface Modeling using Fixed-Wing UAV-based Photogrammetry

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Abstract—High-res multi-temporal digital terrain data is a potential valuable source for geomorphological research and/or monitoring studies, yet often difficult and costly to obtain. Unmanned Aerial Vehicles (UAVs) provide a promising and flexible platform for the acquisition of multi-temporal digital surface models (DSMs) and orthorectified airphotos. In this research we demonstrate preliminary results with UAV-based photogrammetry with a fixed-wing aircraft, and we assess the quality of derived DSMs and terrain properties in a geomorphologically active agricultural catchment near Pamplona, N-Spain. In 4 sequential flights 200 ha was captured at 3 cm ground sampling distance (GSD ~ 185 m flight altitude) with which a 12 cm DSM was created. Subsequently, a single flight at 90 m altitude enabled creating a DSM of 7 cm spatial resolution of a subarea. Both datasets have been compared by visualizing small rills and a superficial landslide. Results suggest that 3 cm GSD was found sufficient for identifying small-scale geomorphological activity. Yet, small rills and tractor tracks which are potentially interesting for hydrological or hydrogeomorphological studies required smaller GSD. The preliminary results show high potential of the utilization of UAVs in different domains of geomorphological research.

I. INTRODUCTION

Digital Surface Models (DSMs) are recognized tools in geomorphology. Modern technology to generate high-res digital surface models is frequently based on LiDAR data or photogrammetry using aerial stereophotos. Data acquisition can however, be costly, especially when repeated flight campaigns are required. Yet, multi-temporal data can potentially be very valuable for e.g. mapping geomorphological features and analyze their change over time [1,2] or for analyzing effects of land management to landscape development.

Unmanned Aerial Systems (UAS) provide a promising tool for the acquisition of such multi-temporal aerial stereophotos and

high-resolution digital surface models. A UAS often comprises an Unmanned Aerial Vehicle (UAV) with autopilot navigation and desktop software. In general two types of light-weight UAVs are currently commercially available, i.e. multicopters and fixed-wing aircrafts. Multicopters can often carry more payload, resulting in the possibility of installing more advanced sensing systems [e.g. 3], but their coverage area is limited [e.g. 4] due to their relatively low flight speed and high battery drain. Fixed-wing UAVs, equipped with light-weight digital cameras are therefore more suitable for capturing stereographic images of larger areas.

This study presents experiences with a fixed-wing UAV and shows first results on digital surface modeling and the visualization of geomorphological features. It shows the entire work flow of UAV photogrammetry and illustrates the effect of flight altitude on the detail of derived digital surface models and terrain properties in a gully system and a landslide complex.

II. STUDY AREA

The UAS was tested in the agricultural catchment of Latxaga, near the municipality of Beortegui, approximately 20 km east of Pamplona, N-Spain (Fig. 1). The catchment area is approximately 200 ha, altitude ranges from 500-690 m.a.s.l. and mean annual precipitation is 800-850 mm. The area is underlain by marls with mostly clayey soils. The area is characterized by sheet, rill and occasional gully erosion. The relatively flat valley bottoms provide temporal storage of sediment coming from adjacent hillslopes. After wet periods shallow landslides are common.

III. MATERIALS AND METHODS

A MAVinci Sirius 1 fixed-wing UAV was used with on board a Panasonic Lumix GX1 16 MP digital camera and 20 mm lens. The wing span is 1.6m and the total weight of the aircraft

including camera is approximately 2.6 kg. Average ground speed approximates 60 km/h depending on wind conditions. The camera is able to collect 8-bit JPEG and RAW images but in this study only JPEG images were used. The work flow and characteristics of the Sirius I model are typical for fixed-wing solutions.

