High Precision LiDAR Mapping for Complex Mountain Topography

Julien Vallet
Helimap System SA, France

Abstract

During the last decades, the arrival of new mapping technologies such as Lidar brought new possibilities for the mapping of complex or inaccessible areas. The development at EPFL of a hand-held helicopter based mapping system relying on Lidar-photogrammetry issued on a commercial production system: Helimap system®. The integration of the Lidar, Direct georeferencing techniques and digital photogrammetry into a hand-held unit permits to fit the topography with a flexible oblique mapping and provides high accuracy and resolution Digital Terrain Model and orthoimages. Then the use of the helicopter allows mapping extremely complex terrain such as high cliffs or steep slopes. Several practical experiments lead in geology or natural hazards studies during the last years confirm the potential of the technique and its accuracy of 10-15cm.

1. Introduction

Over the past the years, emergent new mapping technologies such as LiDAR altimetry or GPS-INS direct georeferencing changed the world of classical airborne mapping occupied by photogrammetry and then propagated to end-users.

Thanks to the high spatial resolution of the laser data and digital imagery, invisible details of shape and topography can be identified. The direct georeferencing permitted the suppression of the usual required ground control points. Thus, it is possible to affordably remotely map with high resolution inaccessible or very complex areas.

The development of Helimap system® started in 1998 in the photogrammetric and geodetic laboratories of the Swiss Federal Institute of Technology of Lausanne (EPFL), in collaboration with the Swiss Federal Institute for Snow and Avalanche research of Davos (SLF) and Ulrich, Wiesmann + Rolle SA. The initial goal intended to provide a mapping technique to measure the snow volumes on large avalanche experimental field (Vallet, 2002, Gruber, 2000). The harsh environment, the complex topography and the sporadicity of the events required a fast deployment, accurate (~10 cm) and affordable mapping technique for such small areas. Initially based on hand-held helicopter photogrammetric measurements, combined to direct georeferencing technique, the system integrated a Laser Scanner unit and a high resolution digital camera in order to automate the terrain model acquisition and the orthoimagery production. The system is manually operated from a helicopter and provides a flexible maneuverability to fit the most complex terrain.

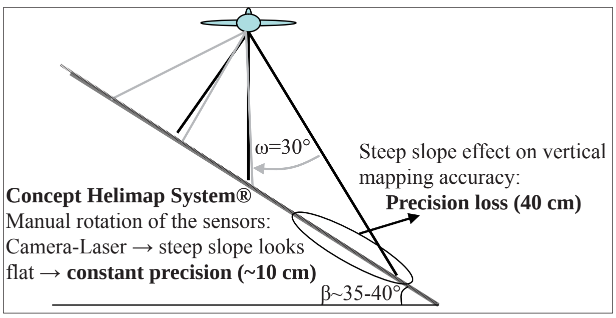


Fig. 1: Crucial concept of the design: a handheld operation to fit the slope.

Since 2005, the system is commercially used and about 40 flights were realized in the domain of natural hazard mapping and Mountain topography.

2. System design

2.1. Basic concept

The design of system is based on five key points:

- A flying flexibility provided of the helicopter in complex topography
- Get a constant accuracy of the data whatever the inclination of the slope. The accuracy of standard vertical mapping operated from fixed-wing aircrafts strongly decreases at the bottom of steep slopes (Fig.1). Only oblique mapping avoids this effect. The handheld operation of the system confers a free motion and rotation of the sensors to fit the slope. The system can be used either in vertical or oblique configuration within the same flight (Fig. 2).
- Allow the mapping of dangerous or inaccessible areas with remote access. This can be achieved thanks to the direct georeferencing GPS-Inertial technique providing a mapping accuracy of 10-15cm.

- Fast deployment in a short time notice and independent of the type of helicopter. Most of the conventional airborne mapping system requires a complex setup. The manual operation of the system allows being in the field in few hours.

- Fast delivery results thanks to LiDAR technology. Digital terrain modeling is then highly automated. First results can be available few hours after the landing.

2.2. Components of the system

To meet the needs, the system presents a modular assembly composed of four sensors assembled with a rigid aluminum frame (Fig.3):

- A 22 Mpixels CCD camera with 22 wide angle lens (FOV of 57°)

- A Riegl 2D Scanner laser measuring 10,000 points/sec. The measurement range spread from 50m to 300 – 400 m with a filed of view of 60° similar to the camera. The wavelength of 900 nm allows good performance of mea surement on snow, bare ground, vegetation or urban areas.

- A dual frequency GPS receiver and an Inertial Measurement Unit (IMU) for the direct georeferencing of the system.

