Design and system architecture of the GEOIM rockfall monitoring system

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Rocks are commonly found on the pavement of roads servicing mountainous areas. Rocks detached from a mountainous slope may reach the pavement, trigger a new rockfall through the detachment of other rocks, or even stop somewhere on the slope (i.e., due to vegetation). It is evident that early identification of a rockfall is vital for minimizing impacts on roads, infrastructure and human lives. Several techniques and methods have been proposed for this purpose ranging from monitoring of geophysical signals induced from the falling rock to identification of surface change using conventional and advanced geodetic measurements. The architecture of GEOIM, a rockfall monitoring system for near real-time detection of rockfall incidents, is hereby presented. The proposed system relies upon the integration of geophysical sensors and image analysis techniques and aims to be cost-effective and continuously operating while minimizing false alarm incidents. Suitability of the individual components was verified by small-scale experiments in controlled test environments. The instrumentation for the establishment of efficient and reliable communication links for sensor management and data archival and analysis is also presented.

Keywords: seismographs, motion detection, near real time rock-fall monitoring

INTRODUCTION

Rockfall incidents that may lead to road closure, infrastructure damage and loss of human life are a potential threat in European highways and mountainous roads. Two such incidents namely the large size rockfall at the area of Tempi, Central Greece causing one casualty and the closing of the national road for several months [1] and the rock that fell on the top of a school bus fortunately without any casualty in southern Crete, Greece were the motivation for the research project "ISTRIA". The main goal of this project is to develop an operational rockfall monitoring and early detection system by integrating instruments, innovative algorithms and data management center with a user-friendly interface.

In this work the capabilities and limitations of different rockfall monitoring techniques is investigated through small-scale experiments. The operational scenario used for the design of the overall system architecture is discussed, along with the procedure to be followed for issuing an alarm. Finally, conclusions regarding the practical constraints of a near real-time

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operational rockfall monitoring system with the selected instruments as well as the future work plan are provided.

EXPERIMENTAL PROCEDURE

Two main categories of rockfall monitoring techniques have been selected for evaluation: geophysical acquisition and signal processing and image analysis. The former relies upon the identification of the vibration signals while the latter is capable for detection of surface changes caused by the falling rocks. The selected methods were evaluated as follows:

The first experiment for vibration detection involved the free fall of three rocks with different weights, ranging from 0.8 to 4.0kg, dropped from a height ranging from 1.1 to 1.6m. Four sets of three geophones recording in perpendicular directions were installed in a straight line at a distance of 1m, 5m, 10m and 15m from the impact location (Fig. 1).

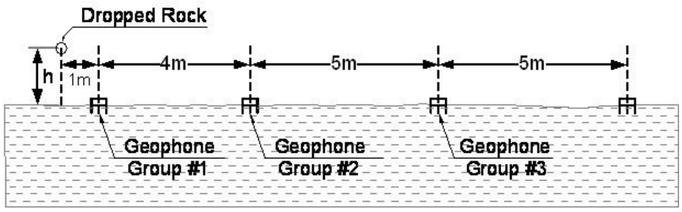

Fig. 1. Experimental arrangement of geophones.

The main outcomes of this experiment are that a) it was possible to discriminate rock events into vibration signals, b) small energy (<60Joules) rock falls could be monitored at a distance of 15m, c) empirical equations published in [2, 3] for larger impact energies performed well for all experimental data, and d) the frequency range generated by the rockfalls was between 19 and 320Hz [4].

The second experiment focused on the evaluation of close range photogrammetry towards rockfall incident detection. The monitored slope was captured through a pair of identical stable cameras while a total geodetic station was used for ground control point measurements.

This photogrammetric experiment included four main phases: 1) acquisition of image pairs before and after a series of manually induced rockfalls, 2) construction of digital elevation models (DEMs) using dedicated photogrammetric processing, 3) development of 2D and 3D difference DEM maps by simple subtraction of the ‘after’ from the ‘before’ DEM, 4) visual interpretation of the derived difference DEM maps reported on the capability of the technique to monitor rock events along with the magnitude of false alarms (Fig. 2).

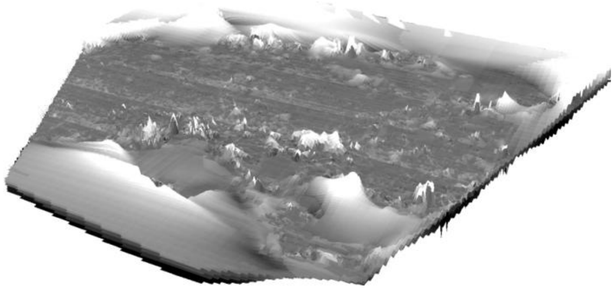

Fig. 2. Random rock fall resulted in several surface changes that cannot clearly be discriminated by false alarms.

