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To Drone or not to drone? & Impact of UAV Photogrammetry on the flood simulation process of bridges in mountain regions

Hydrolink

TO DRONE OR NOT TO DRONE?

EXPERIMENTING THE USE OF UAV FOR FLOOD MODELLING IN DATA-SCARCE REGIONS

BY PAOLO PARON, MAURIZIO MAZZOLENI, ANDREA REALI & LUIGIA BRANDIMARTE

Background and problem setting

Floodplains are among the most valuable ecosystems for providing goods and services to the environment and supporting biodiversity[1]. At the same time, people tend to settle in floodplains as they offer favorable conditions for agriculture, trade and economic development[2]. This has been the case since the earliest recorded civilizations, such as those in Mesopotamia and Egypt that developed in the fertile riparian areas of the Tigris and Euphrates and Nile rivers. It is estimated that almost one billion people, the majority of them the world's poorest inhabitants, currently live in floodplains[3]. As a result, flooding is nowadays one of the most damaging natural hazards[4] and causes about half of all deaths from climate-related disasters[5].

Given the relevance of floodplain studies, many flood inundation models have been presented by ecologists, geomorphologists, hydraulic engineers and hydrologists over the past decades[6]. They range in complexity from simply intersecting a plane representing the water surface with digital elevation models[7],[8] to sophisticated numerical solutions of the Navier–Stokes equations[9]. These models have been proved to be valuable tools in understanding flood propagation while supporting sustainable floodplain management and flood risk reduction[10].

Yet, most African floodplains did not benefit from this scientific progress in hydrological and hydraulic modeling of floods, as the necessary information (input and calibration data) is often missing or incomplete. In particular, there is a lack of topographic data, key input of flood inundation models, as well as flood extent maps, crucial to calibrate and test models. While satellite data can help getting this information for larger river systems and large-scale studies, their spatial and temporal resolution (or cost in case of higher resolution) is not appropriate for small to medium river systems and local scale studies. Flooding processes in Africa also have higher impact in modifying the topography of floodplains than elsewhere, since there are fewer structural flood protection measures in place and much less regulation in the way these floodplains are occupied by human activities. Recently, the necessity to counterbalance time-consuming traditional topographic survey techniques in inaccessible areas generated a strong interest in building on remote sensing techniques and data, and eventually led to the birth of Fluvial Remote Sensing (FRS) as a sub-discipline[11]. However, the freely accessible data have limited use for hydraulic risk analyses in small to medium scale areas due to their coarse resolution. On the other hand, the high accuracy laser sensing topography is often too expensive, due to the need of small planes or helicopters to carry the LiDAR equipment, which does not always justify its use and is rarely available in low income countries.

Figure 1. The trans-boundary Limpopo River Basin and the study area highlighted in red in the Lower Limpopo. (Background image from http://www.limpopo.riverawarenesskit.org/LIMPOPORAK_COM/INDEX.HTM)

At the same time, the Unmanned Aerial Systems (UAS) or drone industry has seen a huge development in the last few years and has now become mature enough to enter the surveying business. Both hardware and software have made very large progresses in few years' time, allowing people with little surveying experience to be able to generate highly accurate Digital Elevation Models at low cost. Moreover, the safety of operating drones has dramatically increased thanks to the development of user friendly application software (apps) and on-board navigation hardware (obstacle avoidance systems) used to control these devices.

For these reasons, we decided to experiment the acquisition of DEM for hydraulic modelling by means of a commercial UAS and compare different DEMs over the same area to assess the advantage of using drones on a systematic scale for flood modelling purposes.
A growing number of research and application papers have been published in the last years. For example, Zinke et al.[12] obtained underwater bathymetry data in a Norwegian river from UAV imagery using an algorithm developed for coastal bathymetry modelling; Perks et al.[13] flew a UAV during a flood event of the Alyth Burn in Scotland to capture real-time videos and, with an application of the Kande–Lucas–Tomasi (KLT) algorithm, estimate the free surface velocity by tracking the movement of objects in the water; Leitao et al.[14] used a drone-based DEM for urban surface flow modelling to be potentially connected to a drainage modelling of a Swiss town; while Mourato et al.[15] developed a Digital Surface Runoff Model (DSRM) from UAV imagery for flood hazard mapping.

