Integrating Geophone Network to Real-Time Wireless Sensor Network System for Landslide Detection

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Abstract— **Recent years has show an increase in the occurrence of natural disasters, threatening human life and property. Early warning systems could help in reducing the impact of such disasters. We have designed and deployed a real-time wireless sensor network for landslide detection, in one of the landslide prone areas in India. The current wireless sensor network for landslide detection system is real-time, 24/7 operational and uses heterogeneous wireless networks for reliable data delivery. This research work proposes to incorporate wireless geophones to detect and analyze ground vibrations that may arise before, during and after the landslide. A nested wireless geophone methodology is designed to collect and analyze the relevant signals. The proposed system incorporates a novel signal processing algorithm, to detect landslides. Pilot deployment has been performed with one axis geophone, and the new design of nested 3C geophone will be implemented and validated in our existing system. The newly developed Wireless Geophone Network captures the slope instability vibrations. This data is analyzed and used for disseminating landslide warnings.**

Keywords- Wireless Geophone; Landslide Detection.

I. Introduction

Natural disaster such as landslides, debris flow, avalanches, earthquakes have gained importance as a subject for monitoring in recent years. The main aim of such a monitoring is to understand the way they occur and possibly predict their occurrence. An advanced warning of such an event could help in taking emergency measures like evacuation of the area, blocking the traffic or human movements in the disaster prone area.

A landslide is an event where a part of earth slips down a steep surface. A debris flow is a mass flow of earthen material mixed with water. Both these phenomenon are common in hilly area during heavy rainfall. While an avalanche is similar to landslide but it is mass movement of snow. An earthquake is the mass movement of the molten material from the centre of the earth. These disasters induce vibrations which travel within the surface of the earth. Analyzing these vibrations and correlating it with the occurrence of such disaster could lead to a system for advanced monitoring. But to have a fool proof system, monitoring should not be restricted to vibrational analysis. There are other parameters that could also be monitored. For example in landslide could monitor the pore pressure response, changes in the shear strength of the soil [1].

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The onset of wireless technologies had helped in monitoring otherwise dangerous and inaccessible sites such as active volcanoes, remote locations. Wireless sensor networks (WSN) are now used for real-time monitoring of landslides and other related events.

Our pilot deployment of WSN was done for detecting landslide at Anthoniar Colony, Munnar Idukki (Dist), Kerala, India. This site has been well known for its repeated landslides in the past. We deployed several Deep Earth Probes (DEP) containing dielectric moisture sensor, pore pressure piezometer, tiltmeters strain gauges and geophones. The dielectric moisture sensor detects the level of water saturation in the soil, while strain gauges sense any deformation movement and the tilt meters is used to validate the strain gauge measurement. Geophones were placed externally and are connected to the wireless node of DEP. Fig.1 shows the schematic of the assembly. From our pilot deployment we learned geophones could be utilized effectively to reduce the system power constraints, and cost. The geophone can also be used to localize the slip and predict the direction of motion. Incorporating all these ideas a more effective design for geophone in landslide detection is presented here.

The remainder of the paper is a organized as follows. Section II describes related work in landslide monitoring using geophone. In Section III, we describe the architecture of the system, Section IV explains the design considerations for the geophone, and Section V details the signal processing algorithm. Finally, in Section VI, we conclude with brief description of future work.

II. Related Work

Zan et al. deployed an early warning system for landslides where they have used geophone for sensing the seismic noise [2]. The paper elaborates the data acquisition, data management and warning issued through mobile phones, local alarms. Terzis et al. details a method for localization of slip surface using WSN [3]. They used geophones to analyze distances between the sensor columns. Such analysis could help in identifying columns which

