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Data Reduction and Energy Sustenance in Multisensor Networks for Landslide Monitoring

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***Abstract*:- Data reduction and energy minimization in Sensor Networks for landslide detection. started as a simple homogenous network of rainfall sensors has evolved into a complex heterogeneous network of 20 wireless probes with each probe consisting of four different types of sensors to measure rainfall, moisture, pore pressure, and movement. Each probe runs on solar power and the frequency of sensor data measurements from the probes is dynamically and adaptively throttled in real time, based on climatic conditions to minimize the total energy consumption. The probes also work together to identify who among them is sensing the maximum parameter, after which all other sensors are switched off for a predetermined duration. Present detailed analysis of data reduction and energy savings, and also relate them to the effectiveness of landslide detection. which facilitated pre-emptive action by the local government and community to prevent loss of human life.**

Index Terms—Sensor networks, rainfall monitoring, landslide detection, data reduction, energy minimization, wireless nodes.

I. INTRODUCTION

Sensor networks and wireless technologies offers the capability of quick capture, processing, and transmission of critical disaster data in real-time from inaccessible sites, incurring minimum maintenance as well. 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 focuses on sensor networks for detecting landslides, paying particular attention to data reduction and energy minimization. The entire system evolved from first a network of homogeneous sensors, then a network of dual sensors, followed by a tri sensor network, and ultimately a quad sensor network. All of the above sensors use solar power for their energy needs. Solar power tends to rapidly diminish during the rainfall season. Hence minimizing the energy becomes an overwhelming priority for sustained operation of the network, particularly during the imminence of landslides. This indeed is the goal of this paper. Using a heterogeneous wide area network consisting of Wi-Fi and long-haul satellite. considerations, have experimented multiple policies for throttling the frequencies of data measurement of the climate parameters, without unduly impacting the efficacy of landslide detection then compute statistically significant parameters such as maximum and identify the sensor(s) generating the maximum. All other sensors except the ones generating the maximum are switched off for a forecasted duration, so as to further minimize energy have implemented these energy minimization algorithm in Multi-Sensor Probes (MSPs) each consisting of a group of four sensors (rainfall, moisture, pore pressure, and movement), a wireless mote and a processing unit. Twenty such MSPs are embedded 25m deep into the earth over a seven acre region in the hilly equatorial forest of Kerala, India also present lessons learnt from deploying sensor networks in remote inaccessible regions and inclement climatic conditions. Fortunately for us, this entire research project fructified into a truly 24 × 7 operational system that culminated in the delivery of life saving landslide warnings, heeded and appreciated by the local community, media and the governmental administration during the recent monsoon season.

II. EXISTING SYSTEM

Sensor networks has been an active research area for almost a decade. Environmental monitoring, as well as energy conservation have been significant priorities in many of these studies. Some of the earliest schemes propose keeping sensors on only when there is data [for example, Ye, Heidemann, and Estrin]. Another popular technique to reduce data is by aggregation and fusion [He, Blum, Stankovic, and Abdelzaher], [Baek, Veciana, and Su]. Our distinguishing contribution is to present studies from siginificant amounts of data collected from a real field deployment that has been kept operational for sufficiently long duration amidst inclement weather conditions. We analyze each sensor for its data generated and energy consumption, then compute its sustainability for the entire monsoon season, and correlate the predictability of landslides from the sensor data. In existing all the sensors node values is passed through the wireless network through Gateway node at a time, so data logging and time delay will occur its spoils the efficiency of the system.

III. PROPOSED SYSTEM

Proposed techniques to dynamically throttle the data collected, with the goal of minimizing energy consumption without diminishing the effectiveness of landslide monitoring. Here using the different sensor networks like 1) single 2) dual 3) tri sensor and 4)quad sensor networks to maintain both data reduction and energy minimization. In proposed the individual sensor node value can be passed through the wireless network through Gateway node, so time delay and data logging will be totally reduced and also it improves the efficiency of the system.