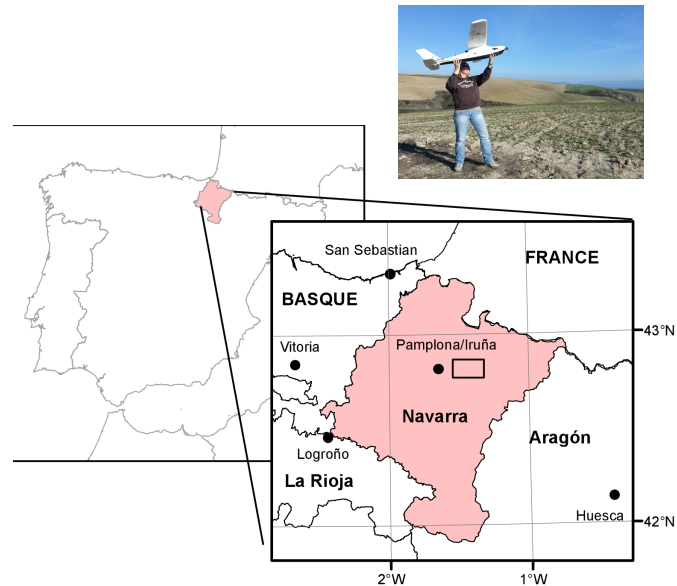


Figure 1: Left and bottom) The study area is located in the Latxaga catchment, approximately 20km east of Pamplona, Spain; Top-right) Typical hand-launch of the UAV in the study area.

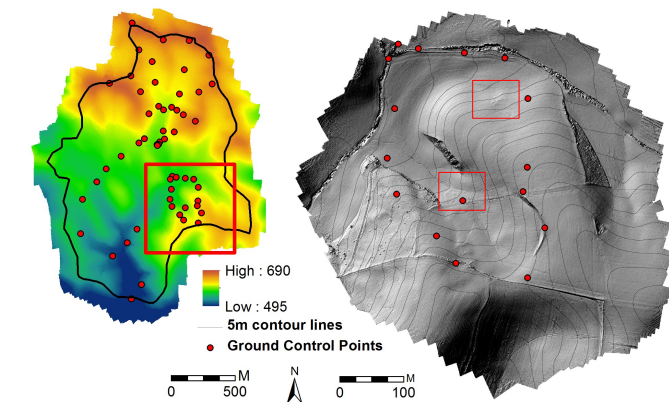


Figure 2: Left) 12 cm DSM of the entire catchment area (200 ha), highlighted by the black outline. The red rectangle shows the location of the detailed study area; Right) 7 cm DSM of a subset (20 ha) of the catchments area. The red rectangles show the locations of the subsets in Fig. 3

The UAV comes with desktop software to prepare flight plans (i.e. 3D GPS waypoints) based on amount of overlap and camera specifications. The flight lines are optimized for minimizing flight time, wind direction or topography. Flight plans were prepared to obtain 85% image overlap in flight direction and 60% side overlap. The UAV is launched by hand and flight lines are followed with an autopilot GPS waypoint navigation. Images were taken at specific time intervals to obtain the predefined overlap. Maximum flight time is typically 45-60 minutes with a single battery, depending on wind condition. To ensure sufficient time for safe landing, flight time was maximized to 35 minutes. To reach 3 cm ground sampling distance (GSD) for the entire catchment flights were carried out at an average altitude of 185 m above the surface. A smaller area was selected for higher resolution imagery (1.6 cm GSD) which was flown at 90 m. In total 50 ground control points (GCPs) were collected, including 10 GCPs in the selected area, which have been used for DSM alignment and accuracy assessment.

Post-processing was carried out with Agisoft PhotoScan Professional 0.9 on a modern processing PC (6-core Intel Xeon processor, 40 GB RAM, 4 GB GeForce GTX680 videocard). PhotoScan is able to semi-automate the processing of ortho-photos and digital surface models. The work flow consists of 1) image matching and calculating tie points to create a sparse point cloud using 'Structure-from-Motion' [5] (automated, uses embedded GPS and camera orientation), 2) positioning of GCPs in the images to georeference and fine-tune the initial point cloud (assisted, estimated GCP location is projected on top of raw images which eases GCP positioning), 3) calculating geometry from the initial tie points using multi-view stereopsis [6] to create a dense point cloud and digital surface models (automated), and 4) texture rendering for creating orthophotos (automated).

IV. RESULTS

With the current setup it was possible to capture the entire 200 ha catchment with 3 cm GSD in a single day, in four sequential flights, totaling approximately 5000 images (Fig. 2-left). Post-processing took 36 hours and DSM resolution was automatically optimized to 12 cm resolution. The estimation of optimal cell size is done in the PhotoScan software and is based on average point density. Despite registration of detailed topographic variation (Fig. 3-bottom) absolute deviations from dGPS points were considered too high (~45 cm) for monitoring applications on subtle geomorphological activity.

A single flight at an average flight altitude of 90 m above the ground surface collected approximately 1200 images with 1.5 cm GSD covering approximately 35 ha. Post-processing required about 12 hours and optimal DSM cell size was determined at 7 cm. Also here, the absolute deviations from dGPS points were considered too high (~35 cm). Table 1 summarizes the DSM specifications per altitude and the standard deviation from dGPS.

