Smart Geophone Sensor Network for Effective Detection of Landslide Induced Geophone Signals

Deekshit V N, Maneesha Vinodoni Ramesh, Indukala P.K, and G. Jayachandran Nair

***Abstract*—Landslides are one of the major natural disasters and an early detection of landslide can be achieved by identifying the landslide triggering vibrations recorded using a geophone network. The major research challenges in this effort are network energy consumption, noise removal and development of a wireless network for transmitting the captured signals. This paper presents design and testing of a wireless smart geophone network with enhanced signal processing capability at the site for recording and analyzing geophone signals. The system has the capability to detect landslide induced signals and remove different types of noises produced by footsteps, vehicular movement, rainfall, and stream flow, and transmit the event data to a local processor. For this purpose, a simple and cost effective Arduino based data acquisition system with geophone inputs is developed. This system helps in reducing the system energy conception and is highly reliable, low cost compared to other traditional systems. This paper mainly focuses on the hardware design of sensor system and algorithms for identifying the characteristics of geophone signals for detecting landslide induced seismic signals. The characteristics of geophone signals for different seismic events recorded by the system are also provided.**

***Index Terms*—Landslide; Data acquisition; smart geophone, Arduino, wireless**

I. INTRODUCTION

A wireless sensor network is a collection of various sensor nodes, which are distributed spatially to monitor the environmental conditions. Currently, wireless sensor networks have many applications such as: monitoring, surveillance, and tracking for environments. Wireless sensor networks have a significant role in detection of natural disasters, especially landslides. Landslides are major natural disasters, which are highly unpredictable and they occur within a short period of time. In the case of India, most of the landslides occur during monsoon and cause large loss of life and property. Design of an early warning system will lead to reducing these losses to a minimum.

The main causes of landslides in India are extreme rainfall and earthquakes. Landslides affect approximately 15% of the land area of the Indian subcontinent. India has an unusually high number of catastrophes due to landslides [1-2]. Abanc et al [3] deployed a wireless geophone network for the debris flow detection. The paper describes the main characteristics of debris flows and other torrential processes using the seismic signal recorded at the two stations. The experiment is conducted in a real time environment. They did not consider the influence of noises in their data processing. Our proposed system considers different types of noises, which are present at the raw signal and how their effect can be reduced. Feng et al. [4] analyzed the Shaolin landslide, and they identified the characteristics of landslides. They used Hilbert transform to distinguish the landslide signal from the raw signal. The authors explained their data analysis but did not address real time detection. Kunnath et al. [5] designed a wireless geophone network for the effective detection of landslides. They explained sensor placement methodology and a localization technique. A novel signal processing algorithm was designed for automatic detection of landslides. Here, influence of noise is not considered while designing the algorithm. An experimental soil-monitoring network using a WSN is also presented in reference [5], which explores real-time measurements at temporal and spatial granularities.

In this work, a wireless geophone network for effective detection of landslides is presented. The landslide prone areas may be monitored using this network of geophones. The paper also present event detection algorithm for the leaf nodes which also removes background noises. The monitoring region will have an access point, which is connected to the local server. The local server further processes the geophone data for extracting the original landslide signal and for providing alert messages to the authority.

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978-1-5090-0396-9/16/$31.00 ©2016 IEEE

The paper is organized as follows. In Section II, we summarize the smart geophone system. In Section III, we give a brief overview of the system architecture. In Section IV, we discuss the signal processing algorithm for event detection and noise removal. In Section V, we demonstrate experiments and results. We conclude our paper in Section VI.

II. SMART GEOPHONE SYSTEM

The key parameters that need to be measured for monitoring, detecting and early warning of landslides are vibration generated due to cracks developed in the soil structure, soil layer movements, and seismic signals. The sensors that are best used for capturing these ground vibrations are geophone, accelerometer and microphone. The geophones are chosen for monitoring the incoming ground vibration signal. As per Nyquist theorem [6-9] the sampling rate has to be twice the maximum frequency of the signal to avoid aliasing. Since the landslide signals are in the frequency range of 5-100Hz, a sampling frequency of above 200Hz can be chosen. The target locations for deploying the sensors have to be determined based on site-specific parameters such as geometry of the landslide, expected frequency of vibrations, sensor coverage, fault tolerance, and distance from the flow line[10].