Objective of the research and study area

The main goal of our exercise was to compare the accuracy of Shuttle Radar Topography Mission (SRTM) vs LiDAR vs drone derived DEMs for use as input data in a 1D hydraulic model of a tropical river in Mozambique, the lower Limpopo River.

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The study area is a stretch of 30 Km along the Lower Limpopo River between an irrigation weir upstream, and a road bridge downstream (Figure 1). The nearest gauging stations are about 1 km upstream and about 100 m downstream of the study area, with no tributaries in this stretch of river. In our study area, an aerial borne LiDAR dataset acquired during the month of February 2017 (under extreme dry conditions) was available and was used as a benchmark for comparing both the SRTM (of February 2001) and the Drone derived DEM in January 2018.

Drone survey and DEM production

The drone campaign was carried out in January 2018 under extreme hot weather conditions with air temperature above 40 degrees in few days. We did not use any Ground Control Point (GCP) due to issues with the equipment. We have used two drones (at the same time), a Phantom 4 Pro (P4Pro) and a Phantom 4 Advanced (P4Adv). They carry the same camera on-board which is summarized in the specs available online at https://www.dji.com/nl/phantom-4-pro/info

We designed and performed the flight plans using the app DroneDeploy[16], which is very versatile, allowing for designing of the flying areas in Google Earth and then importing them in DroneDeploy for further adjustment based on the flying parameters. Moreover, this app allows to work on both desktop/laptop and tablets using either iOS or Window or Android operating systems.

Different tablets were used during our surveying: for the P4Pro drone we used an iPad Air 2, while for the P4Adv an Android tablet (a Huawei Media pad M3). We experienced a series of problems with the Android-based tablet such as loss of video communication, flight plans not initiated, image capture not starting, image not been displayed on the tablet and other similar problems. This has been a known issue with Android-based tablets for some time, and the users forum[17] offer plenty of examples. The iPad equipped drone, on the contrary, did not show major issues apart from the ones related to high temperatures during the flights, which in few occasions grounded the drone.
The survey was designed to collect transects perpendicular to the main river channel, starting from one end of the floodplain, continuing over the river banks and flying over the (almost) dry river bed, and ending in the opposite floodplain. This way, we focused on defining the morphology and elevation of the river bed and of the river banks with the goal of calculating the volumes of bank full waters.

A total of 13 flight plans of different extent were carried out (see Figure 2a). The selection of the locations was done according to the homogeneity of the river bank and river bed morphology, and considering the logistics of field work and a limited amount of time available for the survey.

The flight lines' directions were kept almost always perpendicular to the river bed to have a consistent direction of flight with respect to the natural features that we wanted to capture and model. An example of the flight plan of the most upstream one area, including the Macarretane weir is shown in Figure 2b.

Because of the flat topography, we opted for a flight plan with 75% of frontlap and 65% of sidelap between consecutive images. This allowed for the same objects to be captured by at least 3 images and observed by three