The setup of the system takes about 30 minutes on most of the helicopters.

2.3. System performance

The main output data are composed of high density Digital Terrain/Surface Model (DTM/DSM) (1 to 10 points/m2) and high resolution orthoimages (ground sampling dimension of 3 to 10 cm). Then derived products can be extracted for 2D or 3D analysis (volume, object classification, etc.).

In order to estimate the reliability and performance of the system, terrestrial control measurements were conducted on numerous flights (Skaloud et al. 2005). The diagrams in Fig. 4 represent the mapping accuracy from the photogrammetric and LiDAR vs. surface aspect.

3. Practical experiences in mountain and natural hazard mapping

Initially designed for snow volume measurements on steep slopes, the application field widened considerably to other domains such as corridor mapping (river, coast, road and power lines). Nevertheless, the original use of a hand-held system represents a unique advantage for complex terrain mapping. It is in the precise context that most of the flights were conducted.

Fig. 3: Components of the Helimap System. A camera, GPS receiver, Inertial Unit and laser scanner.

Fig. 2: Vertical (nadir) and oblique configuration of the system

3.1. Volume / mass balance

The high density and accurate Laser DTM's involves precise volume measurements when comparing two or several episodes. This can be applied to any mass transport or surface evolution such as avalanche, landslide, debrisflow or glacier mass balance, snow melt. The experiences conducted over the avalanche study of the SLF, ice and rockfalls in the east face of Monte Rosa (University of Zürich), or on the snow melt modeling (ETHZ) shows that it was possible obtain a volume measurements with an error inferior to 5% even on very complex terrain such as the Haut Glacier d'Arolla watersheds (2000 ha). The differential error between the two episodes did exceed 10 cm (comparison made on common areas) (Fig. 5).

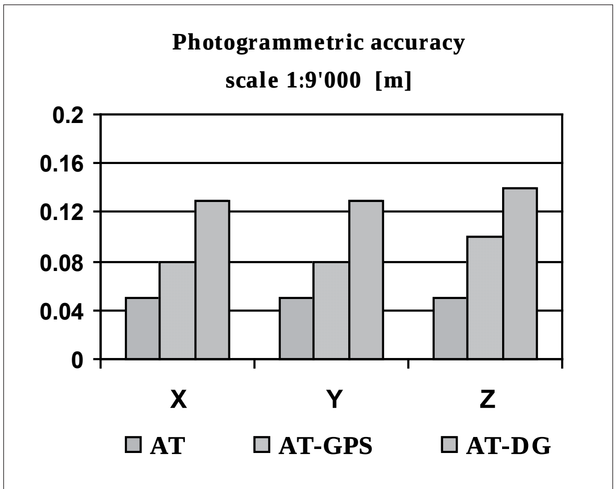
3.2. Morphology

The high resolution of laser data shows morphologic details that were invisible with the use of conventional photogrammetry because the cost to get such density was too high.

Then those high resolution DTM's are particularly useful for geologist either in terms of monitoring of instable regions or for geo-structural analysis.

The Fig. 6 depicts a landslide area near the Lac of Monteynard (France) studied by the CISM (University of Savoie). A local height variability analysis permits to identify waves characterizing the unstability of the flank.

High resolution DTM's permit to identify surface deformation or faults. Combined to geophysical data (ground penetrating radar…), it is possible to model the 3D structure of the subterranean layers. Several oblique projects were



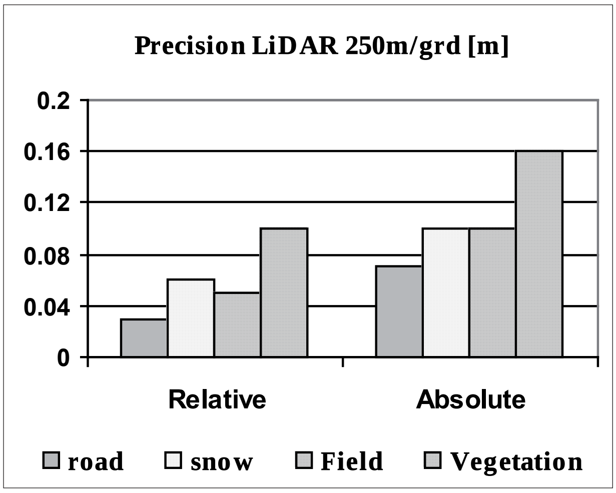


Fig. 4: Left: Photogrammetric mapping accuracy according to georeferencing used dé (AT : standard technique with ground control points (GCP), GPS : Use of GPS only with no GCP's, AT-DG : Direct georeferencing using GPS-IMU). Right: Mapping accuracy of the laser scanner vs. the surface aspect - relative precision (inner noise between several overlapping scans) and absolute precision extracted from Ground measurements.