Based on the above requirements , comparison of existing wireless sensor networks for real-time signal capture and analysis are done. The Table I describes the different parameters used for comparing and choosing the most appropriate wireless sensor node. The comparison results show that Arduino nodes allows to sample the sensors in a higher rate, process the data in a faster rate, and provides better connectivity option at a lower cost.

TABLE I

COMPARISON OF WIRELESS SENSOR NODES

Name	Manufacturer	Cost	Connectivity	Clock	Voltage	Maximum Sampling rate
Wi sense	WiSense Technologies	20$	TICC1101	8Mhz	1.8-3.6V	5000Hz
MicaZ	Memsic	95$	NA	8Mhz	2.7-3.3V	4000Hz
Arduino	Arduino	8$	Bluetooth, Wi-Fi	20MHz	2.5-5V	9000Hz
BTnode	BTnode	215$	Bluetooth, 802.15.4	8MHz	2.2-3.7V	3500Hz

A Smart Geophone System is designed and developed by integrating a geophone based sensing system with a data acquisition device and processor using an Arduino microcontroller, along with a communication modules for Wi-Fi and Bluetooth. This complete system is made smart by integrating specific algorithms for data collection, processing, event detection, and energy management of the nodes. Thus, each Smart Geophone Node has the capability to locally detect the event and transmit the relevant data through upper layers of the network to local server for further processing.

The sensing element is a 3 component geophone (3C) and the output signals are amplified and inputted to the Arduino based data acquisition board. The circuit diagram of the analog board for amplification, filtering and level shifting, is shown in Fig. 1.

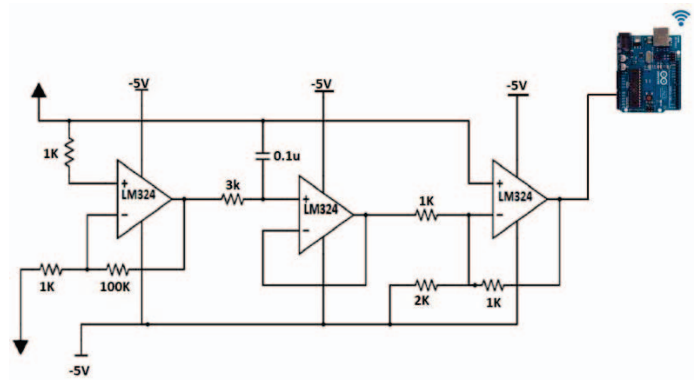

Fig. 1. Circuit diagram

The output of the geophone will be in the range of millivolt, so an amplifier with higher gain, a feedback resistance of 100K and input resistance of 1K can be used. According to the equation of gain for the non-inverting amplifier

$$Gain\ stage\ rate = 1 + Rf/Rin = 101 \qquad (1)$$

A Nyquist filter is used for digitizing the signal. For low pass filtering, an RC circuit is used. A Nyquist filter with a cutoff frequency of 500Hz is designed. The equation for finding the cutoff frequency (fc) for a low pass filter is given below

$$fc = 1/2\pi RC \qquad (2)$$

The resistance value can be taken as 3K, hence the value of capacitor should be 0.1u. As per the Nyquist theorem, for the sampling frequency 1000Hz, a Nyquist filter of 500Hz is used.

III. SYSTEM ARCHITECTURE

The area for monitoring is divided into different regions, and the smart geophone systems are deployed in each region. Each region of the landslide prone area has a network of smart geophones having the same frequency to monitor a particular type of signal of interest. This will allow the system to monitor signals of different frequencies, which are initiated at different regions at different time periods. The proposed system architecture is shown in Fig. 2.

The landslide prone area can be mainly divided into three areas: the crown, middle and toe. Most of the landslide signals are initiated from the crown region; hence, high frequency geophones are to be placed at the crown area. The low frequency signal are produced in the toe region, so low frequency geophones are installed in this region.

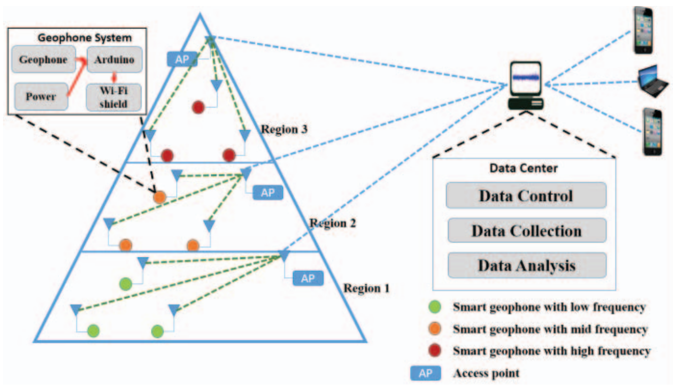

Fig. 2. System architecture

The leaf nodes are connected to the access point, and each region has separate access points. The access points forward the data to the data center. The data center has different functions such as data control, data collection, and data analysis. Gain and sampling rates are controlled by the data control section in the data center. The data analysis section has three functions: signal denoising, detailed analysis, and based on the results of the analysis, a warning is provided to the corresponding authority.

