Quick Deployment Heliborne Handheld LiDAR System for Natural Hazard Mapping

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Abstract

Classical nadir setup for photogrammetry or airborne LiDAR reaches its limits when covering steep slopes or complex terrain. The resolution and accuracy of data are heterogeneous. The development of a helicopter-based handheld LiDAR/photo system started in 1998 at EPFL to permit avalanche mapping. This system which is now in production since 2005, allows oblique or vertical mapping and about 300 various projects were flown. The accuracy level of the data is about 10 cm at the ground level even in cliff or steep slopes. During those numerous projects, several focused on natural hazards mitigation or studies. The unrivalled flexibility of the system permitted to map inaccessible areas, either in space or time.

Keywords: LiDAR, helicopter-based, Photogrammetry, natural hazard, risk mitigation, complex terrain

1. Introduction

Airborne laser scanning is now a recognized technique to provide accurate 3D data of our environment. This technique released in the mid 1990's proved quickly its great performance for high resolution mapping of remote areas. The combination with digital photogrammetry compensated the drawbacks of the laser technique for thematic classification of land cover (using orthoimage) or accurate linear objects modeling.

In both cases, the sensors are fixed to the aircraft and look downward ("nadir"). This conventional configuration suits well for smooth terrain or large area mapping but it reaches its limits when facing to complex terrain with steep slopes or cliffs. In a conventional way, the slope involves a non uniform scale of imagery and thus a non uniform mapping accuracy (e.g. Kraus 1998). Regarding the LiDAR, the slope acts on the footprint size of the laser beam and on its incidence angle. Thus, the bigger is footprint, the more uncertain is the distance measurement due to averaging effect inside the footprint. Moreover, all the planimetric errors induce altimetric errors while the slope increases (Favey, 2001).

On flat areas, for a given planimetric/altimeric accuracy of 20/10cm, the altimetry decreases to ~25cm for 45° slopes and can be significantly more for cliff or vertical areas (Vallet, 2002). Moreover, the vertical configuration does not permit to map overhangs or caves. An oblique acquisition allows getting more homogenous laser and image data because the aiming axis is close to the surface normal and then any slope is considered as flat.

The second drawback of a fixed system is generally the complexity of the system setup or the availability of the carrier if the system is permanently mounted, which prevents from using it in an emergency way at reasonable cost.

The market of small area and high accuracy mapping did not seem to hit sensor providers and no commercial system permitting fast setup and oblique mapping is sold.

It is in this spirit that a handheld helicopter based mapping system, combining photogrammetry and LiDAR is born. (Skaloud et al., 2005).

The purpose of this paper is first to present this original and unique concept and its mapping performance. As originally designed for avalanche monitoring in the Alps, we will show through several experiences the real potential of such light and flexible system in the field of natural hazards mitigation, monitoring and disaster management.

2. System description

2.1. Context

The development of Helimap System started in 1998 in the photogrammetric and geodesy laboratories of Swiss Federal Institute of Technology of Lausanne (EPFL), in collaboration with the Swiss Federal Institute for Snow and Avalanche Research (WSL-SLF), to measure snow volume on avalanche sites (Vallet, 2002).

Needs were a high mapping accuracy (~10cm) in complex terrain, a fast deployment to react in real time with weather condition and an affordable cost for small surfaces (< 2’000 ha).

The project initiated with photogrammetry based on simple handheld camera and enhanced with Direct Georeferencing (DG) sensors, a digital camera and a laser scanner. Since 2005, the system is operated by Helimap System SA and is still evolving with sensor technology. Among 300 flights, about the half were realized for mountain areas and natural hazard purpose.

