Use of Wireless Sensor Network to Control Landslides Interacting with Infrastructures

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1 Introduction

The occurrence of landslides in slopes, more common in areas under harsh environmental conditions, suppose a high-risk danger for infrastructures located close to the risky point and to the people that live around. In order to minimize this risk, in this work it is proposed a real-time monitoring of landslides with high risk of geological disaster, such as ones formed by easily erodible rocks with water contact, or geographical areas with hard weather conditions along the whole year (water, snow, ice, wind, etc.).

An example where one of these danger areas can be found is the N-634 road, included in the Spanish national roads system, placed in Vizcaya, in the North of Spain, between the cities of Getaria and Zarautz. This road supports a high level of traffic. In this area there is a high risk of landslide according to the literature [2–5]. It is a road which extends along the north face of the Cantabrian Mountain Range, isolated by the Cantabrian Sea and this mountain range. There is a very

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Fig. 1 Overview of Km 22 in N-634 road

unstable weather conditions the whole year due to the peculiar location. In general, the weather conditions are characterized by high relative humidity, copious rains in spring and autumn and abundant snow in winter. Besides, the stratification of this ground is composed by limestones, sandstones and black slates, especially sensitive materials that can be eroded by water and snow. For these reasons, there are frequent landslides in this area during the rainy season.

The stretch road covers a total surface of 9 km long, nevertheless this study is just focused on the km 22, which is near a tunnel between Zarautz and Getaria (Fig. 1), where a high risk slope of 100 m is located with a surface of 22.25 ha.

During last years it has been quite common these kind of problems in this spot. The 6th of December of 2008, there was a huge landslide causing the close of the road for a couple of days. The effect of the landslide can be seen in Fig. 2, showing that the damage was quite significant.

To provide security and environment protection, currently many techniques can be used to measure the inclination of a slope: from classical methods, such as cracking detectors made of two wood boards, to modern techniques like new inclinometer sensors, which can measure vertical inclination at several axis.

Another common problem in this scenario is the monitoring on real time, mainly because landslides are unpredictable. It is necessary to know the conditions of the slope at every time, checking if the displacement has not changed in each point. Thus, one of the most effective solutions is the arrangement of a wireless sensor network (WSN), in such way it will be able to place several nodes in different points along the slope. Each node sends obtained measures to the gateway, so that the communication among nodes allows a continuous flow of information to make possible control the situation on real-time.

Fig. 2 Landslide occurred in the studied spot on 2008

To sum up, the final aim of this work is the implementation of a WSN that measures the inclination of high risk spot through inclinometers [7, 14].

2 Objectives

The goal of this study lies on the development of a capable system of monitoring a slope with high risk of landslides. To that end, it is proposed the implementation of a WSN, working on real time and autonomous enough to run without human intervention in long periods of time.

With regards to the WSN, its tasks to accomplish are:

- Collect the information that comes from the previous fixed spots, by storing all the measures within a database.
- The design of a sustainable source of energy able to provide power to the nodes during long periods of time.
- Reduce costs, either on setting in and maintenance.
- Make possible to cover a large area through long distance communication between nodes.

3 Materials and Methods

3.1 Inclinometer

The LCF196 is a biaxial inclinometer packed in a 22 mm diameter stainless steel case, very hard and appropriate for adverse weather conditions (Fig. 3). This family of inclinometers has three different devices, depending on their maximum

Fig. 3 LCF196 inclinometer

inclination measure range: 14.5, 30 and 90°. In this study after analysing the possible scenarios, it has been used the 14.5° model.

The sensor works with an output voltage between +5 V and −5 V, depending on the inclination angle. The main and starting position is 0 V, which usually takes place on a vertical arrangement. When the inclinometer detects a voltage over ±5 V, the manufacturer of the product cannot ensure a reliable linearity of these values, and therefore the angle of inclination may be incorrect.

3.2 Wireless Sensor Network

A WSN is a group of small devices, called nodes, equipped with sensors [1, 11, 13]. These nodes can communicate with each other by wireless communication protocols, which allow them to monitor any kind of scenario easily and quickly. The main features of a WSN are its energy-saving and its adaptation to the field.

