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Brief Communication "The use of UAV in rock fall emergency scenario"

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Abstract

In recent years, the use of Unmanned Aerial Vehicles (UAVs) in operations in civilian/commercial contexts is becoming increasingly common also for the applications concerning the anthropic and natural disasters. In this paper, we present the first results of a research project aimed at defining a possible methodology for the use of micro-UAVs in emergency scenarios relevant to rock fall phenomena. To develop and support the presented method, the case study results relative to a rock fall emergency occurred on 7 March 2014 in the San Germano municipality (north-western Italy) are presented and discussed.

1 Introduction

In mountainous regions, transportation corridors are often susceptible to landslides (Michoud et al., 2012). In particular, rock falls constitute a major hazard in numerous rock cuts. Generally, rock falls size ranges from small (less than a cubic meter) to large boulders hundreds of cubic metres, and travel at speeds ranging from few to tens of metres per second (Cruden and Varnes, 1996). Emergency situations related to rock falls occurring on settlements or roads, require an a-priori detailed characterization of the instable areas, as well as of its potential evolution over time. The latter areas, however, are often difficult to access due to their typical morphology. Moreover, during emergency scenarios, field operations are prevented due to the potential risk associated to further gravitational phenomena. Therefore, there is a real need of straightforward procedures allowing to obtain robust and reliable dataset in a rapid and safe manner, aiming at a quantitative analysis of the rock mass.

In recent years, the use of Unmanned Aerial Vehicles (UAVs) in operations in civilian/commercial contexts is becoming increasingly common (Chiabrando et al., 2013). For example, an important application domain is in the area of emergency assistance and management, with scenarios including both anthropic and natural disasters

NHESSD
2, 4011–4029, 2014

The use of UAV in rock fall emergency scenario

D. Giordan et al.

(Tien-Hin et al., 2010) such as floods, earthquakes, and landslides. Micro-UAVs are used to carry light-weight instruments, such as consumer digital cameras, to acquire photographs of the area of interest and eventually allow for photogrammetric processing (Neitzel et al., 2011). Moreover, micro-UAVs are also used as a test bed for the integration of multiple instruments, as well as for the development of new sensors (Colomina, 2007).

As an example of application in a real-case scenario, after the Hurricane Katrina micro-UAVs equipped with three different sensors (pan-tilt thermal and visual sensor, and a fixed visual sensor for pilot view) were used to inspect collapsed buildings (Pratt et al., 2009). In addition, images from a micro-UAVs and unmanned sea surface vehicle were used for inspection of bridges and seawalls for structural damages (Murphy et al., 2008). Also, after the earthquake in L'Aquila, April 2009, UAVs equipped with cameras were used for building inspection and situation assessment (Nardi, 2009).

In this paper, we present the first results of a research project aimed at defining straightforward methodologies to use micro-UAVs in emergency scenarios relevant to rock fall phenomena, carried out by the Geohazard Monitoring Group of CNR IRPI and the Civil Protection of the Torino Province. The main purpose of the project is the use of micro-UAVs equipped with high-resolution digital video- and photo-cameras to build up in a rapid and straightforward manner georeferenced 3-dimensional solid images (Gonzales, 2009) in areas potentially affected by rock fall. The solid images can be used for the recognition and the characterization the most instable sectors, and to support the management of emergency situations. In the following, we present the first results relevant to the application of the developed methodology during a recent rock fall event occurred in the San Germano municipality, north-western Italy.

2 The San Germano rock fall event

At the beginning of March 2014, a critical instability involving a large portion of a rock wall was detected along the Provincial road SP 168 (Torino province, NW of Italy, see

NHESSD
2, 4011–4029, 2014

Fig. 1). The SP 168 is the sole route connecting the Pramollo municipality with the bottom of the valley, and allowing the population to reach services, schools, and workplaces. The instability involved an outcrop mainly composed of Dora Maira micashist (Borghi et al., 1985) about 100 m long and 40 m high. Despite stabilization works performed about 20 years before, a large fracture progressively developed along the entire rock wall. On 6 March 2014, this fracture started opening with a rate estimated in several centimeters per day, and minor falls affected the wall. In order to comply with these signs of criticality, the pathway adjacent to the rock wall has been closed to the traffic by the authorities responsible of the viability (Viability Service of the Torino Province, VSTP). In addition, VSTP informed the Torino Province Civil Protection Service (CPS) about the hazard potential related to the San Germano rock mass.