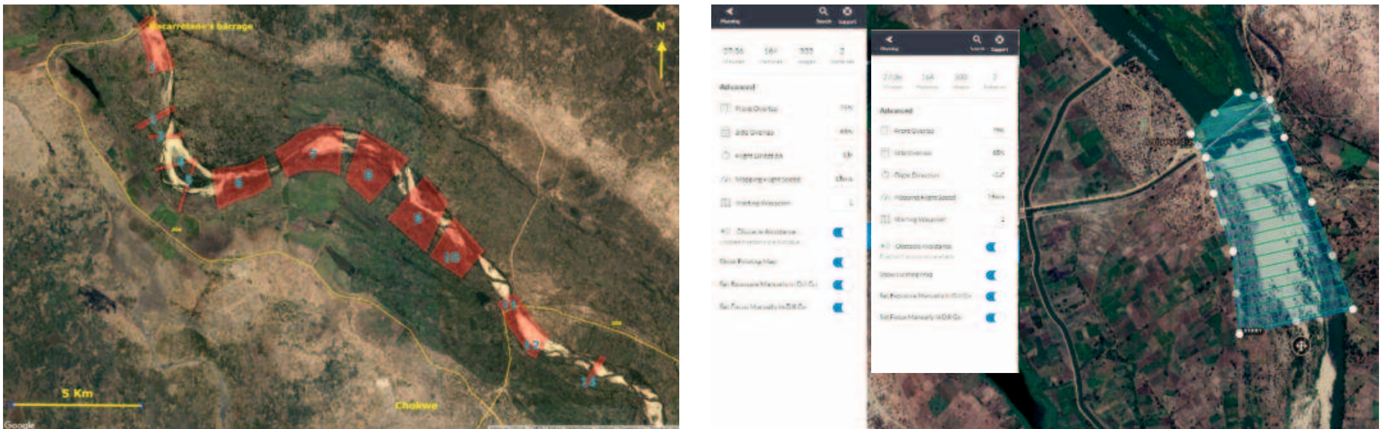


FIGURE 2. (A, left) Flying areas (red shaded areas) distributed in the study area. (B, right) Example of a flight plan with flight details on the left hand-side panel

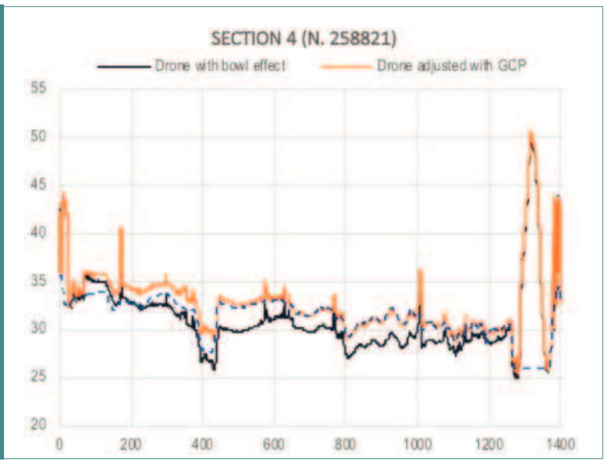
different angles. Using this geometry of the flight plan we could then input our images in a Structure from Motion software (Agisoft Photoscan Pro version 1.3) that would generate the orthomosaic and Digital Elevation Model (DEM) of each flight plan. During the survey we were not able to use any Ground Control Point (GCP) so we relied only and exclusively on the onboard GPS.

The topography of this area is quite flat with the major topographic variations being the banks and river bed. Because of the 3 years of ongoing drought in the area, we were able to capture the dry river bed in some sections, thus providing very useful information for the 1D flood model. However, the environmental conditions were not very favorable due to very high temperatures, exceeding 40 degrees, and very strong winds, and posed different challenges. The high winds prevented the drones from taking off safely; the high temperatures affected both the Tablet (which did not work at a temperature of 40 degrees), the onboard instrumentation, and the compass and onboard GPS signal.

The post processing phase followed a standard Structure from Motion (SfM) workflow. As mentioned above, one hindering factor was the inability to use Differential or Real Time Kinematic (RTK) GPS to add Ground Control Points (GCP) to the dataset.