A WSN is formed with two different types of nodes:

- A central node or gateway: its task consists in receiving all the information data from the sensor network and storing it in a database. It is also the gateway to the outside network, since it is possible to send and receive data from other networks.
- Sensor nodes or motes: they are placed in pre-studied important spots of the slope to make measurements during certain periods of time and they send the information collected to the gateway node. Besides, these nodes are totally autonomous and they don't need any kind of wire connection to run.

Table 1 ZigBee vs Bluetooth

	ZigBee	Bluetooth
Consumption transmitting	30 mA	40 mA
Consumption in sleep mode	0.3 µA	0.2 mA
Data transfer rate	250 Kbps	3 Mbps
Maximum length	75 m	10 m
Maximum number of nodes	65353	8

The topology used in this study is based on a star topology, which fits perfectly with the needed requirements of this work. The star topology consists in several sensor nodes placed around a central node or gateway, which is the responsible of receiving messages from the nodes and storing the useful information in a database. In this topology, the key element is the gateway due to the management of all data sent by the nodes. Furthermore, when data is compiled and organized on the gateway, useful information is sent out to a PC connected with the gateway through an internet connexion. In that way, gathered information is available from everywhere and the system is more useful.

Besides, this nodes system follows a fail-safe design, because it might present a fault in any node but the rest of the network would run properly. Although, on the other hand, if the problem lies at the gateway, the whole system will stop working completely and information will not be kept.

3.3 Communication Protocol

The used protocol is ZigBee [8, 9] due to the fact that presents many advantages in regards to other wireless protocols, such as Bluetooth.

Table 1 shows the main differences between Bluetooth and ZigBee. Besides, it is needed to remark that the way Bluetooth works requires a permanent communication, thus devices have to be active most of the time. On the contrary, ZigBee only requires being active during the sending task. Once it finishes, the node automatically enters in a sleep mode which lasts until the next sending operation.

3.4 Imote2

Nowadays Imote2 (Fig. 4) is considered one of the most advanced nodes in market for carrying out this process. Imote2 is an advanced node developed by Memsic, Inc. and specifically designed for WSN. This design is based in a low power consumption CPU, PXA271 XScale from Intel, which works with a very low voltage (0.85 V) and low frequency (13 MHz). A radio frequency (RF) antenna is also integrated within, which allows communication under the IEEE802.15.4/ZigBee standard. The final goal of this device is to work with a low voltage and high performances in a small space, giving it a great versatility.

Fig. 4 Imite2

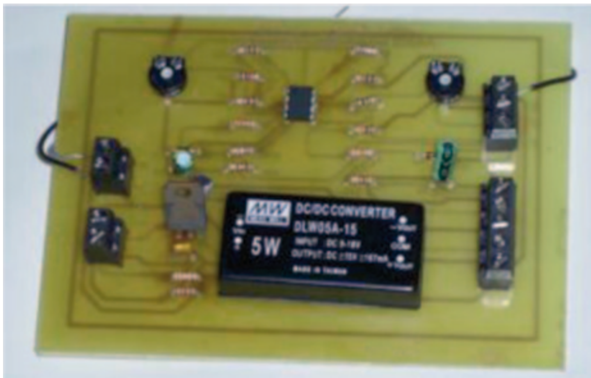

Fig. 5 Signal adapter and source power board

Furthermore, its work possibilities are endless due to several additional boards that can be added to the device and improve the features of the node, thanks to the modular and expandable design based on the expansion board connectors. Besides an operating system (OS) can be installed on it, which is a great help to design and program new applications.

3.5 Signal Adapter and Power Supply Board

Each mote must be equipped with an additional circuit for signal adaptation and for power supply, this is necessary to feed each device installed in the spot (both inclinometer and Imote2). This fact is also totally necessary because the output range of the inclinometer (± 5 V) does not match with the input range of the ADC integrated on Imote2 (0–3 V). Thus, it was performed a small design capable of converting the inclinometer output voltage into the input voltage of the Imote2 ADC. The final result is shown in Fig. 5.