In this scenario, GMG and CPS operated the first survey during the afternoon of 7 March 2014. GMG performed a preliminary field observation aimed at identifying the instable area and recognize the main evidences of activity. The principal indication of the instability was the presence of a large fracture on the frontal side of the rock wall, and the presence of trenches in the upper part of the slope over the steeper sector. The lateral side of the rock wall was suffering an increasing number of minor rock falls, and the evolution of the opening of the main fracture started to be extremely evident. The frequency of minor falls increased during the afternoon, and at 17:00 CET the road was totally closed to the traffic. At 17:15 CET the rock cliff collapsed, and more than 1×10^3 m^3 of rock deposits covered the entire road path. After the collapse, the communication with the upper part of the valley and the Pramollo municipality was interrupted and an emergency procedure to restore the street and to assure an emergency communication and support to the population was immediately settled on. The SP168 remained closed until 15 March 2014, to allow the removal of the rock fall deposits, as well as to stabilize the new profile of the rock wall modified by the event.

NHESSD
2, 4011–4029, 2014

Use of micro-drones during the San Germano emergency

During the MASSA Project (Lanteri et al., 2014), the GMG and CPS have developed a protocol to support survey activities relevant to rock fall events in order to provide decision makers with quantitative data useful to deal with emergencies scenarios. In this context, GMG and CPS have postulated also to use of micro-drone equipped with digital video- and photo-cameras to obtain a complete survey of the instable rock mass.

According to the MASSA Project indications, a first survey with a micro-drone has been performed on Friday 7 March 2014, shortly before the San Germano rock fall event. Moreover, a second survey has been repeated also on Saturday 8 March 2014. In the event's aftermath, several complementary investigations have been performed, including terrestrial photographic surveys (Nikon AW 100) as well as a Terrestrial Laser Scanner (TLS) acquisition. The micro-drone available was a 6-rotors multicopter Carnboncore 950 equipped with a GoPro Hero 3 digital video-camera (hereafter referred to as GoPro). The remote control ensured the management of the flight of the micro-drone and of the gimbal orientation. The ground control station was equipped with a monitor displaying in streaming the data flow acquired by the GoPro. In this modality, the survey operation was performed by a team composed of the pilot, taking care of the drones stability only, and a geologist, monitoring in real-time the position and the point of view, and eventually indicating changes of trajectory. In this scenario, due to the complexity of the operations and the morphological characteristics of the area investigated, the autopilot solution was not envisaged. Table 1 summarizes the dataset collected during several surveys and considering different settings and instruments.

The data acquired during the micro-drone surveys have been processed with the Agisoft Photoscan software (hereafter referred to as Photoscan). Photoscan is based on the "Structure from Motion" technique (Westoby et al., 2012), and is capable to process the digital images and extract point clouds relevant to the common areas of the scenes acquired, and identifying the shooting points of an image sequence. To automatically obtain the image sequence of interest also from the GoPro videos, the

NHESSD
2, 4011–4029, 2014

Title Page
Abstract | Introduction
Conclusions | References
Tables | Figures
◀ | ▶
Back | Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion

MPEG2 original video was processed by means of an OpenSource video editing application, VirtualDub (v1.10.4 stable, http://www.virtualdub.org). After the selection of the suitable content, the video frame rate was downgraded to 0.20 fps and finally exported as image sequence (JPEG, full quality).

