Wireless Sensor Network for Landslide Detection

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Abstract— *The power of wireless sensor network techonology has provided the capability of developing large scale systems for real-time monitoring.This paper describes the evolution of a wireless sensor network system for landslide detection in the Idukki district of the southern state of Kerala, India, a region known for its heavy rainfall, steep slopes, and frequent landslides. The deployment and data retrieval or collection from geophysical sensors, the design, development and deployment of WSN, the development of data collection and data aggregation algorithms needed for the network, and the network requirements of the deployed landslide detection system, data analysis system etc has been disuceed in this paper.*

Keywords: Wireless Sensor Network, Distributed Algorithms, Heterogeneous Networks, Landslide

1. Introduction

Real-time monitoring of environmental disasters are one of the prime necessity of the world. Different technologies have been developed for this purpose. Wireless sensor networks(WSN) is one of the major technology that can be used for real-time monitoring.

WSN has the capability of large scale deployment, low maintanence, scalability, adaptability for different scenarios etc. WSN has its own limitation such as low memory, power, bandwidth etc, but its capability to be deployed in hostile environment, and low maintanence requirement made it one of the best suited technology for real-time monitoring.

This paper discusses the design and deployment of a landslide detection system using wireless sensor network[1] at Anthoniar Colony, Munnar, Idukki (Dist), Kerala (State), India. The deployment site has historically experienced several landslides, with the latest one occurring in the year 2005, which caused a death toll of 10 (people).

The remainder of the paper is organized as follows. Section II describes related work in WSN systems, and other methods for landslide prediction. In Section III, we describes about landslide phenomena and Section IV describes about the sensors needed for monitoring rainfall induced landslides. Section 5 details about the enhanced sensor column design used along with this system. Section VI describes about the wireless sensor architecture used used for landslide scenario and Section VII details the different wireless sensor network algorithms implemented in the landslide detection network. The wireless sensor testbed for landslide detection is described in detail in Section VIII. Field deployment, its design concerns, and experiences are described in Section IX. Finally we conclude in Section X and in the same section future work is also discussed.

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2. Related Work

The evolution of wireless sensor networks has fostered the development of real-time monitoring of critical and emergency applications. Wireless sensor technology has generated enthusiasm in computer scientists to learn and understand other domain areas which have helped them to propose or develop real-time deployments. One of the major areas of focus is environmental monitoring, detection and prediction. The Drought Forecast and Alert System (DFAS) has been proposed and developed in paper [10]. This system uses mobile communication to alert the users, whereas the deployed system uses real time data collection and transmission using the wireless sensor nodes, WiFi, satellite network and also through internet. The real streaming of data through broadband connectivity provides connectivity to wider audience.

An experimental soil monitoring network using a wireless sensor network is presented in reference [11], which explores real-time measurements at temporal and spatial granularities which were previously impossible. This paper also discusses about the reception of real-time measurements at temporal and spatial granularity.

Research has shown that other than geotechnical sensor deployment and monitoring, other techniques such as remote sensing, automated terrestrial surveys, and GPS technology, etc. also can be used by themselves or in combination with other technologies to provide information about land deformations. Paper [12] describes a state-of-the-art system that combines multiple sensor types to provide measurements to perform deformation monitoring.

Reference [9] discusses the topic of slip surface localization in wireless sensor networks, which can be used for landslide prediction. A durable wireless sensor node has been developed [13], which can be employed in expandable wireless sensor networks for remote monitoring of soil conditions in areas conducive to slope stability failures.

In this paper, real time deployment of a heterogeneous network in India for landslide detection has been discussed. This study incorporates both theoretical and practical knowledge from diverse domains such as landslides and geomechanics, wireless sensor, Wi-Fi, and satellite networks, power saving solutions, and electronic interface and design, among others, which paved the design, development and deployment of a real-time landslide detection system using a wireless sensor network.

