# Signal Processing for Wireless Geophone Network to Detect Landslides

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Abstract— Rain fall induced landslides are a common cause of damages to life and property in the Western Ghats region in south India. Work have been in progress to develop a monitoring system to predict the landslides to 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. This paper discusses the enhancement of the existing system by incorporating a Wireless Geophone Network to locate the initiation of landslide, and the direction and velocity of motion of the slide. A nested geophone methodology and triangulation method was designed to collect and analyze the relevant signals. A novel signal processing algorithm was developed to analyze the geophone data and automatically detect the landslide signal. A feedback method used to reduce the traffic congestion in the network is also detailed here. The design and developed system was tested and validated, in the landslide laboratory set up at our university, for which results are shown in this paper.

# Keywords- Geophone Signal Processing, Landslide detection, Wireless Geophone.

#### I. INTRODUCTION

Landslides are a common disaster in the western ghat region of India. In the past they have caused wide damages to human life and property. In order to reduce the damages monitoring and prediction of landslides are being developed.

We have developed and deployed a Wireless Sensor Network (WSN) to monitor and predict rainfall induced landslide. The deployment was done in Munnar, one of the Landslide prone areas in the Western Ghats, India. The wireless technology has provided solutions to monitor otherwise inaccessible and remote areas. A successful warning was issued during the monsoon 2009 using the system. The warning issued facilitated evacuation and disaster management in the area.

The system consists of more than 50 sensors including the pore pressure transducers, dielectric moisture sensors, strain gauges, rain gauges, tiltmeters, and geophones. The

This work is a part of Wireless Sensor Network for Real-time Landslide Monitoring project, funded by Department of Information Technology (DIT), India. 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 was used to record the ground vibrations [1]. Different combination of these sensors are interfaced to and deployed in several Deep Earth Probes (DEPs).

This paper focuses on the geophone sensor, the design of the interfacing circuits and related signal processing algorithm. Geophones can produce readings that, once analyzed, can locate the beginning position of movement and thus predict the direction of motion. This wireless geophone network will be incorporated with the existing system, wireless network for landslide detection, and early warnings will be real-time streamed to the internet.

The remainder of the paper is organized as detailed. Section II describes related work in landslide detection and signal processing. The design is elaborated on in section III. Section IV describes the signal processing algorithm. Finally, section V concludes with brief description of future work.

#### II. RELATED WORK

Krohn et al. explains how to place the geophone properly in the ground, accentuating ground coupling to provide worthwhile data [6]. Baule et al. has developed a system to detect the ground vibrations using geophones [7]. The detected ground vibrations are processed to produce audio output. Shinji discusses how to distinguish between ground vibrations and noise thus clearing the data received by the geophone [4]. Arattano et al. uses geophones to locate where the landslide is about to initiate [5]. The landslide initiation point is located by analyzing the measured distances between the sensor columns of a WSN. This was a simulation study. Mario et al. used geophone data to indicate the direction of movement of the landslide [3]. Zan et al. uses geophones to provide early warnings for landslides [2]. This system used Mobile phones and local alarms to issue the warnings.

A WSN for detecting rainfall induced landslides has been fully operational, three years prior to this paper. The deployed system is capable of issuing local alarms as well as online streaming through internet. This paper describes the incorporation of a Wireless Geophone Network (WGN)



Figure 1: Flow diagram showing geophone data processing

to the existing system. The WGN has been tested and validated in a medium sized laboratory set up at our University. Results of the tests are presented in this paper.

### III. WIRELESS GEOPHONE NETWORK

The developed WGN is capable of enhancing the existing WSN system by automatically predicting the initiation point of the landslide. The system is also capable of predicting direction and velocity the landslide will take. A geophone is used to capture the vibrations induced during the landslide event. It is a transducer which senses vibrations and converts them into an electrical signal. The electrical signals from the geophone are enhanced and transmitted through the wireless network. At the receiving end the data is analyzed and processed.

Not all vibrations obtained from the geophone can be associated to a landslide. So the data from the geophone requires noise isolation and analysis. This can be achieved by proper signal conditioning and processing. Furthermore, an important role is also played by the appropriate selection and placement of geophone.

