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Comparison of Photogrammetric Techniques for Rockfalls Monitoring

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Abstract. The use of Unmanned Aerial Vehicles, UAVs to image capture for monitoring natural hazards has had a major boost for its wide possibilities in the last decade. These are, for example, the studying and monitoring of unstable slopes, glaciers and rocky escarpments. Moreover, to evaluate the risk after a rockfall or debris flow event, for example measuring volume of displaced material, trajectories of blocks or building and/or infrastructure damaged. But the use of these devices requires a specific treatment regarding the studied case and geomatic techniques suitable to get the adequate precision of the movement, size of items or events to study. For each application it is necessary to determine what kind of capture is the most appropriate to obtain an optimal benefit-cost ratio. A comparison of the use of terrestrial photogrammetry, UAV photogrammetry and video from UAV has been done. The best result has been obtained combining techniques aerial and terrestrial since ground points with a best quality can be identified and measured and all the surface has a best image coverage.

1. Introduction

Over the last decades, geomatic techniques have been widely used in natural risk-monitoring. If the focus is established on geological risk as landslides, debris flow, rockfall, etc., SAR [1], Terrestrial and Airborne Laser Scan [2-5] and Photogrammetry are the more used systems. The last one being a tool to analyse from historical images very useful techniques used recently is the terrestrial digital photogrammetry from historical images before and after a rockfall, landslide, etc. [5, 6]. On the other hand, it is important to highlight the change suffered by the airborne photogrammetry since UAVs are used in the image capture [7].

The UAV is a low cost system compared with the use of manned plane or helicopter. Moreover, it allows being closer to the object without risk, but it has the drawback of less autonomy and the limitation in the weight of the capture sensors (photographic and video cameras). However, since the obtaining of the first high resolution Digital Terrain Model (DTM) in 2005 with an unmanned helicopter [8] the technology has developed smaller and lighter cameras but with higher resolution.

When the work area is difficult to access and a high risk exists, other systems were employed, for instance balloons or zeppelins [9, 10] but it must be considered that their use is limited to certain environments and conditions, not being suitable for mountain areas or important rocky escarpments.

This article is focused on image capture from UAVs considering two different format sources: image and video. The first one provides more resolution, but the second one works faster. The limitations of both modes will be analysed for assessment rockfalls.

In the study of a rockfall, the objective is to evaluate the potential volume for breakage escarpment. An unstable rock mass detached from a slope can be a massive block or a set of intact blocks delimited by pre-existing discontinuities depending on the fracture pattern. A characterization of the discontinuities can be performed with photogrammetric techniques in order to obtain a range of sizes of the blocks by the In-Situ Block Size Distribution (IBSD) [11].

2. Geomatic techniques in geological hazards monitoring

The most used methodologies for monitoring slopes today are based on massive capture of 3D information. Among the most commonly used methods are LiDAR systems, both in the air and terrain, ground-based radar, based on aerial and terrestrial photogrammetry and from unmanned platforms (UAV). These methods are to replace or supplement other classic methods based on visual analysis of photographs, sampling grids slopes or scan-line [12]. Dense DTM (around 1 point/m^2) were obtained by using Airborne LiDAR System (ALS). They allow studies of large areas but it becomes very difficult to interpret geological phenomena of a small size [2]. Frequently, other works must be done to densify and fill the possible hidden areas by the perspective of the model itself (heads of cliffs, big blocks, etc.) [13].

In the terrestrial case (Terrestrial LiDAR System, TLS), the LiDAR allows us to work with a higher density than in the aerial case, and the point clouds can achieve densities greater than 100 points/m^2. The scan is set in different places and in that way the cloud of points is captured from different points of view, filling in the gaps caused by the perspective and the hidden details are completed by varying the working distance from the head to the surface to survey [14]. Generally, these systems have less range of work and are used for surveys in small areas.

The most common use for ground-based radar is the monitoring and warnings in unstable hillsides [15], with good visibility, long and continuous time period, and large component horizontal displacements. The ALS is generally used for wide surfaces with vertical displacement, produced by removal of material in depth, as is the case of some mines [16], or by extraction of water or other fossil deposits.