3. Landslide

Landslide is a general term used to describe the down-slope movement of soil, rock and organic materials under the influence of gravity. It can be triggered by gradual processes such as weathering, or by external mechanisms including:

- Undercutting of a slope by stream erosion, wave action, glaciers, or human activity such as road building,
- Intense or prolonged rainfall, rapid snowmelt, or sharp fluctuations in ground-water levels,
- Shocks or vibrations caused by earthquakes or construction activity,
- Loading on upper slopes, or
- A combination of these and other factors.

Once a landslide is triggered, material is transported by various mechanisms including sliding, flowing and falling. The types of landslides vary with respect to the:

- Rate of movement:
  - This ranges from a very slow creep (millimetres/year) to extremely rapid (metres/second).
- Type of material:
  - Landslides are composed of bedrock, unconsolidated sediment and/or organic debris.
- Nature of movement:
  - The moving debris can slide, slump, flow or fall.

Landslides constitute a major natural hazard in India that accounts for considerable loss of life and damage to communication routes, human settlements, agricultural fields and forest lands. The Indian subcontinent, with diverse physiographic, seismotectonic and climatological conditions is subjected to varying degree of landslide hazards; the Himalayas including Northeastern mountains ranges being the worst affected, followed by a section of Western Ghats and the Vindhyas.

In India, landslides mainly happen due to heavy rainfall, so this study concentrates on rainfall induced landslides. Earthquakes can also cause landslides, however in India this is primarily confined to the Himalayan belt. High rainfall intensity accelerates the sliding and slumping in the existing hazard zones. The annual loss due to landslides in India is equivalent to $400 million.

4. Sensors Needed for Monitoring Rainfall Induced Landslides

Under heavy rainfall conditions, rain infiltration on the slope causes instability, a reduction in the factor of safety, transient pore pressure responses, changes in water table height, a reduction in shear strength which holds the soil or rock, an increase in soil weight and a reduction in the angle of repose. When the rainfall intensity is larger than the slope saturated hydraulic conductivity, runoff occurs [3].

Three distinct physical events occur during a landslide:

- the initial slope failure,
- the subsequent transport, and
- the final deposition of the slide materials.

The initial slope failure can ocuur due to the increase in pore pressure and soil moisture content, under heavy rainfal, which necessitates the inclusion of geophysical sensors for detecting the change in pore pressure and moisture content with the warning system developed for landslide detection. So the system discussed in this paper also includes geophysical sensors such as pore pressure transducer and dielectric moisture sensor for capturing the in-situ measurements.

After the slope failure the subsequent transport of the material happens that will generate slope gradient change, vibration etc, which has to be measured and monitored for effective issue of warning. So the warning system inclds strain gauge, and tiltmeter, that can be used for measuring in-situ slope gradient changes. Along with them geophone is used for analysing the vibration.

5. Enhanced Sensor Column Design

Commercially available wireless sensor nodes do not have implanted sensors to measure pore pressure, moisture content, vibration, earth movements, etc. This constraint has lead us to implement data acquisition boards to connect the external sensors to the wireless sensor nodes. The geological sensors were placed inside a sensor column and they were connected to the wireless sensor node via a data acquisition board as shown in Figure 1. The sensor column design discussed in this paper is an enhanced version of the sensor column discussed in [9], which uses a homogeneous structure, whereas our design uses a heterogeneous structure which differs with respect to the terrain conditions and the geological and hydrological parameters of the deployment site. Also, in this sensor column design all the geological sensors (such as geophone and dielectric moisture sensor) are not placed inside the column but are connected to the same wireless sensor node. The sensor column design also includes tiltmeters which can be used for validating the deformation measurements captured using strain gauges.

