Real-Time Monitoring System for Landslide Prediction Using Wireless Sensor Networks

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***Abstract*— The paper describes details of real time landslide monitoring and prediction system using wireless sensor networks (WSNs). The system consists of wireless nodes, gateway, base radio, server, geosensors and solar power arrangement. The system continuously monitors different parameters affecting landslide. Landslide prediction is done based on multivariate statistical analysis of various parameters and analytical hierarchy process method. The system provides different audio-visual alarms and short message services depending on prediction of landslide danger levels so that precautionary measures can be taken by nearby residents and local governing body. The paper also enumerates calibration procedure of geosensors used for landslide prediction by conducting laboratory trial in simulated condition.**

***Index Terms*— Wireless sensor networks, Geosensors, Landslide prediction system, Multi-parameters based landslide prediction, landslide prediction software**

I. Introduction

Landslide is a frequently occurring natural hazard in hilly regions. Major landslide prone areas in India are the Himalayas, Indo-Burmese Range, Western and Eastern Ghats, Nilgiris, and Vindhya Region. It affects around 15% of land area of India, which accounts approximately 0.5 million square kilometer [1–3]. Landslides on mountainous terrain often occur during or after heavy rainfall, resulting in loss of valuable life and property. To minimize these losses, there is a need for continuous monitoring of landslide prone hill slope and providing early warning before the occurrence of landslide. Different technologies have been developed for landslide monitoring, namely, geographical positioning system [4, 5], optical fiber sensors [6], remote sensing technique [7, 8], geographical information system [9–11], radar technology [12], laser technology [13-14], wireless sensor networks [15–21], cellular automaton [22], acoustic techniques [23, 24], local displacement monitoring instrument [25] etc.

After studying the features and limitations of above referred systems, it is found that there is a need to provide a reliable landslide monitoring and prediction system by using solar power based long-range wireless sensor network for continuous monitoring of different prevailing parameters of landslide in a large area.

An accurate prediction of landslide using multi-parameters based prediction model is required for giving warning to nearby residents as per the danger levels of impending landslide in hard rock and soft strata. Considering the requirement, a landslide prediction system has been developed using wireless sensor network for continuous monitoring of landslide prone hill and providing early warning. The paper describes details of landslide monitoring system, prediction software, laboratory experiment for calibrating geosensors and field installation of the developed system.

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II. SYSTEM DESCRIPTIONS

The landslide prediction system using wireless sensor networks Fig. 1 is a combination of a plurality of different geosensors, wireless nodes, base radio, gateway and server, and landslide prediction software. Raingauge, tiltmeter, in-place inclinometer, crackmeter and piezometer sensors are installed in the landslide prone hill slope for continuous monitoring landslide affecting parameters Fig. 2. Wireless nodes are strategically placed to form a unified wireless mesh network for transmitting sensor data to server in the control room through intermediate wireless nodes. The landslide prediction software is used for monitoring, analyzing, storing, viewing information received from the said wireless nodes connected to different sensors and providing audio-visual, short message service (SMS) and email alerts to the local governing bodies and nearby residents by predicting impending landslide. In the developed system, power supply unit of wireless nodes are recharged with the help of solar panel.

