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Multi-sensor system designed for monitoring rock falls: the experimental test-site of Acuto (Italy)

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ABSTRACT

This paper illustrates the design of a multi-sensor monitoring system located in Acuto (Frosinone - Central Italy) where an abandoned quarry was devoted to experimental test-site. The test-site is managed by the Research Centre for the Geological Risks (CERI) and is focused on testing and comparing multi-sensing and multi-parametric remote techniques for early-warning, applied to rock falls with strategic infrastructure targets. The final aim of this testing is to process the data collected by techniques integrated by a network of conventional and smart sensors, following observational-bases and statistical approaches. The installed multi-sensor monitoring system consists in 2 control units for weather monitoring, 1 thermometer for the rocky mass temperature, 10 strain-gauges for rock mass joints, 2 optical devices (Smart Cameras) and 1 nanoseismic monitoring network.

KEY WORDS: experiment in test-site, multi-parametric monitoring system, smart cameras, rock falls, mitigation of natural hazard.

INTRODUCTION

In the last few years, much attention was focused on the monitoring of fast to very fast failures, which include landslides from rocky slope, e.g. rock falls, topples and wedge sliding (Cruden & Varnes, 1996). The relevance of such events is mainly related to the short time available for taking action in case of exposed infrastructures (i.e. highways and railways). In this regard, two possible strategies can be depicted to mitigate the related geological risk: i) monitoring precursor by using micro- or nano-seismometric devices as well as of acoustical emission records (Amitrano et al., 2005; Lenti et al., 2012); ii) monitoring the slopes as well as the exposed infrastructures, by using optical devices (e.g. cameras, interferometers, videos) for detecting fast topographic changes as well as anomalous and unexpected objects which can be hazardous for specific infrastructures (Antonello et al., 2004; Lai et al., 2006; Gaffet et al., 2010; Bigarre et al., 2011; Martino & Mazzanti, 2014).

In the framework of several expertise managed by the CERI a test-site was planned and designed for realizing a multi-sensor installation to carry out specific tests under natural and forced conditions for evaluating the suitability of multi-parametric approaches to manage the early-warning for infrastructure targets.

Thanks to the availability of an abandoned quarry, provided by the Municipality of Acuto, the designed multi-sensor device was installed in the Autumn 2015.

The final aim of such a test-site is to perform a comparative analysis of heterogeneous environmental data, comparing an observation-based approach (OBA) with a statistical (clouding analysis) one (SA). The first approach is focused on searching objective co-relations among forcing triggers and induced effects; the second one adopts statistically based cross co-relations among different parameters to output anomalies due to trends of continuously recorded parameters as well as scatter of cumulative values. The goal of this experiment is to bets-tune control indexes for identifying several alert levels suitable for managing the infrastructures in order to mitigate the geological risk and reduce the "response" time for interventions.

TEST-SITE

Acuto is a small Italian village, located NE of Frosinone (Latium region), about 80 km S of Rome (Fig. 1). The village rises on a carbonate hill, which is part of the Mt. Ernici ridge.

Fig. 1 – Location of Acuto municipality on satellite optical image. The red frame indicate the disused quarry test-site where the multi-parametric monitoring system is installed.

The quarry area selected as the test-site is located NE of the village (see the red frame in Fig.1), at an elevation of about 750 m a.s.l.; Mesozoic wackestone with rudists outcrop in the quarry walls, dislodged up to 10 m by normal faults about NW-SE oriented (Accordi et al., 1986). The quarry wall where the monitoring system was installed is SE exposed and corresponds to the NW boundary of the quarry front characterized by height ranging from 15 m up to 50 m.

Geomechanical scanlines were performed on the monitored quarry wall, following the ISRM (1978) standards. Four joint sets were distinguished and average attitudes were attributed according to a dip direction/dip convention: S1 (130/13) corresponding to the limestone strata, S2 (270/74), S3 (355/62) and S4 (190/64). The uniaxial compression strength of the rock, determined by Point Load test (ISRM, 1994), results to be of 84 MPa. According to Deere & Miller (1966), this result corresponds to a stiffness value of about $6 \cdot 10^4$ MPa.

A rock block was selected as a main focus of the multi-sensor monitoring system (Fig. 2). The block is isolated by several joints and it is cracked, so providing a high number of discontinuities to be instrumented. Moreover, the block dimensions are suitable for optical monitoring by smart cameras and its location is favorable for installing nanoseismic network to records falling precursors. A main fracture separates the back-side of the block from the rock mass and the general resulting set of the block is protruding respect to the adjacent quarry flat where a railway track was posed as a target for falling blocks. The geometry of the block as well as the orientation of the joint sets in the adjacent rock mass highly predispose to rock falls and topples.

