International Journal of Modern Trends in Engineering and Research
www.ijmter.com
e-ISSN No.:2349-9745, Date: 2-4 July, 2015

Landslide Monitoring system based on Wireless Sensor Network

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Abstract — The emerging field of wireless sensor networks combines sensing, computation, and communication into a single tiny device with the capability of developing real-time monitoring systems. A landslide, also known as a landslip, is a geological phenomenon that includes a wide range of ground movements, such as rock fall, deep failure of slopes and debris flows causing significant damages to civil infrastructure. This paper presents an autonomous landslide monitoring system based on wireless sensor networks and detail analysis of data reduction and energy conservation algorithms with wireless sensor network.

Keywords - Wireless Sensor networks, Threshold, landslide detection, data reduction, energy conservation.

I. INTRODUCTION

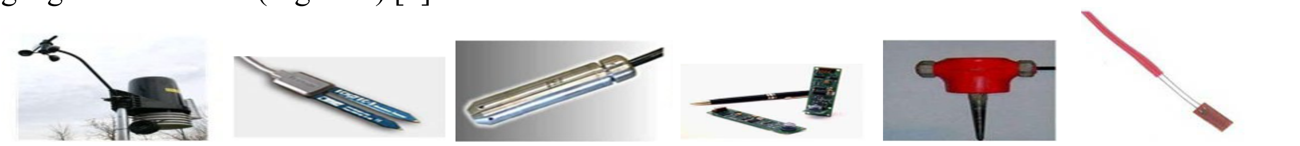
A landslide is a short lived and suddenly occurring phenomenon, and its causative factors can be accumulated rainfall, moisture and pore pressure saturation in the soil, or a steep slope angle, among others. This research converges on development of Prototype of sensor networks for detecting landslides, focusing primarily to data reduction and energy minimization. All the sensors use solar power for their energy needs. Here we are presenting rainfall induced landslide and solar power tends to rapidly diminish during the rainy season. Hence minimizing the energy becomes an uttermost priority for sustained operation of the network, which indeed is the goal of the paper. Data regarding the rainfall, moisture, pore pressure and movement in the earth is collected. As per energy considerations, multiple policies for throttling the frequencies of data measurement of the climate parameters are tested, without unduly impacting the efficacy of landslide detection. With regards to the contents of the paper section 2 relates erstwhile work. Section 3 takes us through the development of the solo, duo, triple and four sensor networks and their effectiveness in monitoring and detecting landslides. Section 4 proposes algorithms to be implemented to reduce the frequencies of sensor measurements. Section 5 proposes the deployment of the sensors in sensor column for each node. Finally we conclude in section 6.

II. RELATED WORK

The fruition of sensor networks has promoted the development of real-time monitoring of critical and emergency applications. Several measurement techniques have been proposed to identify slope instability and to estimate the risk of landslides [1]. For example, map analyses and aerial reconnaissance are used to assess the risk of landslides based on the interpretation of terrain and geological information. These methods, however, are known to be costly and labor-intensive as well as highly subjective because the results depend on the experience and judgment of the human experts. Another approach towards landslide monitoring is based on geotechnical instrumentations using, for examples, inclinometers, extensometers, or piezometers .The instruments are usually installed on the slope and wired to computer systems hosting data analysis software. Several cable-based landslide monitoring systems have been reported [2]. However, cable-based monitoring systems are costly, require continuous maintenance, and are limited in their communication flexibility. An experimental soil monitoring network using a WSN is presented in [3], which explores real-time measurements at temporal and spatial granularities. Reference [4] describes a state of art system that combines multiple sensor types to provide measurements to perform deformation monitoring. Reference [5] 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 [6], which can be employed in expandable wireless sensor networks for remote monitoring of soil conditions in areas conducive to slope stability failures. Here, we systematically quantify effectiveness of different types of sensors for monitoring disasters, particularly, landslides. We analyze each sensor for its data generated and energy consumption, then compute its sustainability for the long period, and correlate the predictability of landslides from the sensor data. Thereafter, we propose techniques to dynamically throttle the data collected, with the goal of minimizing energy consumption without degrading the effectiveness of landslide monitoring

III. SENSOR NETWORKS

As we headed towards developing a sensor network to monitor and detect landslides, our first task is to determine which sensor (or sensors) to use. Since landslides are commonly triggered by intense downpours or prolonged medium intensity rainfall, our first choice was a tipping bucket type rain gauge as the sensor (Figure 1) [9].



Rain gauge **Moisture sensor** **Peizometer** **Tiltmeter** **Geophone** **Strain gauge**

Figure 1. Types of sensors used for Landslide Detection.

