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WIRELESS SENSOR NETWORK FOR LANDSLIDE MONITORING

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ABSTRACT

Every year all over the world many lives and properties are lost due to many geological catastrophes like, landslide or landslip. Manual and electronic monitoring systems are used for predicting the landslide. The manual monitoring system is laborious and not practical. And most of the electronic systems are complex and expensive. A wireless sensor network in conjunction with an underground pretension cable with a strain gage sensor attached at one end is proposed for a simple landslide monitoring system. A mathematical model has been developed for the system and the model is verified by simulation. The result shows that an early prediction of the landslide is possible by using the developed system.

Keywords: Wireless Sensor Network, Landslide, Automated Monitoring System, Strain Gage Sensor, Geological Catastrophe

INTRODUCTION

Worldwide, landslides cause about 1,000 deaths per year and property damage of approximately US$ 4 billion [1]. Existing manual solution is insufficient and sometimes it is costly for landslide prediction and detection. Installing a single sensor for monitoring a wide hilly target area is not sufficient. Most of the cases, the property of the hill is changed in about every 10-15 meters distance. Wiring with multiple sensors to a central data logger is also not reliable and practical as well since it requires frequent maintenance. Therefore, wireless sensor network system is used for real-time landslide monitoring. Thin film strain gage pressure sensor with high accuracy pressure measurement is clamed in the system [2]. A simple pretension underground cable attached with a strain gage at one end can be easily used to measure the pressure of the soil as shown in Fig. 1.

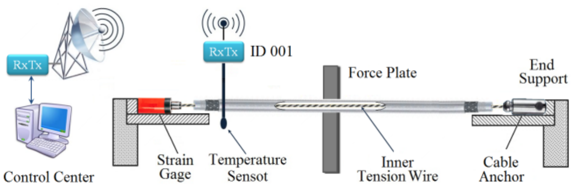

Fig. 1 Basic arrangements of the proposed wireless sensor network system for landslide monitoring.

The measured pressure can be used to calculate the landslide prediction and detection. A number of same kinds of sensor setup can be used for monitoring a wide land area. In this case, each sensor is defined by a unique number within a wireless network. This ID number can be easily used to locate the landslip zone. A majority of the wireless sensor network arrangements [3], [4] are mainly data collection networks. The wireless sensor network recurrently collects the respective data and collaboratively processes the measurements from the field under study before forwarding them to the central monitoring station. The central monitoring station executes more computationally-intensive algorithms such as finite element modeling and parameter identification [5], [6] and acts as the expert interface to the system. A wireless communication system can be used to transmit the sensors sampled data and relevant information to a distant central database server computer for analysis purpose. The instant conveyed information would allow us to implement instant disaster rescue measures and to notify the land user to protect the people's lives and properties.

SENSOR MODELING

A simplified force diagram of the proposed landslide pressure sensor that is, pretension cable with strain gage is shown in Fig. 2. Assume that a pre tensioned still cable length of L is attached at two end supports under the soil. If the linear expansion coefficient of the cable is α_L and the surrounding temperature of the cable is changed ΔT degree Kelvin then the change of cable length ΔL_T can be calculated as follows:

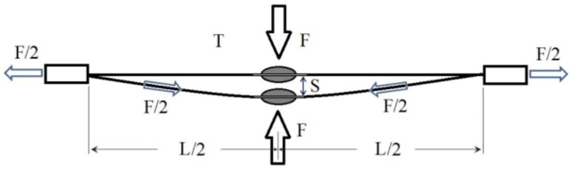

Fig. 2 Simplified force diagram of the proposed landslide pressure sensor.

$$\alpha_L = \frac{1}{L}\frac{\Delta L_T}{\Delta T} \qquad (1)$$

Or, $\Delta L_T = \alpha_L L \Delta T \qquad (2)$

When the land is slightly moved *S* distance from its initial position then it creates a force *F* on force plate as well as on the cable. If the Yang's modulus of the cable is *E* then at force equilibrium condition,

$$E = \frac{F/A}{\Delta L/L} \qquad (3)$$

Where, *A* is the cross section area of the cable and ΔL is the change in length of the cable due to force.

By considering the temperature effect, Eq. (3) can be rewritten as,

$$\Delta L = \frac{F(L + \Delta L_T)}{EA} \qquad (4)$$

The work U_E done by the soil movement can be calculated by Eq. (5).

$$U_E = FS \qquad (5)$$

The potential energy U_W stored in the cable can be calculated as follows:

$$U_W = \int_0^{\Delta L} F\, d\Delta L \qquad (6)$$

From Eq. (4) and Eq. (6),

$$U_W = \int_0^{\Delta L} \frac{EA\Delta L}{(L + \Delta L_T)} d\Delta L$$

Or, $$U_W = \frac{EA\Delta L^2}{2(L + \Delta L_T)} = \frac{\Delta LF}{2} \qquad (7)$$

From Eq. (5) and Eq. (7), the potential energy U_S stored in strain gage substrate is calculated as follows:

$$U_S = U_E - U_W = FS - \frac{\Delta LF}{2}$$

Or, $$U_S = F\left(S - \frac{\Delta L}{2}\right) \qquad (8)$$

Again, if the Yang's modulus of the strain gage substrate is E_S then at force equilibrium condition,

$$F_S = \frac{E_S A_S \Delta L_S}{L_S} \qquad (9)$$

Where, A_S and L_S are the cross section area and length of the substrate respectively. F_S is the force on the substrate and ΔL_S is the change in length of the substrate due to force.

