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Real-Time Landslide Monitoring on IoT Platform Using Lora

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ABSTRACT: Rockfalls and landslides are hazards triggered from geomorphological and climatic factors other than human interaction. The economic and social impacts are not negligible, therefore the topic has become an important field in the application of remote monitoring. Wireless sensor networks (WSNs) are particularly suited for the deployment of such systems, thanks to the different technologies and topologies that are evolving nowadays. Among these, LoRa modulation technique represents a fitting technical solution for nodes communication in a WSN. In this paper, a smart autonomous LoRa-based rockfall and landslide monitoring system is presented. The structure has been operating in Pantelleria Island, Sicily, Italy. The sensing elements are disposed in sensor nodes arranged in a star topology. Network access to the LoRaWAN and the Internet is provided through gateways using a portable, solar powered device assembly. A system overview concerning both hardware and functionality of the nodes and gateways devices, then a power analysis is reported, and a monthly recorded result is presented, with related discussion.

KEYWORDS: wireless sensor network (WSN); monitoring; Internet of Things (IoT); LoRa; rockfall monitoring; energy harvesting; sensors; risk prevention

I. INTRODUCTION

Landslides and rockfalls are natural hazards linked to the combination of geomorphological and climatic factors in response to triggering mechanisms, such as heavy rainfall or seismic events, vegetation interaction, and human action [1,2]. Due to the rising awareness of economic and social impacts of landslides and rockfalls, the risk control of these events has become a topic of major interest. The effects include economic losses, the threat to human safety, environmental endangerment and impact on the possibility of urbanization [3]. A clear example about the danger of these occurrences is shown by events in combination with transport routes [4], where in addition to damages to infrastructures, there are unfortunately monetary losses due to the service disruption. The interest of the scientific community in the major hazards of these phenomena is well known worldwide, especially in areas where the presence of rock formations or unstable terrains represent a high source of risk [5].

The island of Pantelleria, located between the coasts of southern Sicily (Italy) and Tunisia, represents the emerged part of a volcanic structure. The structure of this island is deforming due to volcanic and tectonic activity [6]. It is necessary to monitor the rockfall and landslide activity along the surfaces of slopes and rock faces for safety purposes and to track the degradation and change of the territory. The morphology of the rocky walls in Pantelleria, especially along coastal areas, makes the development of a wired structural monitoring system difficult. Wireless sensors networks offer an advantageous mechanism for monitoring purposes because it is possible to implement a network of nodes without wiring, and to use sensing units to gather information. Earlier, engineers have employed wired and single-hop wireless data acquisition systems to acquire useful data for structural monitoring [7,8]. However, power and wiring constraints can combine in increasing the cost and complexity of data acquisition, most importantly by limiting the number and applicable location of sensor nodes. Maintenance and deployment costs can be increased too. Considering these, wireless sensor networks can often help address these issues.

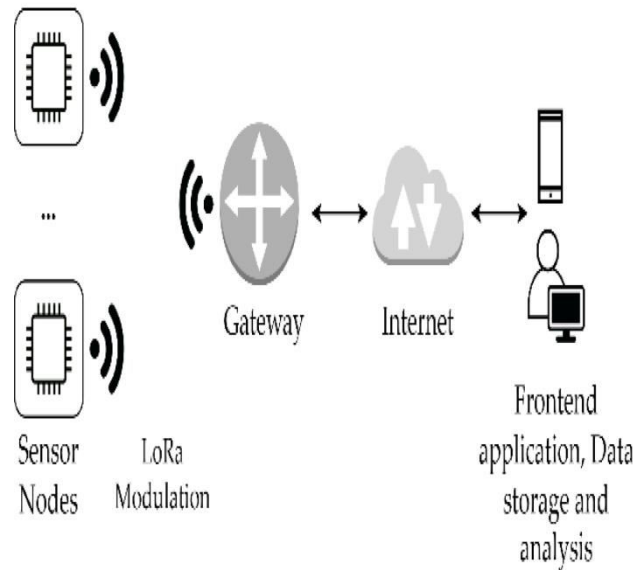


Fig 1: Work Flow

The current trend is to embrace Internet of Things (IoT) paradigms, benefiting from smart nodes to build flexible and powerful infrastructures for data acquisition and analysis. The physical devices equipped with sensing instrumentation are connected to the internet, which allows data exchange between heterogeneous platforms, making the system technology independent from a certain point of the acquisition chain.