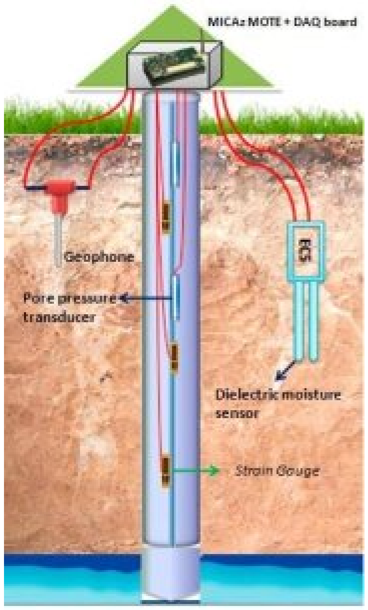

Fig. 1: Enhanced Sensor Column Design[14]

6. Wireless Sensor Network Architecture

The wireless sensor network at the deployment site follows a two-layer hierarchy, with lower layer wireless sensor nodes, sample and collect the heterogeneous data from the sensor column and the data packets are transmitted to the upper layer. The upper layer aggregates the data and forwards it to the sink node (gateway) kept at the deployment site.

The geological and hydrological properties of the whole landslide prone area differ in each location, so it can be divided in to regions having unique properties. Our deployment area is divided into three regions such as crown region, middle region, and toe region as shown in Figure 2, and numerous low level nodes attached to homogeneous sensor column are deployed in these regions.

7. Wireless Sensor Network Algorithm

The wireless sensor network uses four algorithms for implementing clustering, distributed consensus among the data, energy efficient data aggregation and time synchronization, which will contribute for the development of an efficient landslide detection system.

The real-time monitoring networks are constrained by energy consumption, due to the remote location of the deployment site and the non-availability of constant power. Considering these factors, the wireless sensor network at the deployment site implements a totally innovative concept for distributed detection, estimation and consensus to arrive at reliable decisions, more accurate than that of each single sensor and capable to achieve globally optimal decisions as discussed in research papers [16],[17], and [18]. In landslide

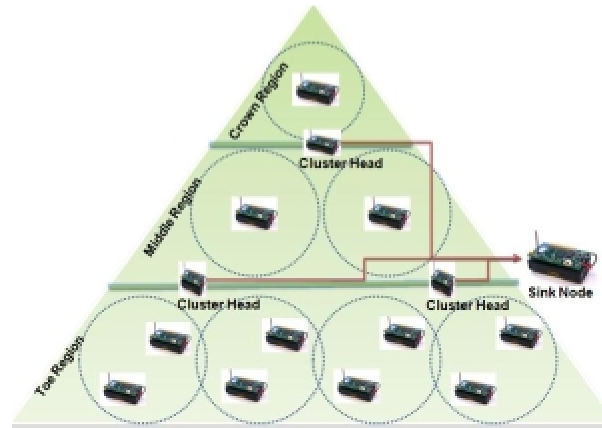

Fig. 2: Regionalized Wireless Sensor Network Architecture for Landslides

scenario, the implementation of this algorithm imposes a constraint of handling heterogeneous sensors in each sensor column. The different methods that can be used for implementing this algorithm, for landslide scenario are:

1) *Homogeneous sensor columns deployed in each region can be compared and a consensus value can be achieved for all the sensor columns in that region*
2) *All the sensors deployed in the landslide prone area can be assigned with a weightage with regard to its impact on landslide detection, and a common consensus value can be achieved executing the algorithm at once, for all deployed sensors*
3) *Decentralized consensus performed for the same type of sensors in all sensor columns in a region*

Decentalized consensus for the same type of sensors has been developed for the deployed network. The decentalized algorithm will be executed for each type of sensors, one by one, for all homogeneous sensor columns deployed at each region. After initial set of sensors achieve its consensus, the next set of sensors will execute the decentalized algorithm and so on, as shown in Figure 3. The other designs demand apriori knowledge of correlation between different geophysical sensors, whereas this method does not require this apriori knowledge, but the processing delay will be more compared to other methods, due to the multiple execution of same algorithm.

