rt Anno 2010_Numero 133

rapporti tecnici INGV

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Istituto Nazionale di Geofisica e Vulcanologia

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EXPERIENCE IN MOBILE LASER SCANNING BY MEANS OF LYNX SYSTEM IN L'AQUILA CITY

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Introduction

The terrestrial laser scanner is an efficient topographical instrumentation used to acquire a redundant number of points distributed over a physical surface. The goal of laser scanning is the definition of very accurate models of the studied areas. In this way, deformations or changes can be monitored by means of repeated surveys in different epochs [Pesci et al., 2005; 2007].
The laser signal is characterized by highly collimated, monochromatic, and coherent radiation that is well suitable for very short impulse generation in the nanosecond scale. The operating methodology of a time-of-flight laser scanner is similar to a laser range-finder, measuring the time it takes a laser pulse to travel from a transmitter to the surface surveyed, and back to a detector device. The range *d* is computed using the relation $d = ct/2$, where *t* is the time of flight and *c* is the speed of light. The advantage of this instruments is the laser beam deflection over a very accurate angular grid, that can be obtained by oscillating and rotating mirrors, thus providing a wide coverage area between adjacent points. Each point is collected into a local reference system consisting of the origin at the instrument sensor, well-known angular parameters, and very accurate measurements of range.
Together with point coordinates (x, y, z), radiometric values related to the surveyed object's reflectivity can be calculated from returned signal energy. The maximum measurable range depends on the illuminated material roughness and color, and the laser wavelength [Fidera et al. 2004, Pesci and Teza, 2008].
Divergence values for new generation long-range scanners are extremely reduced, illuminating very small surface elements for each shot. The spot dimension increases linearly with the distance, and is always greater than the lower limit of the instantaneous field of view (IFOV) due to physical diffraction.
Effective laser scanner characteristics are defined by a set of parameters, including: range resolution (depending on telemeter efficiency), single point measurement accuracy (depending on the internal electronic device, signal-to-noise ratio and critical time needed for pulse recognition), beam divergence (which defines the IFOV, depending on laser wavelength), and minimum angular step (depending on the internal mirrors calibrated system) [Wehr and Lohr 1999].
Overlap is the laser scanning strategy that can reduce errors, because redundant points are acquired belonging to the same illuminated area. A common overlap is obtained by fixing the ratio between spot dimension (the area illuminated by a single pulse with a given divergence) and angular step so that a given point is measured 10 times. For instance, if the divergence is 3 mrad and angular variation about 0.3 mrad, at 100 m distance, an element included in a 3 cm area is observed 10 times.
The final result of a laser scanner application is a very dense point cloud, with radiometric reflectivity data for each point.

1. Introduction to the Lynx system

The mobile laser scanner systems are designed to collect huge data in short times on very large portion of the interesting areas, that are impractical to survey with static sensors.
The LYNX Mobile Mapper (fig.1) is the SINECO system that uses a platform rigidly mounted on top of a vehicle. The platform hosts two laser sensors, fixed on calibrated positions, as well as the inertial measurement unit (IMU), a distance measurement instrument (DMI) and GPS two antennas. The mounting structure is characterized by high rigidity, in order to maintain the components in a fixed relative position the ones respect to the others. Each sensor is able to measure about 100000 points per second, covering 360° field-of-view (FOV); a resolution up to 1 cm per measured point is assured (http://www.sineco.it).