IV. SIGNAL PROCESSING ALGORITHM FOR EVENT DETECTION AND NOISE REMOVAL

Event detection and noise removal algorithm described below is uploaded in the sensor node. The captured sensor data is forwarded to the access point without any processing. Most of the captured sensor data may not contain any event signal. Thus, there is a wastage of power and increase in traffic data. The on-site processing technique is developed to detect the event from the leaf node itself so that the node will send only required data to the upper node. The geophone based signal processing algorithm and the flowchart are shown in Fig. 3.

The important functional blocks of the signal processing algorithm are wavelet denoising block, Short term average block (STA), Long term average block (LTA), and comparison block. The wavelet denoising technique removes random noise from the geophone data. Then the short term average and long term average of the signal are computed to determine the STA/LTA [10] ratio. In the comparison block, the ratio STA/LTA is compared with a preset threshold value. If the value of STA/LTA is greater than the threshold value, then continuous event data is forwarded through the wireless sensor network to a local server. Similarly, when the value of STA/LTA becomes less than the threshold, the digitized signal from the geophone is not sent to the access point.

The second level of processing for the removal of noise and advanced signal processing is done at the local server. Once the digitized signal from the Arduino data acquisition (DAQ) board is obtained, correlation and other techniques are applied to differentiate the landslide signal from the noise signals such as footsteps and vehicle movement signals. The signals from more than two geophone sensors are collected and compared. Footsteps and vehicle movement signals have higher frequencies, hence these signals become attenuated rapidly while travelling through the earth's surface. Therefore, noise cannot be received by all the three geophones at the same time. If all the three geophones in a region registers an identical event, then the signals can be considered as a landslide signal. Then the WSN system forwards the data to the local server.

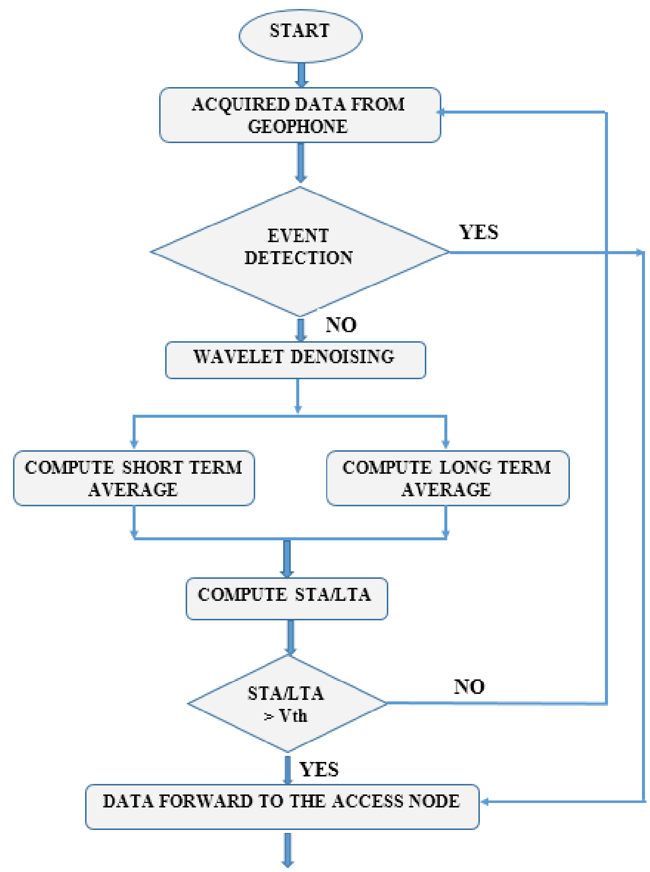

Fig. 3. STA/LTA Algorithm

V. EXPERIMENTS AND RESULTS

The components which are used for the experiments are: a 3C smart geophone and a laptop. The ground vibration can be effectively detected with the help of a 3C smart geophone. The smart geophone contains a pre-amplifier and a wireless enabled Arduino for on-site digitization and processing. The amplified signal is given to the Arduino board ADC input, and the incoming geophone signal is analyzed. An event detection algorithm is used for avoiding unwanted data transmission. The geophone sensor is highly sensitive and it will capture many seismic signals. Usually continuous signals are transmitted to the upper node without any processing, and this requires great deal of power. In the present design of the geophone system an event detection algorithm is used to detect an event and only relevant event data is transmitted to the local server. The stem was used in field environment for collecting a real-time seismic signal. The experimental field setup for collecting data is shown in Fig. 4.

