

Design of Deformation Monitoring System for Volcano Mitigation

M R F Islamy¹, R A Salam¹, M M Munir^{2, 4, a}, M Irsyam^{3, 4}, and Khairurrijal^{1, 4, b}

¹ Physics of Electronics Material Research Division, Faculty of Mathematics and Natural Science

² Theoretical High Energy and Instrumentation Research Division, Faculty of Mathematics and Natural Science

³ Geotechnical Engineering Research Division, Faculty of Civil and Environment Engineering

⁴ Research Center for Disaster Mitigation

Institut Teknologi Bandung, Ganesha 10, Bandung 40132, Indonesia

a) miftah@fi.itb.ac.id

b) krijal@fi.itb.ac.id

Abstract. Indonesia has many active volcanoes that are potentially disastrous. It needs good mitigation systems to prevent victims and to reduce casualties from potential disaster caused by volcanoes eruption. Therefore, the system to monitor the deformation of volcano was built. This system employed telemetry with the combination of Radio Frequency (RF) communications of XBEE and General Packet Radio Service (GPRS) communication of SIM900. There are two types of modules in this system, first is the coordinator as a parent and second is the node as a child. Each node was connected to coordinator forming a Wireless Sensor Network (WSN) with a star topology and it has an inclinometer based sensor, a Global Positioning System (GPS), and an XBEE module. The coordinator collects data to each node, one a time, to prevent collision data between nodes, save data to SD Card and transmit data to web server via GPRS. Inclinometer was calibrated with self-built in calibrator and tested in high temperature environment to check the durability. The GPS was tested by displaying its position in web server via Google Map Application Protocol Interface (API v.3). It was shown that the coordinator can receive and transmit data from every node to web server very well and the system works well in a high temperature environment.

1. Introduction

Volcano is an active mountain that had erupted before and potentially would erupt again in future [1]. The negative impact of volcano to world population would be severe in the future. This prediction was concluded from the fact that although the number of active volcanoes increased slightly but the growth of world population is increasing significantly [2]. Therefore, a volcano eruption mitigation system needs to be improved to prevent victims from this disaster. Some observed parameters used to monitor the volcano eruption hazard are seismic activity, temperature increase, CO₂ gas escalation, the rise of sulfur gas concentration, and the deformation on the slope of volcano [3-6]. The abrupt change of deformation parameter is a strong indication that a volcano is going to erupt [7]. Deformation of volcano is caused by high pressure from magma that is going to erupt thus inflating the ground [8]. Therefore, developing a robust system to monitor volcano slope deformation is urgently needed.



Volcano deformation monitoring has been conducted by using a tilt meter [5], satellite and GPS [9]. The tilt meter is able to measure the deformation immediately but unfortunately it cannot locate the position of the observed ground. The GPS can be used to measure the deformation and position of the observed ground nevertheless it needs good environment, high cost GPS, and special data processing analysis. Therefore, the use of tilt meter and low cost GPS simultaneously in one node/system is challenging to be investigated. In this research, the combination of tilt meter sensor employing inclinometer sensor for deformation monitoring and low cost GPS for locating the position of node has been examined.

2. Experimental setup

On developing the volcano monitoring systems, sensors must be selected correctly. Since the strong indication of deformation for volcano eruption is around two to three milliradians [7], the accuracy of selected sensors has to be higher than that value. Therefore, the inclinometer SCA100T D02 that has great accuracy is the best sensor to use for developing the systems. It has been proven that this type of inclinometer sensors has the precision about $0.07^\circ \approx 1.40 \text{ mrad/LSB}$.

The developed volcano monitoring system consisted of two main modules, the end device as child module and the coordinator as parent module which would send data from the child to the server. The child module included the inclinometer sensor SCA100T D02 as deformation detector, Xbee pro Series 1 as communicator with the parent module, GPS for marking the position of the child, 9 V power supply which has two kinds of output, 5 V and 3.3 V, and it was equipped with the AVR ATmega 8 microcontroller as main controller with Arduino boot loader. By using the Serial Peripheral Interface (SPI) communication, the microcontroller would receive and process the observed data from the SCA100T D02 and then deliver it to the parent module.

