Large and Small Scale Multi-Sensors Remote Sensing for Landslide Characterisation and Monitoring

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Abstract

In the last years, the use of Unmanned Aerial Vehicles (UAVs) has developed rapidly across several field of earth sciences application, including landslides characterisation and monitoring, therefore providing a strong support for hazard and risk management activities especially with the introduction and advances in the miniaturization of traditional and new generation sensors. The flexibility, low cost, easy operability, and rapidness of intervention in emergency situation gives to these instruments, a strong potential in opening up a vast new area of opportunities in remote sensing for observation, measuring, mapping, monitoring, and management in various landslide environment. Unless initially only air photography was the main application for UAVs, recently new sensors, both passive and active, are being increasingly used. This paper, through some case studies on landslide investigations, aims at giving an overview on several sensors and techniques using UAVs platform addressed to landslide detection, characterization and monitoring.

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Introduction

Displacement monitoring of unstable slopes is a crucial tool for the prevention of hazards. It is often the only solution for the survey and the early warning of large landslides that cannot be stabilized or that may accelerate suddenly (Travelletti et al. 2012). The techniques to monitor displacement are broadly subdivided into two main groups: ground based and remote sensing techniques. The firs group needs installation of sensors in and/or out the target area measuring data in time nevertheless they suffer of their punctual nature and relatively high cost of installation and maintenance. The Remote sensing techniques are basic tools for applying spatially distributed information of unstable slopes (Delacourt et al. 2007). The main advantage of using UAVs remote sensing payload sensors for landslide investigations is the capability to provide spatially continuous data with very high spatial resolution, especially if integrated with the point-wise measurements typically acquired by ground-based techniques. In this work a resume of drone and associated typology of sensors application is described for landslide characterization and monitoring.

UAV Classification

Unmanned aircraft vehicles are classified mainly into 3 categories: fixed wing, rotary wing and aerostatics. They have different characteristics, advantages and drawbacks.

A fixed wing UAV is basically an airplane, where the lift is produced by an aerodynamical appendix that moves fast in the air but is fixed with respect to the aircraft axes. Fixed wings need high relative airspeed to generate the lift then take-off and landing maneuvers are critical. More space or the catapult method is needed to gain speed during take-off; landings are often uncontrolled because they are accomplished by releasing a parachute. During the acquisition, the high flight speed, usually more than 20 m/s, can blurry data:

high level of sensibility sensors are needed to obtain sharp data when high resolution is the key point. Also, data geo-referencing can be affected by speed: 100 ms of delay in the triggering at cruise speed can add metrical error in the geotagging chain of data. High speed GPS and precise detection of acquisition time stamps are crucial. Speed can be useful in long distance cruise and big areas to cover, combined with a high efficiency of fixed wings leads to long flight time which make them more suitable for long survey campaign.

Rotary wings UAV have a propeller that produces lift rotating in the air. This category is populated by helicopters and multi rotors. Multi rotors or multicopters are the most common rotary wing UAV because the mechanical design of the rotors is simplified due to the lack of cyclic and collective to control the helicopter movement. Change in direction, altitude, rotation and speed are operated only changing the speed of the motors: a mechanically safe and simpler method that relies on the electronics and software that operate a synchronized change of speed of the propeller. The drawback is that multi rotors cannot be maneuverable without a software to manage the motors: it is not possible to override with manual control if the software fails. Helicopters, like fixed wings can still be maneuverable and flyable only from a pilot input. The main advantages of rotary wings are the very fast deployment on field, vertical take-off and landing and high mass useful load respect dimensions. The possibility of hovering in a fixed point or acquiring at low speed can be very useful to increase quality of data in all conditions and the georeferencing accuracy. Rotary wings are energy hungry and do not excel in flight endurance.

Aerostatics UAV are the most common because of the dimensions and the limited operational weather conditions. Dirigible are the most used in this category for low altitude flight and they excel in flight time.

Fixed wings and rotary wings can merge in VTOL airplanes (Vertical Take Off and Landing) to overcome some reciprocal drawbacks and obtain a better flight endurance and easier take offs and landings. The merging is not a definitive solution because disadvantages can add up resulting in an aircraft made for specialized operations and tasks.

Sensors Classification

UAVs can carry different kinds of sensors, one or even more at time, according to the payload capacity and connections with the control station. Their usage depends on several factors as the type of investigation, the topography of the area, the required products and the economics resources. The most commonly used in the field of landslides mapping and monitoring are listed in Table 1, together with their characteristics and applicability.

They can be divided into two main categories, active and passive sensors. The first one can be defined as sensors that actively send a pulse and measure the signals backscattered to the sensor itself. Conversely, passive sensors detect some type of input from the physical environment, always receiving and not transmitting signals.

