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Use of unmanned aerial vehicles (UAVs) for photogrammetric surveys in rockfall instability studies

RIASSUNTO

L'utilizzo del drone (UAV) per l'esecuzione di rilievi fotogrammetrici nello studio delle frane da crollo

Si riportano i risultati preliminari di uno studio geostrutturale effettuato su due costoni rocciosi per i quali è stato realizzato un rilievo fotogrammetrico (DTP) basato sull'utilizzo di un drone (UAV). Tale rilievo ha consentito di ricostruire in maniera dettagliata la geometria del fronte e di risalire al pattern fessurativo dell'ammasso roccioso individuando un elevato numero di discontinuità, la loro orientazione nello spazio, le famiglie rappresentative nonché i volumi di roccia potenzialmente instabili.

Le pareti, localizzate sul promontorio di Posillipo (Napoli) ed in una stretta gola a Praiano (Costiera amalfitana), risultano essere state interessate in passato da numerose frane da crollo. Esse risultano molto articolate con settori posizionati ad altezze elevate e spesso variamente orientati rispetto alla direzione generale del fronte.

I risultati preliminari raccolti evidenziano i numerosi vantaggi della tecnica DSP-UAV in quanto consente di ricostruire topograficamente pareti localizzate in zone difficilmente raggiungibili con tecniche tradizionali vuoi per la localizzazione geomorfologica della stessa (Gola di Praiano) vuoi per la quota e la orientazione di alcuni settori rispetto al versante (Coroglio, Capo Posillipo). Il drone può volare autonomamente su traiettorie di volo prestabilite oppure no ed è per questo molto versatile alla logistica dei luoghi. Esso restituisce coppie di foto sterescopiche sia zenitali che variamente angolate rispetto al fronte. Infine esso è in grado di raggiungere distanze molto piccole rispetto al fronte (poche decine di metri) e ciò si traduce nella restituzione di una nuvola di punti (xyz) molto densa che permette di ricostruire, con tecniche automatiche e/o manuali, la geometria degli elementi geomorfologici (nicchie di frana, diedri e pinnacoli isolati) e geostrutturali (giacitura dei piani di discontinuità) e di definire i volumi delle masse rocciose instabili.

KEY WORDS: *Unmanned aerial vehicles, landslides, photogrammetric survey, rockfall stability.*

INTRODUCTION

The study of stability conditions of a rock mass is based on the systematic and quantitative description of discontinuities found therein. Geostructural analysis is traditionally performed with a geological compass with which the dip and dip direction of the joints are directly measured.

In some circumstances this type of approach presents difficulties, insofar as the rock face (or parts of it) may be very high and extensive, hence not easily accessible. In such circumstances *in situ* data acquisition becomes time-consuming and costly. This problem of directly acquiring geostructural data regarding discontinuities in a rock face, together with its topographic, geometric and geomorphological reconstruction, may be tackled with alternative methods to the traditional techniques. Such methods are based on more or less sophisticated types of topographical surveys which allow reconstruction, by means of a fairly dense "point cloud", of the rock face morphology and identification of the discontinuities in terms of position on the slope and orientation, spacing, persistence, and joint hierarchy.

To set up a 3D geometric model of the rock mass the two most widely used methods are currently: Digital Terrestrial Photogrammetry (DTP) (DI CRESCENZO & SANTO, 2007; FERRERO *et alii*, 2011; FIRPO *et alii, 2011*) and Terrestrial Laser Scannering (TLS).

In general, for very high cliffs (>50m) DTP may be carried out by using a digital metric camera positioned, according to the case in hand, on a reamed bar, an aerostatic balloon, inhabited (helicopter) or unmanned motorized aerial vehicles (such as a drone).

Use of one of the methods in question depends on the size (height and width), geographical location (high coast, high mountain, very urbanized area, etc.), morphology and articulation of the cliff and the degree of detail required. The latter, regardless of the metric camera used, clearly depends on the possibility of getting as close to the rock face as possible. In this sense, a remotely controlled vehicle (drone) allows acquisition of vertical (from the bottom to the top of the slope) or horizontal (a different heights) strips. It may reach a distance of a few tens of meters from the rock face and hence attain a better measurement accuracy of the discontinuities and slope surface.

This paper deals with the application of UAV photogrammetry based on the use of a drone helicopter. The study regards two different geological and geomorphological rock slopes, frequently subject to rockfalls, located on the Amalfi Coast (Praiano) and at Cape Posillipo (Naples). In particular, for the cliff of Coroglio (Cape Posillipo, Naples) we present preliminary geo-structural results and compare them with those obtained by direct analysis of the cliff face and from less detailed photogrammetric surveys (from a helicopter).