2.2 System Description

The system concept is based on 5 key points:

- The high flexibility of the helicopter which permits to rove easily in the most complex terrain
- A constant accuracy and information density whatever the slope: the accuracy distribution for conventional nadir flight is highly heterogeneous in steep slopes especially at the bottom of the slope. The only way to prevent this phenomenon is to look the slope obliquely, perpendicular to the surface. Operating the system as “handheld” provides a full freedom of motion and rotation to fit to the slope (fig. 1). Thus the system can be used either in vertical or oblique configuration. (fig. 2).

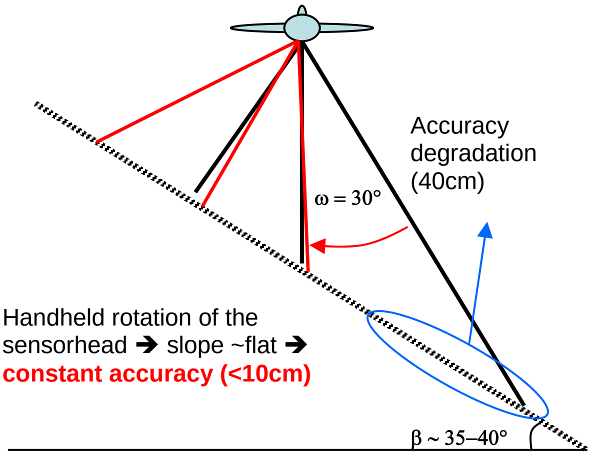


Figure 1: Basic concept of the system: handheld sensorhead to fit to the average slope. ω represents roll and β the slope.

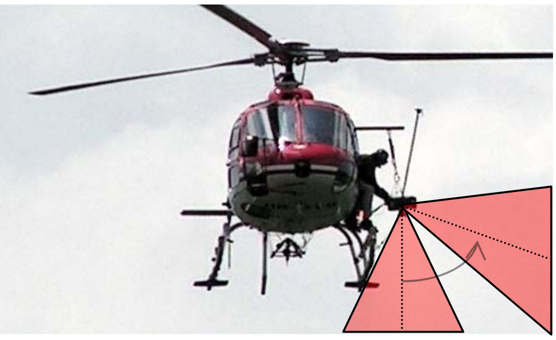


Figure 2: Vertical (nadir) and oblique configuration

- To allow inaccessible area mapping. Thanks to DG techniques (GPS-IMU), it is possible to have a mapping accuracy better than 10cm without any Ground control points (GCP) in the field.
- Time flexibility and fast deployment. Independent from helicopter type, the system can be operational in few hours.
- To provide fast delivery results: Thanks to LiDAR, Digital Terrain Model (DTM) extrcation is highly automated. The first results are available few hours after the flight.

2.3. Components

To meet the needs, the system is designed with a modular assembly that integrates 4 sensors into a unique rigid bloc: a digital camera of 50 MPix with a Field of View (FOV) of 57°, a carrier phase dual frequency GNSS receiver, an inertial measurement unit (IMU) and a Riegl laser scanner with a measurement rate of 10’000 to 150'000 points/sec. The maximum range of the scanner is about 700 m and the FOV is similar to the camera (60°). The setup time is less than one hour on most helicopters.

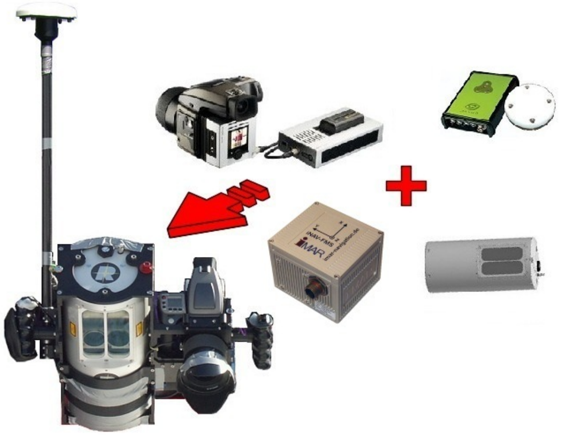


Figure 3: components and system assembly

2.4. Mapping accuracy

The absolute mapping accuracy of LiDAR data with such system can be derived from all error sources (position, orientation, distance measurements) (Schenk, 2001). The figure 4 shows the evolution of planimetric and altimetric accuracy with flight height, for a theoretical flat terrain.