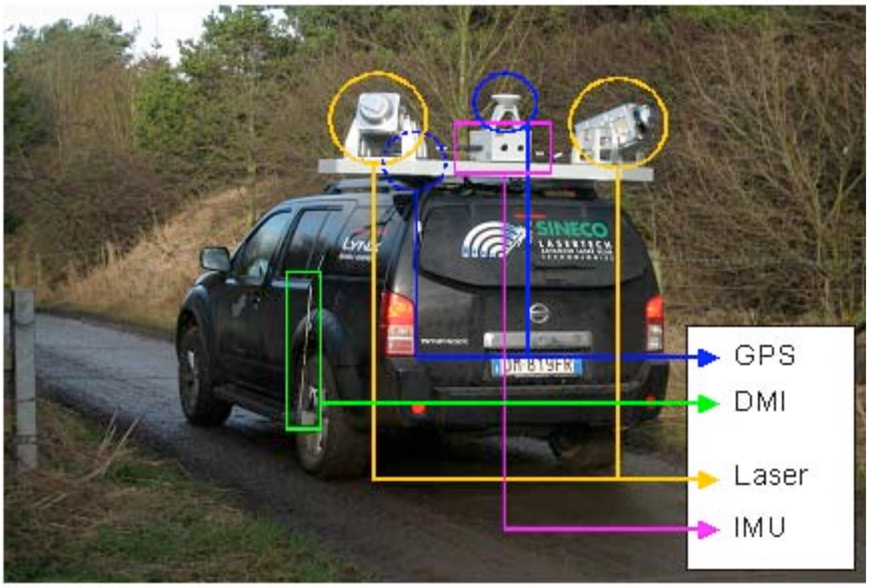

Figure 1. LYNX system; GPS, DMI, Laser and IMU units.

2. Lynx characteristics

The main features of the LYNX system are:

- The 360° FOV allows the simultaneous data capture of road/rail surfaces, ancillary structures at the side of the vehicle and overhead objects, reducing times for acquisition as well as for data processing.
- Each laser scanner head allows data collection rates better than 100 kHz. This high collection rate means that survey-grade data can be collected at high vehicle velocity while maintaining engineering level resolution. The system is designed to operate for different car velocities , and produces positions (i.e. points coordinates in a fixed reference frame), with accuracy better than 10 cm (when the vehicle velocity is 50 km/h). The range accuracy is about 7 mm at 100 m, while the resolution, in terms of distance between acquired points on the surfaces, can be comprised in a few centimetres at 50 km/h.
- The fact that multiple laser scanner units are used leads to several benefits, related to the well positioning and orientation of the vehicle. First of all, the achievable resolution is improved These sentences are unclear. This means that data can be collected at a high resolution for a same velocity, or maintain the same resolution, when velocity increases (for example, 20 km/h respect to 10 km/h). Moreover, the dual-sensor configuration scans the entire survey area and minimizes the shadowing caused by objects along the roadside while optimizing the field-of-view to full coverage (fig.2).
- The velocities of rotating mirrors of incorporated scanners are greater than 150 Hz and the high scanner speed generates a uniform measurement spacing that can be maintained even at high vehicle speeds.
- The LYNX Mobile Mapper sensors detect and measure up to four distinct return measurements from each laser pulse in last-pulse mode. Simultaneous collection of multiple laser return pulses is critical for a complete area coverage and in running software algorithms that enable analytical tools such as vegetation removal and feature detection.
- The class 1 laser devices (http://faculty.virginia.edu) operate in infrared band and ensure a complete operational functionality never limited by risks associated with potential eye safety hazards. Moreover, the eye-safe beam is invisible making it impossible to distract drivers and onlookers during the survey in populated areas.