Among them, optical imagery is certainly the most spread technology, due to its cost effectiveness, easiness of use and variety of achievable products such as DEMs, DSMs and Orthophotos (Colomina and Molina 2014; Kršák et al. 2016; Niethammer et al. 2012; Remondino et al. 2011; Rossi et al. 2018). The basic principle is to reconstruct objects in 3D through the process of recording, measuring and interpreting photographic images. UAV photogrammetry can be considered a low-cost alternative to the classic aerial manned photogrammetry, with respect to whom it allows more detailed surveys but on smaller areas. The resolution is the main variable of this kind of survey, and it is strictly connected to the resolution of the camera itself as well as the flight height.

The same principle applies for the thermal cameras producing thermograms, i.e. images of the radiation in the long-infrared range that is emitted by the investigated objects. The presence of fractures, moisture and voids influences the heat transfer of materials generating thermal anomaly in the observed thermal imagery (Casagli et al. 2017; Frodella et al. 2017; Pappalardo et al. 2018; Zhou et al. 2020). These can give fundamental information about the fracturing of rock walls as well as drainage systems or more in general of weak shallow surfaces. As in the case of photogrammetry, this technique has some limitation connected to the boundary circumstances at the time of the survey. Both require indeed an optimal atmospheric conditions and sun exposition (Wierzbicki et al. 2018; Yu et al. 2017), limits that could be however overcome when considering the low-cost effectiveness of the sensors.

Multispectral and hyperspectral sensors are passive instruments capable of recording the amount of reflected energy of objects on the earth's surface in the different wavelengths of the electromagnetic spectrum. The outputs are therefore multiband images that allow to extract spatial information and produce accurate thematic maps with the use of classifiers (Baccani et al. 2018; Natesan et al. 2018; Lin et al. 2017). The NDVI (Normalized Difference Vegetation Index) is one of the most used indicators achievable through these technologies, helpful to assess whether the observed target contains live green vegetation (Carlson and Ripley 1997).

As previously explained, passive sensors (like all those mentioned so far) are limited in observing and detecting external inputs. For this reason, the obtained information (such as images or thermograms) need to be carefully post-processed. On the other hand, active sensors acquire

Table 1 UAV sensors and their applicability

Optical camera	Passive	3D point cloud, DEM, DSM, Orthophoto	Landslides volume estimation, deformation maps trough multi-temporal surveys, georeferenced layer for further elaborations, emergency plan	Low
Thermal camera	Passive	Thermogram	Detection of fractures, subsoil voids and moisture	Middle-Low
Multispectral	Passive	Spectral Images	Extraction of spectral index, Soil characteristics (mineralogy), land use	Middle
Hyperspectral	Passive	Spectral Images	Spectral signatures, extraction of spectral index, soil characteristics (mineralogy), land use	Very High
LiDAR	Active	High resolution 3D point cloud, DEM, DSM, Orthophoto	Landslides volume estimation, deformation maps trough multi-temporal surveys, georeferenced layer for further elaborations	Very High
Ground Penetration Radar	Active	Profiles of the signals reflected from the subsurface	Detection of non-conductive materials, voids, sand and gravel deposits, fractures and faults	High

measures, gathering usually the required information without the need of further elaborations, saving thus processing time.

An example of active sensor that can be adaptable to drones is the Ground Penetrating Radar (GPR). In this case, a transmitting antenna sends high frequency pulses of electromagnetic energy into the ground, while another antenna receives the reflections that bounce back up from layers and targets. The depth of the targets can be therefore evaluated if the Relative Dielectric Permittivity is known (Lanzarone et al. 2016). The information is therefore recorded by the instrument and the user has only to interpret them. Depth penetration is a function of the antenna frequency and the electrical conductivity of the soils in the survey area. Lower the frequency of the antennas, greater the penetration depth is. GPR is best suited for low conductivity or high resistivity materials like sandy soils, limestone and granite and work well in most saturated environments (Benson 1995; Mellett 1995). GPR on drones are a quite recent technique, but these kinds of radar have been already used several times in the field of landslides mapping, characterization and monitoring (Bichler et al. 2004; Hu and Shan 2016; Sass et al. 2008).

Thanks to the increasing reliability of drones, also heavy and costly active instruments can be safely transported with low risk of damage. It is the case of LiDAR (Light Detection And Ranging), a consolidated remote sensing technique used to obtain high resolution 3D point clouds of the topographic surface through the emission of highly collimated, directional, coherent and in-phase electromagnetic radiation (Jaboyedoff et al. 2012). The 3D point cloud can be then easily transformed in DEM, DSM and orthophotos, that are the same typical outcomes of a photogrammetric survey. However, while optical imagery requires optimal weather conditions, illumination rates and sun exposition, laser scanners can properly work even in low-light conditions. Moreover, in a wooded terrain, LiDAR can penetrate the canopy, allowing to detect and map landslides in forested areas, that is a competitive advantage over the use of optical cameras not able to compute feasible surveys in this kind of areas, thus justifying the higher costs of the LiDAR technique (Guzzetti et al. 2012). Because of these aspects, and considering also the higher precision obtainable, UAV laser scanners is becoming a very widespread technique (Karantanellis et al. 2018; Kwon et al. 2019; Pellicani et al. 2019).