Since the study concentrates on the detection of rainfall induced landslides, the most relevant data will be arriving during rainy season. So rainfall based alert levels have been developed which will influence the sampling rate of the geological sensors and the transmission of data to higher layers as discueed in the threshold based algorithm [14]. This algorithm will help to reduce the energy consumed during the low alert levels and also in collecting and transmitting large amounts of data, only when the environmental and geological conditions demand the same. Other than these

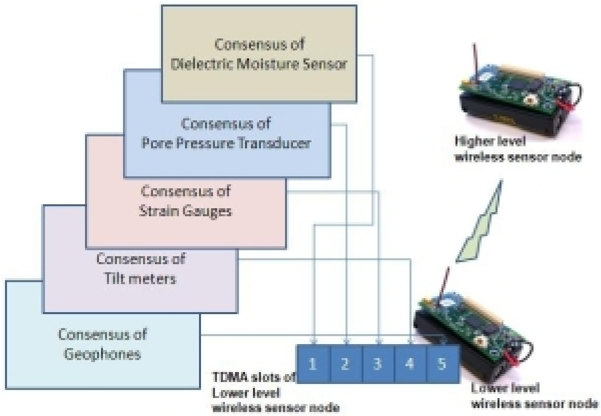

Fig. 3: Decentralized Consensus for Same Type of Sensors

methods, state level transitions have been incorporated to reduce the energy consumption per node which will also contribute to reduced energy consumption throughout the network. These requirements, however, lead to the need of time synchronization, and the algorithm planned for implementation in our network is discussed in research paper [19].

8. Wireless Sensor Testbed for Landslide Detection

The design and development of a wireless sensor network for the landslide scenario involves consideration of different factors such as terrain structure, vegetation index, climate variation, accessability of the area etc. The prerequisites of wireless sensor network development are selection of sensor column location, sensor column design and its data collection method, understanding transmission range and necessity of external antennas or additional relay nodes, identification of the communication protocol, development of application specific algorithms for data aggregation, routing and fault tolerance etc.

The wireless sensor testbed deployed at Anthoniar Colony, Munnar, Idukki (Dist), Kerala (State), India, follows a two-layer hierarchy, with a lower layer and an upper layer. The lower layer wireless sensor nodes are attached to the sensor columns. They will sample and collect the heterogeneous data from the sensor column and the data packets are transmitted to the upper layer. The upper layer consists of cluster heads, which will aggregates the data and forwards it to the sink node (gateway) kept at the deployment site. Data received at the gateway has to be transmitted to the Field Management Center (FMC) which is approximately 500m away from the gateway. A Wi-Fi network is used between the gateway and FMC to establish the connection. The FMC incorporates facilities such as a VSAT (Very Small Aperture Terminal) satellite earth station and a broadband network for long distant data transmission. The VSAT satellite earth station is used for data transmission from the field deployment site to the Data Management Center (DMC), situated at our university campus 300 km away, while the broadband connection provides fault tolerance for long distance transmission and can also be used for uploading real time data directly to a web page with minimum delay. The DMC consists of the database server and an analysis station, which performs data analysis and landslide modeling and simulation on the field data to determine the landslide probability. The wireless sensor network architecture for landslide detection is as shown in Figure 4.