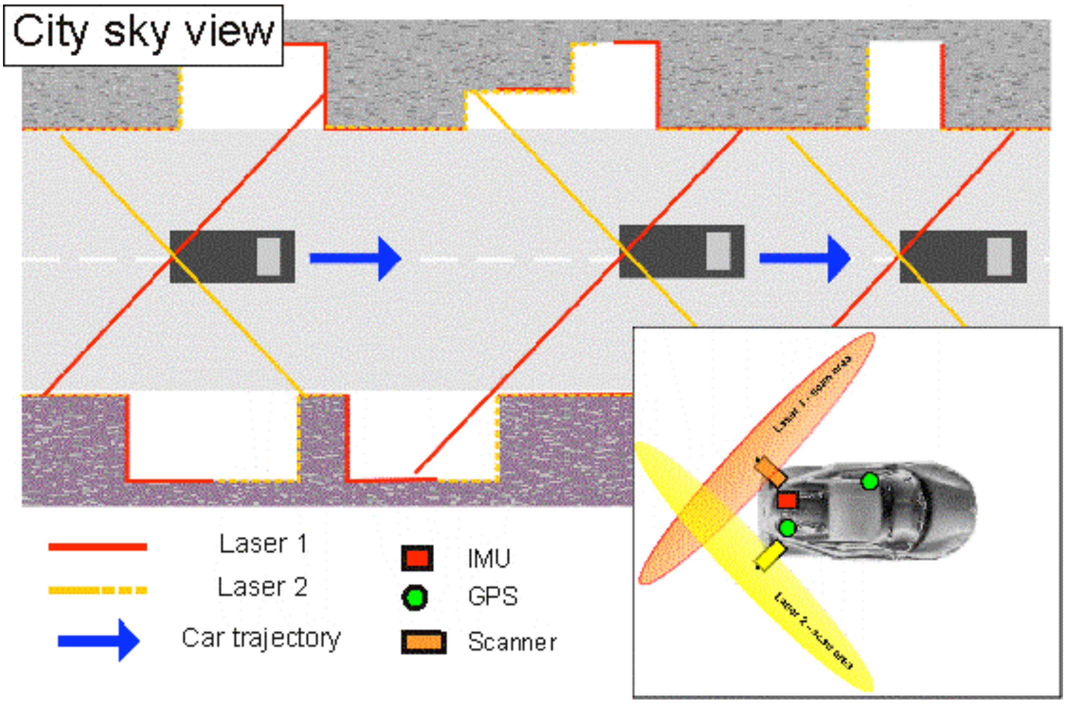

Figure 2. Scheme of LYNX surveying. The red and yellow lines represent the area (sky view) acquired by the two laser scanners. Several areas are overlapped and the shadowing is minimized using this geometrical configuration.

The navigation is a critical component for any mobile system as it is used to reference the collected laser scanner data and imagery. It typically uses IMU, GPS and DMI units. In particular,

- The IMU is a mechanical/electronic device, composed of a combination of accelerometers and gyroscopes, which measures vehicle velocity and orientation. The GPS antenna provides the vehicle tracking and the DMI, which is an odometer, indicates the traveled distance.
- The presence of trees, buildings, tunnels, subways and others makes it difficult to solve for ground based mobile navigation, since time intervals in which satellite signal is lost occur. The LYNX system uses auxiliary sensors and advanced processing solutions to preserve accuracy in presence of GPS outages.
- The Position and Orientation System (POS) Applanix POS/LV 420 is used to correct the orientation and position of the two laser scanners generating a complete geo-referenced point cloud in automatic way.
- The additional GPS antenna can be used to aid in heading calculation in areas of high latitude while the DMI is used to provide accurate vehicle velocity updates. This aids in the overall solution when the vehicle is moving but the GPS quality is poor.

The exact position and orientation of laser sensors with respect to the POS unit installed above the platform must be accurately measured by means of accurate calibration after sensors are mounted on the vehicle.

3. L'Aquila experiment

In may 2009, was planned a mobile LYNX survey in the neighborhood of L'Aquila. This city was recently struck by the 2009 earthquake sequence (main shock April, 6, 2009 M=6.3, Anzidei et al. [2009]), was used as an experimental location to test the dynamic laser system efficiency in a earthquake damaged area, due to the capability of the LYNX system to provide rapid and accurate 3D information on damages induced by an earthquake. Such surveys can

be potentially performed a few hours after an event, and can be used for geophysical, engineering and Civil Protection applications.
Measurements were authorized by the Dipartimento di Protezione Civile in two peripheral damaged zones, as shown in figure 3, located in an area which lies on a debris-slope at the foot of a steep regional fault-scarp (i.e. Faglia di Monte Pettino; Galadini and Galli [2000]). Here, previous macro-seismic investigations pointed out worrying damages on impressive edifices, probably caused by earthquake phenomena site-amplifications or characterized by fault in the constructions.
The experiment started at 11:41 of May, 28, 2009 and the state of surveying was continuously monitored by the operator during the measurement sessions using a wireless PC, connected to the LYNX system. In particular, the vehicle speed and orientation, GPS signal coverage and sensor status were checked in real time. The trajectory of the vehicle was visualized in an interactive map. In Figure 5, the scheme of the software interface to communicate with LYNX during scanning, is shown.