Materials and Methods

Battery life, payload capacity and flight safety are key and critical characteristics for a UAV. According to these points, a new multicopter concept has been thought by Earth Sciences Department and Center of Civil Protection of the University of Florence (Italy) to overcome some lack of traditional drone configuration. The patented Saturn drones are designed with an innovative ring perimeter airframe that allows the weight reduction in multi-rotor configurations improving the load capacity or flight autonomy.

Furthermore, the rigid connection between the motors, crucial for a correct flight dynamic, take place along the ring perimeter frame avoiding the central structure and cutting the vibrations spreading to the sensors and the flight instruments. Flight safety of the drones is enhanced through the use of an automatic engine positioning system along the chassis that allows a reconfiguration of the engines even during the flight: in the event of an engine failure, it is possible to rebalance the flight attitude in order to complete an emergency landing without payload damage or uncontrolled fall with harm of people.

Fig. 1 The Saturn Mini X-21 drone

The Multi-Copter Saturn Family

The ring perimeter frame patent led to the development of two drones each specialized in different tasks: the Saturn mini and the Saturn M2. Both drone editions, designed and built by the Department of Earth Sciences of the University of Florence, have a configuration with six motors, whose propulsive redundancy reduce the falling chances during emergency situations or limiting the ground impact in case of failure up to 2 engines. The extremely rigid frame in flight and the aerodynamics of the Saturn drones allow remarkable performance both uphill and downhill. The descent rate is a critical parameter of the multi-rotors which offer the capacity to handle rapid altitude losses without threatening aerodynamic phenomena that can lead to an uncontrolled fall. The control radio frequencies are redundant and differentiated to increase operational safety even in case of strong radio interference. A third frequency is dedicated to the pilot camera placed in the bow of the drone with very low latency. The dedicated pilot camera allows to operate safely even during flights that require the aiming of the sensors in different directions to those of the vehicle's progress. This configuration is extremely practical during nadiral acquisitions in confined spaces within gorges or with vertical walls. The landing gear is a tripod that guarantees stability on takeoff but above all on landing even in rough terrain and in case of sustained winds and gusts.

The Saturn mini (Fig. 1) has a diameter of 55 cm, maximum payload of 1.5 kg and take-off operating mass under 4 kg, with a maximum autonomy of 30 min. The frame is entirely produced by 3D printing and offers a high integration with instruments and sensors. The maximum take-off weight under 4 kg lets it to be classified in a less restrictive category and together with the payload capacity of up to 1.5 kg make it suitable for a wide range of scenarios.

The maximum speed of the Saturn mini is about 90 km/h giving it an excellent resistance to wind and possible gusts. The extreme maneuverability and the reduced flight restrictions make it particularly suitable for photogrammetric survey during rapid intervention for emergency or in areas with

Fig. 2 The Saturn M2 drone

limited accessibility. The Saturn M2 drone (Fig. 2) has a 100 cm diameter frame, a maximum payload of 10 kg and a take-off operating mass of 22 kg. This take-off mass puts it in a category with some restriction of use. The maximum flight autonomy is approximately 30 min, which may vary depending on the flight conditions and the payload carried. The Saturn M2 can be used in emergency scenarios even in adverse weather and climatic conditions (strong winds or rain). The drone can be used safely in critical areas as it is equipped with appropriate failsafe, independent flight termination system and parachute. The characteristics of Saturn M2 are ideal for performing flight activities with multi-sensor platforms thanks to the high stability and flexibility in the implementation of loads of various shapes, sizes, weights and positions.

The Multi Sensor Family

Drones are used to provide all kind of data required for the analysis of hydrogeological instability, even in emergency conditions when the rapid acquisition becomes the priority, minimizing risks for operators. Within the sensors that can be mounted on Saturn drones there are: Haigh resolution

Panchromatic camera, Thermal camera, Hyperspectral camera, Lidar, Ground-Penetrating Radar, Radar.

With height resolution panchromatic camera three products can be achieved (Remondino et al. 2011): orthophotos, Digital Surface Model (DSM) and Digital Terrain Model (DTM). The orthophoto is a product created from aerial photos that are ortho-rectified and geo-referenced. The resolution on the ground can be increased to cover a large area by composing mosaics of images without signs of discontinuity through the photogrammetric technique. The orthorectification requires a digital model of the DSM, which is normally produced together. The DSM is a three-dimensional rendering of what is visible to the drone's camera through a programmed acquisition of images and subsequent processing on the fly. The DTM is the three-dimensional representation of the geodesic surface mapped. It is an interpolated product, which provides, through automated algorithms, the removal of vegetation and anthropogenic artifacts, fixed or not (buildings, vehicles, poles, etc. …).