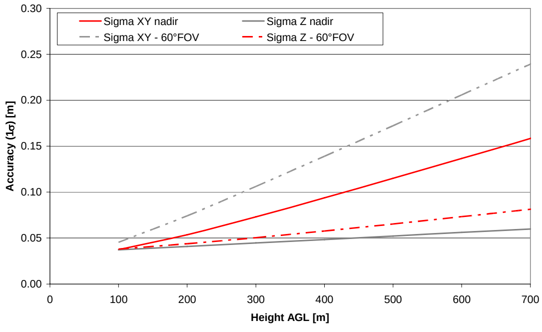


Figure 4: Horizontal (XY) and vertical (Z) accuracy on flat terrain vs. flight height. The mapping accuracy is given at the nadir of the sensor and the edge of the FOV.

This theoretical chart has been confirmed with ground control measurements and internal analysis within the point cloud. At a flight height of ~300m, the absolute and relative accuracy of Helimap System is shown on the figure 5 (Skaloud et al. 2005).

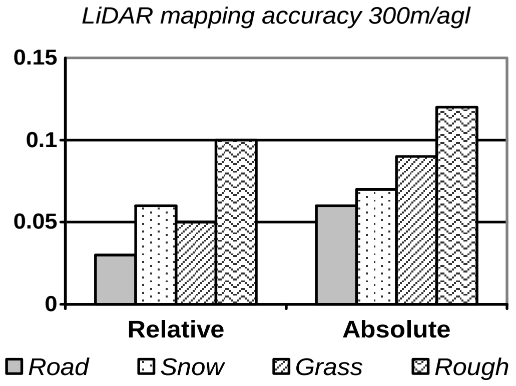


Figure 5 : Absolute and relative altimetric mapping accuracy of point cloud in function of ground rugosity.

3. Natural hazard experiences

Initially designed for snow volume measurements in avalanche slopes, the application panel of Helimap System strongly widened during the last 5 years especially for corridor and infrastructure projects. Nevertheless, the heli-handheld setup of the system is a unique advantage for mountain mapping.

Complex terrain is often the cradle of natural hazards such as landslide, rockfall, debrisflow, floods or other phenomena such as permafrost and glacier melting.

The high and homogenous resolution / accuracy of the data issued from this system generate 3D DTM with a global accuracy of ~10cm. In the field of natural hazards, the numerous experiences lead those last years can be classified according to:

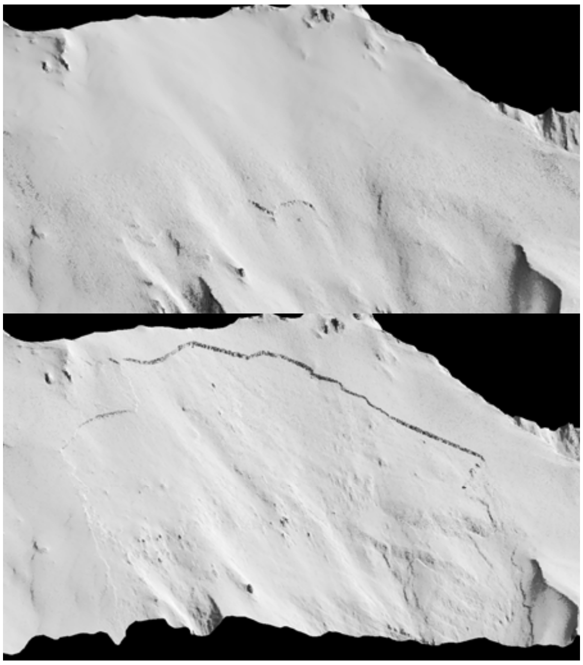
- Surface evolution: Time series, monitoring, volumetry, change detection…: Here, it concerns essentially the follow-up of a phenomenon. It can be used to record it as historic event, to model it or to generate alarms;

- Morphologic and trajectory analysis: this class includes the phenomenon studies and modeling for risk mitigation and prevention;

- Post disaster inventory: After a disaster, it is very important to take a geo-referenced snapshot of the extent of the damages. It can be used by insurances, for feeding event database or to manage land use.