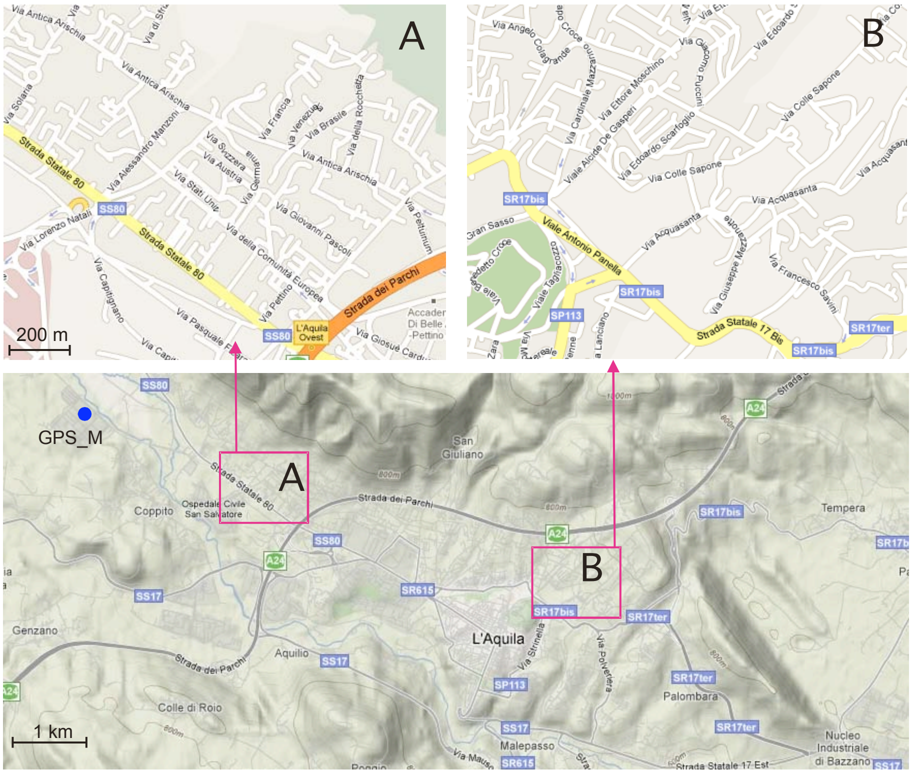

Figure 3. The two test areas for LYNX surveys in L'Aquila neighborhood. Before starting the surveys, a reference GPS station (GPS_M master station) was installed in a protected site at DICOMAC (Direzione di Comando dei Vigili del Fuoco, i.e. Firefighter Command), located at a short distance from A and B test areas (< 10 km). The acquisition rate of the master and rover GPS stations, was set at 1 s. The survey started in the A and B districts, along a path of about 5 km in each of these areas.

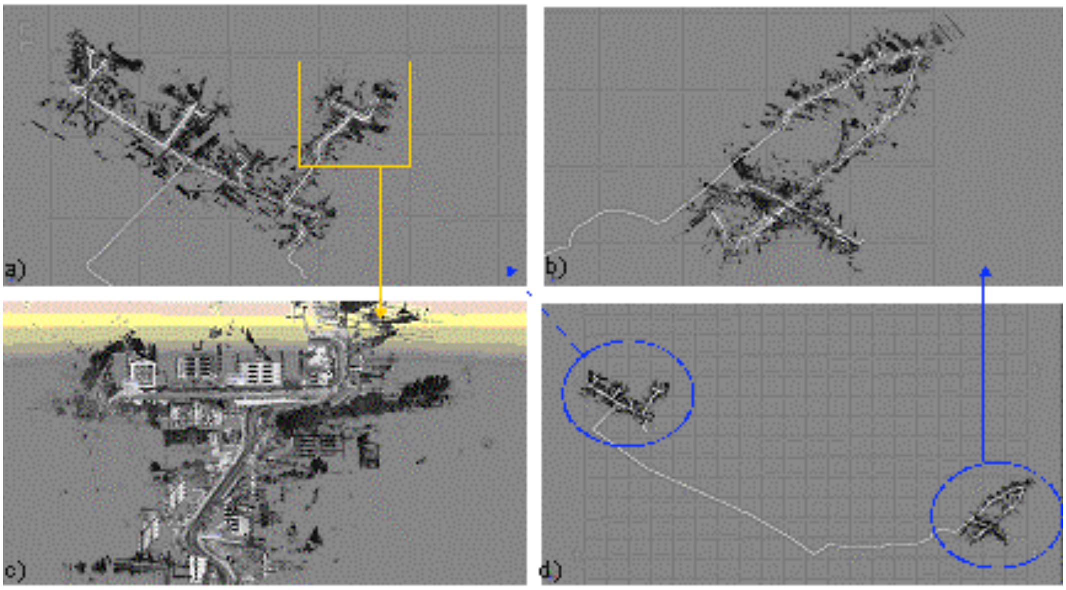

Figure 4. a, b) The sky view of the A and B surveyed area point clouds; c) prospective view of a part of A area; d) the sky view of the whole surveyed areas and the vehicle trajectory (white line). The grid step is 200 m in the figure.