In recent years, infrared thermography (TIR = Terrestrial Infrared Thermography) has seen its use grow in the field of identification and characterization of landslides (Frodella et al. 2017; Morello 2018). Interesting studies have been carried out in the identification of critical elements in rock slopes, such as sub-superficial hollows, humidity areas linked to fractures and intensely fractured or detensioned sectors of rock mass. The dependence of physical thermal parameters linked to the density and composition of geological materials, such as thermal inertia, suggests the use of TIR in order to characterize the physiography of very heterogeneous deposits such as landslides. Thus, TIR constitutes a valid ancillary technique, which integrated with other remote sensing techniques (ex: Lidar, GBInSAR), can provide an important contribution for the purpose of a detailed characterization of slope-level instability phenomena.

Hydracam (HYperspecral DRone Advanced CAMera) is a hyperspectral camera for drone environmental monitoring by using an electro optical liquid crystal technology combined with a commercial camera, which allows to continuously space in a wide range of wavelengths (Baccani et al. 2018). The sensor works between 650 and 1100 nm and has a resolution of about 10–20 cm from a flying elevation between 30 and 150 m with a field of view of 40° (Fig. 3). Compared to a mechanical device with classic mobile filters, with this sensor it is possible to have high spectral resolution images in a short time. Moreover, the high integration of electronics, combined with the computing power of modern processors, allows to develop integrated and compact hyperspectral systems reducing the mass, making it a drone payload, and costs.
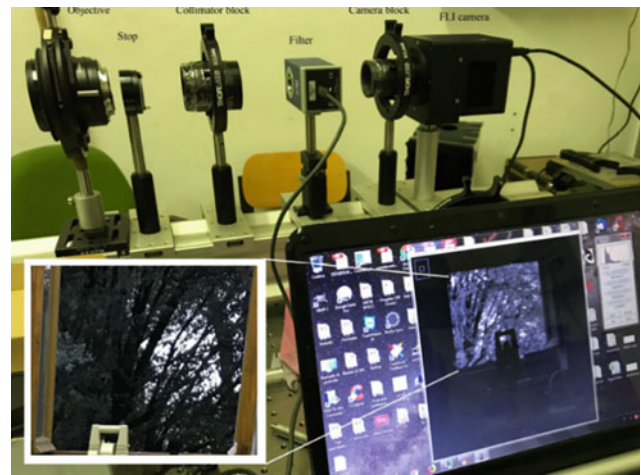
Fig. 3 Laboratory setup aligned using self-centering jaw clamps and a theodolite. A FLI camera in place of XIMEA GmbH sensor has been used. The actual acquisition at 800 nm fixed by the tunable filter is enlarged in the box at the bottom left

The Ground-Penetrating Radar (GPR) is a geophysical method that uses electromagnetic radiation pulses in the microwave band (UHF/VHF frequencies) to reconstruct the subsurface detecting the reflected signals from underground surfaces and structures. GPR can be used through rock, soil, water and concrete and can detect buried objects, material properties changes, voids and cracks (Altdorff et al. 2014; Neal 2004). The GPR sensors for drone platform use high-frequency radio waves (from 10 MHz to 2.6 GHz) that allow, with a flying elevation between 30 and 50 m, to explore the subsoil from a depth of a few meters to a maximum depth of a few tens of meters.

For the radar system, an experimental lightweight Frequency Modulated Continuous Wave (FMCW) radar system has been developed to produce low resolution DEMs from long distances (Tarchi et al. 2017). This experimenting technique has great potential that still have to be improved with the opportunity to pierce into snow and low vegetation coverage and a wide range of applications.

Applications

In soil sustainable exploitation planning and land resource evaluation, modern and accurate up-to-date scale maps of soil properties is one of the most important need such as inexpensive and non-invasive mapping methods. In that respect, geophysical sensing techniques allow to acquire rapidly a large amount of data on soil conditions with respect to conventional direct field sampling and traditional analyses which are generally invasive, time-consuming, expensive and often require a large number of samples to capture

variability of the soil properties (Brevik et al. 2003; Kweon 2012). Among existing geophysical techniques, hyperspectral (Hs), results as particularly interesting as it allows characterization of relatively large areas with fine spatial and/or temporal resolutions. For soil and landslide characterization, clay content is one of the most important data to investigate. Ciampalini et al. (2015), Garfagnoli et al. (2013), Ben-Dor et al. (2009) applied hyperspectral analysis using a push broom aerial hyperspectral sensor to investigate the soil clay content and clay minerals. In their research the authors produce a map that represents the different clay minerals and their total amount in percentage (Fig. 4). In this map brown corresponds to the higher percentages and blue corresponds to the lower percentages. A mask was applied to the neighboring grassland. The maps of hillite and montmorillonite (Fig. 4a, b) show a similar trend. They assume that the lower values clustered in the northern part of the parcel, is due to a topographically more elevated area, while an increasing trend towards the south (i.e., parallel to the flow direction, towards the bottom) can be observed for both minerals. This tendency can be interpreted as a normal effect due to soil erosion by rainwater and the consequent removal and concentration of finer material downhill. On the contrary, the map of kaolinite content (Fig. 4c) displays a completely inverted trend, with higher concentrations located to the northern and south-eastern parts of the field. As shown in Fig. 4d, the distribution of the total clay content closely resembles that of illite and montmorillonite. A comparison among the maps shows that kaolinite scarcely affects the total clay areal distribution.