Moreover, the parent module consisted of the ATmega 328 microcontroller with Arduino boot loader as main controller, real time clock RTC DS1307, Xbee Pro Series 1, SD Card, and GPRS module to communicate with the server. This module would receive the measured data from the specific child address after pinging the child to send their data. Afterward, the parent would transport the data to the web server through GPRS communication.

After the system has been built, the sensor was tested by calibrator of inclination and physical modeling on ground deformation using sand and spherical balloon as magma chamber [8]. This model matched with the Mogi model for ground deformation caused by expanding spherical object below it [10]. The GPS was tested by showing the data of GPS on web server. The topology of WSN used was star topology with digimesh protocol based on the XBEE1.

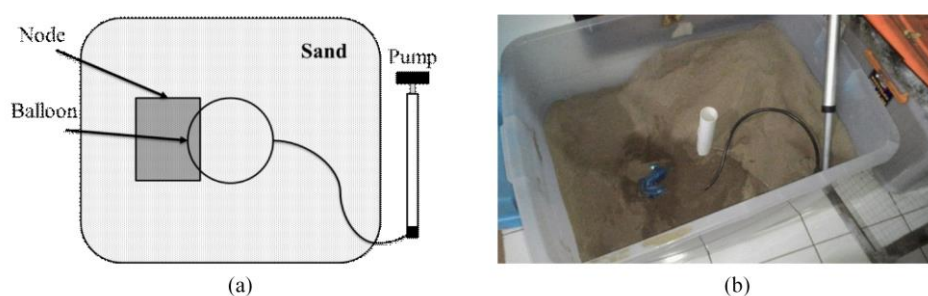


Figure 1. (a) Schematic diagram of deformation model and (b) Physical demonstration of deformation simulation.

The tilt calibrator was built with a bipolar stepper motor with step precision of 1.8 degrees. To improve the precision of this motor, the special gear was made using acrylic material. There are two special gears connected each other so the precision of this calibrator was improved to 0.03 degrees.

The ATmega8 microcontroller was used to control the rotation of this calibrator back and forth. The high current power supply for this motor was supplied by the bipolar motor driver L293D.

Figure 1 (a) shows the ground deformation model scheme. The simulation was built with a hand pump, a spherical balloon, sand, a container and node. The system would record sand deformation data that was caused by expanding balloon. The node was placed at above left side of balloon. In Figure 1 (b) the blue object at center is the spherical balloon without gas. A hand pump was used to fill the balloon with gas until fully expanded. This event would affect the sand around the balloon and cause deformation on it. The characteristic curve of this event was then recorded.

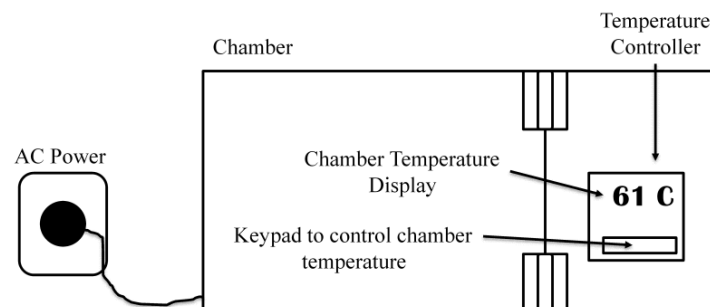


Figure 2. The chamber for temperature simulation.

To test the durability of sensor, the chamber that can control temperature was used. This chamber uses the AC source to power up the system. This chamber has ability to set and display the temperature inside of it. To prevent air from entering the chamber, a sponge was used to isolate the room from outside air. The test was done by increasing the temperature of chamber from room temperature to 65°C. The sensor module would send data when detected the change of temperature inside the chamber. The data of temperature and two axes of sensor were recorded to see the characteristics of sensor when working in high temperature. The chamber can be seen in Fig. 2.

3. Results and discussion

The calibration of inclination sensor has been performed. A stepper motor with configured gears was used in the calibrator to rotate the sensor precisely. The full scale of sensor was investigated by rotating the sensor back and forth for 180 degrees. The zero offset data of sensor was verified using a water pass. The data were used to confirm the normality of sensor. The calibration of both axes was observed by placing an axis at normal position (0,0) while the another axis changes with the spindle of calibrator.