Table 2 Electrical features of each one of the sensor nodes

Feature	Values
Working voltage	12 V
Average current	0.165 A
Nominal power	1.98 W
Daily use time	24 h
Daily current demand	3.96 Ah
Daily power demand	47.52 W

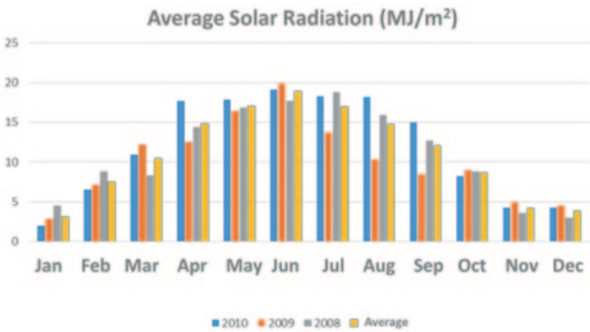

Fig. 6 Solar radiation data from Zarautz during 3 years (2008–2010)

The final conversion is given by Eq. (1).

$$V_{ADC} = 0.3 \cdot (V_{sensor} + 5)V \tag{1}$$

In this way, the voltage obtained can be received by the ADC, without losing any resolution.

3.6 Power Supply

The power supply design represents a critical part of this study, mainly because this power supply reinforces the autonomy of the system without any human intervention [10]. An estimation of the main features of each node, related with the power used by the nodes is shown in Table 2

The implementation of a small size solar panel has been chosen to supply the necessity of power of each node and to provide them total autonomy, so that the results comparing to use regular batteries are improved [6].

Previously to the design of this power supply, it is necessary to carry out a solar radiation analysis of the area where the WSN will be located. This analysis was made with data collected from the meteorological station of Zarautz, a city close to the study spot, which has measured its solar radiation for several years. Data obtained from this weather station during 3 years (2008–2010) are shown in Fig. 6.

As it can be seen in Fig. 6 during the winter solar radiation is less intense than in summer. Taking this into account, the total sun energy in a year was calculated in order to estimate the life of the batteries, trying to avoid any kind of uncharged element during the project life. This analysis estimates that a power of at least 27 W can be obtained from the solar panel. Therefore, a solar panel of nominal power equal to 30 W was the chosen, being these 30 W more than enough to supply energy to each mote, and using solar panels of small dimensions to reduce the environmental impact as much as possible.

3.7 Software

Imote2 can work under different operating system (OS); in this study, after analysing advantages and disadvantages, the OS Linux was chosen. The main reason was the versatility and simplicity to program under C language. Moreover, the programming methodology is very similar to the required in a desktop computer, with only one difference, it is necessary a cross compiler due to the Imote2 microprocessor architecture.

The developed software is based on four different processes: acquisition, sending, reception and register.

- Acquisition: process that reads measures from the sensor through the ADC; subsequently these measures are collected by the mote. It is advisable to bear in mind the relation between the digital value and its proportional inclination, this value is given by Eq. 2, where "D" responds to the data measured.

$$Angle = 7.08 \cdot 10^{-2} \cdot D - 14.5^{\circ} \qquad (2)$$

- Sending: process that transmits data from the mote to the gateway.
- Reception: the gateway accomplishes this action, where is constantly alert to receive data coming from the motes.
- Register: this action is accomplished by the gateway, where the received data is converted to readable information and stored for further interpretations. Besides, this function keeps the gateway always alert, waiting for the request of sending data from a PC.

3.8 Position of Nodes and Inclinometers in the Field

The last step of this work is the positioning of each node in their exact position, according to Suarez [12].

- It is really important a good positioning of the nodes at a medium height, between the road and the highest point of the slope, otherwise the measurement will not be accurate (Fig. 7).

Fig. 7 Comparison between different motes location along the slope

Fig. 8 Location of each node

- Furthermore, there must be a distance of 20 m between the measurement spots. The most convenient location of the nodes is in line, with equidistant distances between them (Fig. 8), in a way that finally the system can cover around 100 m.

4 Results

This system has not been implemented in the suggested area yet, but the laboratory experiments were very successful. Sending and reception between sensor nodes and the gateway work correctly, and data measurements registered match perfectly with the inclination of the inclinometer (Fig. 9).