In this section, some examples of landslide characterization and monitoring using different UAV sensors are presented. The first cases are related to the application of optical cameras and therefore photogrammetric processes, focusing in particular on surveys in emergency conditions and multitemporal analysis. Concerning the latter, the comparison of terrain 3D models acquired in different times allows indeed to evaluate changes occurred on the surfaces. This technique founds application in several environments such as river dynamics, erosion processes and several geomorphological processes (James et al. 2013; Riquelme et al. 2019), but it is widely used to reconstruct volume changes due to the occurrence of a landslide.

An example on landform reconstruction at different stages and estimation of volumes has been performed in the village of Ricasoli, an area strongly affected by diffuse slope instability in the Upper Arno river Valley (Tuscany, Italy). The substrate of the basin where the village is located consists in flysh-type formations constituted by sandstones interlayered with siltstone, overlain with fluvial-lacustrine sediments. Several landslides affect this area, mainly made by sands and sandy silts and characterized by high slope angles. The study here presented focuses on two shallow landslides occurred respectively on March 1st (Landslide 1, LS1) and March 30th, 2016 (Landslide 2, LS2) after a period of heavy rainfall (Fig. 5) (Rossi et al. 2018).

Three aerial photogrammetric surveys were performed on the study area with the Saturn Drone, respectively on July 30th, 2015, March 2nd, 2016, and April 6th, 2016, using a Sony digital RGB camera with 8-MP resolution and flying at a constant altitude of approximately 70 m a.g.l.. Data have been handled in Agisoft Photoscan Professional software and the acquired 3D point clouds have been processed and appropriately filtered removing all the points corresponding to buildings, unwanted elements, and high vegetation, to obtain high-resolution DTMs (0.05 m/pix). The DTMs were
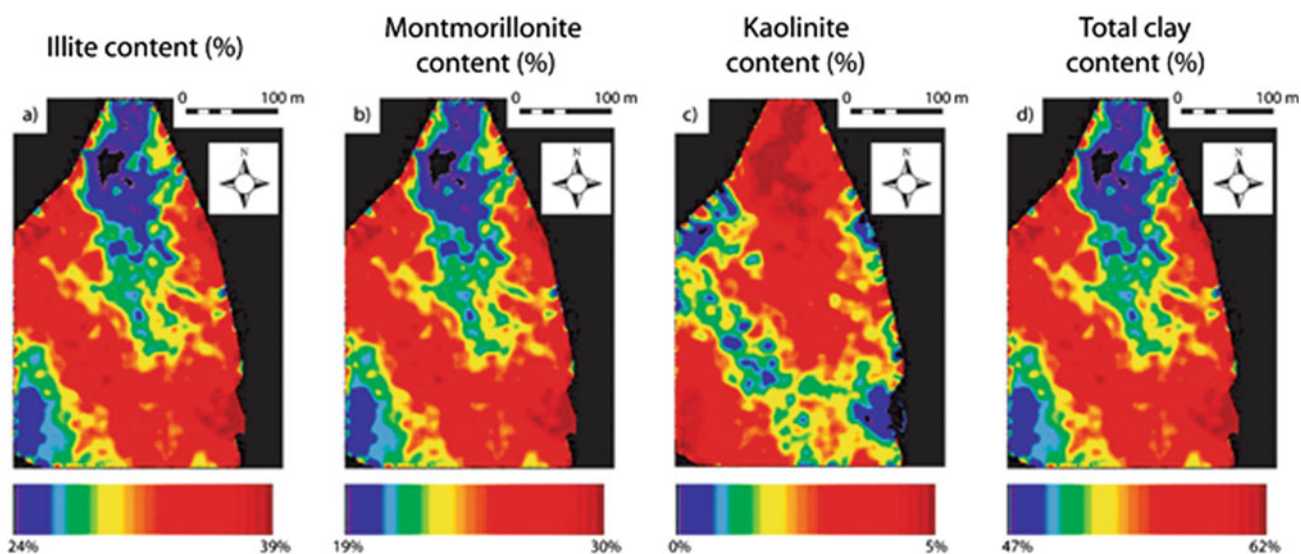
Fig. 4 Hyperspectral-derived clay map for illite (**a**), montorillonite (**b**), kaolinite (**c**) and total clay (**d**)