Fig. 4. Field setup for data collection

Four types of seismic signals such as, footstep, vehicular motion and weight drop are collected and analyzed. The footstep signals, weight drop signals, and vehicular signals are collected from the outdoor using smart geophone network. The collected signals are analyzed using Matlab tool. For the removal of ambient noise 4th order Butterworth filter is used. The collected signal undergoes high pass filtering as well as low pass filtering.

The foot step signal of a single person with normal footsteps is shown in Fig. 5. The Fourier transform of footstep signal is computed, and from which the high frequency and low frequency bands of the footstep signal is obtained. The frequency range of the footstep signal for this particular condition is identified as 22-75 Hz. The footstep signal clearly distinguishes each step of the person. Based on the number of people, weight of each person, and style of walking, the signal varies.

The weight drop experiment is conducted and vibration due to weight drop are collected. A weight of 2kg is dropped from one meter above ground and vibration due to the drops are analyzed. The shape and size of the dropped material has a significant role in production of vibration. The FFT of the weight drop signal is computed and the high frequency and low frequency component are identified. The plot of signal and FFT of the signals are shown in figure 6. The frequency range of weight drop signal for this scenario is identified as 15-115 Hz.

The vehicular movement will create ground vibration with unique characteristics. The characteristics of the vehicular signals are identified. The experiment was conducted on the public road near Amrita University where the road has minimal traffic. The smart geophone is used to capture the ground vibration signal. Primarily, the ground vibration due to a motor bike and a car are analyzed. The sensor output is different for the movement of the car and bike; hence, each vehicle signal has distinct features and properties. The weight, size, and shape have high impact on the generation of the ground vibration signal. The smart geophone was placed near a speed breaker to record the features of ground vibration at a particular speed. Similarly, the features at various speeds can be found out by implementing the smart geophone network at other places rather than the speed breaker. The plot of vehicular signal (bike) at particular speed is shown in Fig. 7. The frequency range of vehicular signal at a particular speed is identified as 46-80Hz.

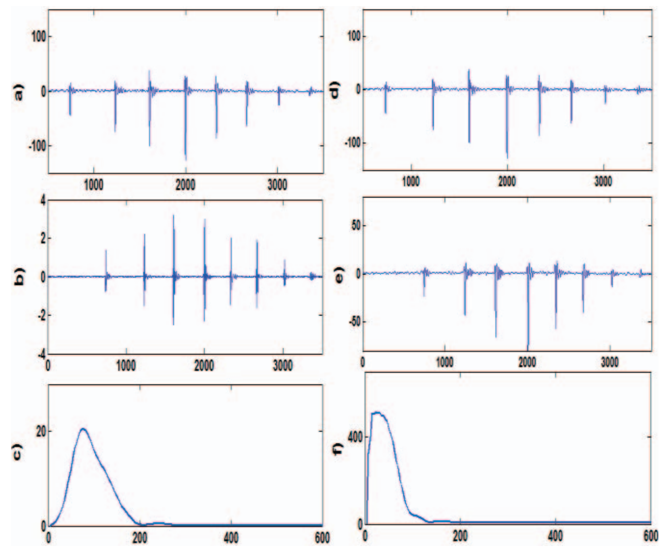

Fig. 5. Footstep signal, a)-d) Footstep signal, b) High pass filtered signal, c) fft of footstep signal(High pass signal), e) Low pass filtered signal, f) fft of footstep signal(Low pass signal)