We generated two solid images by considering the data acquired via the GoPro. Further, an additional solid imaged was created by using the data collected via a Nikon AW 100 dataset, in order to compare the results obtained by using the micro-drone to terrestrial acquisition. In total, a dataset of about 200 pictures has been processed for the generation of pre- and post-event solid images. In Table 2, we present a synthetic comparison of results obtained.

The 3-dimensional solid images obtained have been used to generate a first order of digital surface model (DSM), which can supply quantitative information about the dimensions and the orientation of the main discontinuity identified in the rock mass. Figure 2 shows an example of the shaded relief derived from the DSM obtained from the survey of pre rock fall survey. This class of results can be used to perform first order quantitative analyses of the instable volume, as well as detection of joints and their classification.

3 Progressive results obtained by micro-drones in rockfall scenarios

The San Germano case study can be considered as test bed to set up standards for the use of micro-drones during rock fall emergency conditions. During emergencies, the processing time required to obtain the results is a very important element that has to be carefully considered. Time-consuming processes have the advantage of providing highly accurate results, but they are not suitable in emergency contests, where the rapidity of the response is crucial. Accordingly, we propose a procedure for the employment of micro-drones in rock fall scenarios consisting in several steps, which mainly depend on the processing time required to obtain the results and on their accuracy in terms of geo-positioning. The procedure considers the mission planning of a micro drone and, in particular, the sequence of obtainable products that can be used to study the bedrock structures and instabilities. After the micro-drone landing and the download of the acquired digital images, three different levels of results can be obtained in a timely progressive fashion: (i) video and photos of the instable area. These results are immediately available on site without any post processing activity. The immediate availability of videos of the area can be a very useful support in the field, mainly because the analysis of this data allows to image the instable area from different points of view, unlikely obtainable with field surveys. Also, aerial photos taken from the micro-drone can be very useful; however, the pictures sequence are usually not exploitable on site in a user friendly manner. To cope with these problems, procedures of photo mosaicking can be considered to obtain a better overview of the surveyed area. At this stage, the information obtained from videos and photos is not geocoded, thus allow only qualitative and semi-quantitative evaluations on the instable rock mass. (ii) 3-dimensional solid images. By using dedicated software, as for example the herein considered, it is possible to extract first a DSM and generate a photographic solid image of the investigated area (Hugenholtz et al., 2013). By considering the geographic coordinates acquired by the onboard GPS, the solid image can be geocoded. This second-stage result allows operators involved in the emergency scenario to have an additional tool, which can be now used for quantitative evaluations. The resolution of the 3-dimesional solid image can be very high (in the order of 2 to 10 cm pixel resolution), and may allow for very detailed analyses of the structural settings of the rock mass, even in the zones with limited access. It is worth to mention that most of the micro-drones available in the market are equipped only with L1 GPS, thus the attainable geocoding accuracy is limited (in the order of 5 to 10 m). The time required to get this second-stage result depends mainly on the computing capabilities and on the size of the investigated area. In general, we can consider a range of 2–3 h for small areas, to 10–15 h for larger instable sectors. (iii) The third-stage result differs from the previous one mainly because of the level of geocoding accuracy the 3-dimensional solid image. To obtain high accuracy in the geocoding, a set of ground control points (GCP) is required. The coordinates of

GCP have to be measured by considering high accuracy geodetic instruments, such as terrestrial laser scanners, theodolites, and/or GPS receivers (Paar et al., 2012). The key point is to identify a network of GCP that have to be first recognized in the solid image and then measure in the field their position with a high accuracy. This kind of topographic survey can be time consuming, and increase the complexity of both the field activities and the number of people and instruments involved in the operations. In this latter case, the results are characterized by a high accuracy in terms of geographic positioning and image resolution, allowing for the definition the absolute orientations of joints families (e.g. Ferrero et al., 2011), as well as permitting for a more accurate estimation of the instable volumes. The high accuracy level of these products gives also the possibility to use this dataset for monitoring purposes using a multi-temporal approach. Figure 3 describes these three different levels of output and considers also an indication of the time necessary for the restitution of different results. The indication of necessary time depends on the dimension of the studied area and/or on the available computational capacity.