As suggested by the SfM procedure using Agisoft Photoscan Pro version 1.3 we followed these steps: 1) Aligned the photos, thus building a preliminary sparse point cloud that, for each overlapping photo, identifies homologous pixel in all the photos. During this phase the software also performed bundle adjustments and precise geolocation; 2) Densified this sparse point cloud, increasing the number of homologous pixels identified during the first step. If allowed in this phase, the software can also generate a point classification based on their color. Normally this step works well in highly contrasting environments where the pixels show highly contrasting colors; 3) Generated a Triangular Irregular Network based on millions of points from the previous steps. This was a very important step because it formed the basis for the generation of the DEM that was the focus of our study; 4) After generating the Dense Point Cloud and the Mesh, the software created the orthomosaic and exported the desired outputs (DEM and Orthophoto), 5) finally, we were able to extract river cross sections at particular locations using the estimated orthomosaic.

Figure 3. Comparison of the raw drone topography (dark blue line) with the corrected one (light blue) and with the reference LIDAR (red line). The spike on the left-hand side is due to the reflections of the water body in the river active channel, and it was smoothed out before processing in the 1D flood model



Results: comparing topography from different sources

The processing of drone data without GCP resulted in the use of only drone GPS coordinates. These were not accurate enough to generate geometrically correct topographies. In particular, we faced the known problem of dome (or bowl) effect. The DEM showed a fake convex shape at the center (Figure 3).

However, we used the LiDAR and associate orthophotography to generate virtual GCPs that allowed us to rectify the dome effect of the drone data (Figure 4).

This way it was possible to obtain a geometrically corrected DEM from the drone photos. From Figure 4 it can be seen how the drone results are in good agreement with the LiDAR

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Table 1. Details of drone, LIDAR and SRTM DEMs

	Drone	LIDAR	SRTM
Date of acquisition	Jan 2017	Mar 2015	Feb 2000
Method used to generate the DEM	Structure from Motion	Return time of the Laser impulses	Radar
Spatial resolution	6 cm (orthophoto) – 25 cm (DEM)	1 m	30 m
Extent	30 km stretch, in small transects	The whole Limpopo River Floodplain	From +80° North to -80° South
Cost (order of magnitude)	10^3 USD	10^6 USD	free
Repeatability	As desired, operated by national staff, at very low cost	As desired, operated by specialized firms, at very high costs	One-off

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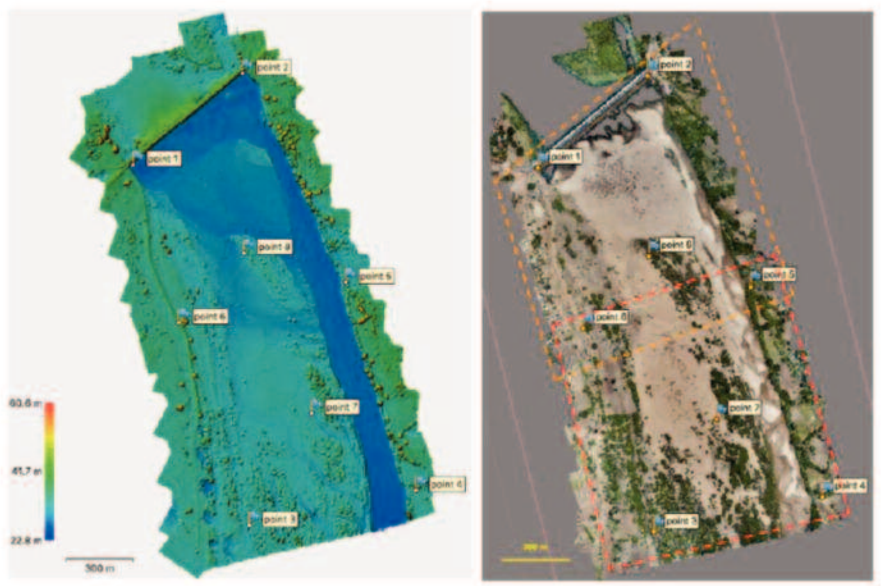
Figure 4. DEM (left) and orthophoto (right) of the Macarretane area after correction using the GCP derived from LiDAR data to remove the dome or bowl effect



IMPACT OF UAV PHOTOGRAMMETRY ON THE FLOOD SIMULATION PROCESS OF BRIDGES IN MOUNTAIN REGIONS

BY JÜRGEN HACKL & BRYAN T. ADEY

Hydraulic risk assessment of bridges in mountain regions is an essential task because a bridge failure could have serious social-economic consequences, especially if it renders an area inaccessible. Nowadays, UAVs could provide a fast and cost-effective way to obtain the information with the high temporal and spatial resolution required for such a risk assessment.