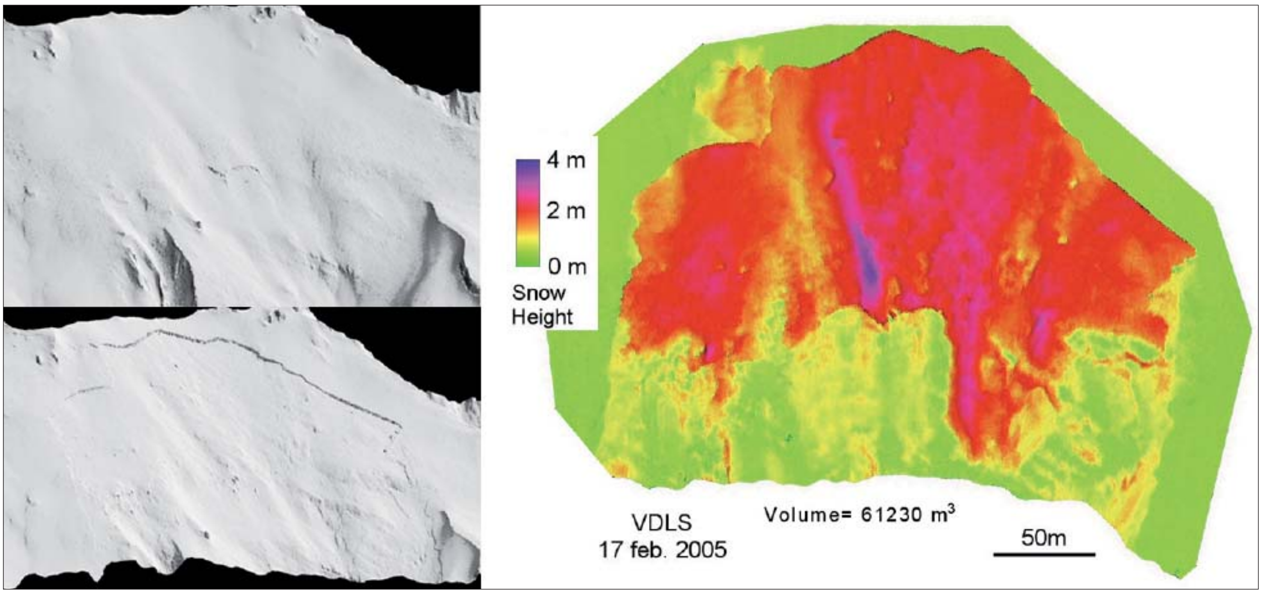


Fig. 5: Snow volume measurement of avalnche. Slope surface before and after the release of the avalanche. Snow height distribution of the slab (release area) (SLF).

lead to bring high resolution data in vertical areas. Then every detail even in overhanging zone is captured. The Fig. 7 represents a DTM of cliffs acquired for geo-morphological studies in Svalbard (CIPR-Uni. Bergen/UNIS) that will be used to validate a 3D geo-structural model.

3.3. Damage inventory

Damage inventory after a catastrophe is a useful task to first have precise measurements of the phenomenon in order to better understand it and mitigate it, and secondly to document the damage for insurance companies for example.

The flexibility of the system offers the possibility to be deployed on a very short time notice. It is then possible to map an event just after its occurrence.

The Fig. 8 illustrates the post debris flow event occurred in June 2007 in Grossbach (Canton of Schwyz, Switzerland). The flight was made one day after the event to cover the damage areas (deposition zone) and the watershed that feed the catastrophe. It required only one and a half day to produce the orthoimages , DTM and a comparison with the swiss national laser DTM before the events.

4. Conclusions

LiDAR mapping technique is a very efficient tool for alpine mapping in such different domains as natural hazard study, land management or alpine environment monitoring.

Data acquisition realized with Helimap system in the field of mountain mapping brought accurate and high resolution topographic data in inaccessible areas and complex terrain. The reduction of the data processing time, related the conventional photogrammetry, reduces drastically the costs while the spatial resolution increases. The high flexibility of the system allows mapping quickly any type of surface until the critical area of 1,500 – 2,000 ha. Beyond this size, the system is less adapted because of the numerous flight lines required to cover the area. The use of more powerful laser, but also bigger and less flexible to handle could be an alternative that is in development.