Methods based on classical aerial photogrammetry require photographic coverage adjusted to the terrain, where the scale of work should be kept as constant as possible, as well as photographic base relations and distance to the model [17]. High quality models are achieved but the equipment used has a high cost. Products derived from this coverage can be very varied: DTM, vector restitution, orthophotographs, etc. Similar to LiDAR, the terrestrial photogrammetry case has more limits than the aerial one. The work from the ground facilitates field work but limits the area to survey from each stereo photogrammetric pair. All terrestrial techniques have difficulties in common. On one hand, if a high data density or resolution is desired, an approach to the study area, with the risk that entails, is needed. On the other hand, it is necessary to capture from many positions that are not always accessible to complete models. All this can be avoided by employing aerial photogrammetry using UAV. In risk issues to be analysed, it is necessary to have DTM's and photographs of several campaigns, since it aims to study changes in volumes after different events and characterization of sets of fissures. Other studies using these DTM and orthophotographs analyse the evolution of movements or the mobilized mass [18, 19]. In this last case, the limit of both the flight range by the rapid consumption of batteries and of weight for the camera on the UAV has to be considered. This fact is a condition to determine the selection of the sensor.

3. A case study

In the case of the characterization of discontinuities, photogrammetric survey has been performed capturing data from UAVs (video and photo), and from ground (photo). The work area has been one of the fronts of a quarry located in the region of El Garraf. The rock wall of the quarry is about 100 m long and 75 m high and currently presents several scars and cracks with geologic interest, since a rockfall happened month ago, as is shown in Figure 1. The outcrop consists mainly of limestones.

Figure 1. Rockfall between the storehouses

In order to georeference the point clouds obtained with aerial and terrestrial photogrammetry, natural details were selected since it was impossible to set targets without climbers. In the following sections the different works of capture and data processes are described.

3.1. Terrestrial photogrammetry

In this case, to solve the Sun's illumination effect (shadows) of the photographic images, the HDR (High Dynamic Range) technique has been used. This technique allows getting a better dynamic range of luminance among the clearest and more shadow areas in a picture. HDR technique also allows capturing multiple standard photographs of the same subject, varying for each one or more exposure parameters (focus, shutter speed, lens aperture, etc.) usually using a photographic bracketing and finally combine them into a single image. Photography HDR allows distinguishing details in areas with a higher lighting difference than those supported by other formats as the film or compressed image formats. In this case, three photographic coverages were performed. A general one with a base of 2 m and a total of 91 photographs, at an average distance of 20 m, and an average scale of 1/850, leaving the camera on a tripod, in each position 3 photographs were taken to use the HDR system (Figure 2). To cover the entire wall, it was necessary to take several shots, one horizontal and one at a low angle, from several bases and in order to complete the model to take oblique photography.

Figure 2. Image result (down) of combining three HDR images with different range of luminance (up)

Altogether, a total of 172 photographs were taken from the ground surface. The camera used was a Canon EOS 450D in burst mode, obtaining 3 images in Auto Exposure Bracketing (AEB), with values +2, 0 and -2, a resolution of 12.2 Megapixel (4272x2848) and a focal length of 24 mm. With AEB, the camera automatically takes three shots: one in their specific exposure settings; a second underexposed; and third slightly exposed.

The overlap is more than 70% and 50% side lap, both in the terrestrial and aerial case.

3.2. Aerial photogrammetry

The material used for the photographic coverage was a commercial Quadcopter DJI Inspire 1 Pro 4K with GPS and Zenmuse X5. Its characteristics are: range up to 4500 m, speed of 18 km/h, and autonomy about 15 minutes of flight. It has a camera FC550 with a sensor 4/3 CMOS of 16 Mpx (4608x3456), focal length of 15 mm, moreover the possibility of video 4K (4096x2160) is available. So it can take 60 fps (in our case of 23 fps), and a field of view of 94° (FOV) and can be used remotely with a mobile application from the tablet. The capture was made at an average height of 32 m in the photography case and 26 m for video, therefore the average photographic scale is 2250 and 1700 respectively. In the case of video, the frames were obtained every 2 s.

4. Results and discussions

To create the 3D models, Agisoft Photoscan software was used. First, an independent model for each technique was calculated: 1. terrestrial photographs (T), 2. UAV photographs (A.PH) and 3. UAV video (A.V). After that, combined models: i.e. 4. Terrestrial photographs– UAV photographs (T +A.PH), 5. UAV video – terrestrial photographs (T + A.V.), 6. UAV photographs – UAV video (A.PH.+A.V) were processed. As a result, 6 models are available, 3 Digital Elevation Model independents and 3 combinations. The results obtained are shown in Table 1.