#### A. Geophone Selection

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. Geophones respond only to waves vertical to their axis [8]. So we may need three geophones oriented orthogonal to each other to capture all the three waves. For our pilot deployment, we begun with the one dimensional geophone, buried deep in a bore hole. So to capture the vibrations, created during the horizontal movement of soil, the geophone was placed perpendicular to the surface of earth. However this one dimensional geophone having three individual geophones oriented orthogonal to each other and is selected to be used in the new WGN. The 3C geophone helps to determine the direction of movement of soil layers.

Incorporating all these ideas it was decided to implement 3C geophones in our existing monitoring system. The three individual geophones are designed to be connected in series and reference [7] claims that this is effective when needing to sense very low frequency infrasound ground vibrations.



Figure 2: DEP with nested geophone assembly. Note the 3C geophone is placed in three sensitive layers.

#### B. Signal Conditioning

The geophone data is preprocessed to reduce the noise, and increase the SNR. As shown in Figure 1 the preprocessing of the geophone data involves amplification, filtering, level shifting, A/D conversion.

Landslide induced vibrations are very small, usually in the range of 200 mV. Active amplifier with high input impedance, in the range of 10-100 M $\Omega$ , was chosen to measure these small range vibrations. The reference [9] describes one of the advantages of high input impedance is that; it ensures a negligible load on the geophone and avoids a reduction in dynamic resolution. The amplified data is filtered using an active low pass filter. The data loss is minimized by using a high cutoff frequency filter.

The filter is accompanied by a level shifter. Geophones act as an AC voltage sources; as such the geophone data contains both positive and negative values. Since wireless sensor motes work only with positive values, the negative geophone readings need to be represented as positive values. This task is performed by a level shifter. The level shifted data is then fed to the WSN interface, where it is converted to a digital signal and further processed to be sent over the wireless network. The data is relayed through the network cluster to a base station. The geophone data is then sent through a satellite link and finally received at our University Management Server (UMS) to be further analyzed.

# C. Geophone Placement and Integration with the Other Sensors

Landslide event detection requires specific design of DEP in each location. The design and spatial distribution of geophysical sensors on the DEP 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 DEP, and the specific deployment method required for each geophysical sensor.

The soil is made up of impermeable and permeable layers. 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 and are the ones which requires close monitoring. In each of the bore hole interbedded permeable and impermeable layers can be witnessed. A minimum of one geophone is deployed in each of the impermeable layers. Figure 2 shows the new design with nested geophone assembly.

Bore holes are drilled and the DEPs with nested geophones are placed in it. The nested geophone assembly could help in identifying the area, depth and specific layer which causes the instability. These nested geophone assembly are deployed in such a way that they perform a triangulation technique as shown in fig 3. 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 DEP. This will sample, collect, and transmit the data to its higher layer network.



Figure 3: Triangulation method for Deploying the nested Geophone

# IV. WIRELESS GEOPHONE SIGNAL PROCESSING

The main aim of the signal processing is to automatically identify the landslide induced vibrations, confirm their relevance and produce an alert. In order to achieve these goals it is necessary to classify which vibrations are spurious noises or landslide induced vibrations. A three step noise removal technique is used. The first level is a regular filtering followed by a threshold based classification. The classified signals are then correlated with the signal from the neighboring DEPs. These steps make sure that we have a false proof automatic detection. Once the signals are labeled as landslide signals, they are analyzed further to predict the direction the slide will take and to localize the starting point of the slide.

#### A. Digital filtering

Geophones indiscriminately register all sorts of vibrations from traffic, human walking and land movement etc. In this scenario all vibrations other than those caused by land movement are not relevant and require nullification. Landslide induced ground vibrations are generally of low frequency, below 5 Hz. A person walking on the surface could induce a vibration around 20 Hz and higher [10]. A digital bandpass filter was used to remove irrelevant vibrations from the signal. This is a very crucial step since any vibrations other than landslide signal could corrupt further interpretation.