A risk assessment related to bridges in a mountainous region poses several challenges. The probability of occurrence of bridge failures due to hydraulic events (e.g. flood, scour, debris) and the resulting consequences depend significantly on the physical characteristics (e.g. slope, soil, vegetation, precipitation) of the specific regions where the bridges are located. An indication of the effects of these characteristics can be seen in the sediment deposition during floods in mountain catchments [1]. Additionally, there is often no recent topographical information that can be used to develop terrain models needed to generate realistic water flow simulations in mountainous regions. Furthermore, most hydrology and hydraulic models have been developed for lower gradient rivers and often cannot be used directly to model water flow in Mountain Rivers [2].

In an effort to improve the assessment of hydraulic risk related to bridges in mountainous regions, an investigation was undertaken by Hackl et al. [3], to determine whether Unmanned Aerial Vehicles (UAVs) and photogrammetry could be used to generate the topographical information required to run realistic water flow simulations.

The investigated bridge is located in Val da Riein, in the sub-mountainous region of Surselva, a district of Grisons, the largest and easternmost Canton of Switzerland. It is part of the cantonal road network, connecting the towns of Ilanz and Vals (Fig. 1). The bridge is located in the only major road leading to Vals. Consequently, there would be significant economic consequences for the residents of Vals, if this bridge could not be used. The bridge crosses the Riein Creek where it joins the River Glogn. The bridge, built in 1987, is a single span bridge with reinforced concrete (Fig. 2a). It has a span width of 24 m, the bridge deck is 7.97 m wide, and the clearance between the bridge and the water surface is approximately 5.8 m. The abutments were partially protected against scouring with rip-rap (Fig. 2b). The original protection measures were damaged during a flood event in July 2011. This damage has also allowed some erosion of the embankments to occur, as documented in Fig. 2c.

The steps applied to test the use of an UAV and modern photogrammetric technology to obtain and verify the accuracy of the topographical information to improve bridge risk assessment were: (1) mission planning and preparation, (2) in-situ data acquisition, (3) data processing and the generation of a 3D digital terrain model, (4) processing of the 3D terrain model, (5) hydro-dynamic modeling and simulations, and (6) post-processing and verification of the results. An overview of the whole process is provided in Fig. 3.

Figure 2. Details of the bridge. (a) Technical drawing with dimensions. (b) Picture of intact rip-rap taken before 2011 (reprinted from TBA GR [5], with permission from Kristian Schellenberg). (c) Picture of damaged rip-rap taken in July 2016. Photograph: Clemens Kielhauser.

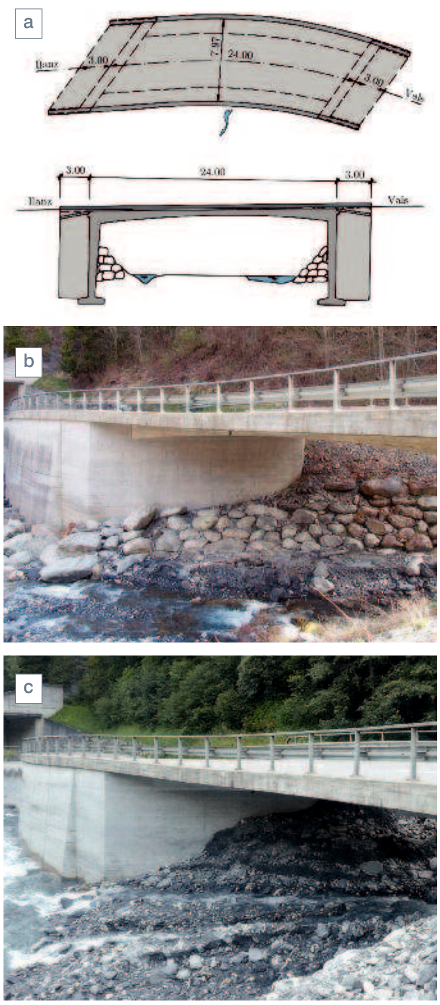


Figure 1. Location of the bridge and the catchment areas of the rivers (map data (c) 2017 swisstopo JD100042).