In the recent years WSNs have reported a rapid growth thanks to various new technologies for wireless communication, new implementations of ad-hoc hardware devices, and important academic and industrial research effort in this matter [9]. The applications served by wireless networks are various and different [10], including environmental monitoring [11], health related applications, including wearable systems [12], early warning tools [13], and industrial control [14].

Overview on State of the Art Rockfall and Landslide Monitoring Systems

The development of an optimal solution for a monitoring system is an open challenge for different reasons. Determining which of the existing ones is the most appropriate solution is absolutely not trivial. The sensing structures are incredibly heterogeneous in many terms: technology, topology, reliability, cost, and complexity. For the aforementioned reason, it is challenging to find a system that fits them all indiscriminately. Furthermore, due to the multidisciplinary nature of the monitoring topic, taking into account all the variables involved is complicated.

In this section, different solutions for rockfall and landslide monitoring systems, based on wired and wireless networks will be briefly reviewed, so to give a perspective on the state of the art. Employing structural health monitoring (SHM), a connected aspect of the aforementioned phenomena, an overview on WSN-based applications will be reported.

In [15] the authors present a survey of technological developments and research work in the IoT, applied to the prevention of geological hazards. It surveys the applications in the monitoring and early warning of various types of common geohazards: rockfall, surface collapse landslides, and debris flow earthquakes. Some IoT-providing technologies are investigated in geohazards, and the challenges are summarized with an address to future developments in the topic.

Wireless sensor nodes incorporating microelectromechanical system (MEMS) inertial measurement unit (IMU) sensors can be used to detect movements on rock or soil slopes. In [16] the authors present a sensing system able to recognize a rock fall event and to monitor the structural parameters of a protection barrier, which can be a gabion mesh or concrete blocks. The architecture is modular, organized with a control unit and sensing nodes disposed on the installation site. With these devices, information about the vibration and the inclination of the falling rock protection barrier is gathered. The data are collected on a web server which handles recording and automatic messages in case of criticisms. A web application has been developed to create summary reports and to analyze the data collected. The system is currently working on a gabion mesh located in the southern part of Italy.

Despite the ability of the IMU-based WSNs to measure accelerations and rotations, there is a significant research effort to describe and distinguish different types of slope movement. Studies have presented distinct patterns of

accelerometer data in physical structures' behavior [17]. The concept of pattern recognition has been utilized in experimental studies that were carried out by the authors using the accelerometer and gyroscope readings to classify movements. This information serves as the fundamental understanding of a landslide in civil engineering, as well as helping in analyzing the stability of the slope and the implementation of safety and mitigation structures. In [18], the authors present a system based on WSN nodes which communicate with a central station using 802.11 g standard [19]. The station is a trailer equipped with computers for onsite data analysis and cellular uplink. The connection is used for internet communication to a central storage server. Experiments using a rock equipped with a sensor device are carried out and results reported to show the different IMU data for possible movements of the mass. In [20], the authors propose a system based on acoustic emission or microseismic monitoring to provide an insight into stress and strain conditions in the subsurface rock mass. Detecting microseismic events originating from an unstable rock mass is important for locating growing cracks and to analyze the triggering mechanisms of possible future collapses. In [21], a network of sensor nodes based on MEMS analog output accelerometers and MicaZ [22] mote hardware is deployed. Each node is equipped with a microcontroller and a 2.4 GHz transceiver. The devices are mounted in a linear configuration along the Golden Gate Bridge, which makes the multi-hop transmission topology particularly suited for the study. Effort is made to analyze the data transmission reliability in pipeline mode to reduce data loss. The mechanism implemented is as follows: the sender transmits the data when it is requested by the receiver, and the receiver identifies possible missing packets and returns a list back to the sender, which resends those until total reception is achieved. A cycle of data sampling and collection is executed in about 9 h and produces 20 MB of data.

