Wireless Geophone Network for Remote Monitoring and Detection of Landslides

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Abstract— **Recent years have shown an alarmous increase in rain fall induced landslides. This has facilitated the need for having a monitoring system to predict the landslides which could eventually reduce the loss of human life. We have developed and deployed a Wireless Sensor Network to monitor rainfall induced landslide, in Munnar, South India. A successful landslide warning was issued in June 2009 using this system. The system is being enhanced by incorporating a Wireless Geophone Network to locate the initiation of landslide. The paper discusses an algorithm that was developed to analyze the geophone data and automatically detect the landslide signal. A novel method to localize the landslide initiation point is detailed. The algorithm is based on the time delay inherent in the transmission of waves through the surface of the earth. The approach detailed here does not require additional energy since the geophones are self excitatory. The error rate of the approach is much less when compared to the other localization methods like RSSI. The proposed algorithm is being tested and validated, in the landslide laboratory set up at our university.**

Keywords- **Geophone based Localization, Landslide detection, Wireless Geophone.**

I. Introduction

Landslides are a common disaster in the western ghat region of India. In the year 2010 rainfall induced landslides in the Western Ghats region of south India have caused wide damages to human life and property. The damages to human life could have been reduced by properly monitoring and prediction of these landslides.

We have developed and deployed a Wireless Sensor Network (WSN) based system to monitor and predict rainfall induced landslides. The deployment was done in Munnar, one of the Landslide prone areas in the Western Ghats, India.

The system consists of more than 50 sensors including the pore pressure transducers, dielectric moisture sensors, strain gauges, rain gauges, tiltmeters, and geophones. The dielectric moisture sensor detects the level of water saturation in the soil. Strain gauges sense any deformation movement. Tiltmeters are used to validate the strain gauge measurement. A geophone is used to record the ground vibrations [1]. Different combination of these sensors are interfaced to and deployed in several Burried Sensor Columns (BSCs).

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This paper focuses on the geophone sensor based system that was developed to detect the initiation and localize the point of initiation of the landslide. The Wireless Geophone Network was developed as an enhancement to the presently deployed system in Munnar with a view to automate the alarm dissemination. The localization is based on Time delay of arrival (TDOA) based multilateration.

The remainder of the paper is organized as detailed. Section II describes related work in landslide detection and signal processing. The system architecture and design is elaborated in section III. Section IV describes the signal processing algorithm for detecting the initiation of the slide and Section V details the localization algorithm. Finally, section VI concludes with brief description of future work.

II. Related Work

Reference [3] has developed a system to detect the ground vibrations using geophones. The detected ground vibrations are processed to produce audio output. Reference [4] discusses how to distinguish between ground vibrations and noise thus clearing the data received by the geophone. Reference [5] uses geophones to provide early warnings for landslides. This system used Mobile phones and local alarms to issue the warnings. Reference [6] uses geophones to locate where the landslide is about to initiate.. The landslide initiation point is located by analyzing the measured distances between the sensor columns of a WSN. This was a simulation study. Reference [7] details a method for localization in a mobile sensor network. They have used few seed nodes with GPS capability.

A WSN for detecting rainfall induced landslides has been fully operational, three years prior to this paper. A successful warning was issued during the monsoon 2009 using the system. The warning issued facilitated evacuation and disaster management in the area. The alerts were online streamed through the internet. This paper describes the incorporation of a Wireless Geophone Network (WGN) to the existing system with enhanced

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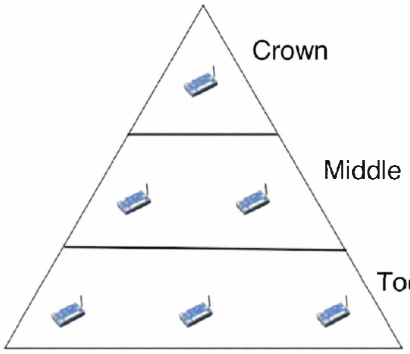

Figure 1: Triangulation method for Deploying the nested Geophone

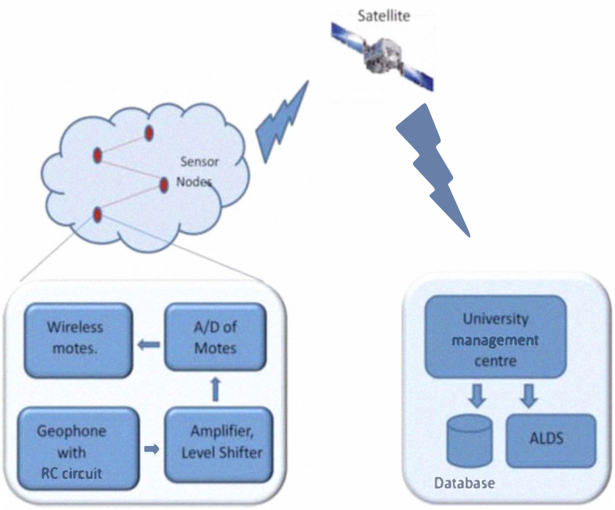

Figure 2: WGN Architecture

capabilities of automatically detecting the initiation of the slide. The system could also be used to localize the point of initiation of the slide. The approach detailed here does not require additional energy since the geophones are self excitatory. The error rate of the approach is much less when compared to the other localization methods like RSSI.

