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THE DESIGN OF A SENSOR NETWORK BASED ON IOT TECHNOLOGY FOR LANDSLIDE HAZARD ASSESSMENT

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Abstract: In the present paper, the authors deal with the landslide issue and the associated risk management. The design of a sensor network for monitoring landslide triggering events is proposed. The network consists of web-sensors using IoT technology to share measurement results and information. Data are acquired and processed to characterize the occurrence of triggering events causing landslides. The aim is to provide timely landslide hazard maps. The projected measurement system is a configurable network of wireless and smart sensors geographically distributed. The monitored area is divided in local zones, each zone is monitored by a smart sensor. Topographical and environmental information is used to cluster the area in order to configure the network and the monitoring process. According to the desired resolution, an algorithm fixes the size and number of local zones. The single sensor is able to measure the sliding and spatial movements of soil by means of accelerometers. Each sensing node transfers data to a Web page by a HSDPA modem for processing stage. Information can be remotely analyzed so to single out hazard and risky situations for the population in the monitored area. Then suitable interventions and actions can be planned from the civil protection.

Keywords: smart sensor network; IoT technology; measurement; landslide triggering, risk assessment.

1. INTRODUCTION

Sensor networks are commonly used for environmental monitoring applications. The basic aim is to improve knowledge on the surrounding environment. Sometimes monitoring campaigns are necessary for risk assessment and management purposes. In fact, attention has to be paid towards those processes that can put people life at risk. In such cases, the main goal of the monitoring is to verify the status of our habitat in order to keep under control the quality level of life. In this manuscript, the authors focus attention on the landslide issue. Landslide is a phenomenon widely spread in the Mediterranean, and it is often cause of death and economic damages. It represents a natural process that shapes the Earth surface, [1]. As a matter of fact, it affects principally mountainous areas and zones with cut slopes. The consequences of such a process can be catastrophic when it occurs in proximity of residential areas. Landslide risk assessment is an interesting field of research where measurements and data processing need specific requirements of accuracy. Risk evaluation, hazard assessment or prediction of landslides are important challenges for researchers, [2]-[5]. Methodological monitoring processes can avoid or reduce possible harms for the exposed population. Suitable measurement systems and data processing models can allow risky situations to be characterized. In this way, warning or alert events can be timely managed by means of corrective actions.

Landslide identification requires a careful knowledge of the slope process and of its relationship with geology, geomorphology, hydrogeology features of the soil. Further influence factors are the climate and the vegetation. The most common monitoring systems are based on topographical and geological data or satellite images, [6], [7]. Segmentation algorithms are used to detect the soil characteristics. In such applications, JSEG algorithm shows the best results, [8]. Models of diagnostic image are based on the analysis of topographic features (slope, soil shape curvature, distance from inhabited areas) and geologic features (geology, distance from lineament), [9]. Further information on type of soil, precipitation, vegetation index is considered for optimizing the recognition of landslide triggering events, [10]. At the moment, assessment or prediction of landslide hazards are based on hydrogeological models. Typically, these models are used to estimate the probability of a landslide occurrence by means of historical or statistical analysis of previous events in the monitored area, [11]. Landslide hazard maps are consequently drawn, [12]. Such statistical models often are cause of possible false alarms. Differently, the availability of real-time data based on measurements of soil movements or triggering events could improve the reliability of such hazard assessment models. Consequently, damages and death can be predicted and reduced by means of suitable emergency plans.

In detail, triggering events represent the starting event of a landslide. Often the time interval between a triggering event and the landslide process is sufficient for executing prompt intervention actions. When real measurements are accessible, more reliable decisions can be taken using a set of parameters or information concerning geology, type of soil, slope steepness, morphology of the area, precipitation, vegetation cover, temperature and humidity, population density and human activity in the area. Nevertheless the resort to measurement systems geographically displaced entails high costs of implementation and management. Furthermore data have to be analysed from experts. But interpretation errors or poor accuracy of measurements are cause of underestimated hazards. For these reasons, most of the present landslide hazard maps are drawn only by using hydrogeological and statistical models, [12].