MULTI-SENSOR MONITORING SYSTEM

The multi-sensor monitoring system was installed in the Autumn 2015 and it consists in (Fig. 2):

- 1 conventional control unit for weather monitoring including rain gauge, thermometer, hygrometer, anemometer;
- 1 innovative control unit for weather monitoring TSA-BOX, that supports the same type of sensors;
- 1 thermometer for rock mass temperature, installed in the barycenter of the monitored block;
- 6 strain-gages installed on micro-fractures of the rock mass, corresponding to main joint sets;
- 2 extensimeter with 25 mm measure range, installed on open fractures;
- 1 extensimeter with 10 mm measure range, installed on transversal fracture;
- 1 joint gauge with 100 mm measure range, installed on a large fracture at the back-side of the monitored rock block;
- 2 smart cameras for optical monitoring;
- 1 Seismic Navigation System (SNS) array.

All the strain sensors have a sensitivity of 0.01 mm regard to the displacement and are set to automatically download each 1

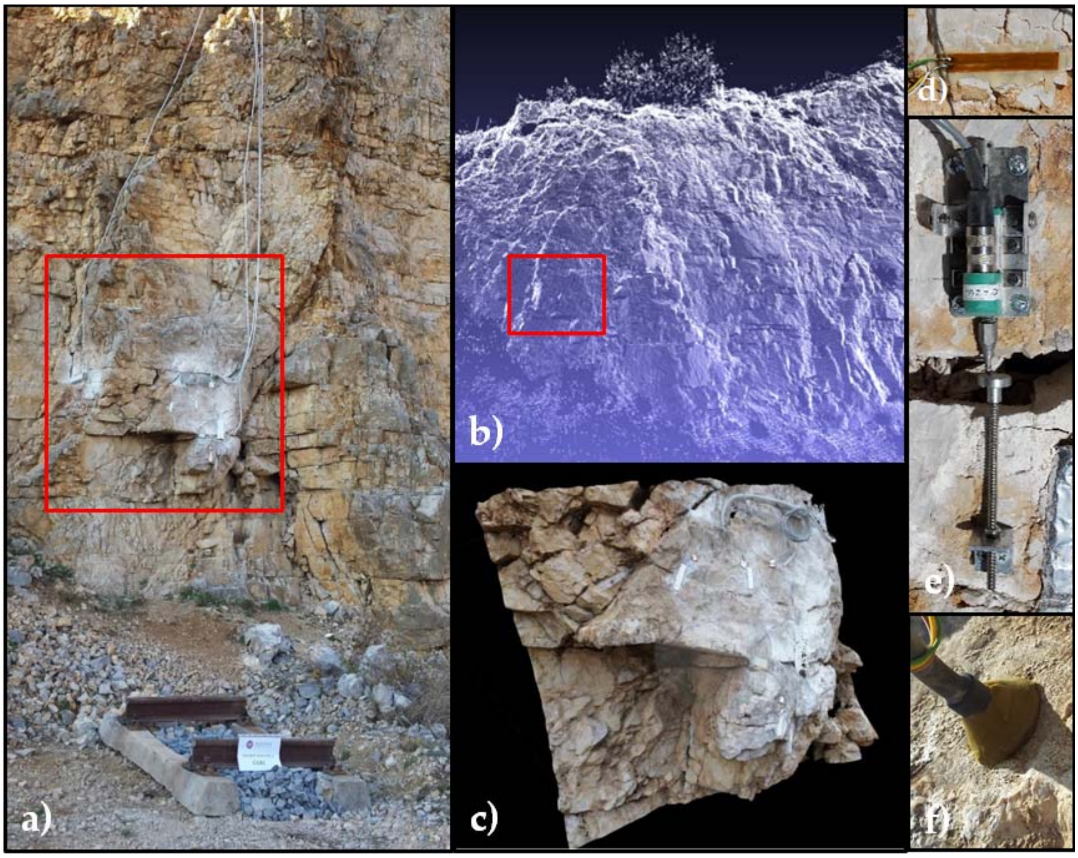

Fig. 2 – Monitored rocky block (red frame) with the railway track located at its bottom and used as original target for the optical sensor (a); laser scanner image, filtered by xray Meshlab (b); 3D photo-view of the monitored rock block (c). Sensors installed in the rock block: strain-gages devices for micro-fractures (d); extensimeter for main joint (e); thermometer for the rocky mass temperature (f).

hour, 6 measurements collected within 10 minutes. The recorded data are stored in a local data-logger CR1000 Campbell Scientific, equipped to 24 acquisition channels. The system is completed by an automatic data transmission system, equipped with a GPRS wireless connection system on local server that allow a complete data storage each 12 hours and enables a remote control of the dataset.

INNOVATIVE MONITORING DEVICES

Optical sensor

The multi-parametric monitoring system installed in the Acuto test-site also includes Smart Cameras (SC; prototype of CNR - ISTI) for the optical monitoring of the rock mass as well as of the example target: for this research the railway infrastructures.

A Wireless Sensor Network (WSN), with hardware connected cameras was also installed to detect morphological anomalies, like rock fall precursors as well as the presence of unexpected objects in the target area. The WSN can transmit real-time data so providing an early-warning system. For all the investigated phenomena, best-tuning the WSN set parameters is a fundamental phase to carry on an optical “change detection” by measuring image-pixel differences between a background scene and a following one, to minimize false alarms and optimize data collection and transmission. This optimized procedure contributes to provide more efficiency to the management process.