III. WGN ARCHITECTURE

The WGN system consists of sensor nodes equipped with geophones and the associated interfacing circuits. A geophone is a transducer which senses vibrations and converts them into an electrical signal. The ground vibrations are 3-Dimensional waves with a longitudinal segment called the P waves, transverse segment called the O waves, and the surface waves called the S waves. Since geophones respond only to waves vertical to their axis a 3C or 3 axis Geophone was used in the WGN system [8].

Geophones are very sensitive self excited sensors so the electrical signal from the geophone needs proper signal conditioning. The raw signals from a geophone is first amplified and then filtered to remove the noises.

The design and spatial distribution of geophysical sensors on the BSC are determined by different factors such as: the number of soil layers, layer structure and properties, the presence of impermeable layers, water table height, bed rock location, depth of the bore hole for deploying the BSC, and the specific deployment method required for each geophysical sensor. The impermeable layers of soil allow water to gather, creating a perched water table, which loosens the soil particles [13]. So theoretically speaking it is the impermeable layers which lead to slope instability, so minimum of one geophone is deployed in each of the identified impermeable layers.

The nested geophone assembly could help in identifying the area, depth and specific layer which causes the instability. As shown in fig 1, the density of geophones decreases from toe of the hill to crown of the hill. It is the toe region of the hill, where the landslide initiates so the more set of nested geophones are deployed at the toe when compared to the crown and the middle region of the hill.

These nested geophones are connected to wireless sensor node on the top of the BSCs. This will sample, collect, and transmit the data to its higher layer network. Each sensor node collects and relays data to higher cluster levels wirelessly. Once the data reaches a base station the data is sent over a satellite to the University Management Centre (UMC) where it will be stored in a database and further processed to automatically detect a possible landslide. A positive outcome from such an analysis will trigger the initiation of localization algorithm. A representation of the system is shown in figure 2.

IV. DETECTION OF LANDSLIDE INITIATION

The WGN was developed with the sole aim of automatically detecting the initiation of the landslide and produce necessary alert. In order to achieve this it is necessary to classify the landslide signals among other noises. To prevent the false alarming, the classified signals are correlated with the readings from other sensors. Once a positive outcome is obtained from the correlation analysis the landslide signals are further processed to do a localization and prediction of the initiation point.

A. Classifying landslide signals

Classifying the landslide signal is a two level process. The first step includes a digital band pass filtering of the signal received in the UMS. The seismic vibrations are usually within the range of 0.1 to 5 Hz [5]. The filter was designed with these cutoff frequencies.

The second step in classification of the landslide signals involves a threshold based peak detection algorithm. Mario et. al. [3] suggested that landslide signals are high amplitude signals with an approximate lowest peak voltage around 200 mV. Signals above this threshold, of 200mV, are classified as landslide signals. Only these classified landslide signals are transmitted to the UMC.

According to the Nyquist Criteria the normal sampling rate of the geophone should be greater than twice the resonant frequency. This means that geophones require a high sampling rate. When monitoring 24/7 this could increase the load on the network. To combat this extra load, the landslide signals are distinguished from the noise, using the threshold algorithm. This allows only the landslide signals to be sent over the network therefore reducing the data load.

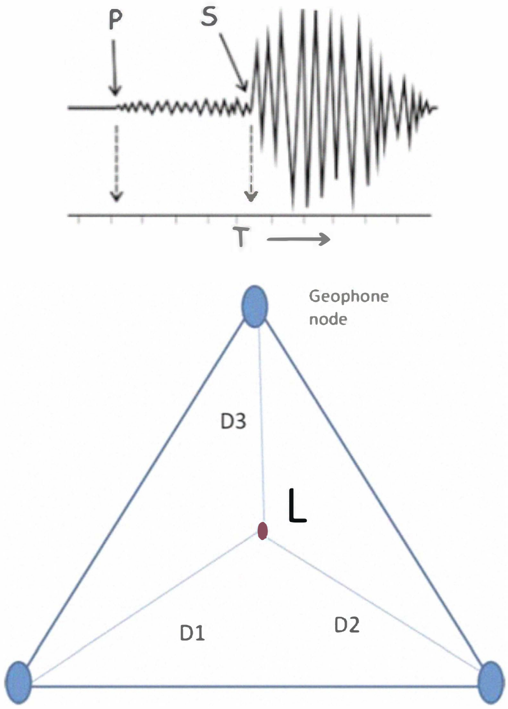

Figure 3: a) Shows the delay in the reception of P waves and S waves. [15] b) Shows geophones placed using Triangulation method. L is the point of origin of the slide and it is distanced D1, D2, D3 from the geophone nodes placed at the edges of the triangle.