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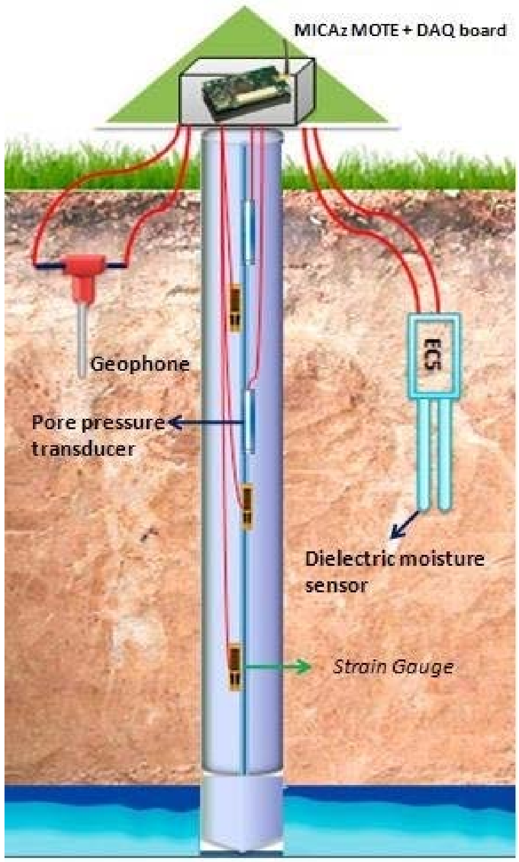

Figure 1. Schematic of Deep Earth Probe (DEP). [1]

moved and the direction of motion. Details of systems and sensors needed to monitor the debris flow are described in [4]. They have done a study on advanced and event monitoring systems. Krohn describes lab-based study on coupling of geophone [5]. The reference stresses on how the placement of geophone in loose soil could interfere the proper reception of the signal. They have carefully modeled field techniques in the lab to validate the study.

III. Architecture of Wireless Geophone System

Wireless geophone network is designed to incorporate with the existing real-time wireless sensor network for landslide detection system [1] at Munnar, India. The existing system consists of 20 wireless sensor nodes and 50 geological sensors that are capable to monitor the changes in moisture content pore pressure, and movement. The system is 24/7 operational and capable to deliver real-time warnings via internet and local alarms. The proposed Wireless Geophone Network (WGN) is capable to capture the slope instability vibrations and these data will contribute in issuing a reliable landslide warning. The newly designed WGN could be enhanced by incorporating a localization algorithm to locate the initiation point of landslide. The proposed localization algorithm could be used to analyze the velocity and the direction of motion of the slide. The

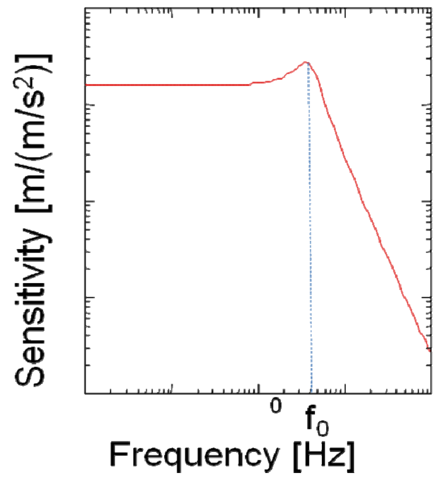

Figure 2. Graph showing the relationship between the geophone sensitivity and frequency of operation . Note the fall in sensitivity after resonant frequency (f_0).

prototype system is incorporated with the existing deployment.

IV. Design of Wireless Geophone System

Disastrous events such as landslides, earthquakes, debris flow and avalanches involve movement of soil or snow layers. This will generate ground vibrations that travel through the surface of earth. These signals can be captured efficiently using geophones. Geophones are self-excited and this is one of the main advantages for long term monitoring.

A geophone is a transducer which senses a vibration and converts it into a relative electrical signal. The electrical signals from the geophone are enhanced and transmitted through the wireless network. These data are stored and analyzed in the data management center at our University.

The geophones are efficient in capturing minute ground vibrations for landslide monitoring and detection. However this requires the proper designing of the interface circuit, signal processing algorithms, selection of geophones with correct operational frequency and bandwidth.

