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The use of multi-copter drones for landslide investigations

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ABSTRACT: In the last couple of years, the combination of the rapid development of low cost Unmanned Aerial Vehicles (UAVs) with improved battery technology and reduction of dimensions and costs of optical sensors has opened the door to a revolution in the geodetic industry. Aero-photogrammetric surveys from high resolution images acquired by light drones flying at very low altitudes (from 50 m to 150 m) are becoming very common. A side benefit for the landslide community is the availability of a new affordable tool to facilitate the acquisition of accurate and detailed morphological data over unstable slopes as a support to geological investigations. In addition to that UAV-based remote sensing has several advantages over the terrestrial surveying, airborne or satellite remote sensing. The most important advantages are represented by the provision of data in near real time, the flexibility in the selection of the most suited sensor, low cost, high resolution and the possibility to get data even in difficult environmental conditions. In this paper, a few case studies on landslide investigations are presented. In these studies the Saturn multi-copter a newly developed tool at the University of Florence, was used to support landslide investigations conducted on different landslides located in Tuscany, Umbria and Sicily areas of Italy. The proposed case studies show how quickly an accurate Digital Terrain Model could be generated by using aerial photographs, acquired with a drone. This technology further aids to perform slope monitoring by comparing multi-temporal acquisitions taken by the drone.

INTRODUCTION

Remote sensing techniques are important tools to obtain spatially-distributed information on kinematics of unstable slopes (Delacourt et al., 2007). These tools can be operated from space-borne, airborne and ground-based platforms. The main advantage of use of remote sensing for landslide investigations is the capability to provide spatially continuous data. with very high spatial resolution (i.e. it approaches to millimeters in the case of LiDAR), which can be very useful if integrated with the point-wise measurements typically acquired by ground-based techniques. However, remote sensing analysis performed using conventional platforms (aircrafts and satellites) highlight some drawbacks such as its high costs and the difficulty in getting repeated data in a short interval of time.

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In the last couple of years, the combination of the rapid development of low cost Unmanned Aerial Vehicles (UAVs), improved battery technology and reduction of dimensions and costs of optical sensors, opened the door to a revolution in the geodetic industry. Low altitudes (from 50 m to 150 m) aero-photogrammetric surveys are commonly used to generate high resolution data by using light drones (Colomina and Molina, 2014; Eisenbeiss and Sauerbier, 2011; Remondino et al. 20122; Fabris and Pesci, 2005). A side benefit for the landslide community is the availability of a new affordable tool to facilitate the acquisition of accurate and detailed morphological data over unstable slopes as a support to geological investigations. For instance, as an important way of obtaining spatial data, UAV remote sensing has the following advantages: real-time measurement, flexibility in usage, high-resolution, low costs, and easy to collect data in unfavorable environmental conditions (Chang Chun et al., 2011).

The time and cost-effective digital photogrammetry surveys (by using drones), has made it possible to generate high resolution point clouds of wide areas. Moreover this technology helps to repeat measurement surveys at regular time intervals and estimate the changes occurred between different acquisitions by comparing the resulting models.
In this paper the results of a few drone acquisitions carried out on different unstable areas in Italy by using the Saturn family of drones, is discussed briefly. These drones were developed by the Department of Earth Sciences at the University of Florence. The landslide investigation data was obtained in the form of point clouds and ortho-photos that has the following three different uses as described:

- Surveying mission: acquisition of a high-resolution point cloud of the unstable slope and optical images aimed at obtaining a detailed geomorphological map of the area under investigated by identifying its main morphologic features.
- Multi-temporal mission: multitemporal photogrammetric survey of an unstable area to quantitatively measure surface deformations in different times.
- Structural mapping mission: acquisition of high resolution point cloud and optical images of unstable rock faces for the extraction of structural data used as input for geo-mechanical analyses.

