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# Distributed real-time monitoring system to natural hazard evaluation and management: the AMAMiR system

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AMAMiR (Advanced Monitoring Action for Mitigation of Hydrogeological Risk) is a real-time monitoring system able to control several heterogeneous remote sensors addressed to a DSS (Decision Support System) and it is useful to support research activities. The different sensors are assembled through "smart nodes", geographically distributed, able to manage the local acquisition, the temporary storage and the transmission of recorded data. Acquired with periodicity of 1 minute, data are stored and trasmitted to Computer Centre if there are significatice changes controlled by prefixed thresholds. A middle-tie software system automatically interacts with both "smart nodes" and the central DBMS. The transmission of signals is achieved using different media and standards: cable, WiFi, GPRS, ADSL. Each "smart node" is independent and acquires data in a self-contained way from one or more sensors. Furthermore, it is capable to store data locally and to transmit them to the data-processing centre, as soon as possible. So far, absences of connectivity or communication network problems do not affect the whole system and do not cause data loss. The managing software processes automatically the information collected by the "smart nodes" and sends them to the Processing Centre. Through a special user-friendly WebGis portal it is possible to query in real time the DBMS and control the sensors distributed all over the territory in a simple and immediate way. On the website, data access is subjected to login authorization consequently, without permission data have only demonstrative purposes. Actually the system is addressed to skilled users. A prototype of AMAMiR has been built in Calabria, Southern Italy, to monitor a wide and deep landslide in San Martino di Finita, a city crossed by an active fault. Available sensors measure different data type: atmospheric parameters (pressure, temperature, humidity, wind, etc.), ground parameters (rainfall, deformations and rotation of buildings, GPS baselines, water springs characteristics like turbidity, flow, Ph, conductivity, etc.), underground data (piezometric level, water soil content, etc.). All the data are collected and processed in real time and they are immediately available on the web. This monitoring system shows good stability and reliability in managing remote data. Addressed to a DSS, actually the system is under calibration to find a robust geotechnical model of the landslide (Zheng et al., 2005). Because of short observation time, still now it is not possible to compare results of the adopted FEM (Finite Element Model) of PLAXIS© software to verify the correctness of the adopted soil geotechnical characteristics. AMAMiR system is designed to be easily upgraded and planned to accommodate different typologies of sensors and a large numbers of "smart nodes". In the AMAMIR acronyim the adjective "Advanced" deals with the capability of the system to support auto-locating data loggers that allow an immediate and simple setup of new heterogeneous remote sensors. These auto-locating data loggers, equipped with small and low-cost GPS, are automatically recognized by AMAMiR structure and, as soon as they are powered on, start the procedure for automatic localization, transmission, reading and updating of the central database. Then, the flexibility of the whole system simplifies the increase of remote sensors and an immediate start up when auto-locating data loggers are used. In general, all data collected by sensors distributed all over the territory reach the Data Processing Centre through the "smart nodes", where they are analyzed and processed for an immediate dissemination through the WebGis Portal. AMAMiR could be implemented to monitor, in real time, a wide range of natural phenomena, like landslides, floods, earthquakes, etc. It is a powerful tool, very cost-effective, which may be installed everywhere and used to support the decision making process of local administrators in order to manage the risks and to protect the population.

***Keywords:*** *Real Time Monitoring System, GIS, Hazard Evaluation, Landslide, Web Devices, Decision Support System*

## 1. INTRODUCTION

Hydrogeological risk affects many areas in various parts of the world. Correct hazard assessment of a site requires the availability of sufficient and heterogeneous information, and the use of an adequate monitoring system is a powerful tool for an informed understanding in order to have correct analysis and interpretation (Angeli et al., 2000; Gabriele et al., 1991). Moreover, where the high costs required to protect the areas exposed to high hydrogeological risk are not compatible with the available economic resources, real time monitoring systems become the main non-structural tool of risk mitigation. Integration of remote-sensor data with geographical information system allows the management of a large amount of data producing very useful information for the decision-makers in disaster mitigation, analysis and planning.