A. Operational Frequency and Bandwidth

An important feature to be considered while selecting the geophone is its resonant frequency and bandwidth. The sensitivity of the geophone falls rapidly beyond the resonance frequency, so the frequency of application should lie below the specified resonant frequency. Fig. 2 shows the Sensitivity Vs Frequency relationship of a geophone. Note the fall in sensitivity after the resonant frequency (f_0).The seismic waves are normally in the range of 1-15 Hz [6]. For our work a geophone with a resonant frequency of 10-20 Hz was selected. Furthermore geophone should be able to sense both low frequency initial vibrations and high frequency

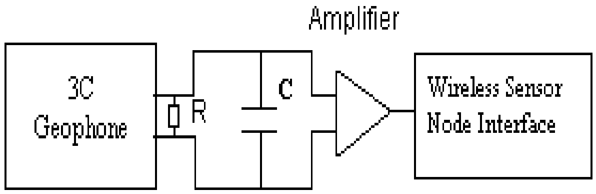

Figure. 3 The geophone circuit. R is the damping resistance. C is the filter capacitor.

vibrations during the course of event. So we need wide bandwidth, but not too wide to allow high frequency stray signals.

B. *Selection of Geophone*

Geophones are of different types, one dimensional, three axis geophone (3C geophone). A 3C geophone has three individual geophones oriented orthogonal to each other. For our pilot deployment we used one dimensional geophone which was buried deep in a bore hole. The geophone responds only to vertical vibrations [7]. So to capture the vibrations created during the horizontal movement of soil we placed the geophone perpendicular to the surface of earth. Our field experience has taught us if we used a 3C geophone we could capture the longitudinal, transverse and the surface waves that travel through the earth's surface. Such a system helps in determining the direction of movement of soil layers.

We have decided to incorporate 3C geophones in our new design. The three individual geophones are designed to be connected in series because the reference [8] claims such a series connection is effective in sensing very low frequency infrasound ground vibrations and the received signal will be a mix of all the three waves detailed above [9].

C. *Interfacing Circuit*

The output from a geophone is first amplified and then interfaced with the wireless sensor node of the DEP. The harmonics of geophone resonant frequency may cause disturbances in the analyzed data [10], so a damping resistor R (Fig. 3) was connected across the geophone [8]. Furthermore a filter capacitor connected across the geophone circuit will help to remove high frequency noise [9]. The resistor (R) and capacitor (C) was designed to keep the sensitivity of geophone constant till the resonance frequency. The relationship of resonant frequency (f_0) to R, C is as given in Eq. 1.

$$f_0 = 1/(2.\pi.R.C) \qquad (1)$$

The amplification of signal by a pre amplifier takes care of any reduction in signal strength during transmission. The design of amplifier should address impedance matching. The input impedance of the amplifier should be high enough to prevent any load on geophone. This is essential to avoid distortions which reduce the dynamic resolution of the system [10]. The amplifier is designed to have a cut off frequency of 10 HZ.