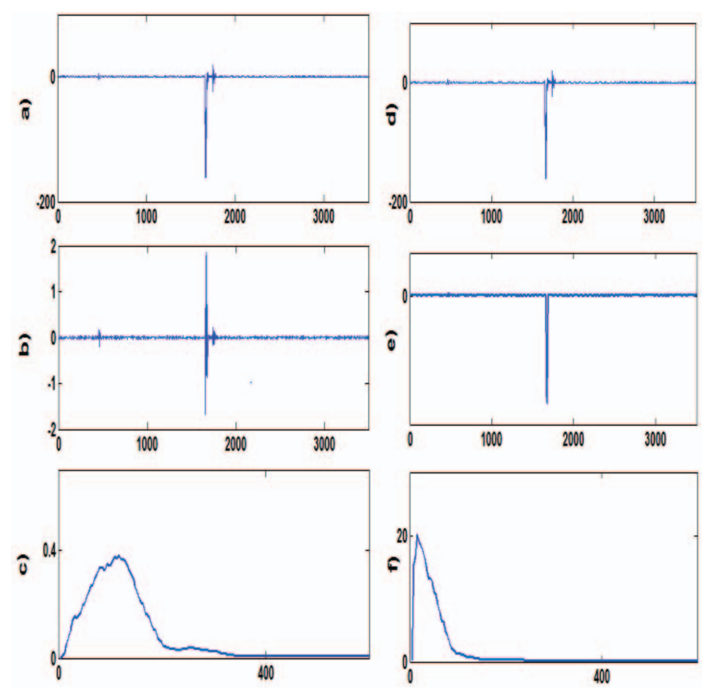

Fig. 6. Weight drop signal, a)-d) Weight drop signal, b) High pass filtered signal, c) fft of Weight drop signal(High pass signal), e) Low pass filtered signal, f) fft of Weight drop signal (Low pass signal)

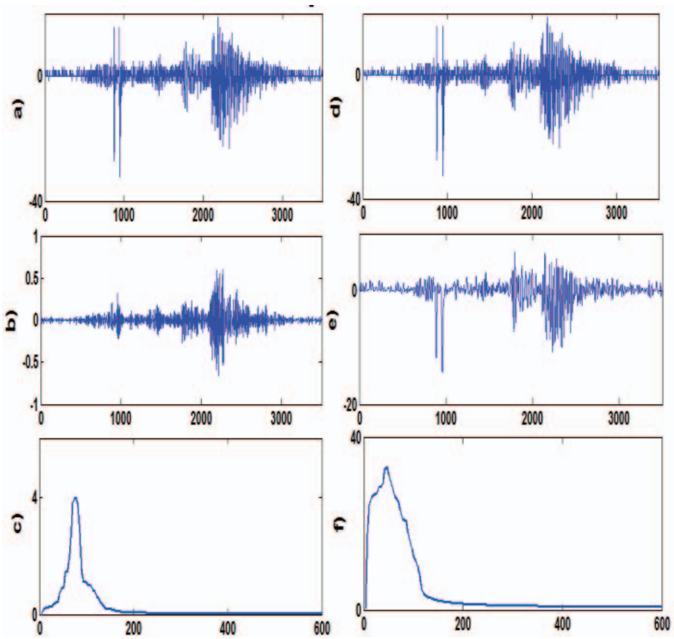

Fig. 7. Vehicular signal (bike), a)-d) Vehicular signal (bike), b) High pass filtered signal, c) fft of Vehicular signal (High pass signal), e) Low pass filtered signal, f)fft of Vehicular signal (Low pass signal)

VI. Conclusion

The early warning system for landslides aids people to get informed about the chance of occurring landslides there by saving several lives. This research introduced a new smart geophone sensor network with enhanced signal processing capability. A simple and cost effective Arduino based data acquisition system using geophones is developed thus reducing the energy consumption of the system. The smart geophones have the on-site processing capability, which avoids the unwanted data transmission. The interference of different types of noise leads to fault detection. The experimental setup is developed by using the smart geophone sensor network in real- time environment and various ground vibration signals such as footstep signals, vehicular signals and weight drop signals are identified. The features of various ground vibration are extracted and can be used for the effective removal of noises from the landslide signal. The frequency band of footstep signal is identified as 22-75Hz and for the weight drop signal the frequency band changed to 15-115Hz and for the vehicular (bike) induced signal, the frequency band become 46-80 Hz. In this paper an efficient algorithm for the detection of landslide events is proposed. The proposed correlation technique improves the accuracy of the signal by eliminating different noises. Therefore, the multilevel processing will help to improve the efficiency of the overall system.

Acknowledgment

I would like to express my gratitude for the guidance, support and motivation provided by Sri Mata Amritanandamayi Devi, the Chancellor, Amrita University, and also to thank my loving parents.

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