In this sight, the authors propose the design of a complex measurement system for monitoring landslide triggering events. The considered case study concerns a populated area neighbour urban centre. An innovative and automated measurement system has been projected for predicting landslide occurrences. The network, by using IoT technology, shares information with a remote workstation. So data are remotely processed by suitable algorithms in order to characterize starting land movements. The aim of the present paper is to provide a methodical approach to the design of landslide monitoring networks. So it intends to overcome the limits of the present monitoring systems reducing possible false alarm occurrences. The technological advances in communication and networking fields suggest new solutions for real-time monitoring, [13]-[19]. Nevertheless, such advances entail new issues concerning the management and complexity of the system. The new concept of Internet of Things (IoT) provides a novel approach in designing wireless sensor networks. Thus a variety of things as sensors, measurement systems, actuators, can exchange data with each other in order to improve available information. Internet can represent the basic communication infrastructure for networks extended along wide geographical areas. Nevertheless, with reference to the considered application case, the landslide monitoring needs specific accuracy and reliability requirements. So different issues are still open. Further important aspects concern the natural changes of the environment. So network architecture has to be adapted dynamically. Sensors have to be added or removed and sampling plans have to be flexible according to the specifications. Consequently, data have to be shared and promptly processed for supporting civil protection actions.

2. LANDSLIDES AND CLASSIFICATION

Landslide is a natural process of soil movement due to slope. High slope angles involve greater stress in the soil triggering movements which can originate a landslide. The probability of a landslide event increases if the soil is made up unconsolidated material and debris, [20]. Low slope angles can unlikely generate landslides due to low gradients. Nevertheless it is not a general rule. So that natural slopes made up bedrock are not necessarily cause of landslides, [21]. As a matter of fact, slope and type of soil are the main factors to be considered in predicting landslide events.

Typically landslides are generated as a consequence of triggering episodes or triggers. So earthquakes, rainfall, snow, human activities can facilitate the arising of soil movements, [22]-[25]. According to the type of triggering event, different impacts on the geographical area can be characterized. Moreover, duration, intensity, and extent of the triggering mechanism play an important role, as well as hydrogeological and morphological features. In this sight, landslides are often difficult to predict. Even natural phenomena and human activities can alter the stability of a slope. Such triggering conditions can be classified into five classes: removal of material (natural erosion, excavation); removal of vegetation (deforestation due to natural events or human activities, fires); moisture (precipitation, damages to water system, artificial deviation of water flow or river); increase of weight (snow, eruption, addition of material); vibration (earthquake, blasting or use of heavy means of transport, loud noise), [26].

A first approach for the risk assessment is based on statistical analysis of geological and environmental factors, [27], [28]. The aim of such models is to estimate the occurrence of landslide in a specific location. They use historical records concerning landslide frequency in the area to predict future occurrences.

Further complex models are based on processing aerial photographs or satellite images. In this case, a deterministic approach is used. In detail, mechanical and cinematic laws allow researchers to control the instability of soil and to predict potential movements. Usually statistical models offer better results when wide areas are considered or when the deterministic model is too complex to be defined. However, historical data on landslide frequency of the monitored area can affect results. In fact when a landslide occurs geological and topographical settings change causing different conditions of instability. Deterministic approach is suggested when landslides are predicable by means of physic laws. Nevertheless the latter models fail when temporal aspects are considered. In conclusion no approach can be considered a definite and general solution to the issue. According to the monitored area and to the type of landslide a specific method can provide better results.

Standard classification of landslides is based on the mechanism of the soil movement and on the type of displaced material: fall, topple, lateral spreading, slide, flows, creeps [29]-[33].

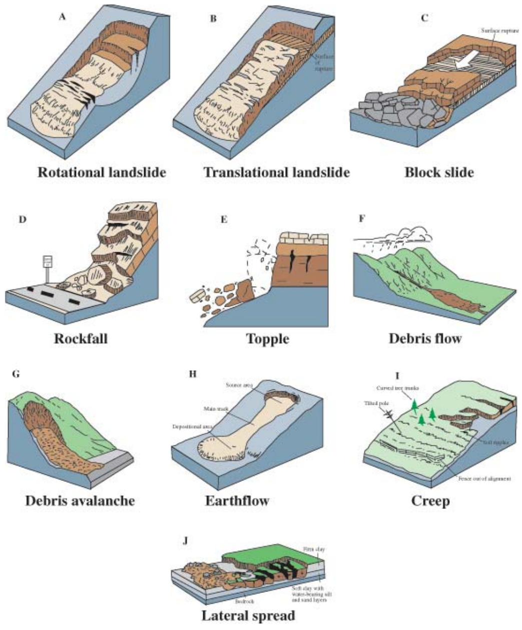

Fig. 1. Landslides classification.