4 Concluding remarks

In this work, we illustrated the results obtained by using micro-drones to survey areas affected by rock fall phenomena. In the San Germano case study, we use the micro-drone to support with photos, videos and solid images the analysis of the instable area and the evaluation of the risk. The descripted products have been used to support the CPS to manage the emergency scenario. The GMG with CPS acquired a large dataset using both the drone than terrestrial instrumentations, even to face the emergency condition than to acquire an important background to develop a possible methodology to use micro-drones in these particular contexts. The presented case study evidenced that the use of micro-drones is a suitable solution to support both qualitative and quantitative evaluations during emergency conditions, where the survey results have to be available in a rapid and straightforward manner. One of the common limitations in rock

NHESSD
2, 4011–4029, 2014

fall emergency scenarios is the availability of only limited point of views of the instable area that impede a complete analysis of the detachment area, which is often difficult (or even impossible), to reach in safe conditions. In this context, the use of drones can be considered as a rapid and low cost solution. Indeed, micro-drones are able to reach the instable area and take several photos and videos from several points and different angles of view. According to the problems that often characterize and have to be faced in emergency conditions, we have analyzed the processing time needed to get a set of results from the surveys, and defined a standard workflow for the use of micro-drones in rock fall scenarios to obtain a set of products characterized by an increase of geopositioning accuracy over time.

The different products obtainable by the proposed methodology have been defined to support the activities connected to the management of the emergency condition that is the principal aim of the presented work. According to the processing time (Fig. 3), the qualitative results obtained are important to recognize the principal instabilities of the studied area that are one of the most important elements for a correct evaluation of the residual risk after a the first activation of a rock fall. In this way, photos and videos taken by the UAV can be used immediately on site to support the first decisions for the management of the emergency (close road and/or evacuate houses etc.). After this first phase, usually it is also important to have a more detailed evaluation of the instable area to set up a first order of possible scenarios to better define the elements at risk. This second task can be supported by a quantitative approach, which allows for a first hypothesis about the instable sectors, their position and geometry. Also in this phase, the products obtained from micro-drones can be considered very useful for the analysis of the phenomenon, as well as for supporting actions of decision makers, which have the duty to manage the emergency condition defining the elements at risk and planning a mitigation project.

In the San Germano case study, the available micro-drone's dataset has been acquired by using a GoPro video-camera. The use of video-cameras has the main advantage of providing images of the rock mass in very different conditions. On the other hand, at the moment videos are limited by a relatively low resolution of 2–4 Mpixel, and the unavailability of the geographical coordinates of the frame acquisitions. Instead, photo cameras are characterized by a higher resolution (10 Mpixel and above), but the quality of the images can be hindered by problems of focusing, in particular in windy or in complex scenarios where the presence of close-up elements (like trees or others) can shadow the real target, i.e. the rock mass. In order to manage these limitations, a possible solution can be to set up a payload composed by both a video- and a photo-camera, which can acquire information concurrently.

The exclusively use of micro-drone can be efficacious for the generation of the first two order or results of the proposed methodology, but may suffer several limitations if we want to consider the dataset for monitoring purposes. In particular, repeatability conditions between successive surveys have to be respected. For this reason, in the San Germano case study we have contextually used with the micro-drone activities a TLS to obtain an high resolution DTM of the studied area to validate and improve the result obtained via micro-drones survey. The TLS DTM is characterized by a high point cloud density and also by a very accurate geographic positioning. The TLS has another important positive element, which is that is the availability of a very detailed DTM (Jabojedoff et al., 2012) that can be used to verify the correct geocoding process of the micro-drone dataset and the correct DTM extraction from the solid image (Henry et al., 2002). The availability of high resolution DTMs of the monitored area can also be used for a multi-temporal comparison aimed to defined the morphological changes of the studied area linked to the gravitational phenomenon's evolution (Niethammer et al., 2012; Giordan et al., 2013).