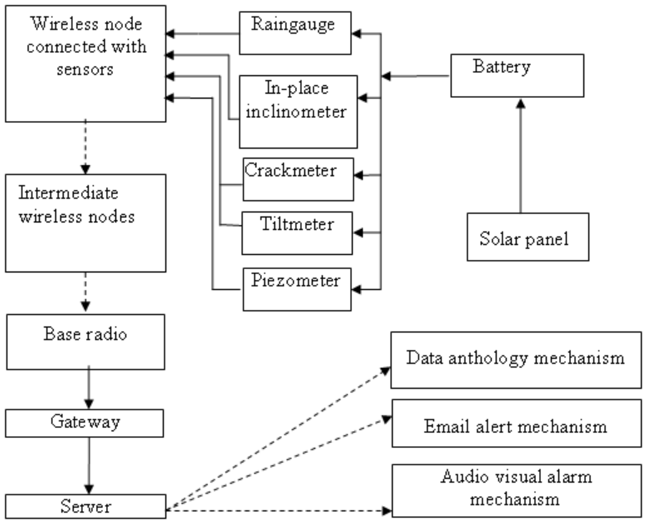


Fig. 1 Block diagram of landslide prediction system

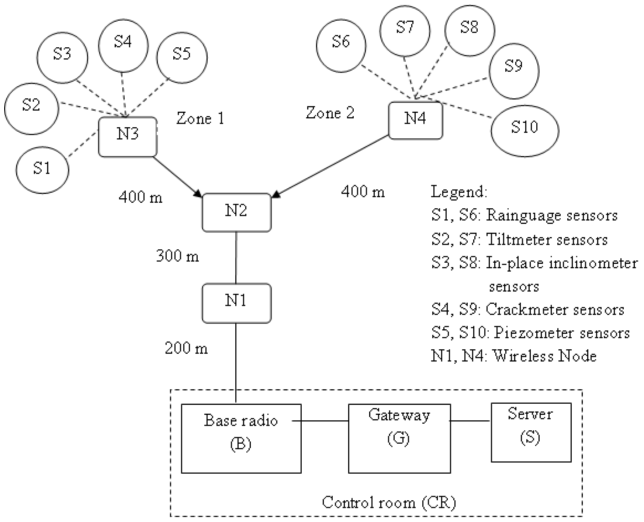


Fig. 2 Connection diagram of system at site

III. ARCHITECTURE

The system architecture for installing in two different landslide monitoring zones is depicted in Fig. 3. Different geosensors (S1–S5) are connected to wireless node (N3) and the remaining geosensors (S6–S10) are connected to another wireless node (N4). The said geosensors (S1–S5 and S6–S10) are placed in two different monitoring zones (Z1 and Z2), respectively. The said wireless nodes (N3 and N4) wirelessly send sensors data to the said server through intermediate wireless nodes (N2 and N1) base radio (B) and gateway (G). Sensor data of different zones are transmitted by wireless sensor nodes to the base radio. Subsequently, base radio sends this data to the gateway. This data then transmitted to the control room server (S) through serial port where it is programmatically stored in a Relational Database Server (SQL Server). The said server is connected to audio-visual alarm mechanism, and also sends short message service (SMS) and email alert to the district administration and local residents.

IV. PREDICTION TECHNIQUES

WSNs consist of wireless node, base radio, gateway and server for transmitting geosensors data from landslide monitoring site to remote control station. Wireless Node is used to receive and transmit sensor data. Wireless node uses ZigBee technology for communication. Wireless node consists of an Omni-direction antenna, analog to digital converter, microprocessor, digital to analog converter, connecting ports, solar panel and power supply unit to power the node Fig. 1. ZigBee works on 2.4 GHz frequency band offset quadrature phase-shift keying (OQPSK) modulation stream [26]. OQPSK uses a maximum phase transition of 90 degrees. Base Radio is used to collect sensor data from wireless nodes Fig. 3. The base radio is integrated with radio board, antenna and universal serial bus (USB) interface board which is preprogrammed with low-power networking protocol for communication with deployed wireless nodes. The USB interface is used for data transfer between the base radio and the application running inside the gateway. Gateway acts as an

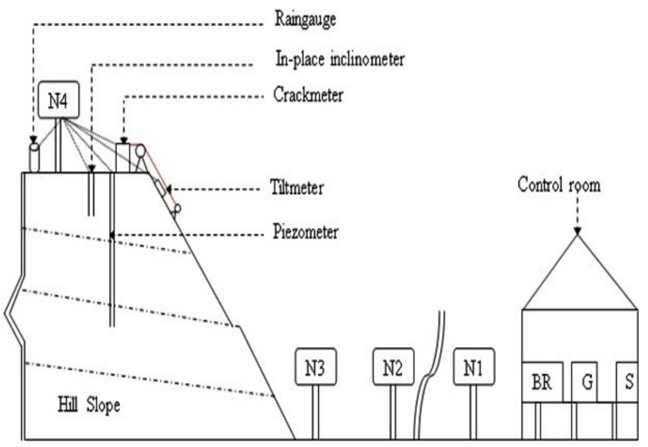


Fig. 3 System architecture

interface between server and base radio Fig. 3. It has preloaded network management and data visualization software packages. These programs automatically start when the gateway is turned on. It receives data from base radio and transmits them into the server storing location in raw format. Server is used for remote operation and monitoring purpose Fig. 3. Server has Dot Net framework as a frontend and SQL server as a backend for storing sensor data. It is used to predict and view landslide parameters in real time using landslide prediction software. Minimum requirement of server are 40 GB hard disk, 2 GB RAM, CPU 2 GHz and windows operating system. Landslide monitoring and prediction system uses five different types of sensors. Rainfall, vertical angle, horizontal angle, slope displacement, and pore pressure are measured by raingauge, tiltmeter, in-place inclinometer, crackmeter and piezometer sensors respectively. The operating principles of these sensors are tripping bucket mechanism, micro-electro-mechanical system (MEMS) based, potentiometric and foil strain gauge in Table I.