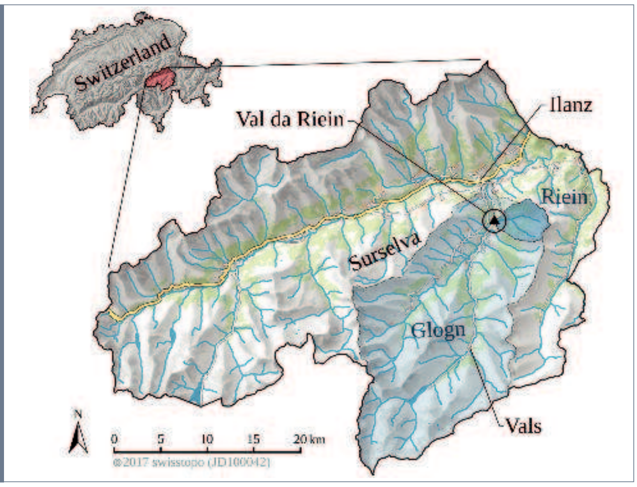
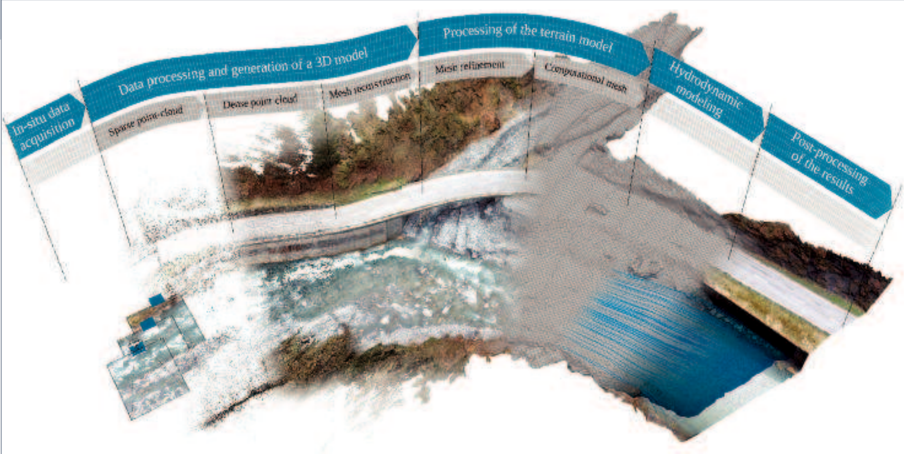


Figure 3. Process from left to right: (1) mission planning and preparation, (2) in-situ data acquisition, (3) data processing and the generation of a 3D model, including sparse point-cloud, dense point-cloud and mesh reconstruction, (4) processing of the terrain model, including mesh refinement, and creation of a computational mesh, (5) hydrodynamic modeling and simulation, and (6) post-processing of the results.



(1) Supporting information about the area and the bridge was gathered in advance. The area covered was approximately 125 x 200 m, considering a length of 100 m upstream of the Creek Riein. To reduce the measurement errors, 26 reference targets (Ground Control Points or GCP) were positioned on the river banks, the dry riverbed and the bridge. No flight permission was needed, according to Swiss regulations [4]. For safety reasons it was decided that two people operate the UAV, a pilot and a camera operator.