In the presented case study, we also tested pros and cons associated with the use of different geodetic instruments for the acquisition of GCP, performing surveys not only with a terrestrial laser scanner (TLS) but also with a Total Station (TS). TS can be considered as a suitable solution to get GCP coordinates on a rapid fashion, because the post processing time is very short. Moreover, if the GCP can be well identified in the field, the measurement of their absolute position can be done using the reflectorless technique. In a time period comparable to the micro-drone survey, the TS can acquire several tens of points. The most important limitation of this approach is the a priori identification of GCP, which is usually critical because it is not always possible to clearly recognize these points also in the solid image generated by exploiting the micro drone survey. On the contrary, TLS is a more time consuming technique, needing more time in the field and for the data post processing. The most important added value of TLS is that it is possible to a posteriori compare the solid image and the TLS colored point cloud and find the best matching points.

Another important limitation for the use of micro-drones is the occurrence of extreme weather conditions. These limitations can be very important in particular during emergency condition, which usually are related to extreme weather events. However, this might be considered as a technical limitation, which will be likely solved and/or provide better performances in the near future. The use of UAV for the management of geo-hydrological instabilities is a new research field that will probably have a progressive increase in the next years. The potential of these vehicle is very high and their development for these application is only at the beginning. At the moment, one of the most important element is the definition of procedures for their correct use that must considers both the limitation and characteristics of the UAV than the kinematics and the studied phenomena. Only in this way the obtainable results will be correct and will improve the use of this new categories of remote sensing data.

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NHESSD
2, 4011–4029, 2014

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NHESSD

2, 4011–4029, 2014

The use of UAV in rock fall emergency scenario

D. Giordan et al.

Table 1. Summary of the data and results obtained for the San Germano case study. D and T stay for Drone and Terrestrial surveys, respectively.

	Date of acquisition	Type of survey	Raw data	Photo resulution	Georeferenced	Dataset employment	Average ground resolution
Gopro video	7 and 8 Mar 2014	D	204 photos	2 Mpix	No	Generation of solid image and DSM	3.5 cm pix^{-1}
Gopro photo	7 and 8 Mar 2014	D	70 photos	10 Mpix	No	Generation of solid image and DSM	1 cm pix^{-1}
Nikon AW 100	7 Mar 2014	T	40 Photos	40	Yes	Generation of solid image and DSM	2.5 cm pix^{-1}
TLS survey	11 Mar 2014	T	24 million points	–	Yes	DTM Generation	–
Reflectorless Total Station survey	11 Mar 2014	T	10 points	–	Yes	GCPs for georeferencing	–

Table 2. Comparison between the results obtained for the San Germano case study.

Dataset	Advantages	Disadvantages
GoPro video	The number of available images taken from the video is very high and allows the restitution of a complete solid image of the area. The use of micro-drone allows the acquisition of images from different points of view.	The resolution of the images is low and this limitation can be a problem for the representation of solid image details. The lack of GPS positions does not allow to generate a georeferenced solid image without the use of ground control points.
GoPro photo	The number of available images taken form GoPro is very high and allows the creation of a complete solid image of the area. Compared with the frames extracted from videos, the resolution allows the restitution of a more detailed solid image.	The lack of GPS positions does not allow to generate a georeferenced solid image without the use of ground control points.
Nikon AW 100	The high resolution of the photos and the GPS positions allow for the restitution of a georeferenced high resolution solid image.	Several sectors are not covered by the solid image because of shadowing.