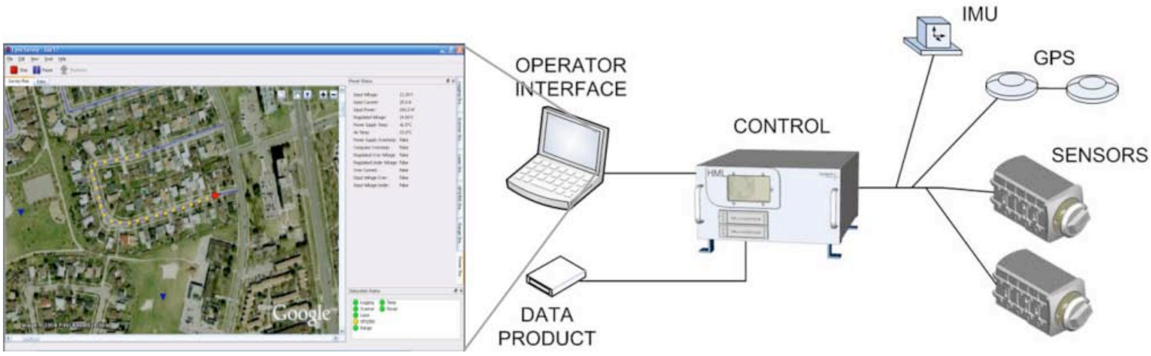

Figure 5. Scheme of the control system: the operator interface allows the real time check of data acquisition, visualization of vehicle trajectory and the control of sensors efficiency.

The duration of the LYNX campaign lasted about 2 hours. Data points were collected and registered into the same reference frame. The contrast between the fast operational times and the quality of results is of immediate understanding: million points were measured in few minutes. The total amount of about 200 million points were acquired along a 10 km long trajectory.

The same results from static scanning need several days of surveying [Zampa and Conforti, 2009].

4. Point clouds

During the data acquisition experiment an electronic failure disconnected one of the two laser sensors and a lowering of the total number of effectively acquired points, occurred.

Despite the off-state of one of the laser sensors, several details are shown from the point clouds due to the high resolution of a few centimetres (fig. 6 and 7).

Figure 6. Point cloud details. a) Drain covers in the street, b) pillars, road signs and dustbins, c) parking lines and d) architectural features are well determined and measured at centimetre level accuracy.

Figure 7. A point cloud represented with and without intensity data to evidence the coverage of observed area in both horizontal and vertical directions. The prospective view shows also the high-voltage electric lines.

Additional and suitable data are given by the cameras mounted on the vehicle and connected to the system. A high number of digital images can be acquired during the survey to create a complete photographic archive with the collected RGB data. In this case, the cameras were set to acquire at regular steps of 5 m on the ground. Each frame is provided together with the camera position and orientation. The RGB images can be also used to texture point clouds with real colours. The cracks in building walls are clearly visible in the image sequence of figures 8 and 9. These features were also detected by the corresponding point clouds.