Fig. 5 Orthophotos of the area affected by the landslides (**a**, **b**, **c**) and DEM differences among different acquisitions (**d**, **e**, **f**) (Modified after Rossi et al. 2018)
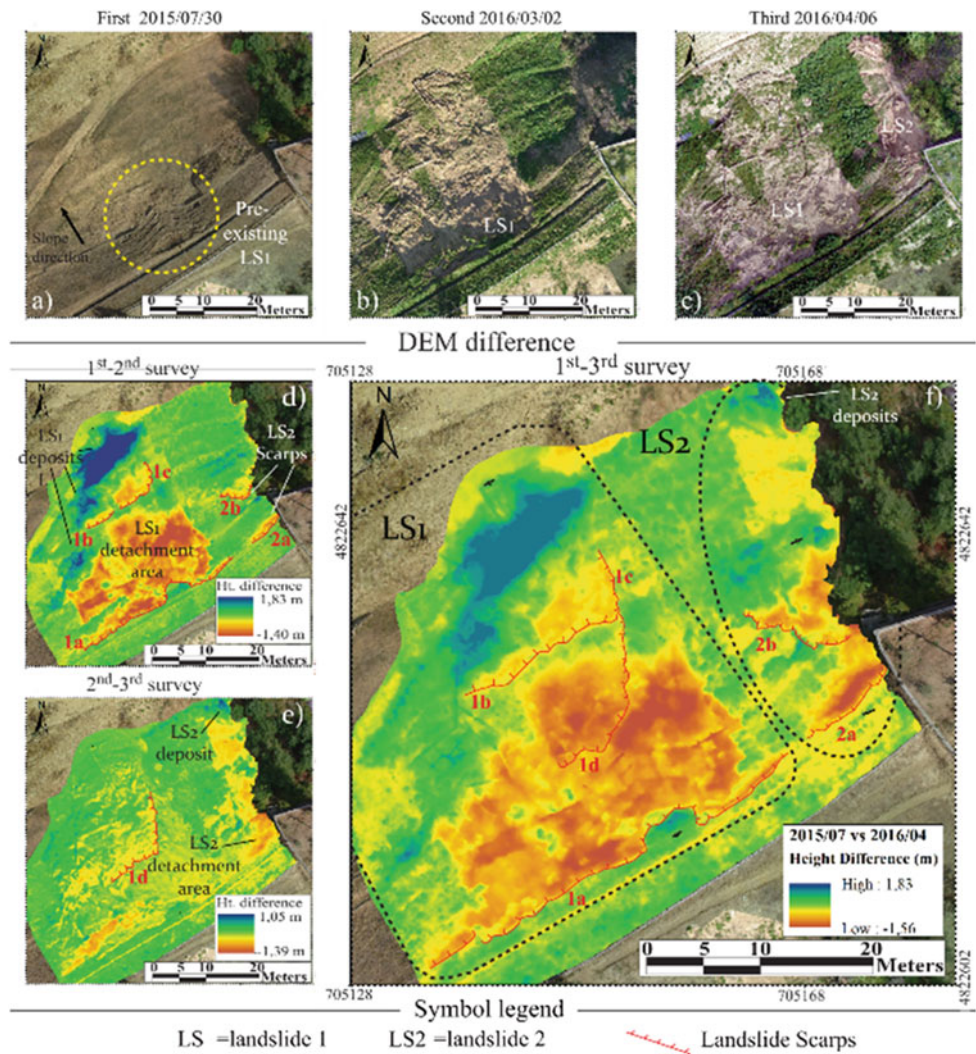
then compared to detect any morphological change between the three acquisitions, permitting to characterize the landslide and, in addition, to precisely point out geomorphological features of landslide-prone areas on the slope (Fig. 5).

In particular, Fig. 5 shows the orthophotos of the three surveys (Fig. 5a–c) together with the DTMs comparisons (Fig. 5d–f).

The results of the first survey carried out in July 2015 showed a deformation on the surface, clearly visible in the yellow dotted circle of Fig. 5, as the only sign of instability. That area was the first signal of a shallow landslide that occurred the 1st of March 2016 after intense rainfall, identifiable in the second drone survey, i.e. the one made in March 2016 as the LS1 area. The comparison of the two DTMs (obtained in 2016 and 2015) allowed to characterize the landslide, making it possible to recognize the detachment, transportation and deposit areas and to estimate an unstable area with an extension of 1250 m^2 (Fig. 5d).

Moreover, the DTMs comparison pointed out the formation of two new scarps, called 2a and 2b in Fig. 5d. Once again, these were the precursor of a new landslide (called LS2 in Fig. 5c, f) verified in between the second and the third surveys, i.e. the one of March and April 2016, respectively. The phenomenon was characterized thanks to the comparison of the DTM obtained from the 3rd survey with the ones obtained in the 1st and 2nd surveys (Fig. 5e, f). The LS2 ground deformation was hence classified as a planar translational slide (according to Varnes 1978) with an extension of 300 m^2 (Rossi et al. 2018).