AMAMiR is a real-time monitoring system which is capable to manage and analyze data from a distributed-sensors network. Different kind of sensors can be used: extensometers, tiltmeters, piezometers, GPS, videocamers, etc. The system allows to gather a comprehensive and sufficient set of data to properly understand the phenomenon. Heterogeneous sensors data are integrated with a geographic information system (GIS) in order to produce synthetic information useful to the decision support system for emergency management and disaster prevention. After the prototypal stage the system will be opened to Civil Protection headquarters for landslide mitigation.

Heterogeneous sensors are organized in “smart nodes”, geographically distributed, able to control the local acquisition, temporary storage and transmission of recorded data. A middle-tie software system automatically interacts with both the “smart nodes” and the central DBMS. Different media and standards are used to achieve signals transmission: cable (TCP/IP, rs232, rs485), WiFi, GPRS, ADSL. Each “smart node” is independent and acquires data in a self-contained way from one or more sensors. Furthermore, it is capable to store data locally and to transmit them to the data-processing centre, as soon as possible, when the communication channel is free. In this way, absence of connectivity or communication network problems do not affect the whole system and do not cause data loss.

Through a special WebGis portal (www.amamir.cnr.it) it is possible to query the AMAMiR DBMS and control in real time the sensors distributed all over the territory, in a simple and immediate way (Figure 1). All the data collected by sensors reach the Data Processing Centre through the “smart nodes”. Here they are analyzed and processed for an immediate dissemination through the WebGis Portal. In this way the sensors managed by the system are web-devices available to users. The system is arranged for the use of auto-locating data loggers that allow an immediate and simple setup of new remote sensors. These auto-locating data loggers are automatically recognized by AMAMiR structure and, as soon as they are powered on, they start a procedure for localization, transmission, reading and updating of the central database.