MATERIALS & METHODS

The multi-copter Saturn family

Usually multi-copters have a “spider” structure with a central body and many radial arms that support the propulsion device. To improve the structure of the existing multi-copters, the Department of Earth Sciences of Florence has developed an innovative perimetric chassis that fully supports flight dynamics, which further allows it to overcome some critical issues for scientific and heavy payload or long flight applications. The new chassis is patented in Italy and patent pending PCT (Patent Cooperation Treaty) applied in 117 countries in the world which received its first positive report in spring 2014. The improved structure has the following key features:

- Increased space without constraints to positioning electronics, flight system and instruments.
- The central payload area can be connected in a rigid manner or even with a flexible mount to dramatically cut down mechanical vibrations from the propulsion system.
- Maximized flexibility of propulsion configuration with a single chassis: without any modifications to the chassis it is possible to vary the number of propulsion systems (three, four, six etc..) even during the flight.
- The flexible propulsion configuration allows it to fit the need of every single mission: e.g. less engines to increase autonomy, more engines to allow for heavy payload.
- Variable propulsion geometry to keep the perfect balance with all types of payloads and to manage an emergency landing in case of a propulsion unit failure.

The drone family based on the above-mentioned chassis, named Saturn, comprises two different configurations, a smaller one called Saturn Mini X-21 (Fig.1) with a diameter of 0.55 m and a larger one Saturn 2 (Fig.2), with a diameter of 1.1 m, based on the same structure. Saturn drone has onboard a complete and fully configurable acquisition system with a frame grabber for scientific instruments including different types of sensors. The Saturn multi-copters are drones capable of autonomous flight, from take-off to landing, and emergency management.

Figure 1. The Saturn Mini X-21 drone.

Figure 2. The Saturn 2 drone, designed and built by the Department of Earth Sciences of the University of Florence.

While Saturn Mini X-21 has been designated mainly for photogrammetric and hyperspectral missions where endurance is more important than payload (it has an average endurance of 30 min), Saturn 2 thanks to its high payload (10 kg at take-off) is able to carry sensors like LIDAR or thermal cameras.

Digital photogrammetry

Digital photogrammetry, based on the concept of stereoscopic photogrammetry, allows the reconstruction of a 3D surface model by triangulating the position in the 3D space of pixels that are visible in two or more images. Once images are oriented and, possibly, calibrated, it is possible to derive DSM and orthophotos along with very high definition point clouds (Colomina & Molina, 2014). Such process can be carried out using one of the several Structure-From-Motion (SFM) techniques (Westoby et al., 2012), by exploiting specific algorithms for image triangulation and bundle adjustment and allowing the reconstruction of very accurate 3D representations of any surface.
Each photogrammetric survey can be resumed in 5 main stages: (1) mission planning, (2) acquisition of ground control points with GPS, (3) flight and image acquisition, (4) image processing and (5) implementation in GIS environment.

The first stage consists in the definition of the flight plan, that has to be created ad-hoc to ensure the best coverage of the target area, with an optimal photo overlap in frontal (overlap) and lateral direction (sidelap), taking into account the camera footprint at a certain quote. To optimize flight time, spatial coverage and ground resolution, the typical flight altitudes for landslide investigations are adopted. Those flight elevations ranges between 50 m and 100 m a.g.l. with sidelap and overlap respectively set to 50% and 60%, in order to guarantee a sufficiently redundant coverage of the area of interest. A significant number of Ground Control Points (GCPs) are then collected using a RTK-GPS based on objects on the ground that can be easily recognized in the aerial photos with a homogeneous spatial distribution on the scene. Nevertheless, if the scene is characterized by the presence of vegetation, with a few suitable elements to be used as natural GCPs, some artificial markers can be placed on the ground during each flight and surveyed with GPS.

Once the images are acquired they can be processed using commercial software packages. In the presented cases, the authors processed the images by using the Agisoft Photoscan Professional (Agisoft LLC, 2016) software and the resulting data were implemented in a GIS environment using the ESRI ArcGIS package. The raw point clouds were then typically filtered for the removal of the points corresponding to vegetation. This step is particularly important for multi-temporal analysis since the vegetation growth between the different surveys may generate an irregular offset of tens of centimeters along the whole scene, hiding the underlying topography.