A.SINGLE SENSOR NETWORK

One tipping bucket type rain gauge was mounted on a pole above the land surface. The tipping bucket rain gauge was connected to a wireless mote through a data acquisition board, and the sensor data was transmitted to our university laboratory located 300 km away via a sequence of Zigbee, Wi-Fi, and VSAT (satellite) networks, with intervening gateways. The rain gauge sensor was programmed to collect and transmit rainfall levels at various sampling frequencies. For the rainfall received, the data transmitted by the sensor network, energy consumed per day, and battery lifetimes for various sampling frequencies are presented in the graphs labeled "single Sensor". The daily energy consumed is computed from the sum of the sensor sampling energy (E_{smp}), and the wireless transmission energy (E_{xmt} * B_{smp}), both multiplied by the number of samples per day, as indicated by

$$E_{day}=S_{day}(E_{smp}+B_{smp}E_{xmt})$$

B. DUAL SENSOR NETWORK

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 Fig. 1, was placed vertically down as far as three meters in order to test the infiltration within the soil layer, and then attached to the data acquisition board and the wireless mote. As before, we investigated the data generated, the power consumed, and the overall costs associated with placing two sensors and the accompanying network. The results are presented in the graphs labeled "Dual Sensor" in Fig. 2. For a range of sampling frequencies from 1/sec to 1/hour, the data transmitted ranges from 10 MBytes/day to 2 KBytes/day, the daily energy consumed ranges from 268.735 Wh to 105.340 milliWh, and battery lifetime ranges from 9 minutes to ~14 days. The cost of the setup also increases to $380. With the moisture sensor data at hand we can try and predict the landslides better using dual thresholds, Rainfall threshold is set at 120 mm/day as before, and the moisture threshold is set at 50% volumetric water content [Caine] - which is the saturation value above which landslides are observed. These two types of sensors acting together help us to better predict landslides. For example, out of the times both sensors exceed their respective thresholds, 70% of the time, landslide is observed to occur. This accuracy of prediction is certainly better than rainfall sensors alone, but we went further to see if it can be improved. 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 buildup inside the soil, called pore pressure, as this pressure could very well trigger a landslide.

C. TRI-SENSOR NETWORKS

The piezometer (either the vibrating wire type or strain gauge type) shown in Fig. 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. We decided to use both versions of the piezometer. So now the sensor mote had three sensors attached to it: the rain gauge, the dielectric moisture (DM) sensor, and the piezometer. The piezometer was placed along with the dielectric moisture sensor embedded within the soil, and attached to the data acquisition board. The pore pressure measurements are presented in the graphs labeled "Tri Sensor" in a range of sampling frequencies from 1/sec to 1/hour, the data transmitted ranges from 15 MBytes/day to 3 KBytes/day, the daily energy consumed ranges from 403.38 Wh to 160 milliWh, and battery lifetime ranges from 5 minutes to 6 days. The cost of the setup rises to $1050 if a strain gauge type piezometer is used, otherwise the cost will increase to $3720 if a vibrating wire type piezometer is used. Since our goal was to build a system capable of issuing advanced warnings, the tri-sensor system served to further improve landslide prediction to about 80% accuracy. But it certainly did not offer false-proof prediction. 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. We wanted to be able to indicate if such a situation was imminent, so it was decided to add a movement sensor.

D. QUAD SENSOR NETWORKS

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 tiltmeter, and the geophone (Fig. 1). The purpose of the tiltmeter is to capture the change in angle of the soil layer during slope instability 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 understood with minimal processing, and the signal is only minimally compromised by noise. Both the tiltmeter and the strain gauge need excitation power, but the geophone sensor is self-excited. The geophone requires relatively high data sampling rates, which leads to a higher bandwidth requirement. The data from the quad sensor was collected and transmitted at various sampling intervals - the results are presented in the graphs labeled "Quad Sensor" in Fig. 2. Now, as the sampling rate decreases from 1 sample per second to 1 sample per hour, the data transmitted ranges from 20 Mbytes/day to 4 Kbytes/day, and the daily energy consumed ranges from 539.382 Wh to 215 milliWh, and the battery lifetime varies from 3.8 min to 4 ½ days. The cost of the setup also increases to $2550 or $5220 according to the type of piezometer and the movement sensors selected shows how much data is transmitted in single, dual, tri and quad network.