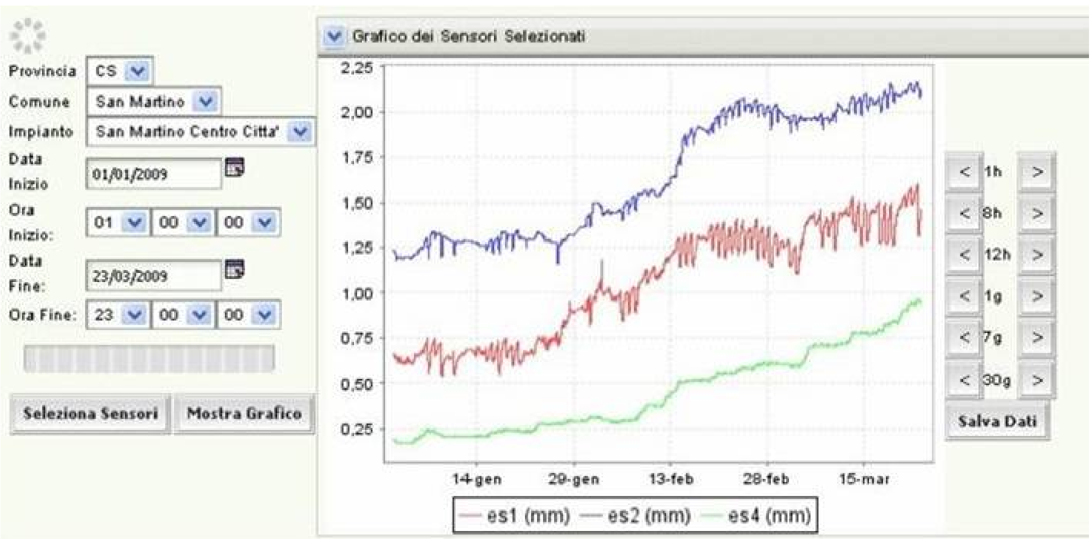


**Figure 1.** WebGis portal for reading remote sensors data in real time: example of extensometers data.

## 2. THE CASE STUDY OF SAN MARTINO DI FINITA

The complex geological history of Calabria, in Southern Italy, makes its territory fragile and prone to hydrogeological disasters (Cotecchia and Melidoro, 1974; Kruhl and Huntemann, 1991; Sorriso-Valvo and Sylvester, 1993). The presence of several active faults testifies the seismicity of the region (Tortorici et al., 1995; Monaco and Tortorici, 2000; Galli and Bosi, 2002). Long the western edge of the Crati graben (Lanzafame and Tortorici, 1981), a N-S striking normal seismogenic fault system is active, culminating with the so-called "San Fili-San Marco Argentano" fault (Tortorici et al., 1995). This fault, developing over 10 km in depth and extending along the foothills band for about 30 km, is associated with a cataclastic band, up to 500 meters thick, along which the rocks are highly fractured and permeable to water. The large presence of underground water and the particular geotechnical characteristics of the materials of the cataclastic band lead to widespread landslides. Landslides can achieve remarkable dimensions inducing high risks to many cities across the fault (Iovine et al., 2006). Among these, the city of San Martino di Finita (Cosenza) is widely affected by a high hydrogeological risk (Figure 2 shows a scheme of the main landslides identified in the city), with signs on the ground and fractures on various buildings up to tens or several tens of centimetres long (Figure 3). In this area, intense and continuous rainfalls may favour the rise of the underground water level, and trigger large landslides.

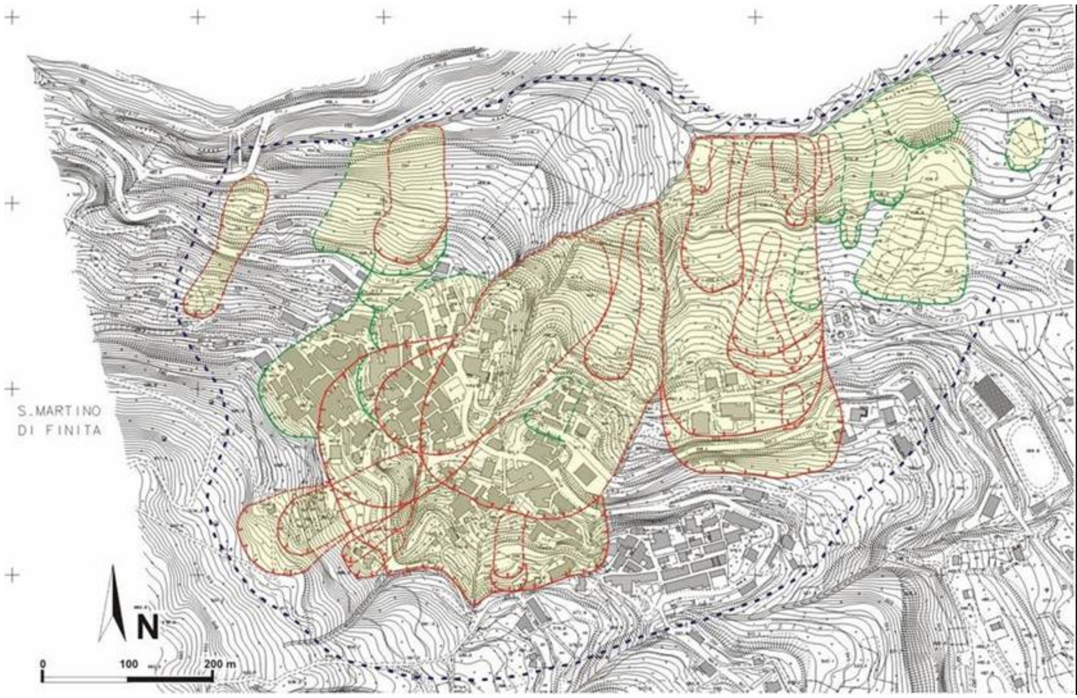


**Figure 2.** Scheme of main landslides in the city of San Martino di Finita, Calabria, South of Italy (showed landslides are contemporaneous and there is not hierarchic relationship among them).