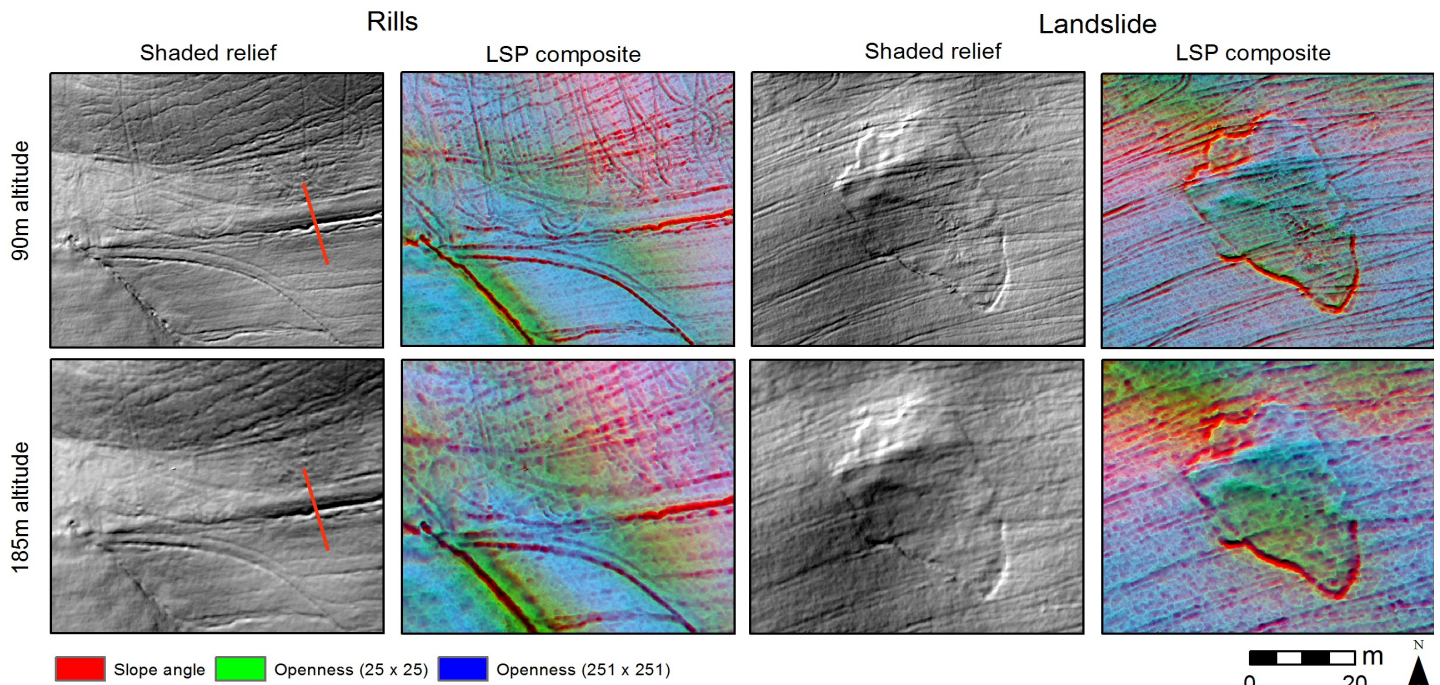


Figure 3: The left figures show the shaded relief images and the right figures show the LSP composites. The red line in the left figures shows the location of the profiles in Fig. 4. Especially the LSP composites show high detail of geomorphological features such as gullies, rills and landslides in the area.

TABLE I. SUMMARY OF FLIGHT AND DSM SPECIFICATIONS

Flight altitude [m]	GSD [cm]	DSM cell size [cm]	Standard deviation [cm]
90	1.5	7	35
185	3	12	45

In Fig. 3 the gray scale subplots show shaded relief maps of rills and a landslide. The color plots show a false-color composite (or Land Surface Parameter, LSP, composite) of slope angle (as red) and topographic openness measured with a 25 x 25 and 251 x 251 cells moving window (as green and blue, respectively). The LSP composites clearly show the topographic variation in high detail. The upper and lower figures in Fig. 3 represent the 7 and 12 cm DSM, respectively. Especially the 7 cm DSM contains subtle features such as rills and tractor tracks. Also landslides are captured in high detail showing sharp edges near the back scarp and the deposition area.

Fig. 4 presents cross profiles of various rills of different dimensions. It is evident that the largest/deepest rills are registered well in both DSMs. The terrain attribute profiles indicate that smaller rills are not well visible in the 12 cm DSM and require higher spatial resolution.