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UAV PHOTOGRAMMETRIC SURVEY

Micro & Mini UAV systems (M-class) are equipped with low-cost navigation sensors like GPS/INS and have the capability to fly completely autonomously or with a predefined flight path (Eisenbeiss, 2009). In this system, a drone (Fig. 1A) consists in remote-controlled 4-8 rotors that make it easy to change direction during the flight. The drone also has a camera capable of making videos and taking high-resolution photos. A GPS and an altimeter record in real time the precise position, altitude and also the distance from the cliff.

The good versatility and also the possibility to reach high altitudes (several hundred meters) mean that surveys can also be carried out in difficult morphological conditions. Through a monitor it is possible to follow the survey constantly and, at the same time, zoom out along significant points. The possibility of flying very close to the cliff (sometimes as little as 10 m away) enables important geostructural observations and also helps recognize open fractures parallel to the rock cliff not easily identified by TLS or manned systems (helicopter) (Fig. 1B). The main advantages of M&M UAV photogrammetric surveys are that the drone can be used in inaccessible areas, at low altitudes and at flight profiles close to the slope where manned systems cannot be flown, like narrow gorges, coastal cliffs and very urbanized areas.

Fig. 1 – The drone and calibrated camera along the "Praiano" gorge (A); distance of the drone flight path from the rock cliff (B).

APPLICATION OF UAV PHOTOGRAMMETRY

Two different surveys were carried out, the first on the Amalfi coast, along the narrow gorge of Praiano cut into the limestone rocks (Fig. 1), the second at "Coroglio" in Naples, along the 150-meter high cliffs of "Cape Posillipo" , where volcanic tuff and pyroclastic deposits are present (Fig. 2). For both sites various photogrammetric strips were performed at different distances and altitudes from the cliffs.

In the case of Coroglio the flight plan was programmed by dedicated software through a 70% longitudinal overlap and a 50% cross; in the case of the Praiano gorge, with no GPS signal, a manual flight was experimented, using the operator's monitor.

Pictures were taken in jpg and tiff format with 14 megapixel of resolution.

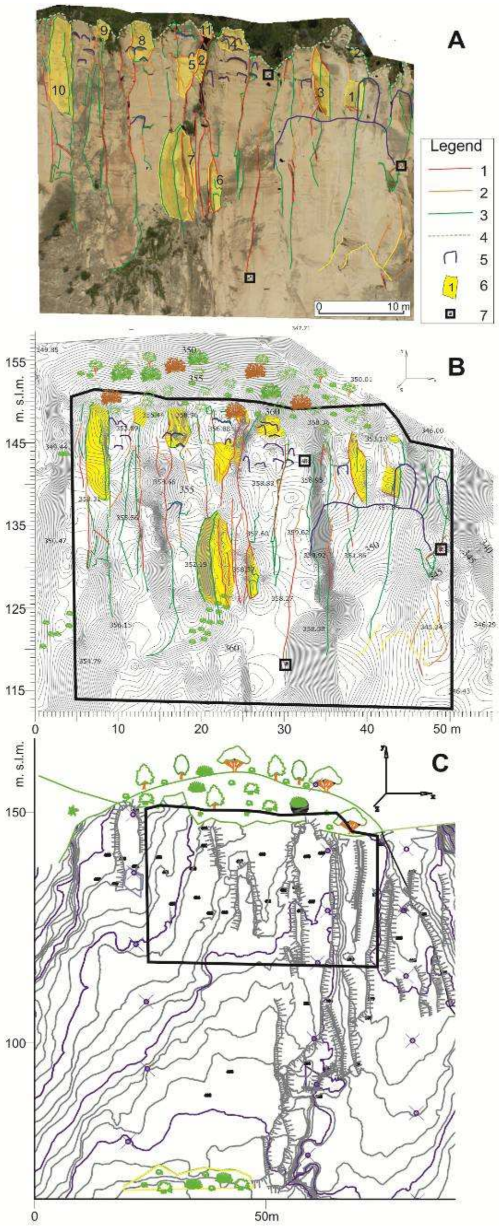

Fig. 2 –Photo by drone of Coroglio cliff and georeferenced (A) on the photogrammetric survey (B): 1) Open fracture (> 1cm wide); 2) Open fracture (0,05-1 cm wide); Closed fracture (< 0,05 cm); 4) Stratigraphic contact between fall pyroclastic deposits and tuff; 5) Rock fall source area; 6) Isolated unstable dihedral and rock pinnacle and referring number ; 7) Target; C) Photogrammetric survey by helicopter (year 2000). The box shows the studied area.

For the absolute orientation of the stereoscopic models we used coordinates of control points acquired by a topographic survey. Targets in forex were positioned along the Coroglio cliff while in Praiano a topographic survey of natural points and those subject to human impact was done to calculate their precise coordinates. In the latter case the photogrammetric survey is undoubtedly less expensive.