The resulting digital ortho-mosaics have a typical ground resolution ranging from 2 to 5 cm per pixel and the 3D point cloud is typically composed by nearly tens of millions of points. Furthermore, from the point clouds it is possible to obtain high-

resolution DTMs (0.05 m/pix), appropriately filtered in order to remove all the points processed on trees and high vegetation.
The above described point clouds and ortho-photos can be used as input for a multi-temporal analysis comparing consecutive acquisitions. These images can be further utilized to detect any possible morphologic changes occurred between the different surveys that can be related to mass movement on the slope, to quantify volume and geometry of the involved masses and to detect areas prone to slope failure.

APPLICATIONS

In the following paragraphs examples of the different missions carried out by using the Saturn drones, described in the introduction part, carried, are discussed briefly.

Examples of surveying missions

In the fall of 2015, a comprehensive geological investigation program was initiated to support the design of the mitigation works of the slopes around the Castello della Sala area of Umbria, Italy. A topographic survey mission was carried out around a famous winery (where the Cervaro white wine is produced), by using the Saturn 2 drone equipped with a digital camera, a Sony-DSCW7 8MPix resolution. The images were ortho-rectified by using 11 GCPs on the ground surveyed using differential GPS, resulting in a ortho-rectified mosaic with a resolution of 10 cm. Moreover, the aerial photos were combined to generate a high-resolution point cloud from which, after filtering out the vegetation coverage, 0.4 m pass contour lines and a 10 cm cell-size DTM were created (Figure 3, Figure 4).

Figure 3. 3D view of the ortho-photo acquired at Castello della Sala projected over the DTM generated from the point cloud.

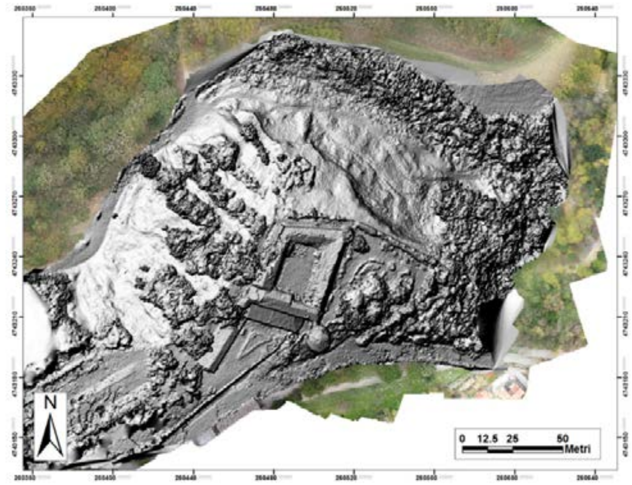

Figure 4. Hillshade of the Castello della Sala generated from the DTM obtained from the photogrammetric point cloud.

Those layers were used to perform a detailed geomorphological analysis aimed at identifying the main topographic features associated to instabilities and as base for the design of the mitigation works to stabilize the N and NW slopes of the hill.

Another example of a surveying mission is represented by the drone acquisitions done on the Scillato landslide in Sicily, Southern Italy. The Scillato landslide is a large earth slide occurred along the main motorway in Sicily. In June 2016 a survey over an area with a spatial extension of more than 1 km^2 was carried out to provide the team of engineers and geologists an accurate topographic map of the unstable area to be used as input of the design of the consolidation works. More than 1060 images were acquired, while on the ground around 70 GCPs were surveyed with differential GPS. The resulting point cloud contains more than 270 millions points (Figure5).

Example of multi-temporal mission

A multi-temporal photogrammetric survey was carried out between 2015 and 2016 on the northern slope of Ricasoli, a compound slide located in Tuscany, Italy. The goal of the analysis was to detect the main morphologic features of the slope with high resolution sensors to detect their evolution in time and to further validate the capability of adopted technique for landslide detection and monitoring. In detail, three aerial photogrammetric surveys were performed, on July 30th 2015, March 2nd 2016 and April 6th 2016 respectively by using the Saturn 2 drone. The drone

Figure 5. 3D view of the ortho-photo acquired at the Scillato landslide projected over the DTM generated from the point cloud. The damage generated by the slope movements to the local road is clearly visible on the image.