A. Sole Sensor Network

One tipping bucket type rain gauge should be mounted on a pole above the land surface. The tipping bucket rain gauge is connected to a wireless mote through a data acquisition board, and the sensor data is transmitted to the master node via RF module, network. The rain gauge sensor is programmed to collect and transmit rainfall levels at various sampling frequencies. Using the symbols listed in Table I, the daily energy consumed is computed from the sum of the sensor sampling energy (E_s), and the wireless transmission energy (E_{tx} * D_s), both multiplied by the number of samples per day, as indicated by (1)

$$E_{dy}= N_{dy}(E_s+D_s E_{tx}) \quad (1)$$

The battery lifetime, in the monsoon season, of the system is given by the equation

$$D_{life} = E_{sto}/(E_{dy} - E_{ch}) \quad (2)$$

where E_{ch} is the daily average energy restored by solar charging (generally computed as the total charge accumulated by a battery during the rainy monsoon season divided by the number of rainy days). For a range of sampling frequencies from 1/sec to1/hour, sensor data should be collected, the energy consumption should be calculated and the battery lifetime ranges in days should be calculated While using the rainfall data for predicting landslides, a threshold based approach is used [7]. There is no exclusive direct correlation between rainfall intensity above the threshold and the likelihood of occurrence of landslides. So, for any given threshold of rainfall, there is no definite probability of landslide. However rainfall only gives a measure of the inflow of water, but no information on how much of that water penetrates into the soil. So, the next significant factor that appears to influence landslide is moisture content variation.

B. Duo Sensor Network

We added a second sensor: the Dielectric Moisture (DM) sensor embedded within the soil layer and the DM measures the level of wetness as the water penetrates the soil. The DM sensor, shown in Figure.1, should be placed vertically down to test the infiltration within the soil layer, and then attached to the data acquisition board and the wireless mote. As before, we should investigate the data generated and the power consumed by setting thresholds for both the sensors. With the moisture sensor data at hand we can try and predict the landslides better using dual thresholds. For example, out of the times both sensors exceed their respective thresholds, it is likely for a landslide to occur. This accuracy of prediction is certainly better than rainfall sensors alone. Moisture sensors tell how much of the rainfall water is actually seeping through the soil layers but don't indicate how much water is being retained in the soil layers, is draining out, or filtering down. So, we opted to use a third sensor to measure the water-induced pressure build up inside the soil.

Table 1. Symbols used in the paper

Symbol	Description	Symbol	Description
T	Total No. of Sensor nodes in the Network	E_s	Energy for sampling a sensor
N_{dy}	Total No. of Samples per day from a sensor	E_{cp}	Energy comparing two sensor values
D_s	No. of bits per sampled sensor value	E_{tx}	Energy required to transmit one bit by a sensor node
E_{ch}	Energy restored to battery by solar charging in a day	E_{rx}	Energy required to receive one bit by a sensor node
E_{sto}	Total energy stored in a battery	E_{dy}	Energy consumed by the WSN in one day

C. Triple Sensor Network

The piezometer (either the vibrating wire type or strain gauge type) shown in Figure 1 is used for measuring the ground water pore pressure. As pore pressure increases, the rainwater infiltration on a slope can lead to slope instability [10]. The piezometer is placed along with the dielectric moisture sensor embedded within the soil, and attached to the data acquisition board. For a range of sampling frequencies from 1/sec to1/hour, sensor data should be collected, the energy consumption should be calculated and the battery lifetime ranges in days should be calculated. Since our goal is to build a system capable of issuing advanced warnings, the triple sensor system serves to further improve landslide prediction to about 80% accuracy. Although pore pressure sensors tell how much of the rainfall water is being retained within the soil slopes and layers, they do not indicate if the slopes or layers are moving, and such movement may act as a trigger to initiate a landslide [10]. We wanted to be able to indicate if such a situation was initiated, so we included a movement sensor.

D. Four Sensor Network

To capture the soil movements caused by the slope and soil layer instability, three different movement sensors can be used individually or combined: the strain gauge, the tilt meter, and the geophone (Figure 1). The purpose of the tilt meter is to capture the change in angle of the soil layer during slope instability in x, y and z direction while the purpose of the strain gauge is to measure the strain experienced in the soil layer during the slope instability. The purpose of the geophone is to measure the vibrations generated during slope instability. When comparing the three sensors, the output from the tiltmeter sensor is easily captured with minimal processing, and the noise induced on the signal is low. The data from the four sensors is collected and transmitted at various sampling intervals as discussed above

IV. ENERGY CONSERVATION ALGORITHMS

In order for a sensor network to be practically deployable, the life time of the solar battery deployed should last for a longer duration of monsoon rainfall season. Now, we will investigate some techniques for dynamically throttling the rates of sensor sampling and transmission, so as to significantly reduce the energy and increase the battery lifetime, without impacting the effectiveness of landslide monitoring and detection.