Table I ─ Technical specification of sensors

Sensor name	Operating principle	Measure parameter	Input voltage (V DC)	Rating output (mA)	Measuring range
Raingauge	Tripping bucket mechanism	Rainfall intensity	12–24	4–20	0–99 mm
Tiltmeter	MEMS based	Vertical angle of strata	18–24	4–20	±5°
In-place inclinometer	MEMS based	Horizontal angle of strata	18–24	4–20	±10°
Crackmeter	Potentio-metric	Displacement of strata	12–24	4–20	0–500 mm
Piezometer	Foil strain gauge	Pour water pressure	12–30	4–20	0–5 kg/cm^2

V. LABORATORY EXPERIMENT

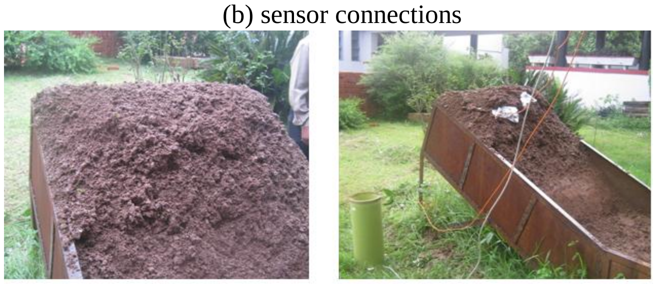
A laboratory study was conducted to understand landslide mechanism and its influencing parameters. Laboratory trials were conducted under simulated conditions to calibrate the sensors employed for landslide monitoring. A test bed was fabricated with iron sheet and angles, and filled with soil to form like a hill slope Fig. 4. Different sensors, namely: (I) Tiltmeter, (II) In-place inclinometer, (III) Crackmeter (IV) Piezometer were installed in the test bed, and (V) Raingauge was kept near the test bed. These sensors were installed in the soil of test bed Fig. 5. The sensors output were connected with an interface circuit, and the said interface circuit were connected with a wireless node and two intermediate wireless nodes were fitted on separate fixed poles at strategic locations to form a dynamic wireless mesh network. Gateway, base radio and server were installed in a laboratory around 600 m away from the test bed. All the sensors were set to zero reading by properly keeping their initial position and converting the initial sensor value as zero. All the sensors were connected with separate multimeter for monitoring sensor output voltage with respect to slope deformation and variation of related parameters.

Water was sprinkled on soil slope of test bed using a water sprinkling arrangement. The soil mass became wet and started sliding. Variations of horizontal and vertical slope angles, displacement in soil mass, water pressure and rainfall intensity were measured using tiltmeter, in-place inclinometer, crackmeter, piezometer and raingauge sensors respectively. All the data were transmitted to server through wireless nodes for storing and analysis. The tests were repeated thrice for precise reading and proper calibration of the sensors. Output voltage of each sensor was measured using a separate multimeter at certain intervals and corresponding sensor's raw data were noted for the particular sensor. Then the raw data were converted to actual sensor values by using calibration sheet of the particular sensor. Finally, a few data were selected from all the measured data and a data table was prepared for actual sensor value. A graph of actual sensor values and corresponding sensor's raw data stored in computer was prepared for the respective sensor.

Regression analysis was carried out to evaluate the best fit equation between actual sensor values and sensor's raw data stored in computer. Based on the regression analysis, best fit equation was developed for each sensor in Table II. These

(a) (b)

Fig. 4 View of test bed for laboratory trial; (a) test bed, (b) sensor connections



(a) (b)

Fig. 5 View of sensor installed at test bed; (a) in-place inclinometer, (b) tiltmeter sensor

equations were used for converting senor's raw data to actual sensor values for the respective sensor. These calibrated equations were incorporated in the landslide prediction software used for continuous monitoring of landslide.

Table II ─ Calibration equation for different sensors

Sensor name	Calibration equation	Regression coefficient (r^2)
Rainguage	Rainfall (mm) = 0.025 × Measured data + 3.287	1
Tiltmeter	Angle (degree) = 0.032 × Measured data – 13.10	1
In-place inclinometer	Angle (degree) = 0.064 × Measured data – 25.59	1
Crackmeter	Displacement (mm) = 0.979 × Measured data – 140.8	1
Piezometer	Pressure (kg/cm^2) = 0.009 × Measured data – 1.232	0.99