In [23], a disaster prevention system tested in a slope area around Taiwan is shown. Monitoring equipment was installed on the protection structure construction to display quantitative data of rockfall events. The accelerometric nodes prototypes are built on commercially available electronic circuits encapsulated in plastic enclosures and are three different types, each one characterized by a different transmission technology. The first is a long range (LoRa) [24,25]-based node, the second uses narrowband-IoT (NB-IoT) [26] and the third communicates with Long Term Evolution (LTE) M1 [27,28]. The LoRa unit does not use a free access media access control (MAC) layer but communicates data to a Raspberry Pi 3B [29] unit which uses Wi-Fi to later transmit to a MySQL [30] server. There is also a wired vibration gauge, VB-200SC [31], interfaced through RS-485 [32] with an IoT gateway to transmit data over Wi-Fi. In [33], the authors implement a LoRa-based WSN on an uninhabited hillside landslide, studying the feasibility of a LoRa-based network in harsh environments and focusing on the zone coverage of the communication and on received signal strength intensity (RSSI)-based triangulation to localize a particular node in the network. However, we do not find an in-depth description on the hardware implementation of the sensor node, a description of the mounting mechanisms on the slope side, or power-related features of the elements. In [34] the authors propose a landslide-monitoring-method-based LoRa network and intelligent sensing for rainfall and landslide displacement in Shuicheng County, Guizhou Province, China. The general structure, hardware, and software design of the system are described comprehensively. The work reports the possibility, for the nodes, to operate in normal or reduced power mode to obtain a lower current absorption of 1 mA.

An application of a LoRa-based wireless monitoring device for SHM is presented in [35]. In a smart city, Remote Structural Health Monitoring (RSHM) is a perfect solution for tracking critical damage to urban structures. The cited paper proposes TenSense M30, an IoT sensor node to enable wide communication coverage, with a long battery duration, for monitoring the health of bolted joints. TenSense M30 has a footprint that can be used as an add-on to current structures. Hardware and mechanical tests are presented.

II. RELATED WORK

Agriculture is one of the biggest food industries in the world and currently one of the most critical sectors of the economy in many countries due to the great demand for food required by the world population. As food demand increases every day, maximizing food production and minimizing food losses and costs are necessary. With the advancement of Internet of Things (IoT) technologies, more companies and organizations are interested in developing new solutions that enable remote monitoring and control to improve crop productivity. IoT is a promising technology that provides great opportunities to support many new applications and services in different domains such as smart home, smart city, smart industry, smart health, and smart agriculture.

The authors in [5] reviewed IoT applications in agro-industrial and environmental fields, identifying different application areas (monitoring, control, prediction, and logistics), trends, architectures, and open challenges covering the time period from 2006 to 2016. The authors in [6] present a comprehensive survey on the state-of-the-art for the role of IoT in agriculture, covering network architectures, technologies, and protocols. Furthermore, agriculture policies for the standardization of IoT-based agriculture and open research issues have been discussed. The authors in [7] developed a

device named “FarmFox” to monitor soil health. The device uses REST API and TCP protocol. The developed sensor node monitors several soil parameters such as pH, turbidity, soil moisture, and temperature based on Wi-Fi technology and sends the sensor information to the end-user. The authors in [8] present a review of the applications of LoRaWAN for future smart farming, which include automatic irrigation systems, small/large arable farming, livestock and animal welfare, and greenhouse/indoor horticulture. The paper covers the basic applications of LoRaWAN for smart farms and highlights technology limits and future research directions. The author in [9] reviews various potential applications and challenges associated with IoT in agriculture and farming applications. Various case studies have been presented and explored regarding communication networks, cloud services, and hardware platforms. In [10], the author studies the impact of variant physical layer parameters on the performance of the LoRa network with respect to range, reliability, and RSSI in a tree farm located in Indiana, United States. The authors in [11] present a hardware and software system for the remote monitoring of vineyards. Two different nodes were developed and deployed to collect atmospheric data and soil parameters based on Wi-Fi technology in Ribeira Sacra, Spain. The authors in [12] propose a user-centered design model where each farmer decides their own installations.