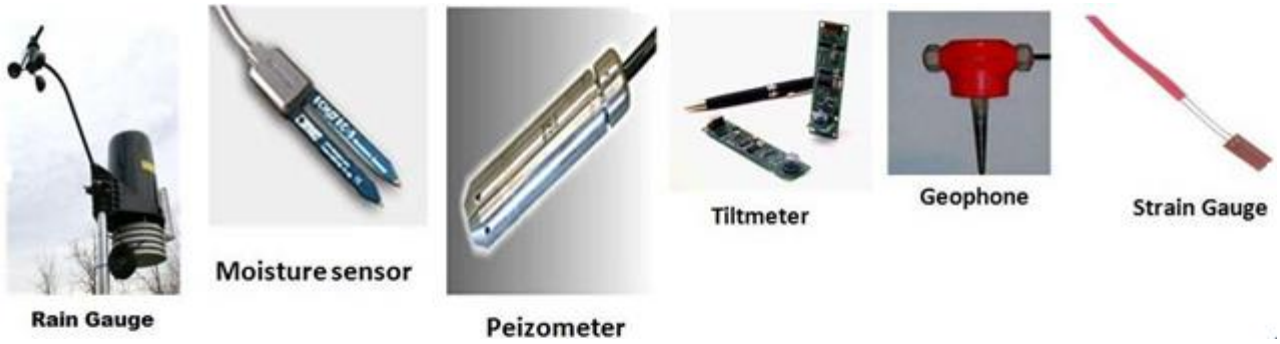

Figure::1

IV. SIMPLE FREQUENCY REDUCTION TO DYNAMIC THROTTLING

In order for a sensor network to be practically deployable in the field, the life time of the solar battery deployed should last at least the several months (four to six at minimum) of monsoon rainfall season Clearly, this is not acceptable, because it may make the sensor network vulnerable to missing occurrences of landslides, there by voiding the very purpose of the setup. 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. In that we are implementing three technique used for data reduction and energy minimization namely A)**Threshold Level Sampling (TLS) B) Adaptive Threshold Level Sampling (A-TLS)** C) **Differential Forecast Sampling (DFS)**

A) THRESHOLD LEVEL SAMPLING (TLS)

In this technique, sensors sample and transmit only when the individual sensor values exceed their respective thresh-olds. The data transmitted under this policy ranges from 500 Bytes/day to 350 Bytes/day and total energy consumed by each quad sensor could be obtained by taking Equation (1), $E_{day} = S_{day}(E_{smp} + B_{smp}E_{xmt})$, and substituting S_{day} = 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 [20 mm, 0%, 0 kPa], labeled Low 1, and increase up to [00 mm, 100%, 60 kPa] for High 4, with almost equal intervals in between. From the figure, it can be seen that energy consumed varies from 21 millWh to 14 milliWh, and the threshold level sampling (TLS) improves the battery lifetime to about 43 days at the lowest threshold level and up to 63 days at the highest threshold level.

B) ADAPTIVE THRESHOLD LEVEL SAMPLING (A-TLS)

Next, tried an adaptive approach among the different sensors to further reduce the energy. In this approach the rainfall sensor threshold was 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 to about 6 milliWh to 2.25 milliWh, and increases the battery lifetimes to 150 days at the lowest threshold levels and to ~400 days at the highest threshold levels, with very little chance of missing any landslide occurrences. Here the data transmitted ranges from 150 Bytes/day to 55 Bytes/day. It should be noted that in this paper, we have not dealt with how thresholds are set for the various climate parameters. Such a discussion would require going into the geotechnical aspects of landslides, clearly out of scope of this publication. However, for purposes of the sensor network, it suffices to say that the climatic parameters' thresholds can be set in one of two ways: (a) If historical rainfall and landslide data for adequate number of prior years is available, the lowest observed rainfall leading to a landslide (however minor it may be), can be used to set the threshold values. (b) In the absence of historical data, the threshold values can be arrived at by using theoretical landslide models applied on soil properties. Both of these approaches which fall more within the scope of earth sciences are discussed in our companion papers [Ramesh and Vasudevan], and are not elaborated further in this paper, which focuses mainly on wireless sensor networks and their energy savings

C) DFS-DIFFERENTIAL FORECASTING

SAMPLING:

The forecast value can be as simple as the repeat of the previous value; alter-natively, 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 differs (by a set threshold) from the received forecast value, and furthermore, only the difference is transmitted also investigated many other threshold setting policies such as rate of change of pore pressure (which measures pressure exerted by water trapped.