From Eq. (9),

$$U_S = \int_0^{\Delta L_S} F_S\, d\Delta L_S$$

Or, $$U_S = \frac{E_S A_S \Delta L_S^2}{2L_S} = \frac{E_S A_S \Delta L_S^2}{2} \qquad (10)$$

By combining Eq. (8) and Eq. (10)

$$F\left(S - \frac{\Delta L}{2}\right) = \frac{E_S A_S \Delta L_S^2}{2L_S}$$

Or, $$\frac{\Delta L_S}{L_S} = \sqrt{\frac{2F}{L_{GS}E_{GS}A_{GS}}\left(S - \frac{\Delta L}{2}\right)} \qquad (11)$$

If the gage factor and the temperature coefficient of the strain gage are *G* and *α* respectively then the change of resistance ΔR of the strain gage with respect to the initial resistance *R* is calculated as follows:

$$\Delta R = R\left(\frac{G\Delta L_S}{L_S} + \alpha T\right) \qquad (12)$$

By combining Eq. (11) and Eq. (12)

$$\Delta R = R\left(G\sqrt{\frac{2F}{L_S E_S A_S}\left(S - \frac{\Delta L}{2}\right)} + \alpha T\right) \qquad (13)$$

From Eq. (4), if the Yang's modulus E of the cable is very large then $\Delta T \approx 0$ and Eq. (13) can be rewritten as Eq. (14).

$$\Delta R = R\left(G\sqrt{\frac{2FS}{L_S E_S A_S}} + \alpha T\right) \quad (14)$$

Eq. (14) indicates that the change of strain gage resistance is directly proportional to the squire root of the force and displacement of the land.

RESULT AND DISCUSSION

A PSPICE simulation is studied for the proposed landslide sensor for monitoring system. The result is shown in Fig. 3. In this simulation, it is considered that the Yang's modulus *E* of the cable is infinity and the temperature coefficient of the strain gage is very low. In Fig. 3, it is noticed that a very slow landslide effect is present at the beginning and about four months later, the effect is more visible. The sensor ID number 001 shows that its resistance is changing exponentially; it means a massive landslide would be happened within short time in the region under the sensor.

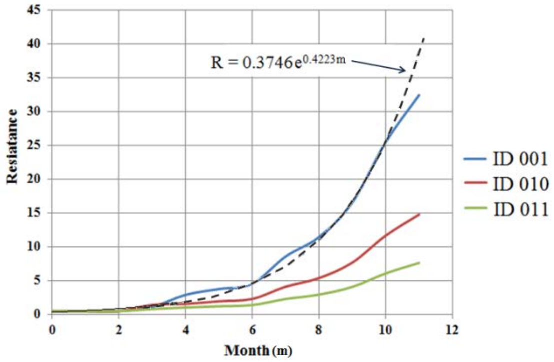

Fig. 3 Change of strain gage resistance with time.

CONCLUSION

A pretension cable and a strain gage sensor can be used for landslide prediction and detection purpose. The change of strain gage resistance is a direct indication of the landslide effect and no need to measure the exact value of the force or displacement of the soil. This principle can help to develop a simple and low cost real-time landslide or landslip monitoring system. According to the mathematical model, Eq. (13), for an efficient system, the Yang's modulus of the cable must be very large. Since, the still and carbon fiber cable have very large Yang's modulus; they can be used in this development.

REFERENCES

[1] Lee S and Pradhan B, "Landslide hazard mapping at Selangor, Malaysia using frequency ratio and logistic regression models", Landslides, Vol. 4, No. 1, 2007, pp. 33-41.

[2] Hongye W, Kun L, Zhichou A, Xu W and Xun H, "Ion-beam sputtered thin-film strain-gage pressure transducers", Sensors and Actuators A: Physical, Vol. 35, Issue 3, 1993, pp. 265-268.

[3] Szewczyk R, Polastre J, Mainwaring A and Culler D, "Lessons from a sensor network expedition", in proceedings of the 1st European Workshop on Sensor Networks, January 2004.

[4] Xu N, Rangwala S, Chintalapudi KK, Ganesan D, Broad A, Govindan R and Estrin D, "A wireless sensor network for structural monitoring", in proceedings of the 2nd international conference on Embedded Networked Sensor Systems, pp. 13–24, USA, 2004.

[5] Kuppusamy T, Sheng J, Parker JC and Lenhard RJ, "Finite-element analysis of multiphase immiscible flow through soils", Water Resources Research, Vol. 23, Issue 4, 1987, pp. 625-631.

[6] Hoshiya M and Sutoh A, "Kalman Filter-Finite Element Method in Identification", J. Eng. Mech., Vol. 119, Issue 2, 1993, pp. 197–210.