(2) The UAV platform DJI Inspire 1 (quadcopter) from DJI Innovations (Shenzhen, China) was used for image acquisition. This is a commercial off-the-shelf solution, which comes fully assembled and equipped. On the UAV platform, a calibrated 12.4-megapixel Zenmuse X3 camera was mounted via a 3-axial gimbal, operated independently with a second remote. During three flights of approximately seven minutes each, a total of 1621 images with an overlap of at least 90% were taken.

(3) To obtain a 3D digital terrain model, 2D-image information was processed using Structure from Motion (SfM) photogrammetric algorithms and computer vision. To calculate 3D models from a large number of images, the following process was used: (a) image pre-processing (e.g. filtering out blurred images), (b) camera calibration, (c) sparse point-cloud reconstruction, (d) dense point-cloud reconstruction, (e) mesh reconstruction, (f) mesh refinement, (g) mesh texturing, and (h) accuracy assessment. In order to achieve this, three open-source software solutions were used. OpenCV was used in step (b), openMVG in step (c) and openMVS for step (d) through (g) (see Tab. 1). The computations were done on a 4x10 Core Intel Xenon E5-2690v2 3.0Ghz, 384GB DDR2 server, running on Linux 64bit operating system (Ubuntu 14.04).

(4) For the creation of a computational mesh which was used in the computational fluid dynamics (CFD) simulations, processing of the 3D digital terrain model, obtained via UAV photogrammetry, was necessary. Due to missing pictures or the inability of the software to compute every part of the terrain (e.g. insufficient lightning), gaps and loose artefacts occurred in the model, (see Fig. 3), these disturbances had to be removed manually from the model.

Table1. Software packages used in the study.

Application	Description	License	Type	Url
openCV	Is an open source computer vision and machine learning software library.	BSD	library	https://opencv.org/
openMVG	Is a library for computer-vision scientists and especially targeted to the Multiple View Geometry community.	MPL2	library	https://github.com/openMVG/openMVG
openMVS	Is a library for computer-vision scientists and especially targeted to the Multi-View Stereo reconstruction community.	GNU-GPL	library	https://github.com/cdcseacave/openMVS
Blender	Is the free and open source 3D creation suite. It supports the entirety of the 3D pipeline-modeling, rigging, animation, simulation, rendering, compositing and motion tracking, even video editing and game creation.	GNU-GPL	standalone	https://www.blender.org/
swiftSnap	Is a Blender addon for creating snappyHexMeshDict and associated files for OpenFOAM's snappyHexMesh application.		plug-in	https://github.com/nogenmyr/swiftSnap
OpenFOAM	Is a free, open source computational fluid dynamic software.	GNU-GPL	standalone	https://www.openfoam.com/
ParaView	Is an open-source, multi-platform data analysis and visualization application.	BSD	standalone	https://www.paraview.org/

(5) To analyze the complex flow field around the Val da Riein Bridge, the open source CFD software package OpenFOAM was used. A number of parameters and settings had to be defined in advance. The CFD analysis process involved: (a) mesh generation, determination of (b) physical properties, definition of (c) boundary and initial conditions, definition of (d) time discretization and iterative solver, (e) simulation run, and (f) post-processing and validation of the results.

(6) The post-processing of the simulation results was performed in order to extract the information from the CFD simulation. The open-source, multi-platform data analysis and visualization application ParaView and Blender were used. The results of most interest for this study were the velocity vectors and streamlines around the bridge, for the estimation of the possibility of scouring, and the water surface for the estimation of the possibility of the river overtopping the bridge. The modelled flow velocities are illustrated in Fig. 4. The output was compared and evaluated with observed historical data of the region.