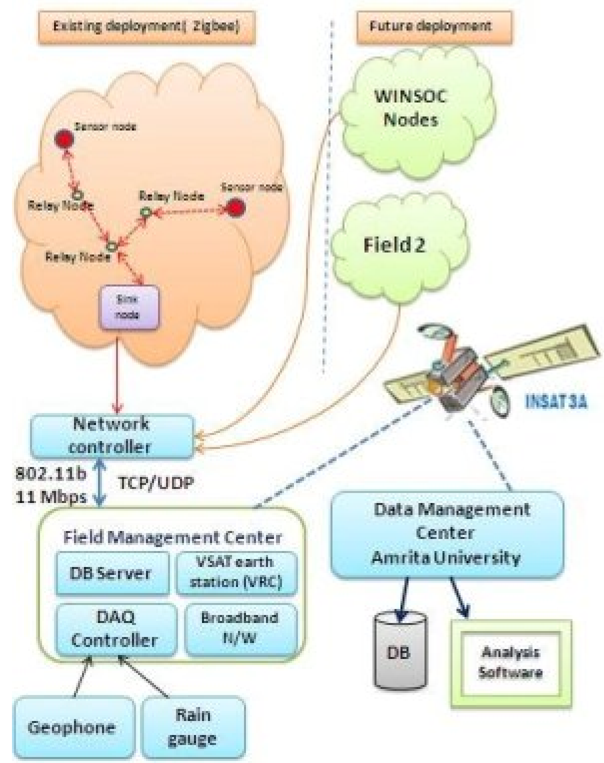

Fig. 4: Wireless Sensor Network Architecture For Landslide Detection [2]

9. Field Deployment

The existing infrastructure has evolved through several iterative phases in its implementation. Important research focal points were deciding the sensor column locations, designing and constructing the sensor columns, sensor column deployment methods, interfacing circuitry, wireless sensor network, Wi-Fi network, satellite network, and power solutions, soil tests, and data analysis.

Extensive field investigations were conducted for identifying the possible locations for sensor column deployment. At the deployment site, Anthoniar Colony, an initial twenty sensor column locations consisting of 150 sensors total, were identified with respect to their geological relevance. The pilot deployment consists of two sensor columns, with ten sensors, are deployed in the field along with six wireless sensor nodes as shown in Figure **??**.

Fig. 5: Field Deployment

9.1 Deployment of Sensor Column

One of the sensor columns is deployed at the toe region where various water seepage lines converge. This fact lead to the installation of pore pressure transducers at different depths (2m, 5m) of the sensor column 1. The other geophysical sensors attached to this sensor column are dielectric moisture content transducer, and a geophone. Both pore pressure transducer and the dielectric moisture sensor are sampled at every five minutes, where as geophone is sampled at the rate of 10 samples/second. The MicaZ wireless sensor node connected to the sensor column transmits the digitized data values to the upper layers of the network.

The other sensor column is attached with movement sensors since the location of it is in an unstable region. This sensor column has three tilt meters(1m, 2m, 3.5m), and three strain gauges(1.5m, 2.5m, 4m) to capture the earth movement from the sensor column bending. A dielectric moisture sensor is also connected to the sensor column at 1 feet depth. The wireless sensor nodes sample these sensors at every five minutes and sent the data to upper level sensor nodes in the network.

The spatial granularity will be increased by further addition of more sensor columns (approximately 20) and wireless sensor nodes (approximately 20) which is in process.

9.2 Design and Deployment of Wireless Sensor Network

The design and development of a wireless sensor network for the landslide scenario involves consideration of different factors such as terrain structure, vegetation index, climate variation, accessability of the area etc. The prerequisites of wireless sensor network development are selection of sensor column location, sensor column design and its data collection method, understanding transmission range and necessity of external antennas or additional relay nodes, identification of the communication protocol, development of application specific algorithms for data aggregation, routing and fault tolerance etc.

The wireless sensor network architecture at the deployment is disussed in Section 4, and the wireless senor nodes used for the deployment are 2.4 GHz MicaZ motes from Crossbow. The initial gateway was stargate with Intel XScale processor 400MHZ and running ARM Linux OS was programmed as the Sink Node, while the new gateway is a single board computer which has 64 MB RAM, 32 MB flash and a fixed base mote that is used to send and receive the messages through the transceiver.

The sensor column is physically attached to a wireless sensor node which is integrated with a data acquisition board. The distance between current sensor columns is approximately 50 meters, at a slope of about 70ř. Due to the terrain structure and vegetation, the data from the sensor columns are not able to reach the gateway. The major reasons for this is, no line of sight path between the columns, between the first sensor column and the gateway, and between the second sensor column and the gateway. The above observations, along with experimental tests, have led us to employ three relay nodes in between the sensor columns themselves and the gateway. One of the relay nodes is a clusterhead for the first and second sensor column. The data from the clusterhead is transmitted to the gateway in the form of packets. At the gateway the received packets are time stamped and stored.