V. DISCUSSION

At the time of writing, vertical accuracies of the 7 and 12 cm surface models are 35 and 45 cm, respectively, which are too high for measuring subtle topographic changes or monitoring studies regarding e.g. rill erosion measurements. Earlier research [7] shows that overall accuracy can be as low as 2-4 cm with low flight altitude (40-50m) and high overlap (75-95%). Slightly more noise was expected due to higher flight altitudes and higher relief which results in higher variability in GSD. However, Fig. 3 implies little random noise in the data, based on the fact that the DSM contains subtle topographic features that have been confirmed by field observations. The results suggest high potential of generating accurate DSMs with UAVs. More tests on post processing are required to eliminate high deviations from dGPS measurements.

In this study, images have been collected in 8-bit JPEG format with minimal compression. For geomorphometrical applications JPEG files were considered suitable. However, more tests are encouraged to analyze the added value of RAW images with respect to the detail and accuracy of derived hillslope geometry. With the current setup, RAW images are limited to > 2.5 cm GSD due to UAV ground speed versus camera processing speed.

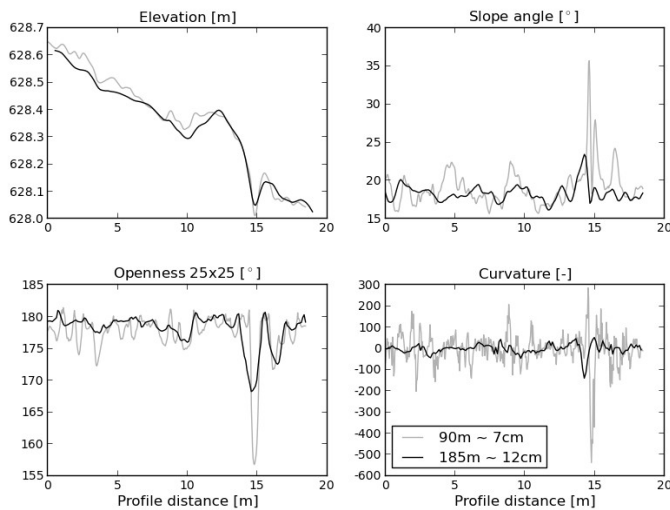


Figure 4: Cross-profiles showing the difference between surface models and derived terrain attributes in smaller and larger rills.

UAV-based DSMs would be valuable for many hydro-geomorphological applications, e.g. in channel connectivity and soil erosion studies. Yet, the amount of data that is produced at smallest DSM resolution may be impractical for large catchment areas with current methods. The 12 cm DSM would likely be suitable for most applications.

Some strengths of fixed-wing UAVs in combination with Structure-from-Motion post-processing are:

- UAVs can be utilized at almost any moment in time, even with (low intensity) rainfall and medium wind speed (< 20 km/h). This makes fixed-wing UAVs flexible for the acquisition of multi-temporal data to study geomorphological processes at fine spatial and temporal scales (e.g. after heavy rainfall events).
- The DSMs contain very high detail for visualizing subtle topographic variation. Narrow and shallow rills are captured which potentially allows detailed modeling of surface flow.
- Continuous developments in making light-weight sensors and increasing UAV payload will allow to equip fixed-wing UAVs with other sensors, such as infrared or thermal cameras and radar. This will enable research in new domains.
- With the exception of marking ground control points, the entire work flow can be automated

In addition, some limitations are addressed:

- GSD is not spatially uniform. The UAV flight lines can be optimized for a single hillslope, but for larger areas in hilly terrain higher parts have considerable smaller GSD

compared to lower situated areas. The final cell size of the DSM is therefore an average of the entire area, but effective resolution is lower in some areas.

- Data quality is highly dependent on the quality and distribution of GCPs. This means that in inaccessible terrain absolute elevation values may be inaccurate.
- When generating points clouds very few ground points are constructed in vegetated areas. This makes it difficult to filter out vegetation points for terrain modeling.
- Processing large areas can be hindered due to large amounts of data. High-end computing or dividing the area into subprojects may be required.

VI. CONCLUSIONS

Fixed-wing UAVs provide a flexible platform for generating multi-temporal surface models. UAVs provide a level of detail that could not have been obtained this easily in the past. Subtle topographic variation is registered so that geomorphological features are visualized in high detail. Yet, more effort is required to better align the surface model to dGPS measurements for more accurate absolute elevation values.

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