Due to the dimension of the landslide bodies known in the area, stabilization works and engineering solutions would be very expensive or impracticable. In these cases, monitoring is important not only to better understand the landslide hazard, but also to make rational decisions on the allocation of funds for management of landslides risk. Another important aspect of the real-time monitoring is the possibility of developing a real-time warning system for issuing landslide warnings: this is the only viable way to reduce the risk when a site, for reasons of size or complexity, is too expensive to protect (Dai et al., 2002).

To mitigate hydrogeological hazard in San Martino di Finita, after a preliminary geological analysis, a prototype of the real time monitoring system AMAMiR (Advanced Action Monitoring for the Mitigation of the Hydrogeological Risk) is implemented.

AMAMiR originates from an agreement between the National Research Council - Research Institute for Geo-hydrological Protection (CNR - IRPI) and the city of San Martino di Finita. The main goal of the project is the analysis of the hydrogeological hazard in San Martino di Finita, and the implementation of a real-time monitoring system to achieve parameters which can detect landslide activity. Also a real time warning system is in development.

**Figure 3.** Fractures on buildings and constructions in San Martino di Finita.

### 2.1. Instrumentation

Available sensors in the AMAMiR system measure different data type (Figure 4):

- atmospheric parameters: pressure, temperature, humidity, wind direction and intensity;
- ground parameters: rainfall, deformations and rotation of buildings, landslide movement;
- underground data: piezometric level, water soil content;
- water springs characteristics: flow, temperature, Ph, conductivity, oxygen content.

In particular, in the monitoring of the San Martino landslides, the measure of surface movements is accomplished using two types of complementary sensors: GPS to register absolute displacements, extensometers and tiltmeters for monitoring buildings deformations. GPS data are automatically processed at the Data Processing Center, in static mode, with the GAMIT software (Malet et al., 2002; Herring et al., 2006), a high level tool developed at the MIT Institute (USA).

In order to obtain real time results, with high precision and accuracy, GAMIT is used with two processing cycles of calculation: i) in real time, with “ultrarapid” ephemeredes, and ii) delayed of a week, using “final” ephemeredes. This strategy allows an immediate solution (although less accurate); in a second step, when final ephemeredes are available, results will be replaced with a fine and precise solution. The reference GPS station used to evaluate baselines is located in the city of Cerzeto (CS), 2 km far from San Martino di Finita.

The stability of the reference GPS station is controlled using IGS (International GNSS Service) referenced frame sites (e.g. Matera). Fixed and mobile GPS stations are spread over the whole territory of San Martino.

Atmospheric parameters are important to understand correctly sensors data: for example humidity affects the measure of concrete or bricks fissures. An important aspect of the monitoring activity is devoted to evaluate the effect of temperature and humidity on measurements.

The characteristics of the water springs can be an important signal of a possible landslide collapse: same days before the catastrophic landslide of Cavallerizzo (Iovine et al., 2006), near San Martino di Finita, many water springs inproved dramatically their flow and turbidity.