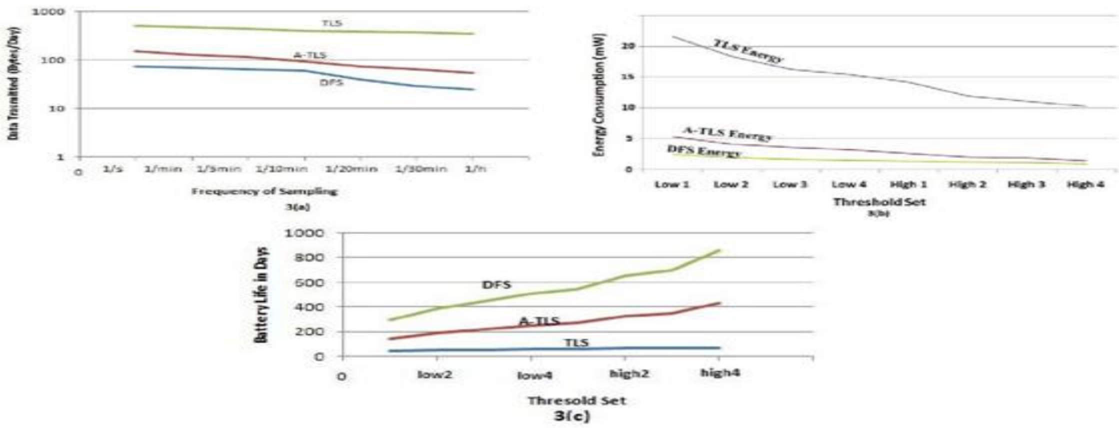

Figure::2

V. DATA & ENERGY MINIMIZATION VIA PEAK ONLY TRANSMISSION

The Multi-Sensor Network (MSN) for landslide monitoring and detection requires real-time data collection, processing, and transmission for long time periods, sometimes even several years. The sensor network is constrained by limited energy availability to perform these tasks. The primary objective when designing a network of multiple sensors - whether rainfall sensors, moisture sensors, pore pressure sensors, strain gauge, tiltmeter or geophone, is to minimize energy consumption, which is directly related to the data transmitted. We propose an energy minimization alternative: The entire sensor network operates in rounds. Each round starts with a computation to identify the peak value among the geological and hydrological sensors (whether it is rainfall, moisture, pore pressure or movement) deployed in a spatially distributed manner in the field. Following this all the other sensors except the peak valued one are switched off for a predetermined duration, after which all of them come back on and the round repeats. The above scheme will keep only one sensor drawing energy much of the time, except for the duration of computation of the peak. The energy consumed in this scheme consists of two components: energy consumed by all sensors from the start of transmission till the peak value is computed, and energy consumed by one sensor (the one with peak value) to be kept on all the time. The energy consumed by this one sensor, which is switched on, to transmit throughout the day is minimized using frequency throttling policies presented in the previous section. The energy consumed by all of the sensors for the duration of peak value computation could be minimized by directly minimizing the time taken for the peak value computation.

VI. REAL TIME PERFORMANCE EVALUATION & VALIDATION

Real time transmission of data from the deployment site to our University laboratory (300 kms) away, a tandem consisting of the sensor network, a Wi-Fi local area wireless network, and a VSAT (Very Small Aperture Terminal) satellite network, each interfacing with the next, has been laid out as shown in. The status of the network, as well as solar battery charge and discharge levels is continuously monitored. Under in a fail-safe manner. On rare occasions, all of the networks may go down simultaneously, during which time, the entire sensor data is locally cached in the Field Management Center, until reactivation of the network connection. Once the network gets reconnected, then the cached data is relayed to the data-base server at the Command and Control Laboratory within our University campus.

All of the sensor data, upon arrival at the Command and Control Laboratory, undergo quick error and consistency check and data normalization, after which, the statistical analyzer kicks in. Finally, a novel decision support system issues a warning level that can range from being Initial (lowest level of perceived danger), then Imminent, up to Immediate (corresponding to highest level of perceived danger). Our real streaming and visualization.

VII. CONCLUSION AND FUTURE ENHANCEMENTS:

We have designed, developed, and deployed a multi-sensor network for monitoring landslides in the equatorial forests of southern India. With data reduction and energy minimization always in the back of our minds, we have evolved the network starting from a set of homogeneous sensors, then into a network of dual sensors, followed by a trisensor network and ultimately a full-fledged quad sensor network. We have kept the network operational for more than two years amidst inclement weather, gathered extensive data from the field, experimented several policies for monitoring the climate parameters, and analyzed their energy requirements. We have then proposed energy minimization mechanisms and their implementation via cooperative and coordinated action by each of the sensors. The network with all of our techniques has proved its validity by delivering real warning to the local community during heavy rains in the last monsoon season. Our system is being extended to other landslide prone areas such as the Himalayas, and is also being adapted for flood, avalanche, and other environmental monitoring applications with suitable modifications.

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