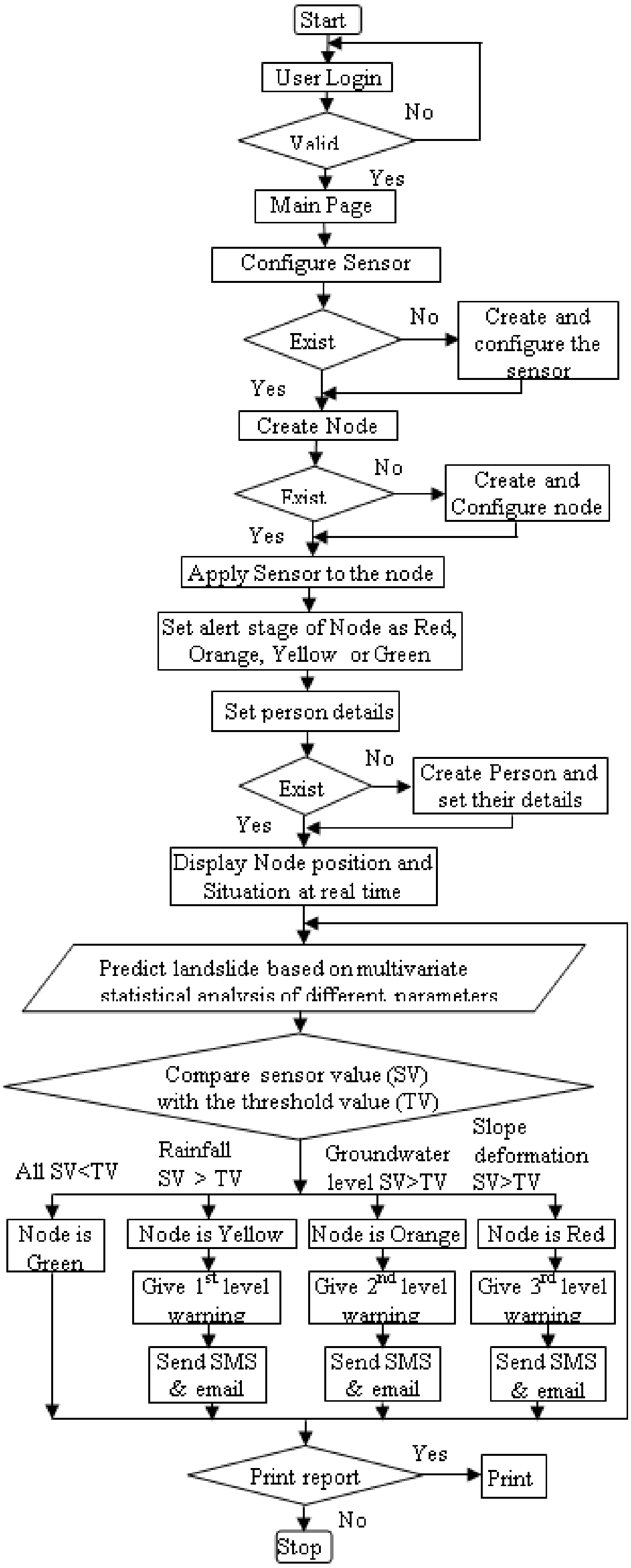


Fig. 6 Flow chat of configuration process and landslide prediction procedure

VI. LANDSLIDE PREDICTION TECHNIQUES

Landslide prediction software is developed for monitoring and prediction of landslide using WSN [30]. The application software was developed using dot net framework as a frontend and SQL server as backend to store geosensor data. Flowchart of landslide configuration process and prediction procedure is shown Fig 6. The geosensor values, which are being stored in the database, are analyzed with statistical method to predict the future event and act accordingly for information dissemination. The system monitors and predicts landslide based on multivariate statistical analysis of different parameters and analytical hierarchy process method [27, 28]. There are two aspects to generate the alarm such as current sensor value with uni-parameter based and multi-parameter based. In uni-parameter based, the alert gets triggered when any one of the influencing factor reaches or exceeds its threshold value whereas in multi-parameter based it considers multiple factors for the threshold. The system compares the sensor values (SV) (current/predicted) with the monitoring threshold value (TV) and works in the following manner:

A. Green Signal (Safe Level or No Warning)

When all the captured sensor value are less than TV, during this period the system only shows a green symbol representing no current risk or everything is in normal situation. This level is only for the monitoring purpose at the base station. In this situation no warning will be given to the local authority or local people.

B. Yellow Signal (Moderate Level or First Level Warning)

When the most valued triggering factor i.e. rainfall intensity reaches or exceeds the TV (raingauge) value, then the system shows a yellow symbol in the developed monitoring software interface representing that there is a chance of occurrence of landslide in the recent future. During this period a warning is given through beeping sound at the monitoring station and text message (SMS) along with email to the local authority.