#### B. Threshold based Classification

The filtered signal is now ready for analyzing. The first method of analysis is to check the data against a threshold. As suggested in Mario et. al. [3] landslide signals are usually of high amplitude and their approximate lowest peak voltage is around 200mV, so this was chosen as the threshold. Signals above this threshold, of 200mV, are classified as landslide signals. Only these classified landslide signals undergo further processing.

### C. Vibration detection for confirming the slope instability

The purpose of this step is to provide a false-proof system, to further classify which vibrations are spurious noises or landslide induced vibrations. This is done with a correlation analysis method introduced by Terzis et al [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 ( $\Delta t$ ) could be determined as shown in Eq (1).

$$\Delta t = D/v \tag{1}$$

Where D is the distance between the DEPs, 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 initial landslide signal will be classified as spurious.

#### D. Localization of landslide initiation

The calculated time delay between geophones reception, as previously discussed, can also be used to localize the starting point of a landslide and also predict the direction the land will slide. To sense land movement, each geophone (contained in a DEP) is strategically placed in the ground of the landslide prone area. When the land moves the DEPs also moves. This movement can be calculated by knowing the initial distance between each DEPs. If  $D_1$  is the distance between DEPs before the landslide initiation and  $D_2$  is the distance after then d2 could be found using the relation shown in Eq 2.

$$D_1/D_2 = \Delta t_1 / \Delta t_2 \tag{2}$$

 $\Delta t_1$ ,  $\Delta t_2$  are the time delays before and after the landslide initiation.

# *E.* Effective data collection and aggregation for reduced traffic congestion

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 a threshold algorithm. This allows only the landslide signals to be sent over the network therefore reducing the data load. Our system is based on three levels of warning. A first level landslide warning is given when moisture sensor readings cross a threshold value. A second level landslide warning is given when the pore pressure sensor readings cross a threshold value. A third level landslide warning is given when geophone sensor readings register a confirmed landslide signal. It is the geophone results that confirms a landslide is definitely about to occur.



Figure 4: Data from geophone without filtering at source. The data is clogged with noise.

All minute variations in geophone data could be relevant to landslide prediction; therefore adaptive sampling has been developed. Adaptive sampling involves varying the sampling rate of the geophone dependent on level of warning. The sampling rate of the geophone will increase with each higher level of warning. When a third level of warning is given the sampling rate will be almost thrice that of the sampling rate at a first level warning stage.

## 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 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.

The lab setup was used to establish the most effective placement, for the geophones, in a landslide scenario. In the first few tests, the geophones were placed in a straight line from toe to crown. Straight line placement of the geophones resulted in observing that the initiation of the slide happens from the toe. Therefore a decision was made to place more geophones at the toe than at the crown. This technique is known as triangulation and is further outlined in Figure 3. Tests were carried out to establish the necessity of using an active low pass filter in the interfacing circuit to remove noise. Figure 4 shows the results of not using the active low pass filter and Figure 5 shows the active low pass filter in use. Comparing figure 4 & 5, it is apparent that data can get clogged with noise, and this makes it difficult to recognize



Figure 5: Data from geophone with an active filter. The data is acquired from the test done in our medium landslide lab set up. The peaks represent the landslide induced vibrations.



Figure 6: Data from geophone without filtering at source. The data is clogged with noise.

the peaks. These peaks are the actual landslide signal. Figure 6 displays the output from the vibration 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. To enhance the capabilities of this deployment we proposed a nested wireless geophone network and associated signal processing algorithm. The design was formulated from various recent works in the area and our experience from the pilot deployment. In our pilot deployment we have done a prototype using one dimensional geophone. In the proposed design we use a 3 axis geophone. 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 rate of sampling differs for each level in our three tier warning system. These proposed design changes will help to build a more effective warning system for landslides.

Our pilot deployment was for landslide prediction. In future the system will be extended to monitor avalanche, debris flow and earthquakes. When it comes to debris flow geophones could be used to calculate the mean flow velocity. Furthermore we will be developing a system to image the layers of earth using the geophone. The application of such a system could help localize the slip and advanced prediction of events.

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