Acknowledgements

Helimap system SA thanks Thierry Villemin from the CSIM of the Université of Savoie in Chambéry for the results of the dtm analysis on the landslide of Hamelière. We also thank Dr. Jan Skaloud and the laboratory of Geodesy of the EPFL and the SLF-Davos for their long collaboration to the system development.

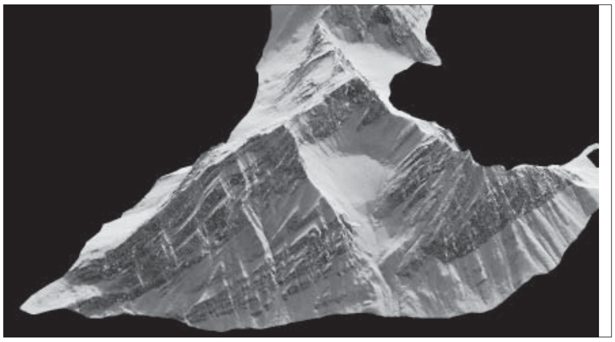


Fig. 7: 3D model of the Mediumfjellet cliff (Svalbard). The identification of the different layers and their shape, combined to geophysical data, offer the possibility to calibrate and validate numerical model.

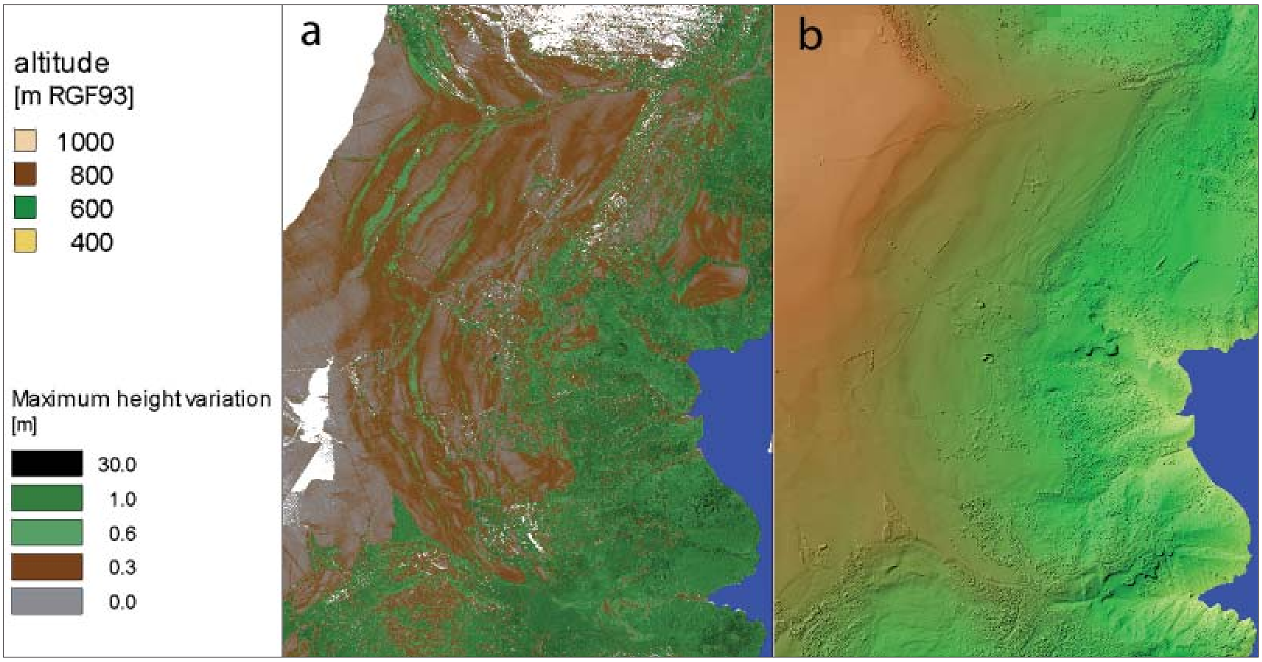


Fig. 6: Landslide of Hamalière (Trièves). Fig. a illustrates the local height variability. These analyses show the micro or local relief. The waves in green and brown depict the sine shape of the landslide. Perpendicular lines (brown) to the slope represent the nose of the laser measurements. The Fig. b shows the shaded relief of the area color-coded with elevation.