The Ricasoli area example shows how the multitemporal analysis not only allows to characterize and monitor existing landslides but can also be a powerful instrument for landslides recognition at a preliminary stage. Furthermore, one of the main advantages is the potential repeatability of the surveys in a relatively short time and with high resolution, especially when compared to other techniques such as terrestrial laser scanning, as well as the low cost.

Another fundamental aspect of the UAVs is the opportunity to make surveys in emergency condition, when the impossibility to directly reach the area affected by the landslide, time and low-cost effectiveness are basics requirements.

It is the case of the Marano landslide, a roto-translational slide located in the Province of Bologna, in Central Italy. The landslide, mainly composed of clayey material, occurred in March 2018, covering an area of 140.000 m^2 and threatening the total obstruction of the Reno river. For this reason, on March 18th, 2018 (14 days after the slide occurrence) a drone survey using the optical camera Canon IXUS 240 has been carried out on request of the Italian National Civil Protection Department. The urgency to carry out the flight has led to perform the survey in non-optimal conditions and therefore to adopt some precautionary measures. Due to difficult climatic conditions linked to the strong wind which reached gusts of more than 15 m/sec, two distinct flights starting from two different points of take-off, respectively near the crown and foot of the landslide were performed (Fig. 6a). A precautionary approach has been adopted also concerning the images superimposition, thus considering an overlap and a sidelap respectively never less than 70% and 55%. The flight height was set from 70 to 80 m a.g.l..

The photogrammetric processing has been done as previously using the Agisoft Photoscan Professional software, obtaining the following georeferenced outcomes: a 3D point cloud with a density of 1500 points/m^2; a 35 million polygons mesh; a DTM and an orthophoto both with a resolution of 4 cm/pixel. All these products allowed a detailed characterization of the landslide that, due to the emergency condition and to the inaccessibility of the area, was of fundamental importance (Fig. 6).

Moreover, the DTM and the orthophoto were essential to have a spatial reference for all data acquired by the in-situ monitoring instrumentations (such as data acquired from a GBInSAR) as well as for emergency activities planning.

As mentioned in Sect. 3, whereas the optical surveys focus on landslide mapping and on the estimation of surface changes, the multispectral survey allows to characterization of the vegetation cover and its partially burned canopy.

In the following case study, the Saturn drone, equipped with a Near Infrared (NIR) sensor, was used to evaluate the wildfire affected area extent and to preliminary assess the effects on landslide susceptibility. The key factor that allows the distinction among the vegetation and burned area is the relevant higher reflectance of green vegetation (Pereira et al. 1999). Furthermore, the combination of NIR-green-blue spectrums can be used to analyse the health condition of vegetation. This special combination results in the NDVI index (Normalized Difference Vegetation Index) (Eq. 1).

$$NDVI = \frac{(NIR - B)}{(NIR + B)} \qquad (1)$$

When green vegetation is burned NDVI decreases owing to a rise of the reflectance in the blue band and a decrease in the NIR (Fraser and Cihlar 2000).