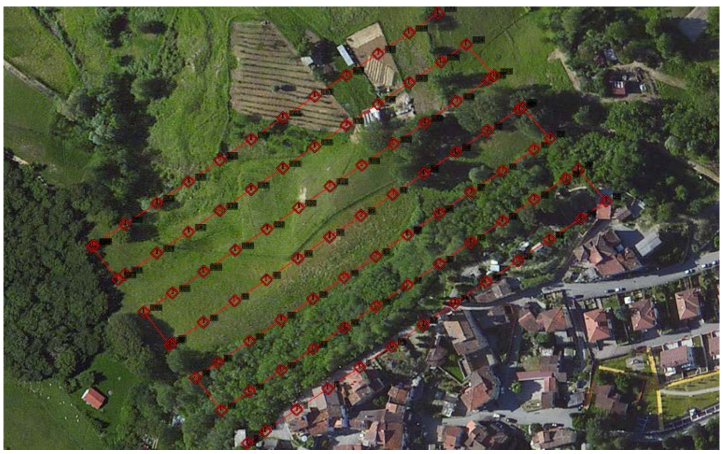

Figure 6. Flight plan of the drone survey over Ricasoli.

was equipped with a conventional digital RGB photocamera with an 8 MPix resolution, mounted on a gimbal fully designed and assembled by the authors. Average flight altitude was 70 m a.g.l resulting in images with a ground resolution of 0.02 m (Figure 6, Figure 7).

The DTM generated from the previous drone survey was also compared, to provide a sort of validation of the technique, with a DTM obtained from a terrestrial laser scanner acquired on the 30th of March 2015. The comparison showed differences between the two surfaces below 0.1 m (Rossi et al., 2015). The main parameters of the photogrammetric acquisitions and of the generated DTM and orthomosaic are reported in Table 1.

Table 1. Main acquisition parameters of the Ricasoli surveys.

	MULTICOPTER DRONE SURVEYS		
	July 2015	March 2016	April 2016
Number of images	58	106	45
Average flying altitude (m.a.g.l.)	70,6	70,3	69,7
Ground resolution (m/pix)	0.019	0,02	0,019
Number of GCPs	12	18	5
Coverage area (km^2)	0.0186	0.0186	0,0151
Number of tie-points	9328	14690	31910
Number of projections	52527	96102	160217
Error XY (m)	0,0741	0,0475	0,0595
Error Z (m)	0,0791	0,0115	0,0221
Error (m)	0,1085	0,0489	0,0635
Error (pix)	0.91	0,07	0,77
Processed points	100000000	99600000	41100000
Orthomosaic resolution (m/pix)	0.02	0.02	0.02
DEM resolution (m/pix)	0.02	0.02	0.02

The quantitative comparison among the three DEMs generated from the three photogrammetric acquisitions allowed the authors to detect two shallow landslides on the observed scenario. First landslide (LS1) occurred between July 2015 and March 2016 with a spatial extension of 950 m^2 and an estimated mobilized volume of approximatively 450 m^3. Second landslide (LS2) was detected by comparing the March 2016 and the April 2016 acquisitions. LS2 was smaller than LS1 with a spatial extension of 320 m^2 and a mobilized volume of 70 m^3 (Figure 7). The difference between the DEMs also allowed to clearly identify the detachment and the accumulation zones of both of the landslides. The main scarps along with the landslide crowns are visible in Figure 8.

Example of structural mapping mission

Thanks to the high resolution of the optical images acquired from the drones, and the resulting dense point clouds generated from them, it is possible for 2D and 3D geo-structural analyses of rock mass discontinuities to be performed, using specific algorithms, such as those included in the DiANA software tool (Gigli & Casagli, 2011).

The present study also discussed, the results obtained from the analysis of a point cloud generated from aerial images acquired by the Saturn Mini X21 drone on a quarry of Carrara marble, in Italy with the DiANA algorithms (Figure 9).