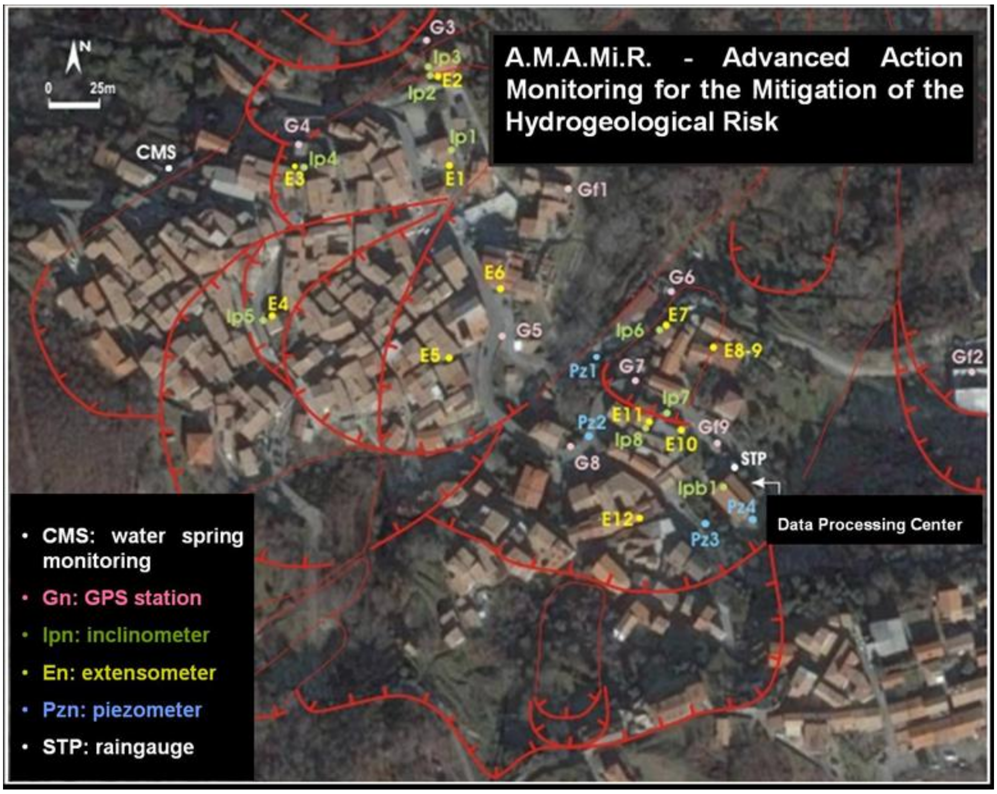


**Figure 4.** Map of the sensors deployed all over "San Martino di Finita" area.

## 3. PRELIMINARY RESULTS

The testing of the prototype AMAMiR system started on January 2008 and, after a period of calibration and validation, sensors data have been storing since March 2008. Sensors previously calibrated in factory laboratory for signal inversion, are tested on site after complete wiring. The possibility of monitoring heterogeneous data allows users to recognize the evolution of the landslide activity in San Martino di Finita. Figure 5 shows the effects of a sequence of ordinary rainfalls occurred on March 2008. After these rainfalls, sensors detect a tiny displacement of the landslide body. In particular, extensometers show an increase of about 0.4 mm in buildings fractures; piezometers indicate a rise of water levels. Although quite ordinary, this first event provides some preliminary information on the behavior of the site under observation.

After this precipitations, the more superficial groundwater at 24.0 mt (the only monitored, at the moment) has a lag time of about 48 hours, while the effects on extensometers are detected after 14 days. This delay is probably related to the time necessary to recharge the deepest groundwater, according to the landslide depth, estimated at about 70 m from tomography results.

Figure 6 shows an example of data processing for the GPS station SMF2. GPS data are analyzed with the GAMIT software using as reference the GPS station of Cerzeto. The Figure shows $Y(t)-Y(t_0)$ function, where $Y(t)$ is the Y-component of the vector position Cerzeto-SMF2; $Y(t_0)$ is the initial reference value. The diagram does not show any significant movement detected by GPS.