C. Orange Signal (Alarming Level or Second Level Warning)

The rainfall induces increase in water level/ pore water pressure [29]. Subsequently, this triggers the next level of warning. When pore pressure reaches or exceeds the TV (piezometer) along with TV (raingauge), the system shows an orange symbol representing further chance of occurrence of landslide in recent future. This also sends alert SMS and emails to concerned authorities. This level of alert suggests avoiding going to that region.

D. Red Signal (Critical Level or Third Level Warning)

Due to increase in pore water pressure, the landmass starts displacing from its original location and in turn triggers the landslide. When other triggering factor i.e. displacement of masses / inclination of natural slopes reaches or exceeds the TV of crackmeter, TV of Tiltmeter / in-place inclinometer, respectively along with TV of raingauge and TV of piezometer, the system shows a red symbol representing a greater chance of occurrence of landslide in recent future. During this level, local people to be alerted about the occurrence of landslide by louder speaker or sirens. This also sends alert SMS and emails to concerned authorities. This level of alert suggests the local people to vacate the place or avoid going to that region.

The system provides the options of configuring the level of users for sending alerts at different levels. This helps in escalating the situation to the higher authority. The landslide

Table III ─ Sensors data stored in server

Date	Time	Raingauge (mm)	Tiltmeter (degree)	In-place inclinometer (degree)	Crackmeter (mm)	Piezometer (kg/cm^2)
2012/09/24	11:54:40	9.5	-0.3136798	-0.10124131	5.474854	0.2791276
2012/09/24	11:54:50	9.5	-0.3136125	-0.10180253	5.476554	0.2713908
2012/09/24	11:55:00	9.5	-0.3135889	-0.10226986	5.478253	0.2757597
2012/09/24	11:55:10	9.5	-0.3137706	-0.10198899	5.473158	0.2711799
2012/09/24	11:55:20	9.5	-0.3137246	-0.10273331	5.473158	0.2788651
2012/09/24	11:55:30	9.5	-0.3137706	-0.10255021	5.473158	0.2758118
2012/09/24	11:55:40	9.5	-0.3138382	-0.10282486	5.473158	0.2757597
2012/09/24	11:55:50	9.5	-0.3136574	-0.10320064	5.473158	0.2758118
2012/09/24	11:56:00	9.5	-0.3137706	-0.10329219	5.471456	0.2713371
2012/09/24	11:56:10	9.5	-0.3138615	-0.10338944	5.476552	0.2758118
2012/09/24	11:56:20	9.5	-0.3139525	-0.10366413	5.473158	0.2757597

prediction software has the following features: (i) obtains real-time information about the sensor parameters, (ii) customizable views of real-time data with bar charts, trend charts and maps, (iii) generates / triggers alert based on threshold parameter through e-mail and SMS, (iv) gives three levels warning based on landslide danger level, (v) landslide monitoring at various zones using different set of sensors, (vi) situation of each zone (safe / moderate / alarming / critical level) is also shown in the window with different colour codes (green / orange / yellow / red), and (vii) administrative user can configure the settings or accommodating more number of sensors and their threshold parameters.

(a) (b)

Fig. 7 View of installation site; (a) site location, (b) server room

VII. FIELD INSTALLATIONS

The developed system was installed in at Karshingsa landslide prone area, where frequent landslides occurred during last two decades. Karshingsa area is located on the bank of Dikrong river near Itanagar in Papumpare district of Arunachal Pradesh. The monitoring location was divided in two zones Fig. 7 and in each zone five different sensors were deployed Fig. 3.

Different sub-systems of landslide prediction system namely, solar power backup and wireless nodes were also installed in the site. Initially data were received at an interval of 10 seconds in Table III subsequently it was changed to one minute to reduce the storage capacity. Rainfall, vertical angel, horizontal angel, slope displacement and pore pressure was measured by using rainguage, tiltmeter, in-place inclinometer, crackmeter, and piezometer, respectively.

VIII. CONCLUSIONS

The landslide prediction system using wireless sensor network is capable of real time and continuous monitoring of different prevailing parameters of landslide such as rainfall, vertical and horizontal inclination of rock mass, displacement of rock mass and ground water level in strata, and providing different levels of alarm and short messages to administrative staffs of different capacities and subsequently to the local residents for evacuating the place of impending landslide. The system would help in monitoring different landslide prone zones in an large area by a single system by installing five or more types of geosensors in each zone and integrating all wireless networks of different zones with the same system. This would help in providing accurate and reliable landslide prediction model based on multivariate statistical analysis of different parameters and analytical hierarchy process method. This would also help in saving valuable life of people residing near landslide prone areas.

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