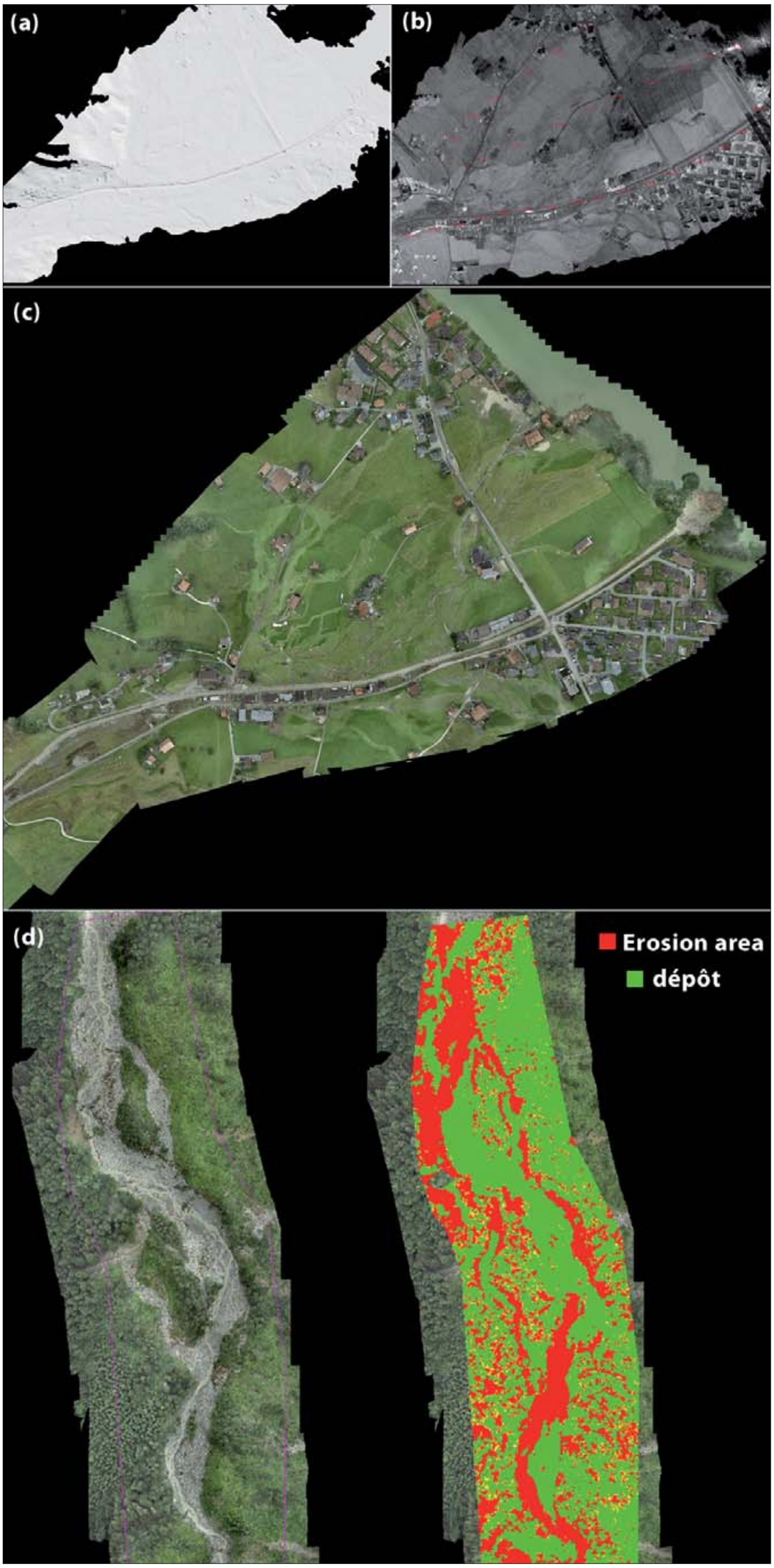


Fig. 8: One day after the catastrophe, a flight over the damaged area permits to capture the topography of the debris flow. First the DTM is extracted form the laser point cloud (a), flooded areas and buildings can be identified on the intensity image (b) and refined on the high resolution orthoimage (c). In the upper part of the river, it is possible by comparison of DTM's to map the eroded/deposition areas (d).

References

Vallet, J. (2002) : Saisie de la couverture neigeuse de sites avalancheux par des techniques aéroportées. Thèse EPFL N° 2610.

Skaloud, J., Vallet, J., Keller, K., Vessyere, G. and Kölbl, O. (2005): Helimap System®: Rapid large scale mapping using handheld LiDAR/GPS/INS/CCD sensors on helicopters. ION GNSS 2005 Congress. Long Beach CA.