The drone flew very near the cliff, allowing restitution of a very detailed tridimensional model and a survey rich in details. With the produced images it is possible to make point clouds, orthophotos, contour lines, profiles (Fig. 2).

In the case of Coroglio, comparison between a previous photogrammetric survey (2000) and the drone flight was also made. In Figure 2 it is possible to see the great differences and the greater detail obtained by UAV photogrammetric analysis.

GEOSTRUCTURAL SURVEY AND PRELIMINARY RESULTS

Stereoscopic model analysis provided the attitude (dip and dip direction) as well as the location of the discontinuities (Figs. 2A and 2B). Their spatial distribution was analyzed statistically to determine the main discontinuities by using the commercial code DIPS (Rockscience). Fig. 3A shows the stereogram reproduction of the isocurves of measured poles and joint sets identified.

The results from this analysis (UAV-DTP) were compared with those obtained by helicopter photogrammetric survey complementaryto engineering-geological survey (DTP) (Fig. 3B). The two stereographic projections show (Fig. 3 and Tab. 1) a good general correspondence among the families identified

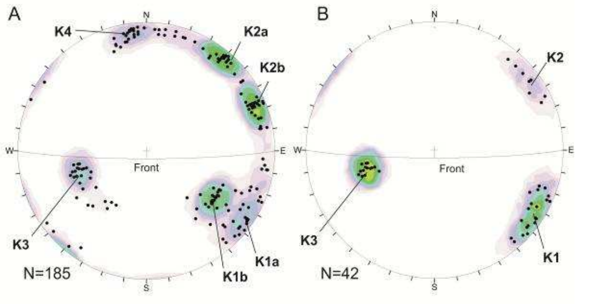

Fig. 3 – Stereographic projections of joints systems: poles from UAV-DTP (A); poles from DTP (manned helicopter) and geological-engineering surveys (B)

(K1, K2 and K3) even if with UAV-DTP some families are better discretized (K2a, K2b, K1a, K1b). One family in particular, namely K4, which is very important for stability of the rock face in that it favors sliding, was not intercepted except by DTP survey. The extreme precision of the UAP-DTP also allowed calculation of the volume of the pinnacles or other geomorphological and geostructural elements by measuring a dense "point cloud" on the rock surface manually (with an operator) or automatically (Ferrero *et alii*, 2011).

In our case, object restitution (isolated rock dihedral or pinnacle) was carried out manually by selecting a minimum number of points necessary for reliable identification of a discontinuity plane (Fig. 4 and Tab. 2).

CONCLUSIONS

Use of an unmanned Aerial aerial vehicle (UAV) is a good terrestrial photogrammetric procedure to reduce operating costs and speed up the external acquisition phases. The procedure described above provides a very powerful tool for rock slope stability analysis, and is able to supply detailed information about discontinuities and slope geometry, even on high cliffs otherwise unattainable by direct measurements. The UAV-DTP system presents the following advantages: high versatility of use in different topographic contexts like high cliffs, narrow gorges or very urbanized areas; high geometric accuracy related to the possibility of drones flying in the vicinity (up to a few meters away) of the cliff. Data from UAV-DTP can be represented on orthophotos and 3D models integrated in a GIS.

These products are often easily accessible and suitable for classifying slopes in different hazard categories in order to create a useful tool for safe planning and decision making.

UAV-DTP		DTP-(manned helicopter)	
System	Dip/Dip dir.	System	Dip/dip dir.
K1a	82/306	K1	81/302
K1b	55/305		
K2a	82/218	K2	80/234
K2b	80/249		
K3	45/66	K3	46/74
K4	80/174	K4	-

Tab. 1– Joint systems geometric data from UAV-DTP and DTP

N.	Volume (m^3)	N.	Volume (m^3)	N.	Volume (m^3)	N.	Volume (m^3)
1	9	4	9	7	69	10	26.5
2	6	5	18	8	12	11	4
3	24	6	9	9	2.5		

Tab. 2– Unstable dihedral and rock pinnacle volume (for location see fig. 2).

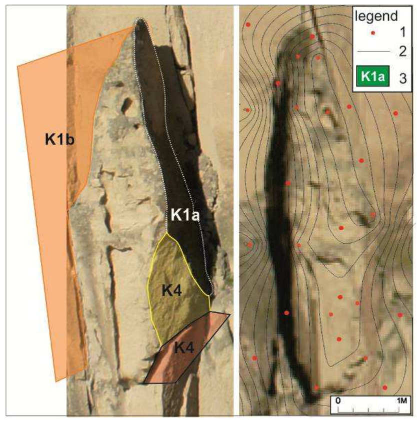

Fig. 4 – Rock pinnacle formed by four intersecting joint sets (no. 6 in fig. 2 and tab. 2): 1) point cloud; 2) contour line of the UAV-DTP (every 0.2 m); 3) joint set of the discontinuities surveyed on the slope (see fig. 3)

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