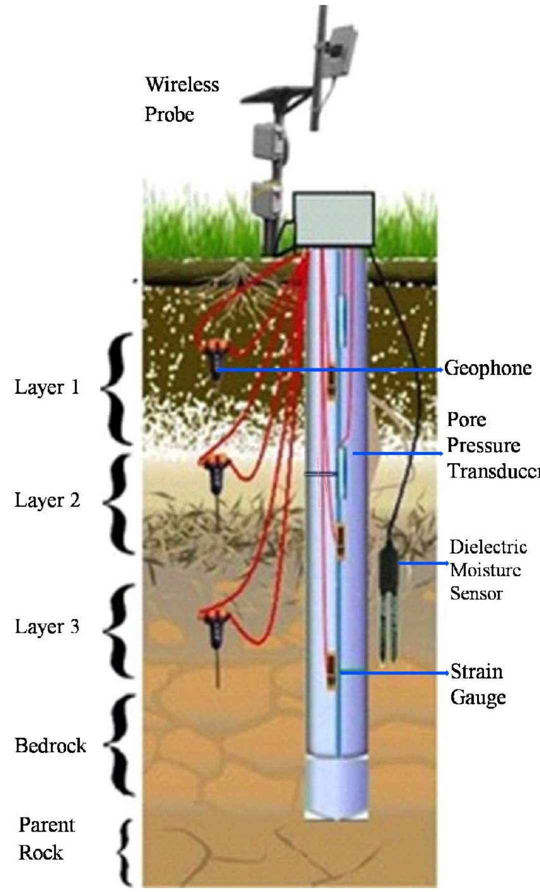

Figure. 4 The new design of DEP with nested geophone assembly. Note the 3C geophone is placed in three sensitive layers.

The output from the amplifier is fed to the wireless sensor node interface of DEP, where it is converted to a digital signal and further processed to be sent over the wireless network.

D. *Landslide Event Detection using Nested Geophones*

Landslide event detection requires specific design of DEP in each location and also determination of spatial distribution of DEP. The design of each DEP and the spatial distribution of geophysical sensors on the DEP are determined by different factors such as: the number of soil layers, layer structure, soil properties and its variability, hydraulic conductivity of soil layers, the presence of impermeable layers (interbedded permeable and impermeable layers will generate a perched water table that will cause slope instability), 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. Each soil layer behaves differently according to its properties. So theoretically it is better to have geophysical sensors in each layer. But in realistic scenario, it is the impermeable layers of soil that can allow water to gather, creating a perched water table, which loosens the soil particles and leads to slope instability. Therefore, it is only necessary to insert sensors into the impermeable layers of soil (and not the permeable layers). Figure 4 shows the new design with nested geophone assembly

In each of the bore holes multiple impermeable layers can be witnessed. So minimum of one geophone is deployed in each of these layers. 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 layers network.

Three sets of nested geophones are deployed at each region (toe, middle and crown of the hill) of the landslide prone area. The three sets of geophones at each region will perform triangulation techniques providing detection of vibrations. This will also help us to determine the direction and velocity of the movement.

V. Signal Processing Algorithm To Detect Landslides

The geophones are quite susceptible to noise for example it easily picks up a vibration induced by traffic or train movement or one caused by normal tapping. These disturbances have to be nullified for an accurate analysis. As a result the data received at the University Management Centre (UMC) has to be processed for a false proof prediction of landslide. The Fig. 5 shows the pseudo code for such an analysis.

The first step in the analysis will be to filter out the noise and classify the data as one caused by a landslide or a disturbance. The landslide signals are usually in the range of 1 - 15 Hz [6]. A digital band pass filter with this bandwidth could be used for noise removal. Farstad claims that natural landslide signals exhibit a pulse pattern different from other disturbances [11]. By analyzing the pulse pattern and the pulse rate of the geophone data signal, we could reject spurious disturbances.

Furthermore one needs to do a correlation study between the geophone data from neighboring DEPs. If a geophone registers an event then there are chances that a geophone on a nearby DEP also registers the same event. 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 pass through the surface of earth. The time delay (Δt) could be determined as shown in Eq (1).

$$\Delta t = D/v \tag{2}$$

Where D is the distance between the DEPs, and v is the velocity of the wave in soil [3]. We have quantified data for the velocity of sound in soil, and the distance between the DEPs could be pre-calculated. If the neighboring column does not report an event within this time delay the event will be classified as spurious.

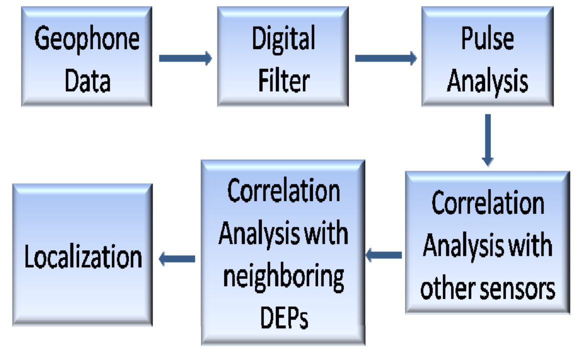

Figure. 5 Shows the pseudo code for the Signal Processing Algorithm for localization

If there is an event the piezoelectric sensor and the moisture sensor will show saturation. The algorithm is designed to give a first level of warning if these sensor signals cross a threshold value. The threshold was determined through extensive field study in our pilot deployment. Before classifying an event as spurious a correlation between the geophone data and the data from piezoelectric and moisture sensor is drawn. If all three signals correlate the second level of warning is made. A slide is intermittent at this stage.