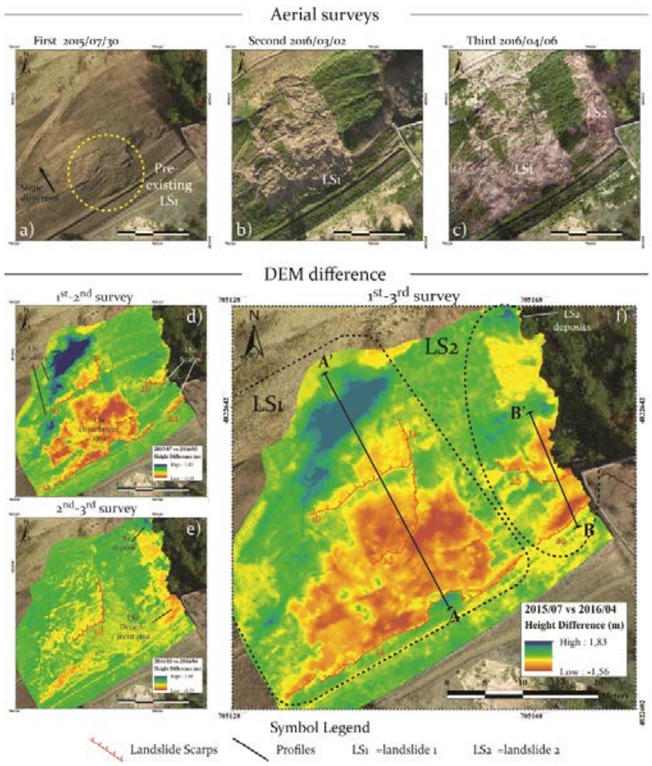

Figure 7. Aerial images over the unstable slope (a, b, c) and DEM difference among the three acquisitions (d, e, f).

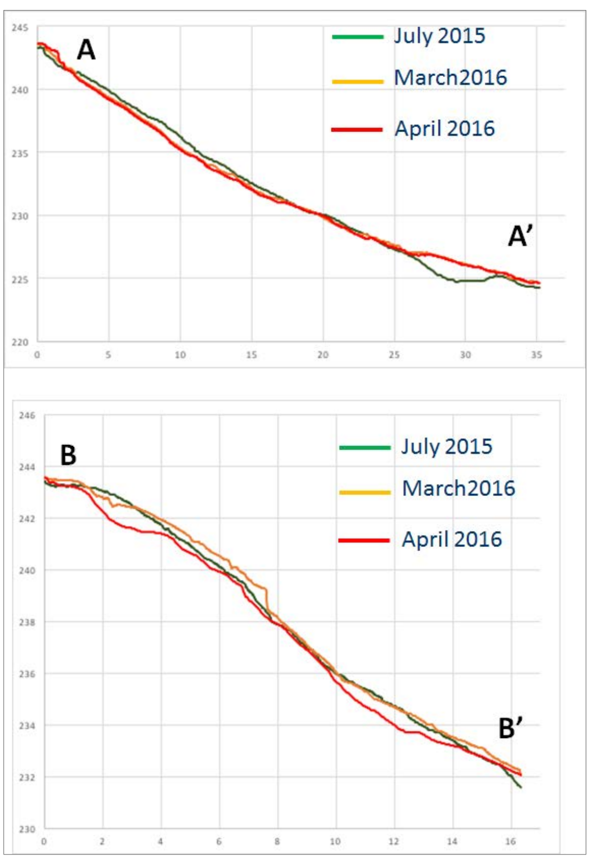

Figure 8. Cross section along the two main landslides (for the location see Figure 7).

The proposed approach is able to semi-automatically retrieve a few rock mass characterization parameters, such as orientation, number of joint sets, spacing/frequency (to derive RQD), persistence, block size and scale dependent roughness, by analyzing high resolution point clouds and optical images. The algorithms for the extraction of discontinuities from the 3D point cloud data are based on the definition of least squares fitting planes on clusters of points, extracted by moving a sampling cube on the point cloud. By selecting the cube dimension and a standard deviation threshold, the adopted method has demonstrated its validity to investigate rock masses even characterized by very irregular block shapes.