4.1. Evolution / Volumetry

The acquisition of datasets for different epochs allows comparing the surface of a given area. Then, volume or height maps can be derived from it. In the topic of the avalanches and snow melting simulation (SLF-Davos, ETHZ), the volume of snow/ice has been measured with an error lower than 5% (Gruber et al. 2000, Sovilla et al. 2006), while the residual error between 2 epochs on area without changing was below 10cm (figure 6) for slopes of 35 to 45°.



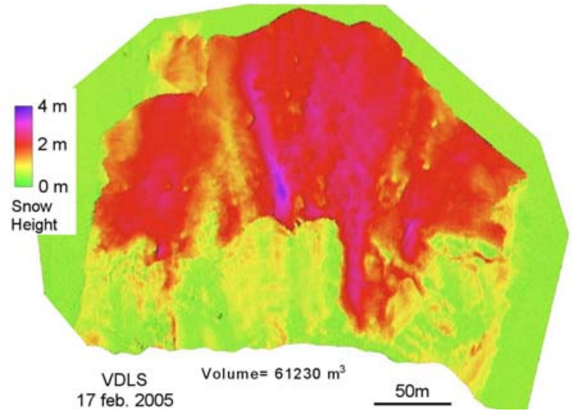


Figure 6 : Snow volume measurement on avalanche sites. Surface before and after avalanche. Height difference distribution map of the snow slab.

Global warming and climate is responsible for glacier and frozen soil (permafrost) metlting. In the Alps many studies are driven to follow glacier coverage (figure 7) and to monitor permafrost areas which can be sources of debris-flow or huge rock falls such as in Monte Rosa east face (Fischer et al. 2011). Quick deployment and fast processing permit to get several 3D dataset per year.

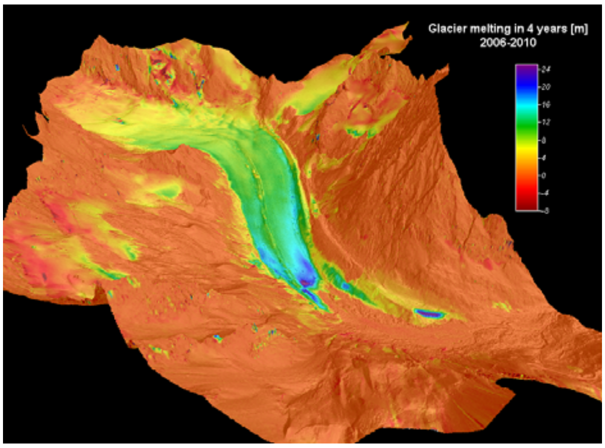


Figure 7: Melting of the Haut Glacier d'Arolla (Swiss Alps) between 2006 and 2010. The average depth loss is about 10m. Parallely, settelements are visible in non glacier area. This is probably due to permafrost melting.

4.2. 3D modeling for hazard studies

The high density of LiDAR point cloud makes visible tiny local details that were invisible with classical photogrammetry. This aspect is especially important when studying phenomena in areas with vegetation. The figure 8 depicts the landslide of Avignonet (France) (Knieb et al. 2009). The high point density makes possible the rendering of typical « waves » of landslide.