The experimental work considered a greenhouse with two levels of communication and processing nodes (edge and fog). In [13], the authors present the major applications of unmanned aerial vehicles (UAV) and IoT in smart farming. The work highlights connectivity requirements, network functionalities, and communication technologies for smart agriculture. In [14], the authors present an IoT scheme based on LoRa technology for long-range communication in the agriculture area. The monitoring parameters consist of humidity, temperature, soil pH and soil moisture. In [15], the authors present a comparative study for LPWAN such as Sigfox, LoRa, and NB-IoT for large-scale IoT deployment with respect to range, coverage, deployment, cost, battery life, latency, and scalability. The authors in [16] present a low-cost solution for an automatic irrigation system. The system consists of a LoRa network between sensor nodes and a local gateway with an internet connection through the Sigfox network. In [17], the authors present a case study for an IoT-based architecture for research and development in precision agriculture and ecological domains. The authors in [18] describe the AFarCloud project that aims to support the integration and cooperation of the agriculture system to offer better productivity, efficiency, food quality, and animal health. [Table 1](#) shows comparisons between previous research work on IoT-based architectures for smart farming.

III. RESEARCH METHODOLOGY

LoRa technology is a promising candidate to support remote monitoring of large-scale agriculture farms due to their flexibility and simplicity. The LoRa network is based on two main components: LoRa physical layer and LoRaWAN. The proprietary LoRa physical layer was developed by the Semtech corporation based on spread spectrum modulation and chirp spread spectrum (CSS), while the LoRaWAN is an open specification developed by LoRa Alliance. Each LoRa transmission includes different parameters such as transmission power, spreading factors (SF), code rate (CR), center frequency, and bandwidth. These parameters affect the data rate, communication range and robustness of the signals

Selection of Database and Keywords

It is advisable to select numerous databases in a systematic review to obtain and review a thorough selection of relevant publications. Scopus, Web of Science, and Google Scholar are the three most often used databases in engineering research. Scopus and Web of Science are also compatible with modern scientific mapping programs, such as VOSviewer. In this study, we only used Scopus and Web of Science as preliminary search database sources for landslide monitoring, although Google Scholar was also employed in the snowballing approach. Following the selection of a search database, relevant keywords were chosen, namely, “landslide monitoring”, to take into account all accessible datasets for monitoring approaches.

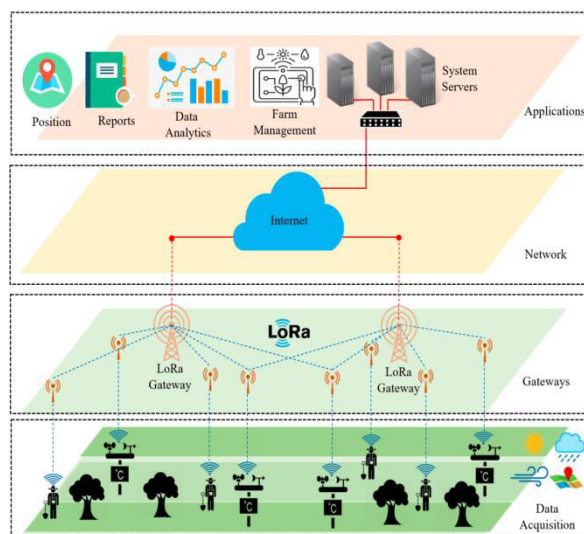


Fig 2: LORA platform

Inclusion and Exclusion Criteria

In any systematic review, inclusion and exclusion are crucial for limiting search results and focusing on the most relevant ones. This research used the following criteria: (1) research focusing on subsurface landslide monitoring, (2) studies published between 2000 and 2023, (3) articles published in peer-reviewed journals, and (4) studies published as articles and review submissions. The exclusion criteria were as follows: (1) papers published in a language other than English, (2) studies with no full text accessible, (3) manuscripts published in a subject area other than engineering, and (4) publications published in a source type other than a journal.

Agriculture is one of the biggest food industries in the world and currently one of the most critical sectors of the economy in many countries due to the great demand for food required by the world population. As food demand increases every day, maximizing food production and minimizing food losses and costs are necessary. With the advancement of Internet of Things (IoT) technologies, more companies and organizations are interested in developing new solutions that enable remote monitoring and control to improve crop productivity. IoT is a promising technology that provides great opportunities to support many new applications and services in different domains such as smart home, smart city, smart industry, smart health, and smart agriculture

IV. RESULT ANALYSIS

This layer includes the different monitoring parameters such as weather conditions, soil moisture and humidity, plant monitoring, machine status, and water monitoring. The farm field includes various sensor nodes, actuators, and measurement devices. These nodes could be fixed sensor nodes, mobile sensor nodes, agro machines, etc. Sensor nodes are used for acquiring different measuring parameters covering, for example, plant, soil, and environment. The main objective of this layer is to enable data transmission with minimum human intervention. This work targets large-scale farms in Chile. The developed sensor nodes are designed to provide real-time tracking of labor activities (human and machines) during harvest for traceability and yield mapping. Furthermore, the system will be used for measuring the field conditions for two fruit species, including blueberry and Hass avocado.