B. *Correlation based Confirmation of Slope Instability*

This step ascertains the slope instability and is necessary to have a false proof warning [11]. If a geophone registers a landslide signal this would indicate that there is a chance that a nearby geophone will also register the same landslide signal. But there will be a time delay in the reception of signals at the geophones in this context. The time delay is equivalent to the time taken for vibration to traverse the distance between the two geophones. The time delay (Δt) could be determined as shown in Eq (1).

$$\Delta t = D/v \qquad (1)$$

Where D is the distance between the BSCs, and v is the velocity of the wave in soil [13]. The velocity of sound in soil is pre calculated. If the neighboring geophone does not report a landslide signal within this calculated time delay the landslide signal will be classified as spurious.

V. LOCALIZATION OF LANDSLIDE INITIATION

The localization algorithm is an extension of the multilateration. The minimum number of nodes for the algorithm to work is three. As the number of nodes scales the error in the estimation decreases [15]. The developed algorithm involves two stages. The first step is to calculate the distance of the initiation point from the receiver nodes in the reception of the signals. The second step is to find localize the point of initiation from the calculated distances.

A. *Distance of the initiation point*

The calculations are done based on the velocity of vibrations through the ground. Consider a point L (fig 3.b) where the landslide initiates. Let it be D1, D2, and D3 distances from three geophone nodes. There will be a delay (Δt) in the reception of the P waves and the S waves in each geophone node (figure 3.a). The velocity of P-wave be Vp km/s and that of S-wave be Vs km/s. Then the distance D travelled by the wave could be calculated using Eq (2)

$$D = 22.63 * \Delta t / (Vp - Vs) \qquad (2)$$

Using the Eq (3) [14] the distances D1, D2, D3 as shown in figure 4.b could be calculated.

B. *Locating the initiation point*

The point of origin of the slide will be the intersection point of the three spheres around the geophone nodes with radius defined by D1, D2, and D3. The geophone nodes are stationary and are equipped with GPS. The solution for the spheres when the coordinates for the centre and radius is given, is as shown in Eq 3. Where (x_1, y_1, z_1), (x_2, y_2, z_2), (x_3, y_3, z_3) are the coordinates of the geophone sensor nodes. Solving the equations will give the point of intersection of the three spheres, which will be the initiation point of the landslide.

$$(x - x_1)^2 + (y - y_1)^2 + (z - z_1)^2 = D_1^2$$
$$(x - x_2)^2 + (y - y_2)^2 + (z - z_2)^2 = D_2^2$$
$$(x - x_3)^2 + (y - y_3)^2 + (z - z_3)^2 = D_3^2 \qquad (3)$$

V TESTING AND VALIDATION IN THE LANDSLIDE LABORATORY SET UP

The design has been tested in a medium scale landslide setup at the University. The medium lab setup is 2 meters long by one meter wide by 0.5 meters tall rectangular box capable of holding 0.6 meters of soil. The setup is capable

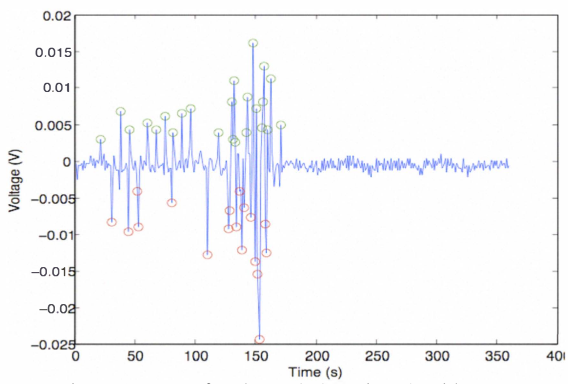

Figure 4 : Data after the peak detection algorithm.

of mechanically simulating the different slope angles of a landslide prone area. It is also able to simulate various levels of seepage and rainfall rates. The soil is packed into the lab setup along with the associated sensors for the experiment. Water is then added in the form of rainfall and seepage, until the slope fails. The setup helps in testing, calibrating the various sensors in before field deployment. It also helps in better understand the nature of landslides. WGN testing was done with a slope angle of 35^0 at the lowest seepage rate possible.

Figure 4 shows the output from a threshold based peak detection algorithm. The circled peaks are the peaks which correspond to the landslide vibrations.

VI CONCLUSION AND FUTURE WORK

We have deployed a Wireless Sensor Network (WSN) for predicting landslide. A nested Wireless Geophone Network and associated signal processing algorithm was integrated with the existing system to enhance its capabilities. The design was formulated from various recent works in the area and our experience from the pilot deployment. Such a system is more effective in localizing the slip location and detecting the direction of movement of the soil layers. Since geophone is a self-excited component, it helps in reducing the power constraint on the design of the system. The signal processing algorithm also takes care of reducing the load on the WSN by selected sampling of geophone data.

The technique used for localization combats the disadvantages related to other multilateration methods. Also the error in the estimation could be reduced by increasing the number of receiving nodes. When there is no common point of intersection then optimization methods have to be called into scenario. Effective localization can be used to predict the direction the slide will take.

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