Especially in case of man-made excavations like in the presented case of the Carrara marble quarry, the rock slope face is planar. In this particular case, only discontinuity traces are detectable from the point cloud, provided with the available data are associated with a high resolution digital image. Discontinuity traces can be represented by 2D polylines on the slope fitting plane, and a 2D quantitative analysis can be performed, based on their length and pitch angle on the reference plane of known orientation. In fact, the 2D approach can be pursued by automatically extracting or manually tracking the discontinuity traces, and projecting them on the best fitting plane of the rock face (Gigli & Casagli, 2011).

In the case of the Carrara marble quarry presented here the photogrammetric data that was used to generate a high resolution point cloud that was further analyzed with the DiANA tool.

This analysis suggests the possible way outs to extract data of the main failure planes, generated by the rock mass discontinuities and their utilization for a geo-mechanical characterization of the slope (Figure 10).

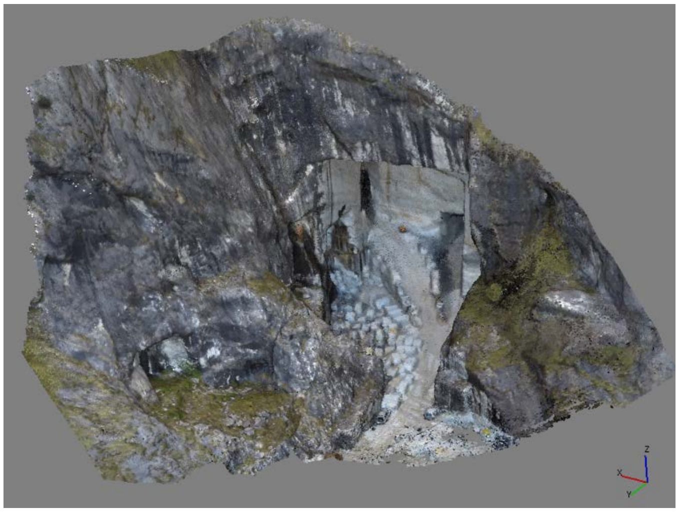

Figure 9. 3D view of the colored point cloud of the Carrara marble quarry.

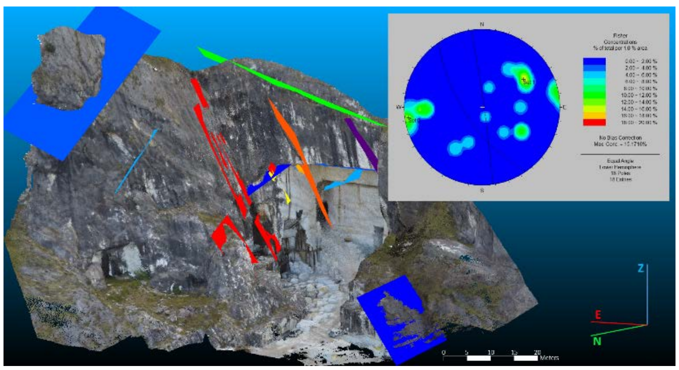

Figure 10. 3D view of the colored point cloud of the Carrara marble quarry with the main extracted discontinuities. The inset shows the stereoplot of the identified discontinuities.

CONCLUSIONS

The current study describes the possible applications of photogrammetric data for landslide investigations, acquired by using Saturn drones, a family of innovative multi-copters, developed at the Earth Sciences Department of the University of Florence.

In this regard various case studies have been presented and briefly discussed to elaborate the adopted methodology. The most common application of the drone technology could be surveying where by the acquisition of a high-resolution point clouds data of an unstable slope and optical images, a detailed geomorphological map of the area under investigation can be prepared by identifying its main morphologic features. Also by quantitively combining photogrammetric acquisitions of an unstable area acquired in different moments, it is possible to measure surface deformations with a vertical accuracy of several centimeters. Finally, high resolution point cloud data and optical images of unstable rock faces can be used for structural mapping by extracting the discontinuities parametrs that could be further utilized as input to geo-mechanical analyses.

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