Hybrid types of landslides can originate by a combination of the previous classes. So landslides with complex movements (rotational and translational) are possible. Sometimes a landslide can develop into a different type. In addition, velocity and distance can affect the landslide mechanism and increase considerably its impact.

Risk assessment requires the identification of the elements at risk (persons, property, infrastructures, environment) and the estimation of their vulnerability, [34].

The purpose of landslide risk assessment is to predict landslide hazards with reference to where, when and how it occurs, [35],[36]. With reference to the first issue, it is possible to characterize different classes of areas according to their use: urban, agrarian, water, forest and arid regions. Differently considering the last issue, to predict the magnitude of the moving mass during a landslide is a complex task because of the variety of landslide types. Moreover, risk evaluation has also to estimate the economic and life loss (damages to infrastructures, buildings, environment, number of people dead or injured), [37]. Typically, progressive and slow movements are not risky for human safety, but can have wide impacts on infrastructures. In this case only economic loss are involved. Differently, rapid and sudden movements of soil put population at high risk. However, consequences are not limited only to structural damages and life loss. So risks include damages to economical and working activities, services, facilities, vehicles.

The most common risk assessment models are based on the estimation of some parameters: likelihood of slide, probability of spatial impact, temporal probability, vulnerability and elements at risk. Vulnerability, for example, depends on the position of the element at risk in respect to the landslide process, the magnitude of the moving soil, its rate and the vegetation, [34]. Vegetation index is typically estimated by satellite images using spectral reflectance measurement in the red and near-infrared regions of the electromagnetic spectrum. All such factors are used to estimate the global probability of landslide occurrence.

Although a variety of models and methods have been proposed in literature, no technique is considered the gold standard. Such methods suffer generally of poor accuracy and reproducibility.

The landslide hazard zoning represents the final step of the monitoring activity, [12]. In this stage, risk assessment results are used to draw hazard maps characterizing the zones with greater risk. Such maps are drawn according to geological and topographical information on the monitored area. The map is clustered in zones with different colours according to the landslide risk level: likely, possible or unlikely.

3. SENSOR NETWORK DESIGN

Landslides affect a wide extent of the European territory. From an economic point of view, it is clearly unsustainable to monitor systematically every zone subject to landslide events. Since in the risk assessment, the population injury and life have greater impact, attention is turned on the populated areas. Consequently, monitoring campaigns are typically performed along wide areas in proximity of urban or peopled zones. In this case, the extent of the area requires the use of distributed architecture for the measurement system. The authors in previous works have developed distributed systems for environmental monitoring applications, [38]-[41]. So the design of a measurement network based on wireless and smart web-sensors is proposed. The sensors are spatially displaced along the considered area according to topographical information. In detail, a partitioning algorithm divides the area in several local zones. The algorithm starts from available information concerning the population distribution and density in order to detect the target area. Such information associated to topographical data allows algorithm to perform the best partition of the area. The number and size of the zones are chosen according to the desired resolution and accuracy of the sampling plan. When the satellite image of the area is acquired, an initial partition grid is applied. In addition, according to the economic resources and the number of sensors, the user can specify the desired number of partitions. The whole area is so divided in several zones with the same size. Lack of economic sources represents the real problem of the actual monitoring campaigns. For this reason the best solution is to characterize the zones which require more attention and a more careful monitoring. In this stage, it is possible to characterize the presence of sensible zones or elements at risk where greater attention has to be paid. The algorithm thickens further the partition of the sensible zones. So, for example, zones which are highly urbanized and densely populated have higher risks in presence of hazardous situations. Consequently the algorithm can perform a further clustering of the zones with higher population density or with elements at risk. In this way, each sensible zone is divided in other four sub-zones, see Fig. 2.