The WSN prototype is particularly suitable for the investigated scenarios as it consists in a sensor node, which has a computational power capable to accomplish the computer vision task envisaged for the target monitoring scenarios. A so engineered WSN is named Smart Camera Network (SCN). In more detail, each single sensor node has a main board that manages both the vision tasks and the networking tasks thanks to an integrated wireless communication module (RF Transceiver). Other components of the sensor node are the power supply system that control charging and permit to select the best energy-saving strategies. The power supply system included the battery pack and an optional module for harvesting energy, e.g. photovoltaic panels.

The SC are customized by a personal algorithm (developed by CNR – ISTI team) that allows a series of immediate operations on the recorded images. This allows to send to the operator only the images of interest for early-warning. The conventional procedure consists in: i) background subtraction, ii) object detection, iii) object classification, iv) object tracking and, v) final data extraction. Moreover, on the SCN it is more convenient to adopt a lightweight approach; in particular, processed data reside only in the Region of Interest (RoI), where the presence of an obstructing object needs to be detected. Based on these detections, flow information are derived without an explicit use of classical tracking algorithms. In the RoI lightweight detection methods are applied to detect pixel changed (in this case it is assigned to the foreground) or unchanged (in this case it is deemed to belong to the background). These options are selected with reference to a “dynamic” background image (Fantini et al., 2015), i.e. upgraded in time, to avoid the detection of slow effects which are no referable to rock falls or slides.

The WSN also includes a “TSA-Box” data-logger, developed by Tecnostudi Ambiente S.r.l., which collects environmental data, to correct and establish the functionality limits of the optical device. This data-logger has a main board, fully developed with Open-Source technology, adapt to perform pre-computations on acquired data and to manage the GPRS communication protocol for transmitting the dataset to the main server. This is a small-size stand-alone system customized for a low energy consumption.

The architecture of the whole system (Figure 3) is based on a cloud for security purpose and data replication.

All the data are sent by the data-logger to the internet server. The main server is based on LAMP (Linux, Apache, MySQL, PHP). The main server manage in near real-time the dataset to analyze and collapse all the data. Finally, there is a client application to allow data visualization and alarm notification.

The final goal of the Smart Cameras installed in the Acuto test-site is to integrate the WSN into a multi-sensor network for detecting rock falls from precursors to failure, in order to provide specific alert signals.

Fig. 3 – Cloud system architecture for recorded data collection.

Nano-seismic sensor

Another innovative monitoring technique to be implemented in the multi-parametric monitoring system experienced at the Acuto test-site, is based on a recently proposed approach of nanoseismic monitoring (Joswig, 2008). This technique allows identification and location of precursory signals as well as the impact point of rock falls. The aim of nanoseismic monitoring, a technique lately developed by the Institute of Geophysics of Stuttgart University for microseismic researches, is to locate weak seismic events with negative magnitude, under low SNR (Signal to Noise Ratio) conditions. The installed SNS array consists of 1 central three-component station and 3 outer vertical stations, installed with an aperture of 27 m. Each station was equipped with one LE-3Dlite MkII seismometer (Lennartz Electronic GmbH) and one REFTEK 130-01 data-logger that acquired in continuous mode with a sampling frequency of 500 Hz.

The seismic records will be managed by NanoseismicSuite software, developed by the Institute of Geophysics of Stuttgart University that includes two main tools: *SonoView* and *HypoLine*. *SonoView* allows to perform a data screening by the “supersonogram” operator (Sick et al., 2012), i.e. a specific spectrogram with an autoadjustment function of noise variation and a color scale that shows the frequencies with higher energy. On the other hand, HypoLine (Joswig, 2008) carried out the localization of the events. The epicenter location as well as the hypocenter position and the local magnitude M_L value can be also derived by applying *HypoLine*.

WORK PLANE

The experiments planned at the Acuto test-site will be performed during at least 1 year and they will be carried out in two different phases (namely A and B). In the phase A, weather and stress-strain monitoring will be carried out by continuous recording to detect seasonal changes due to temperature, wind, rainfalls that can influence the rock mass deformations. These specific weather conditions, (such as rain, fog, snow and wind) can stress the rock mass joints also creating interferences with the optical systems. During the experimental phase A, 3D multi-time scans will be also collected by terrestrial laser scanner technique as well as 3D photos of the rock block and multi-temporal thermal images.

The phase B, will consist in forcing the natural system to induce stress-strain effects under controlled conditions. In particular, rock falls will be induced by applying static/pseudostatic/dynamic actions. The following occupation of the railway target will be detected as well as precursors of detachments in terms of both stress-strain effects, microseismic records and optical change-detection evidences.

The recorded data will be collected in a specific database and remotely managed by a cloud-system. The so collected data will be processed following the OBA and the SA. According to these approaches, threshold parameters will be defined for linking triggers with effects (OBA) while anomalies in the statistical cross- co-relations will be independently analyzed (SA). The efficiency of the two experienced approaches will be evaluated in terms of “correct” alert signals provided for early-warning. Nevertheless, possible combinations of the OBA and SA approach will be also considered.

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