The power supply provides energy to the inclinometers, which measure the inclination on each location, and the wireless nodes, which are in charge of the transmission to the gateway. Once information is obtained from the sensor, the signal is treated to adjust the real value in each mote. Each mote processes the measure and sends messages to the network without losing packets. Besides, the gateway receives the messages sent by the motes and redirects them to a central station, where all the information will be stored.

04/04/2012	12:04:10	2,48492	-0,44620
04/04/2012	12:04:14	2,46368	-0,43912
04/04/2012	12:04:18	2,47076	-0,41788
04/04/2012	12:04:22	1,56452	4,41068
04/04/2012	12:04:26	0,79280	-0,46744
04/04/2012	12:04:31	8,73656	0,89192
04/04/2012	12:04:35	10,87472	0,58748
04/04/2012	12:04:39	10,40744	0,85652
04/04/2012	12:04:43	5,93288	0,90608
04/04/2012	12:04:48	3,53276	1,52912
04/04/2012	12:04:52	-0,21256	2,20880
04/04/2012	12:04:56	-3,96496	3,65312
04/04/2012	12:05:00	-8,17756	4,58060
04/04/2012	12:05:05	-12,46096	0,49544
04/04/2012	12:05:09	-1,16128	0,15560
04/04/2012	12:05:13	-0,62320	3,96464
04/04/2012	12:05:17	0,62996	6,01784
04/04/2012	12:05:21	1,06184	9,85520
04/04/2012	12:05:26	0,89900	10,70480
04/04/2012	12:05:30	-1,48696	-1,29580
04/04/2012	12:05:34	-1,64980	-4,76500
04/04/2012	12:05:38	-2,76136	-7,92976
04/04/2012	12:05:43	-4,39684	-12,09988
04/04/2012	12:05:47	-5,32432	-13,89112
04/04/2012	12:05:51	-0,01432	1,00520
04/04/2012	12:05:55	0,14852	1,67780
04/04/2012	12:06:00	1,35212	1,80524

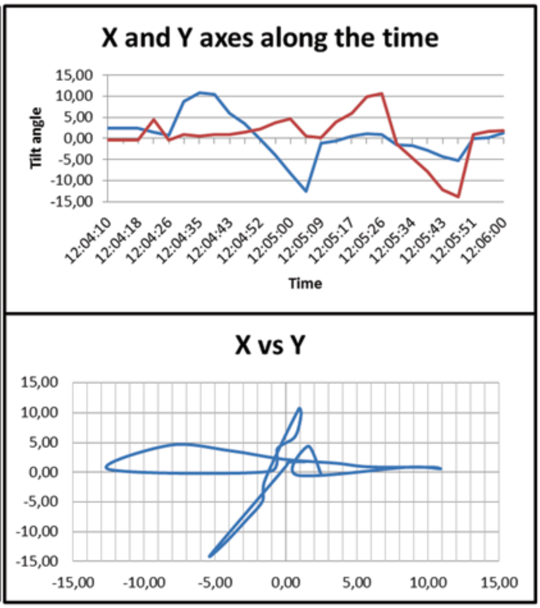

Fig. 9 Example of gathered information and graphs of obtained measures in laboratory

And finally, the stored information is used to show the inclination of the two axes measured by the inclinometer. In each message, the time and date of when the signal was read, and the identifier number of each node are sent. Through this information, a proper monitoring of the network can be performed with the aim of prevent future possible landslides in the area.

5 Conclusions

A WSN has great potential benefits in this kind of scenario, mainly because it is based on a group of spatially distributed autonomous sensors that monitor physical or environmental conditions. Therefore this kind of systems, more specifically the one proposed, can be applied to situations where inclination measures are required, such as different kind of infrastructures or areas with seismic activity.

These networks can be placed in areas where wired networks cannot be situated or where the installation costs become too expensive, thanks to their special features like scalability, ease of use, nodes heterogeneity, adaptation to the environment, power awareness, among others. Moreover, according to the work carried out in this study, it is possible to add new nodes anytime without any kind of reprogramming, just copying to the new nodes the code developed, what means an advantage for further scalability of the system.

To sum up, this work has shown through reliable data and several tests, the multiple advantages that these networks based on autonomous nodes have and how can monitor uneasy locations with accurate and affordable results.

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