In the third level, formation of a slip surface starts and the tiltmeters show a change in its reading. The DEP's where the slip forms moves and the distances between the neighboring DEPs changes. The geophone data is analyzed to determine the distances between the DEPs. and thus slip surface could be localized. Through such an analysis the direction of motion of the soil layers could also be predicted.

Geophone data needs high sampling rate, 24/7 monitoring will increase the load on our WSN network. The data from geophones are sent over the network if a change in the signal level is identified. Normal sampling rate of the geophone should be greater than twice the resonant frequency. Once a first level warning stage is reached the sampling rate of geophone is increased and at the third level of warning the sampling rate is further increased. This adaptive sampling ensures every minute variation is detected. Their relevance to the event is analyzed using the correlation methods.

The digitized geophone data received at the University data management center is filtered using digital filters to remove stray noises. The pulse pattern and the rate of geophone data is analyzed to classify them as seismic waves or other disturbances. If they are classified as seismic waves then we proceed to the correlation analysis. A positive response from the correlation study will result in conveyance of message to the base station, to increase the geophone sampling rate. Thus we will be able to monitor the event closely.

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 proposed signal processing algorithm also takes care of reducing the load on the wireless sensor network (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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References

[1] M.V. Ramesh, "Real-time Wireless Sensor Network for Landslide Detection", Proceedings of The Third International Conference on Sensor Technologies and Applications, SENSORCOMM 2009, IEEE, Greece, June 18-23, 2009, pp. 405-409

[2] L. Zan, G. Latini, E. Piscina, G. Polloni, and P. Baldelli, "Landslides early warning monitoring system", Geoscience and remote sensing Symposium, IGARSS 2002, IEEE International, Vol 1, pp.188-190, 2002.

[3] A. Terzis, A. Anandarajah, K. More, and I. J. Wang, "Slip surface localization in wireless sensor networks for landslide prediction", Proceedings of the Fifth International Conference on Information Processing in Sensor Networks 2006, IPSN 2006, Nashville, USA, pp. 109-116, 2006.

[4] M. Arattano and L. Marchi, "Systems and sensors for debris flow monitoring and warning", Sensors, Vol. 8, pp. 2436-2452, 2008

[5] C. E. Krohn, "Geophone ground coupling", Journal of GeoPhysics, Vol. 49, pp. 722-731, 1984.

[6] A. Burtin, L. Bollinger, R. Cattin, and J. L. Nabelek, "Spatiotemporal sequence of himalayan debris flow from the analysis of high-frequency seismic noise", Journal of Geophysical Research, Vol. 114, pp. 1029-1044, Oct. 2009

[7] D. Lawton and M. Bertram, "Field test of 3-Component geophones", Canadian journal of Exploration Geophysics, Vol. 29, 1993, pp. 19-129

[8] H. Baule and M. Borgers, "Acoustic ground vibration detector", The journal of Acoustical Society of America, Vol. 87, 1990, pp. 923

[9] H. Baule and M. Borgers, "Acoustic ground vibration detector", US Patent file, Patent no: 4849947, Jul. 1989

[10] A. L. Hagedoorn, E. J. Kruithof, and P. W. Maxwell, "A practical set of guidelines for geophone element testing and evaluation", First Break, Vol. 6, Oct. 1988, pp. 325-331.

[11] A. J. Farstad, "Multichanel system for seismic signature determination", US Patent file, Patent no:3913085, Oct. 1975