The main outcome of this experiment was that surface change caused by movement of a 10x10x10cm rock was detected on the 2x2cm difference DEM map. Movement of smaller rocks (i.e, 8x6x4cm) was also detected using a 5x5mm difference DEM map. The enhancement of the spatial resolution of DEMs resulted in a significant increase in computation time and the number of false alarms. Well known constraints of photogrammetric processing (i.e., vegetation) were also identified and reported in [5].

At the same area, a motion detection experiment was conducted. The cameras were now set to record videos with a 30 frames-per-second rate and different size rocks were dropped from the top of the slope. Using a series of motion detection algorithms including differencing, it was determined that falling rocks were easily identified (Fig. 3).

Fig. 3. A sequence of rocks falling and corresponding video capturing.

ARCHITECTURE OF THE ROCKFALL MONITORING SYSTEM

The selected methodologies and instruments showed promising results in the controlled experiments so during the second phase of the project a combined system is being built. The architecture of the proposed system is presented in Fig. 4. It includes five independent sub-systems. Sub-systems 2 and 4 are used to monitor triggering mechanisms, namely weather conditions and earthquake activity, respectively. The geophones (sub-system 1) constitute the heart of the monitoring system and the near real-time detection basically relies upon their ability to detect even small vibrations during day and night. Sub-systems 3 and 5 will be used for image analysis: the former for photogrammetric and motion detection and the latter only for motion detection. They differ on the location to be installed: Sub-system 3 will be installed opposite or in an angle to the monitoring area while sub-system 5 along the area.

All sub-systems operate in a continuous mode and transfer their data to a router through local Wi-Fi connections. In order to minimize the volume of the transferred data pre-processing will occur for sub-systems 1, 2, 3 and 5. When an event is detected by any of the sub-systems it sends a YES/NO message to the application server. There all inputs are weighted and finally an alarm is issued if a dynamic threshold is exceeded.

CONCLUSIONS

Near real-time monitoring of rockfalls is a complex, multi-disciplinary task affected by a series of factors and should be practically considered as site-specific. Thus, it is extremely difficult to develop a universal system that can be applied to any area without modification. The purpose of research project “ISTRIA” is to develop a low-cost operational system that will utilize smart algorithms for early detection of rockfall incidents. Semi-automated training and validation of sensors after their installation in any area will allow relatively easy implementation of the proposed system architecture.

The GEOIM system intents to detect rockfalls by efficient integration of GEOphysical and IMaging sensors and the development of a decision support system for intelligent issuing of alarms. Integration of more sensors (i.e., total geodetic station, global navigation satellite system) will be also investigated, keeping in mind that the overall cost should be kept as low as possible. The critical issue in any monitoring system is to minimize false alarms and ensure its continuous (24/7) operation. To accomplish this task further investigation on monitoring algorithm development and dedicated training procedures will be performed and tested at a pilot study area in Greece. It is expected that this pilot site will be operational by the end of the summer of 2014.

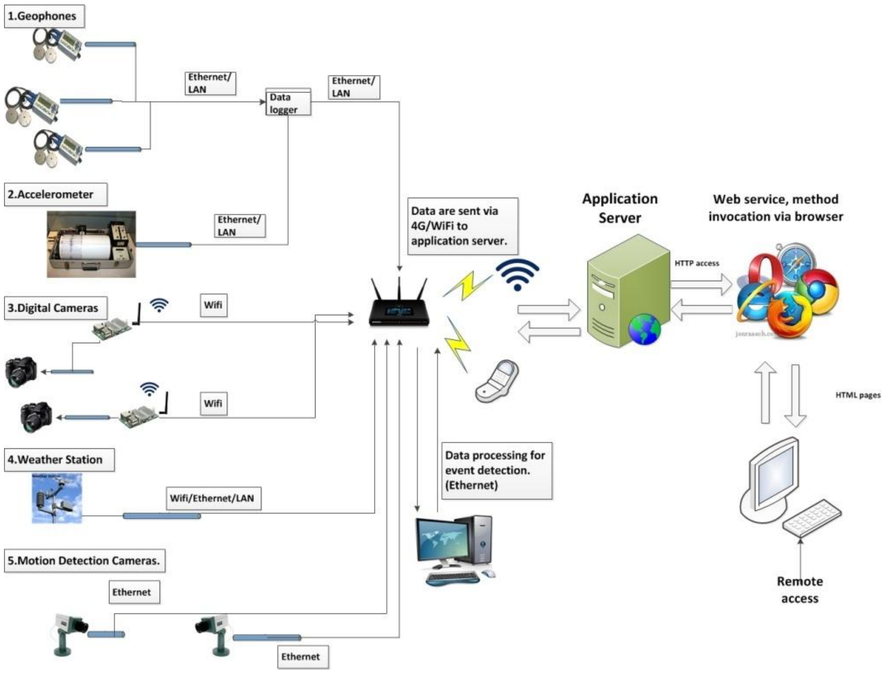

Fig. 4. The system architecture of the proposed GEOIM rockfall monitoring system.

Finally, weather conditions and earthquake vibrations will be monitored and validated against detected rockfalls incidents in an effort to develop clever algorithms for rockfall prediction.

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