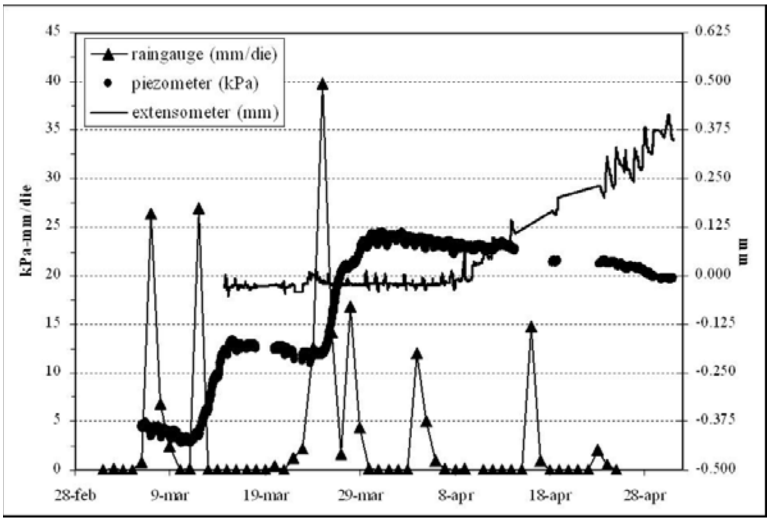


**Figure 5**. Comparison between raingauge data (filled triangles), piezometric data (filled circle) and extensometer data (solid line) for rainfalls over San Martino di Finita occurred in March/April 2008.

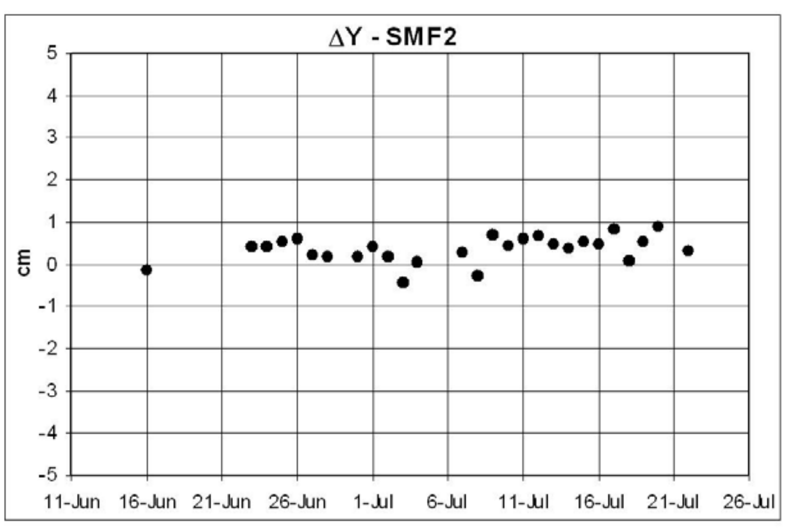


**Figure 6**. Trend of Y(t)-Y($t_0$) for the GPS fixed station SMF2. Y(t) is the Y-component of the vector position Cerzeto-SMF2 in time, and Y($t_0$) is its initial value (June-July 2008).

## 4. DISCUSSION AND CONCLUSIONS

AMAMiR is a real-time monitoring system able to handle spatially distributed sensors of different types. Sensors are locally managed by "smart nodes" which collect, store and transmit data. This particular structure of the system allows to limit data loss in case of absence of connectivity. The managing software processes automatically the information collected by the "smart nodes" and sends them to the Processing Centre. Sensors are configured as web-devices, remotely manageable, and results are available in real time on a WebGis portal for authorized users. The system supports auto-locating data loggers, equipped with GPS, that are automatically recognized and localized by AMAMiR structure and connected with the central database. This allows an immediate and simple setup of new sensors, making simpler and cheaper the system expansibility.

This paper shows a more simple prototype of AMAMiR built to monitor a deep landslide affecting the village of San Martino di Finita, in Southern Italy. This monitoring aims to calibrate a finite-element model of the landslide, by using the PLAXIS© (Brinkgreve, 2002) program, and to mitigate the risk. Until now, the system has shown good reliability and robustness in managing remote data, minimizing data loss in case of connectivity problems. The flexibility and easy expansibility of the whole system has allowed the installation of about 50 different sensors. The information gathered by the system are addressed to research application and to build a DSS.

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