A. Maximum Level Sampling (MLS)

In this technique, sensors sample and transmit only when the individual sensor values exceed their respective thresholds. The data is transmitted under this policy and total energy consumed by each four sensor could be obtained by taking Equation (1),$E_{dy} = N_{dy}(E_s + D_s E_{tx})$, and substituting N_{dy} =Number of times the threshold value is exceeded in a day. Applying this on real rainfall data, the threshold ranges start with the tuple [rainfall, moisture, pore pressure], set at [15mm, 0%, 0 kPa], labeled Low 1, and increase up to [00 mm, 100%, 60 kPa] for High 4, with almost equal intervals in between. This can save battery power to great extent.

B. Adaptive Maximum Level Sampling (A-MLS)

Here we have an adaptive approach among the different sensors to further reduce the energy. In this approach the rainfall sensor threshold will be set at its respective value (corresponding to each of the levels Low 1 to High 4), but the moisture and pore pressure thresholds were activated only when the rainfall sensor crossed its respective threshold. This sensor approach reduces the energy further thereby consuming low power.

C. Forecast Sampling (FS)

In the event of availability of a historical rainfall and other climatic data a forecast model can be used to predict imminent rainfall and other parameters. The forecast value can be as simple as the repeat of the previous value; alternatively, a statistical mean of prior years' measurements can be used as the forecast value. A forecast server at the command and control center computes the forecast values and transmits them at set intervals to the sensor network. The sensors transmit only if their current actual sampled measurement varies (by a set threshold) from the received forecast value, and furthermore, only the difference is transmitted. The total energy consumed by each four sensor will now have an additional factor, E_{rx}, which represents the energy consumed by the sensor node to receive the forecast value, in addition to E_{dy}, given by (1). This could be expressed by (3)

$$\mathbf{E_{fs} = N_{dy} (E_s + D'_s E_{tx}) + N_{fs} D_s E_{rx}} \qquad (3)$$

where N_{fs} is the daily number of forecast values received, N_{dy} is the (average) number of times the forecast differential exceeds the threshold in a day and D' s<<Ds. FS yields, the least daily data transmission, energy consumption and therefore the maximum battery life.

V. FIELD DEPLOYMENT OF THE SENSOR NETWORK

We can implement the above energy minimization algorithms in the processing unit attached to each group of four sensors (rainfall, moisture, Pore pressure sensor, and tilt meter) which together constitute a Multi-Sensor Probe .(MSP). Each probe is topped with a data acquisition board, a wireless mote, and an embedded processor to intelligently manage frequency of sampling and transmission, based on dynamic and adaptive setting of thresholds, and other energy minimization policies and mechanisms discussed in the previous sections. The geological sensors are placed inside a sensor column [11] and they are connected to the wireless sensor node via a data acquisition board. 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. The block diagram of the system is shown in figure 3.Here we are implementing 3 nodes of four sensor network and a master at the remote end as controller for data monitoring and issuing warnings from available data through GSM module.

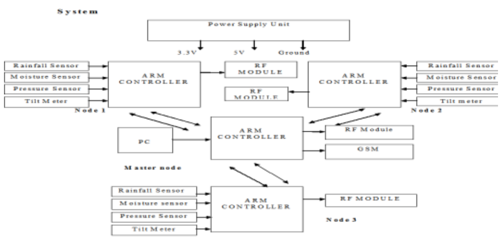


Figure 2.Block diagram of the system

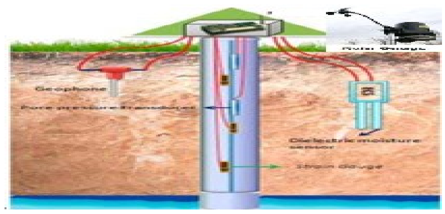


Figure 3. Sensor Column used for a node

VI. CONCLUSION

We are going to design a multi-sensor network for monitoring landslides. With data reduction and energy conservation, we will be evolving with the network starting from a set of homogeneous sensors, to a network of duo sensors, followed by a triple sensor network and finally a full-fledged four sensor network considering their energy requirements. We then propose energy conservation algorithms and their implementation via cooperative and coordinated action by each of the sensors. The system developed with sensor networks and conservation algorithms will prove its validity by delivering real warning during heavy rains in the monsoon season. This system could be adapted for flood, avalanche, and other environmental monitoring applications with suitable modifications in it.

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