Table 1. Information about the MDT generated after the photogrammetric process

	Terrestrial Photo	Aerial Photo	Aerial Video	T +A.PH.	T + A.V.	A.PH.+A.V.
Nº Images	91	316	323	407	414	639
Nº Useful Images	91	310	323	401	414	619
GSD (Image) (m)	0.005	0.008	0.006	0.008	0.006	0.007
Tie Points	10894	12282	17773	22410	24371	22274
Projections	74104	169471	196573	242139	245476	363123
Camera	CANON EOS 45OD	FC550	FC550	CANON EOS 45OD/ FC550	CANON EOS 45OD/ FC550	FC550
Focal (mm)	24	15	15	24/15	24/15	15
Error X (m)	0.005	0.004	0.010	0.009	0.013	0.007
Error Y (m)	0.011	0.013	0.005	0.013	0.011	0.018
Error Z (m)	0.011	0.012	0.016	0.010	0.020	0.011
Error Xyz (m)	0.017	0.018	0.019	0.019	0.026	0.022
GSD (DTM) (m)	0.020	0.030	0.024	0.031	0.023	0.027
Density (Points/m^2)	2476	1074	1698	1013	1964	1342

The process continued is the usual. The first step is the incorporation of the photographs taken with the criteria of overlapping and scale above mentioned. Then the search for image points to compute with precision, in this case 10000 points/frame with 1000 tie points for calculating independent models and calibration values of the camera are adjusted, according to the central projection equations and a distortion function (Brown model), which takes into account the radial and tangential effect. Then the coordinates of new points in the model are calculated with high quality and filter depths, as shown in Figure 3. In the orientation process of all the cases, the number of ground points was similar, 7 points homogenously distributed in the area. With these spatial data meshes, textures and different cartographic products Digital Elevation Models (DEM), orthophoto, etc. can be created.

For the terrestrial model, the pixel size or Ground Sample Distance (GSD) is lower than 5 mm, and the georeferencing has an average error lower than 2 cm (3D). In the aerial photographic case, the average pixel size (GSD) is 8 mm and 6 mm for the photo and video respectively, the value of georeferencing is similar to the previous one. Using terrestrial photographs with the aerial one's lines allows greater ease and accuracy in the georeferencing process and a better block adjustment.

Figure 3. Point cloud obtained from the video capture

In order to obtain the same result using video or photographs, a priority is the use of high-quality video (4K) replacing videos of lower resolution and a greater number of frames since it allows obtaining models with similar density and quality than the photographic ones, as shown by the results in the Table 1. The result in all cases allows identification of most families of cracks, or rockfall scar size distribution of a cliff in order to obtain several volume distributions.

5. Conclusions

Photographic image or 4Kvideo capture from UAV platform, is shown to be advantageous compared with other geomatic techniques and can be used to track unstable slopes and assess damage after the events and control of infrastructure affected. The use of common video does not allow obtaining the same result than the use of photographs. On the one hand, compared to the LiDAR, both terrestrial and aerial, or conventional aerial photogrammetry, the UAV is a less economic investment and provides access to cover the same areas, offering a similar resolution, provided that the study areas are not very large. It should also be noted that for this type of studies, in steep and rugged surfaces, aerial techniques (photogrammetry or LiDAR) do not provide coverage over the entire surface and with sufficient resolution.

On the other hand, compared with terrestrial photogrammetry case, it has the advantage of being able to access any area of the rock face and scree, and allows shooting at close range. While in terrestrial photogrammetry it may be limited by the lack of visibility, lack of sufficient parking space for the camera near the wall and vegetation near the wall.

For the determination of accurate and high quality DTM that allow the determination of families of cracks in rock mass, it is necessary to use UAV. These systems equipment allow high stability in all kinds of terrain and obtaining high resolution photographs; these conditions usually require working with largest drones and cameras with biggest size and weight.

In the terrestrial case, using the HDR technique allows the production of DTM's of higher quality and higher density than those obtained by conventional photographic techniques, both air and terrestrial case. Derived products of higher quality (vector, orthophotos, etc.) are also achieved.

Finally, it is important to plan adequately the photographic coverage, whether they are independent or if they are made combined. In this last case, aerial and terrestrial information is joined, in order to avoid loss of quality due to poor geometry, an incorrect height or lack of a frame. These cases are very likely to make photographs from drone in environments such as those presented (steep slopes, quarries, cliffs, etc.), especially in high mountain areas.

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