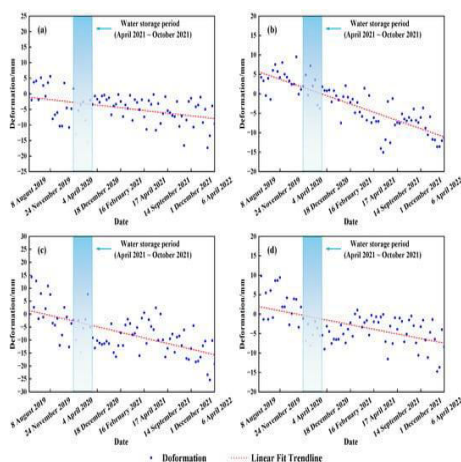


Fig 3: real-time tracking of land activities

Different sensor nodes and measurement devices are installed in the field to collect data (e.g., temperature sensors, soil sensors, weather stations, light sensors, humidity sensors, images, and videos). The collected data are transmitted to gateways or data collection points via wired/wireless communication. Monitoring data from this layer is used to keep track of the crop growth, where different parameters could be adjusted from the control center side, such as irrigation, fertilization, and pesticides.



Fig 4: Monitoring with LORA Platform

The main function of the communication network layer is to enable data transmission from the farm perception layer to the application layer based on different long-range and short-range communication technologies. Such solutions include wired (Ethernet) and wireless (ZigBee, Bluetooth, Wi-Fi, 3G/4G, LoRa, NB-IoT, Sigfox) communication technologies that are used to exchange data with the help of field gateways distributed in the field. Other network equipment includes network switches, routers, gateways, and base station infrastructures. The application layer handles all the data received from sensor nodes and measuring devices via the communication network layer, as well as data storage, analytics, and visualization for different agriculture parameters such as weather conditions, irrigation information, soil quality, etc. The received data allows the end-user to remotely monitor and control farm operations. Thus, the application layer enables farm management, including planning and decision making.

V. CONCLUSIONS

A standalone rockfall and landslide monitoring system, with enhanced environmental monitoring capabilities, was presented, covering the hardware, firmware, and software design of a remote monitoring system, implementing it on low cost hardware and giving a complete view of a real scenario installation. For each element, the following

parameters have been monitored: axial accelerations, temperature, barometric pressure, altitude, relative humidity, gas resistance for air AQI, and battery level. The system is composed of sensor nodes which communicate with gateways in star topology through the LoRa wireless modulation technique, forming a wireless sensor network structure. The WSN was installed in a real scenario, in Pantelleria Island, on rockfall barriers in two risk-subjected locations. The monitoring system is operating in support of safety for local viability and hazard reduction. The hardware structure of nodes was presented, along with the gateway system which allows portable LoRaWAN access using cellular connectivity. Power consumption measurements of the nodes are reported, with considerations on the energetic performances, reporting an energy sufficiency estimated at 2.8 years in absence of solar harvesting interventions. Experimental data extracted from the web user interface are provided for the period of July 2022, showing the measured parameters for different sensor nodes. The inclinations along three special axes, calculated using accelerometric data, do not show significant rockfall events in the reported period. As the sensing elements are placed in two groups at distances that do not allow the environmental conditions to vary in significantly observable manner, the recorded environmental data over the sample period is similar for all the nodes. It is possible to observe different behavior in radio communication due to the unfavorable position of nodes 10–12, with respect to the LoRaWAN gateway. Future developments of this work will be in the optimization of packet transmission in terms of packet loss (as it is possible to observe that nodes that do not successfully reach a gateway introduce information losses), possibly implementing different resource allocation algorithms, such as retransmission-assisted resource management [70]. Other future works will be the introduction of different sensors in the nodes to develop a yet more multifunction-oriented low-cost device.

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