Fig. 6 Photogrammetric survey of the Marano landslide. **a** GPS track of the flight plan. Red squares represent the two take-off points; **b** 3D model of the landslide in real colors. In blue the nadiral acquisition geometry; **c** Digital Elevation Model (DEM); **d** Orthophoto in real colors
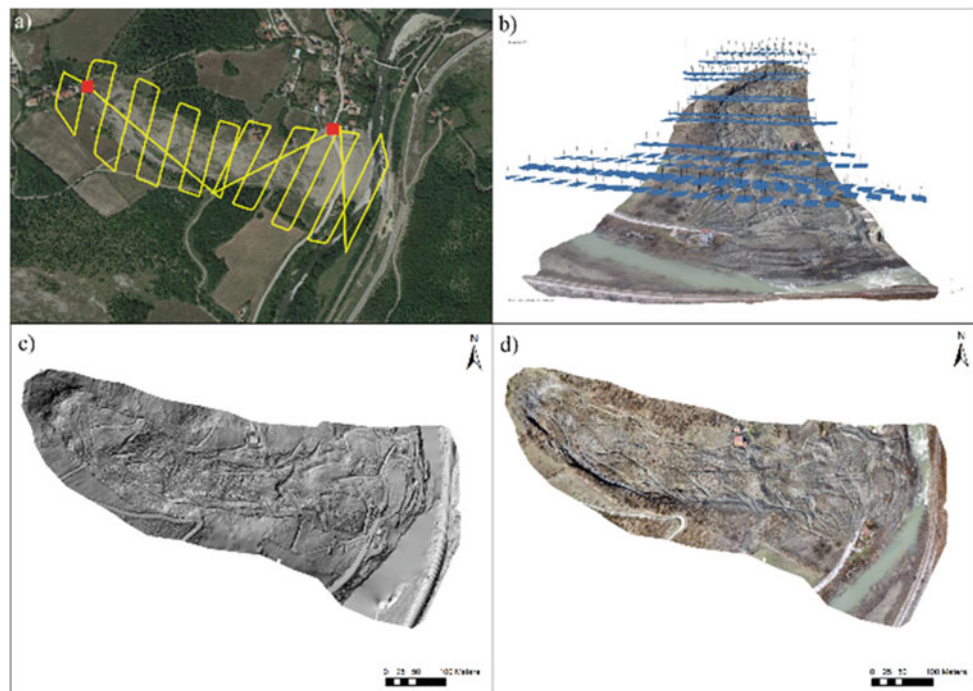
Fig. 7 Comparison of the burned area mapped by the field GPS mapping of the Italian Fire Fighters Department (yellow polygon), and by the NDVI analysis (blue polygon)
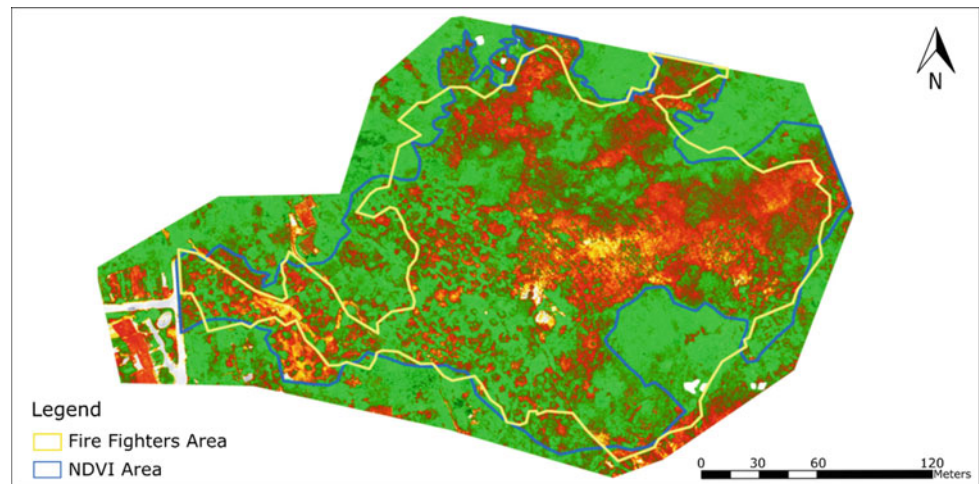
The study area is located near the Vinchiana village, in the Lucca municipality, Italy. From a geological point of view, it is characterized by Holocenic eluvial-colluvial deposits overlying a bedrock composed by massive silico-clastic sandstones stratifications with variable granulometry, ranging from fine to coarse classified as greywackes, and interbedded with silts and clays. The study area, particularly prone to instability phenomena due to the presence of a dormant landslide, was affected by a wildfire on August 8th, 2018.

The UAV survey was performed on November 13th, 2018 using a Canon Powershot S100 digital camera, customized with a filter for the collection of NIR radiation. The flight was carried out with a constant height of 60 m (a.g.l.). Interesting results were achieved by merging false-colour image of the Normalized Difference Vegetation Index (NDVI) on the DTM of the area, obtaining a 3D NDVI map which provided information about the vegetation health conditions and the extension of the burned area.

Results pointed out the complexity of the area affected by the wildfire (Fig. 7). The Comparison between the NDVI mapped burned area and the one mapped by field GPS by the Italian National Fire Corps personnel highlighted the potential of this technique as a tool to remotely and rapidly recognize burned areas, refining the field mapping and providing a wider coverage while granting at the same time the safety of the involved personnel (Fig. 7).

The data quality is affected by the time elapsed from the moment of the extinction of the fire and the data collection (Chuvieco et al. 2002): the longer the time span, the weaker the traces related to the fire will be. Using a multispectral sensing technique with a drone over the area right after the fire, instead of waiting for the satellite revisiting time, can provide better and unaltered data.

The adopted method provides details not achievable with optical cameras, representing therefore a useful low-cost tool to evaluate the terrain conditions as a preliminary input parameter for landslide susceptibility in areas affected by wildfires.

Conclusions

Recently the combination of rapid development of low-cost small unmanned aerial vehicles (UAVs), and new and miniaturized sensors (Active and Passive) have increase the possibility to be used in terms of cost and dimensions, leading to new opportunities in landslides monitoring and classification.

The aim of this work was to make a review of drone and sensors characteristics able to test their use and applicability in landslide characterization and monitoring. Several combinations of drone and payload were considered to better understand the terrain condition in a critical area. In all the examples the drone survey has proven to be an easy and effective approach for landslide monitoring and surveying and thanks to these potentialities and to its repeatability, in many cases it has become an integral part of the monitoring system. The use of multi-sensors (Active and Passive) is increasing in scientific research and this is becoming more and more of common use in commercial activities too. For that reason, the development of drone with a strong reliability both in terms of safety and flight stability is crucial, in this terms the Department of Earth Sciences and the Civil Protection Centre at the University of Florence have developed a new drone airframe that overcomes some critical issues for scientific and relatively heavy payload or long flight applications.

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