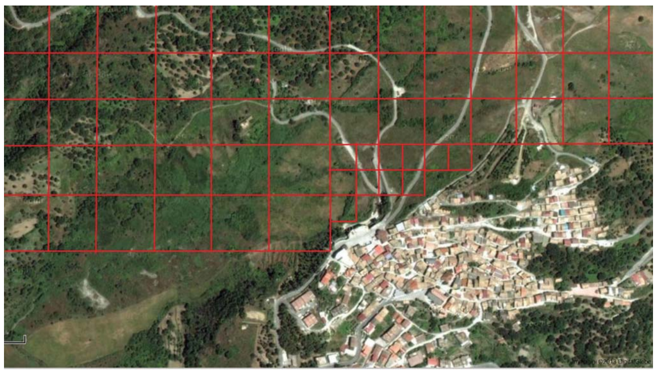

Fig. 2. Partitioning of the area.

Higher levels of accuracy and resolution are obtained by partitioning the area in smaller local zones. In this way, measurements provide more reliable data on the monitored area. Nevertheless, it involves higher costs. So, a balance between costs and desired accuracy/resolution is needed. Information concerning the population distribution and density, the likelihood of slide, probability of spatial impact, the vulnerability of the elements at risk is considered.

The network architecture is configurable on the base of topographical and environmental information on the area. The number and size of the zones can be adapted according to the needs. Each sensor has the task to collect information and data in a fixed point of a specific local zone. Local sampling plans are defined according to the risk level in the sub-zone. The position of the sensor within the single local zone is defined by simulations based on geological and topographical features of the zone. The single sensing node has been projected according to the guidelines of the *IEEE 1451 Standard*, [42]. It is a wireless smart sensor with three accelerometers displaced along the axes of an orthogonal Cartesian system *xyz*. Signals are conditioned by means of a circuit, while a 16 bit A/D converter digitalizes they. Conditioning circuit is based on multiple amplification stages with an auto-scale setting, as previously it has been developed from the authors in [43]-[45]. The control unit is based on a microcontroller architecture which manages the data-flow operations. The single web-sensor sends data to a Web page by a HSDPA modem.

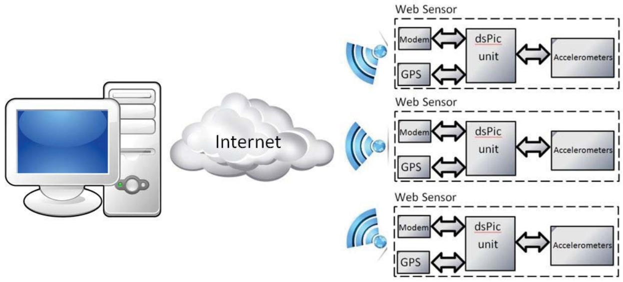

Fig. 3. Architecture of the sensor network.

In this way, the Web page stores information on the whole monitored area. Data are so shared by means of Internet network in order to make easier the access and the exchange of information among several monitoring networks. The IoT architecture offers several advantages like the sharing of data, the timely availability of information and the simple interconnection between sensor networks. In fact the use of IoT technology allows to simplify the design of monitoring systems distributed on wide areas spatially distant. User can get access to the Web page by a password in order to have an overview of the area. So data concerning measurements, *GPS* information, and topographical records are used to characterize each local zone in terms of landslide risk assessment. The aim of the present work is to provide practical tools for civil protection by drawing alarm reports about landslide triggering events. A hazard map is therefore drawn to characterize the zones which require immediate intervention. Consequently, suitable actions can be projected for safeguarding population and infrastructures from damages.

4. CONCLUSION

The design of a wireless sensor network for landslide monitoring is proposed. In literature, several solutions have been developed for landslide risk assessment. Most of these are based on statistical and deterministic models. The first approach uses historical data on landslide frequency in order to estimate the occurrence probability. The second approach uses physical laws and soil information to assess hazard events. Both models can involve possible false alarms. The authors propose a network of web-sensors using the Internet network to share data and information on landslide triggering events. Sensing units consist of accelerometers, HSDPA modem and GPS module. Topographical information is used to optimize the sensor network architecture and the monitoring campaign. The network is geographically distributed on a wide area. It is a complex measurement system, and several management issues have been highlighted. Considering the application case and the complexity of the network due to the extent of the monitored area, different configurations have been analyzed. The IoT based solution has been chosen. This solution allows network to simply the communication of the sensors and the sharing of the amount of data. Hazards maps on landslide triggering events can be drawn in order to single out the zones which need timely corrective actions.

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