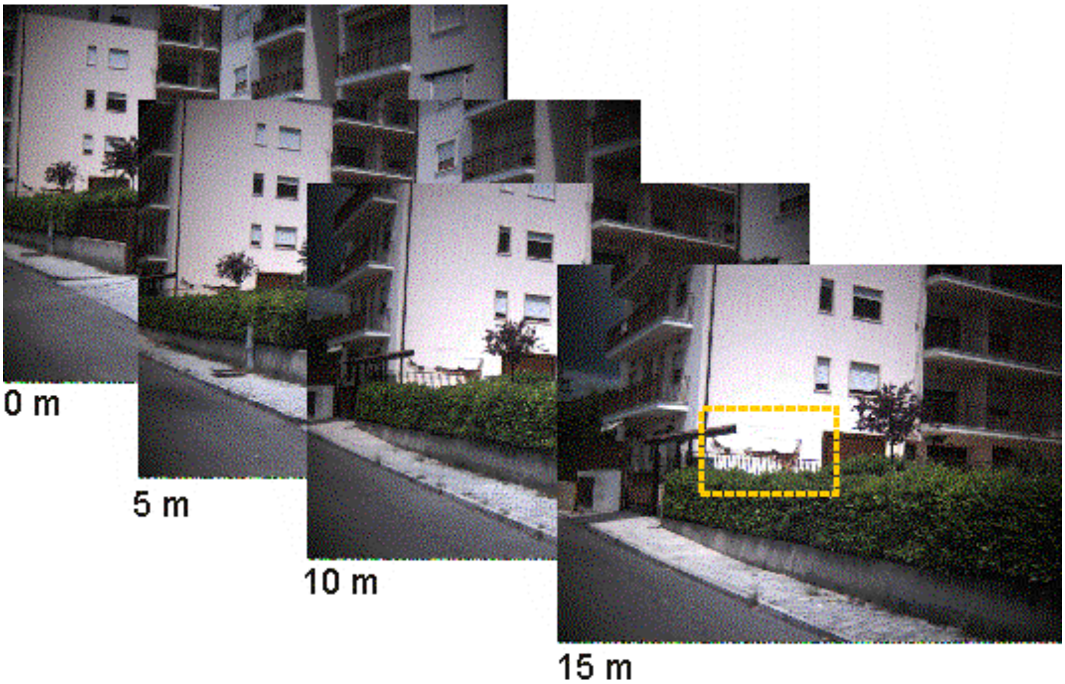

Figure 8. Photographs sequence acquired at a regular step of 5 meters during vehicle motion. The yellow dashed line highlights a building wall crack.

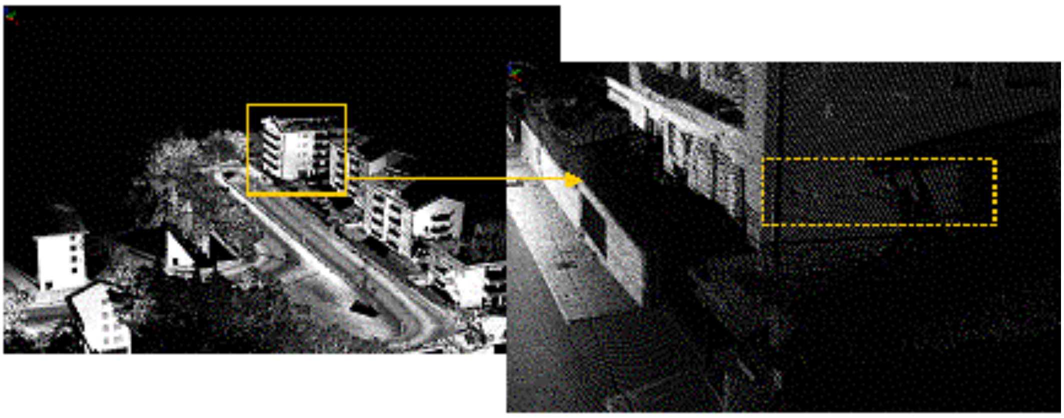

Figure 9. A damaged edifice and a detail of the cracks.

5. Conclusions

The mobile LYNX laser scanner was used at L'Aquila to experiment the efficiency and resolution of this system to provide 3D accurate measurements of damaged buildings, useful for Civil Protection applications. More than 190 million points were collected in a few hours. Buildings and all visible objects in a range of about 100 m from each sensor, were captured during surveys. A complete acquisition was possible driving along the streets at a cruising velocity of about 20/30 km/h obtaining a final resolution of a few centimeters.

This method allows a very rapid and complete survey of the interested area providing full information on the ground and on the vertical sides of buildings, overcoming the limits of acquisition by aircrafts; in fact, the aerial scanning is not an adequate technique for measurements of areas characterized by an high presence of vertical surfaces, due to the geometrical condition. Moreover, the method is fast but provides data similar to the ones

from TLS or terrestrial digital photogrammetry. Therefore, the ability to provide redundant coordinates in the WGS84 reference frame (with an absolute precision of 5 cm) make the method interesting for the definition of a high accuracy altimetric model.
An accurate reconstruction of a scene in short times provides efficient information for a low cost analysis of damages in an area struck by earthquakes or other natural disasters..
The availability of a dense and co-registered cloud-point data set, is useful to support and plan accurate macro-seismic campaigns, saving time and human and economic resources. For example, the number and size of the cracks can be evaluated, as well as the building deformation. In particular, walls tilts, structural failures and relative displacements and rotations between structural parts of the buildings can be accurately examined.
The photographic information, automatically acquired and registered in the same reference frame of the laser scanner data, provides a sequence of true color 2D images of scanned areas and allows the point clouds texturing.
Data are now available at the Dipartimento di Protezione Civile (DPC), and are used as new working strategies to support reconstruction plans of the minor villages near L'Aquila (for more information contact: pesci@bo.ingv.it). In this way, the acquired data will be also used to evaluate the damages of the historical heritage, destroyed by the earthquake shaking.

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