9.3 Deployment of Wi-Fi Network

The Wi-Fi Network is used to transfer the data from the gateway to the FMC and it uses an external antenna and an access point for the same. The Network has been tested with WLAN standards 802.11a/b/g.

The Wi-Fi network allows us to install the gateway in any scalable distance from the FMC. Since the Munnar region experiences frequent landslides and has several landslide prone areas within every 1 sq km, which can be utilized as future extension sites for landslide detection systems by connecting them to the FMC via a Wi-Fi network.

9.4 Deployment of Satellite Network

The basic satellite communication network in the landslide scenario is based on VSAT. The geological data collected at the landslide deployment site is transmitted from the FMC at the deployment site to the DMC at Amrita University's Amritapuri campus, using the VSAT earth station. The data is transmitted using UDP Protocol which includes recovery of lost packets, corrupted packets, secure transmission, route via broadband during unavailability of VSAT, buffering the data to disk in case both networks are unavailable and sending the data as soon as the network is connected, etc.

9.5 Monitoring Using Data Analysis System

The DMC consists of the database server and an analysis station which performs landslide modeling and data analysis on the data received from the field. The software also has the capability of real streaming of data and its analysis results, over internet, which will provide greater capability of effective warning issue at minimum delay.

Data received at the DMC is being been analysed using the in-house designed data visualization software which has the capability to determine factor of safety of the mountain and probability of landslide occurance with respect to the signals received from the deployed sensors. It also has the capability to compare and analyse data from different sensor columns, different sensors in the same sensor column, the same sensors in different sensor column, selective comparison, etc.

Data is successfully received from the deployment site with minimal data packet loss and analysis of data has been performed. Data received from two pore pressure transducers and a rainguage is shown in Figure 6.

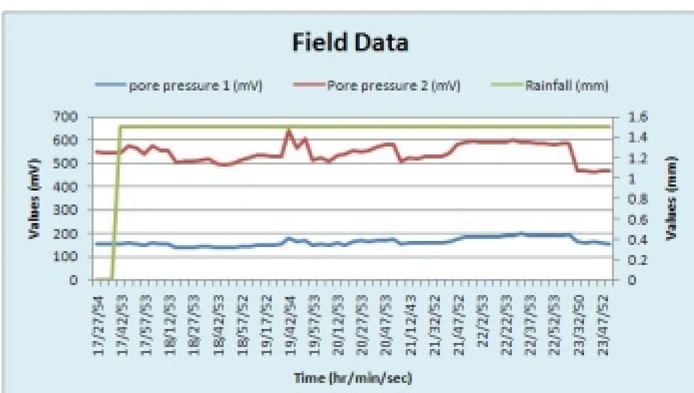

Fig. 6: Real-time Field Data

During 2008 monsoon season, the sensors were able to capture the expansion and contraction of soil mass during heavy rainfall condition and after rainfall. The data analysis software showed respective variations in each of the deployed sensors.

10. Conclusion and Future Work

Wireless sensor network for landslide detection is one of the challenging research areas available today in the field of geophysical research. This paper describes about an actual field deployment of a wireless sensor network for landslide detection. This system uses a heterogeneous network composed of wireless sensor nodes, Wi-Fi, and satellite terminals for efficient delivery of real time data to the data management center. The data management center is equipped with softwares and hardwares needed for sophisticated analysis of the data. The results of the analysis in the form of landslide warnings and risk assessments will be provided to the inhabitants of the region.

The pilot deployment of this system is already in place at Anthoniar Colony, Munnar, Idukki, Kerala, India. In the future, this work will be extended to a full deployment with increased spatial variabilty, and the work in this regard is progressing. Field experiments will be conducted to determine the effects of density of the nodes, vegetation, location of sensor columns etc., for detecting rainfall induced landslides, that may help in the development of low cost wireless sensor network for landslide detection.

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