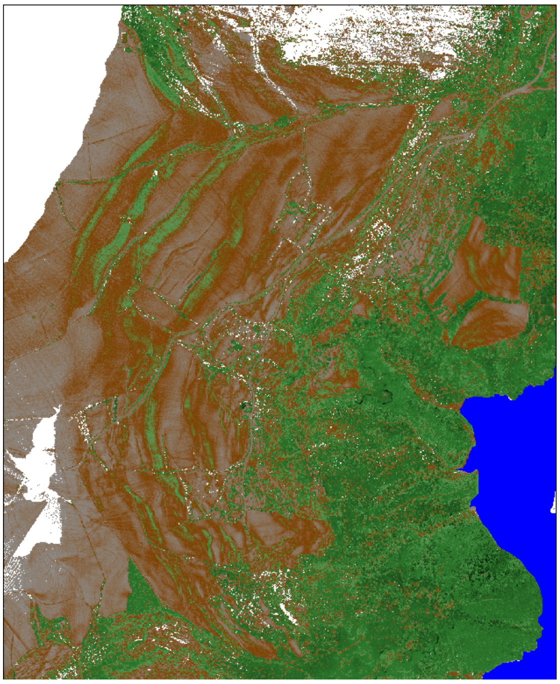


Figure 8: Landslide of Avignonet (Trièves). The figure illustrates the local height variability computed by neighborhood analysis. This technique shows microrelief. The green and brown waves characterize the crumplings.

Geologists also require accurate and dense data in cliffs. When the cliff is small and accessible, the acquisition can be done by terrestrial laser scanning but where the bottom is not accessible or the cliff too high, oblique airborne is the only solution.
The first case shown on figure 9 is the modeling of a rockfall in Vercors (France). A flake of about 30x30m fell. The LiDAR data acquisition was made before and after. The exact volume of the flake and its deposition where measured. This is used for rock fall trajectory studies so as to place mitigation devices (nets, walls…).
Figure 10 shows a 3D textured model of a cliff dominating a road. The definition of the overhangs area permits to take them into account for the rock fall modeling. The use of imagery to texture 3D model allows identifying tiny details such as bands, cracks, unstable blocs…

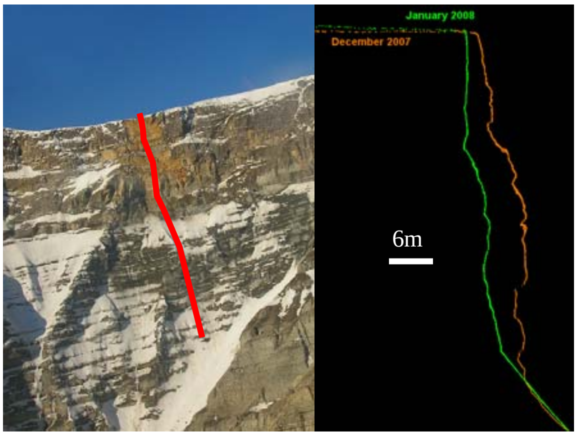


Figure 9: Fall a rock flake in Chamousset (Vercors). The motion of the flake was monitored in real-time. Airborne LiDAR acquisition was made before and after the fall to map the extent of the starting and deposition area. The section on the left shows the thickness of the fallen flake.

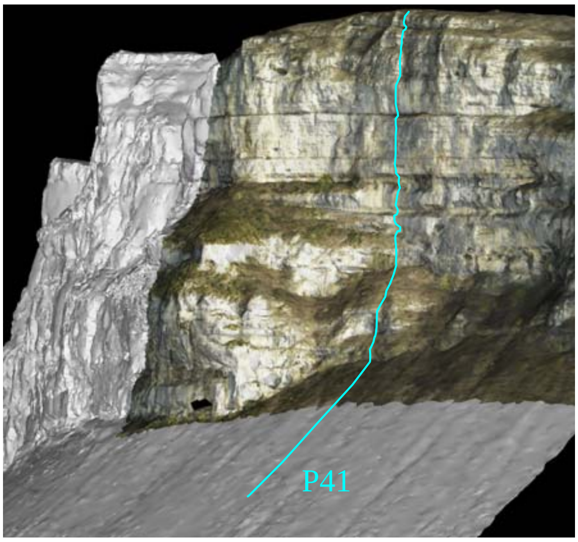


Figure 10: 3D model of overhanging cliff for rockfall trajectory prediction in Tenay (FR). Profiles are defined on the DTM to run trajectory simulation.