NHESSD
2, 4011–4029, 2014

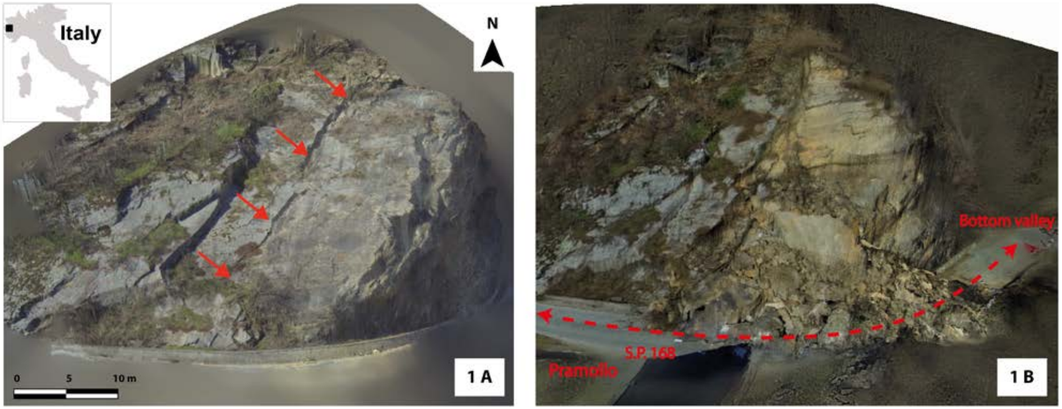

Figure 1. Comparison between 3-dimensional solid images of the study area before **(1 A)** and after **(1 B)** the San Germano rock fall event. Red arrows indicate the main lateral fracture.

NHESSD
2, 4011–4029, 2014

The use of UAV in rock fall emergency scenario

D. Giordan et al.

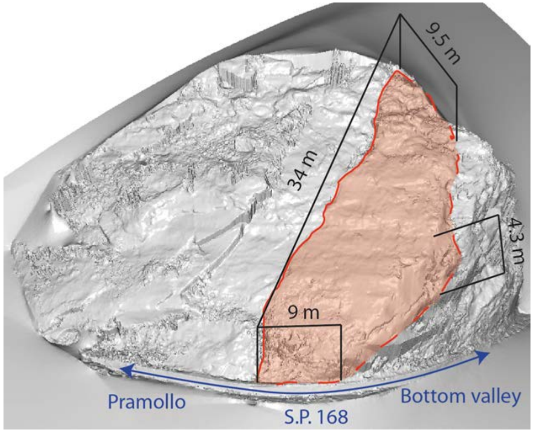

Figure 2. Shaded relief of the studied area with the indication of the dimension of the instable sector (red area). The DSM of the instable area before the rock fall event derived from the Go-Pro dataset allows to define the orientation of the main discontinuities: the principal shear plane has an orientation of 178/45 (dip direction/dip) and the lateral one of 325/81 (dip direction/dip). The maximum opening of the main fracture (continuous line on the picture) is 83 cm.

NHESSD
2, 4011–4029, 2014

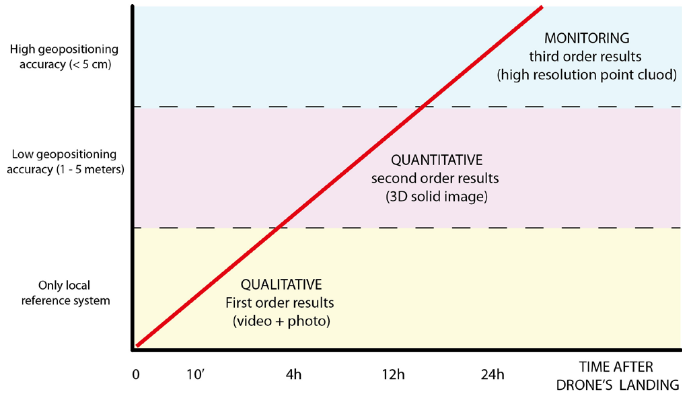

Figure 3. Schematic representation of the different results obtainable from micro-drone surveys in rock fall scenarios. Considering time starting after the drone's landing, there is a direct relationship between the geopositioning's accuracy level of the obtained results and the processing time. Times in the chart are indicative for a study area similar to the San Germano event, which can be considered as representative of rock fall phenomena involving the road network that can be studied through micro-drone's surveys. The processing time is also dependent on the areal extent of the study area and computational availability.

NHESSD
2, 4011–4029, 2014

The use of UAV in rock fall emergency scenario

D. Giordan et al.