Fig. 4 shows the results for a simulation run where the discharge of the River Glong corresponds to the mean annual runoff and the

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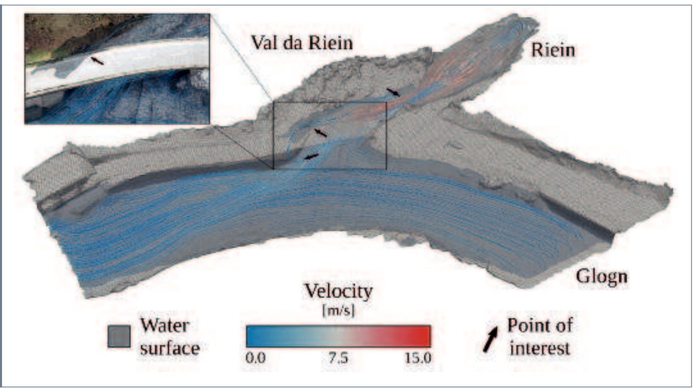

Figure 4. Water surface and velocity trace lines for a 100-year flood event for the River Glong and a 300-year flood event for the River Riein, which corresponds to an average discharge of 489 m^3/s respectively 11 m^3/s.

discharge of the River Riein to a flood event with a 300 year return period. Water surface and velocity trace lines are plotted. Red colored trace lines indicate areas with a high velocity. In this scenario flooding of the road is observed. It can be seen that a bridge overflow is rather unlikely because the water flows over the northern embankment and not over the bridge itself.

The results of the simulation correspond to the observed behavior; namely, high flow volumes and velocities were observed at the northern abutment of the Val da Riein Bridge resulting in a high likelihood of scouring occurrence. Especially during extreme events, the structural integrity of the bridge could be jeopardized. However, the simulation results indicate that bridge overtopping is unlikely because during the investigated events the water flows over the embankment on the road before it overflows the bridge.

To conclude, UAV technology applied in engineering applications has great potential, especially since the availability of inexpensive commercial off-the-shelf UAVs increases every year, and precise GPS and gyroscope technology enable less experienced operators to maneuver the UAV more precisely. This technology provides the ability to quickly deliver high resolution temporal and spatial information, which can be used to generate precise orthophotos, maps and 3D models, within a shorter amount of time than traditional surveying processes. This increases the ability to perform detailed studies in risk assessments. ■

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TO DRONE OR NOT TO DRONE? EXPERIMENTING THE USE OF UAV FOR FLOOD MODELLING IN DATA-SCARCE REGIONS

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data, while SRTM provided an uncertain DEM, which may result in unreliable estimates of the extent of the flooded area.

The table below summarizes the characteristics of the three DEMs used in this study: the LiDAR, used as reference, the SRTM and the drone-generated DEM. They clearly show different characteristics with the LIDAR and drone being more similar to each other than to the SRTM.

Conclusions

The aim of this study was to investigate the potential use of drone-based topographical dataset as a faster and cheaper substitute of LIDAR products and global topographical datasets, for flood modelling, in data-scarce regions. We found that drone-based DEM provided more accurate terrain elevation values than SRTM products and similar values than those from LiDAR surveys.
In addition, during the driest period of the year, drone surveys can be very effective to monitor and quantify morphological changes of river beds and river banks and thus re-calibrate the geometry of the river. The general assessment of drone-based DEM is positive and cost-effective when compared to more expensive and topographical products such as LiDAR. In addition, the topographic survey campaigns using drones can be easily carried out by Water Resource Management Authorities, every year, after short training activities. In our assessment, there is a high return for the small investment in the drone equipment.

However, drone-based topographical datasets also have some disadvantages. In our survey the environmental conditions were extreme, with very high temperatures, which affected the performance of the electronics onboard the drone and remote controller. Also, we could not collect GCPs. Despite these limitations, we managed to georeference our point clouds based on fixed locations visible on the LiDAR flight and corresponding orthophotography, and so we could assess the quality of the drone's topography generated using off-the-shelf drone equipment.

New models of commercial drones with on board RTK GPS are becoming more frequent also in the price range below 10,000 USD. This, we believe, will create a breakthrough in the ability of having repeated, very accurate and very high resolution, topographic surveys at selected crucial river cross-sections, thus allowing improved assessment of high risk areas. ■

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