4.3. Post disaster inventory

The flexibility of the system setup makes it usable in a very short time notice. Right after an event, it is possible to map the extension of the disaster and make the inventory of the damage.
Those data can be useful at different steps: First, most of the time, we have a poor quality of the extension of past events and databases are filled with witness memory which is often inaccurate. Secondly, it permits to quantify the event (volume of debris, flood surface…). This helps in simulation of phenomenon by giving real

calibration values. Thus, the numerical model used to assist the land use management in terms of risk and mitigation device can be improved.

Third, those data can be used by insurances and public administrations to estimate the damages for compensations.

The following example shows the results of a LiDAR-photogrammetric data acquisition one day after the catastrophe of the Grossbach in June 2007. A big storm provoked a debris flow in a small creek which spread in an inhabited area. In less than 30 min, all the data were acquired and one day after, DTM and Orthophoto were available.

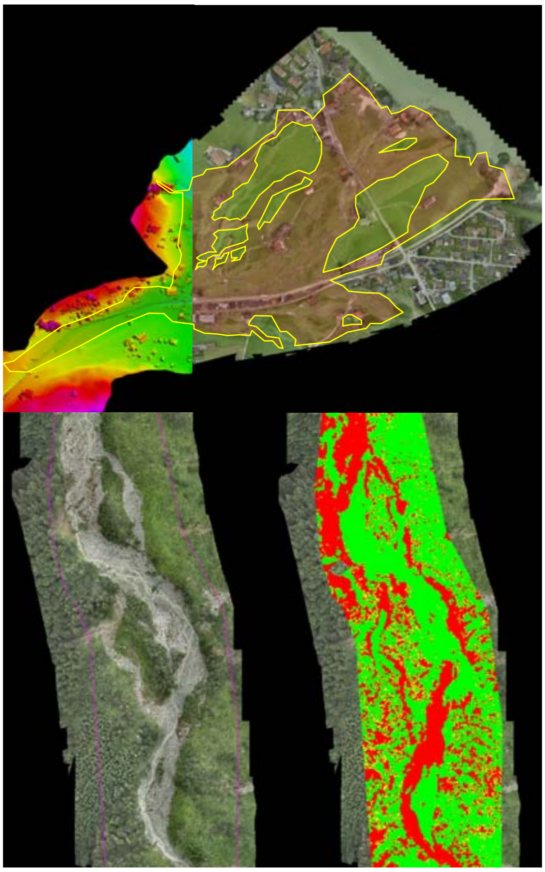


Figure 11: One day after the event, a fast acquisition showed extension of the runoff (red) and illustrate the soil motion (erosion (red), deposit (green))

Figure 11 shows the extent of water/debris runoff in the village and the erosion/deposition in the river banks.

5. Conclusions

The ability of a airborne mapping system to perform oblique data capture is relevant for complex terrain. This allows getting homogenous data all over the territory.

Through more than five years of oblique mapping in the field of natural hazards, the concept Helimap System has been validated for many applications.

The combined mapping accuracy (X,Y,Z) at the ground level is in the range of 10cm in all topographic situation. The combination with imagery brings the best symbiosis between both techniques. The LiDAR provides the “mass” data and photogrammetry completes it with high resolution orthoimage (pixel <10cm) and specific measurements.

The use of helicopter combined to the handheld operation of system guarantee a high flexibility either in time and space. At a time where everything tends to automate, this system shows that simple and manual things can be more efficient.

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