Figure 3 shows hysteresis curves of the sensor. The curves are full scale measurement data of the tangential axis for forward and reverse data. The straight line area of this curve was around -40 to 40 degrees. For the radial axis, it has shown that there was saturation of the sensor in area of 30 degrees or above. Most likely, it was caused by the breaking of the transducer for radial axis. However, the sensor could still be used for measuring data between -30 to 30 degrees. This sensor consists of two transducers for each axis. So if one transducer was broken, it would not affect another transducer. Therefore, the data for tangential axis was better than radial axis data.

The dynamic range of inclinometer SCA100T has been investigated and it is shown in Fig. 4. It describes the resolution of sensor which can be acquired by comparing the angle data from the calibrator and digital data read by the sensor. It has been shown that the tangential axis had the resolution of 0.077°/LSB (1.40 mrad/LSB) and the radial axis had 0.060°/per LSB (1.04 mrad/LSB). There is a different resolution between the tangential and radial axis. It was caused by the dynamic range different between the axes. Therefore, the resolution of each axis would not be identical.

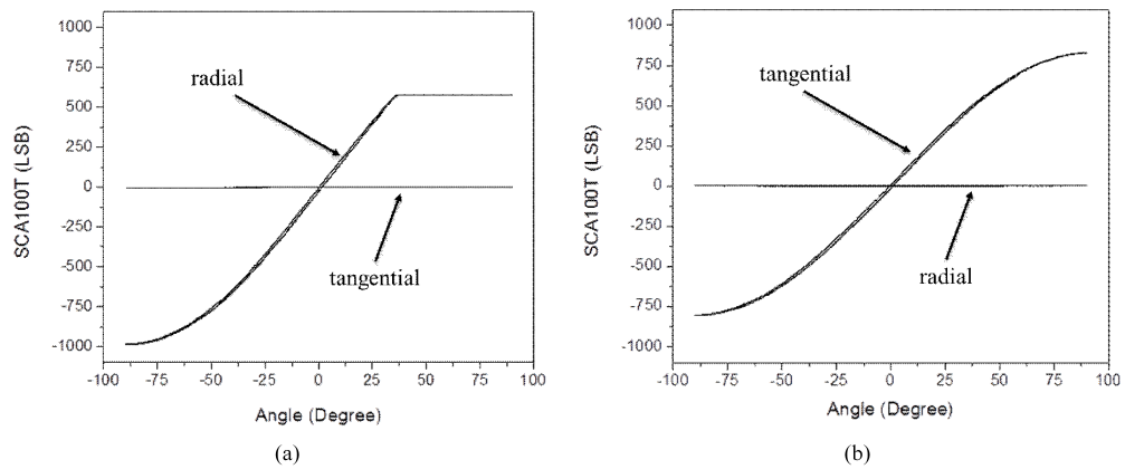


Figure 3. Full scale data (a) tangential and (b) radial.

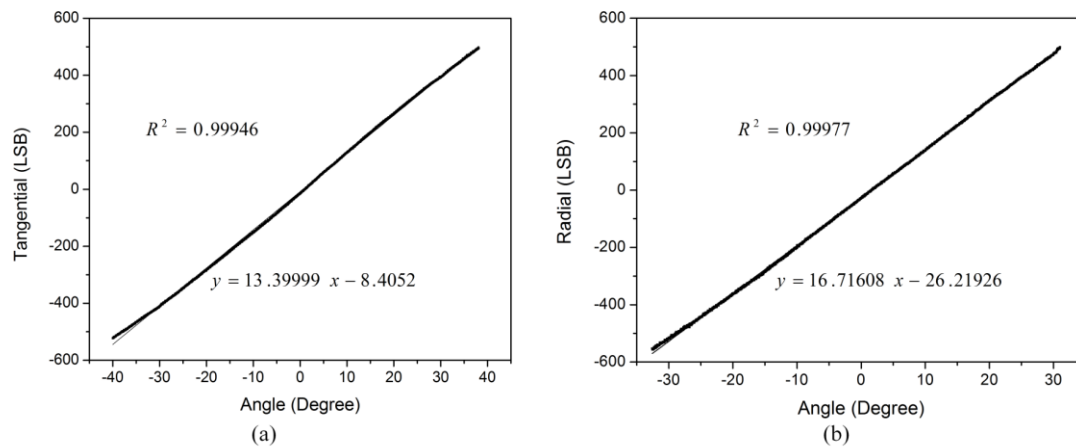


Figure 4. Dynamic range of sensor (a) tangential and (b) radial.

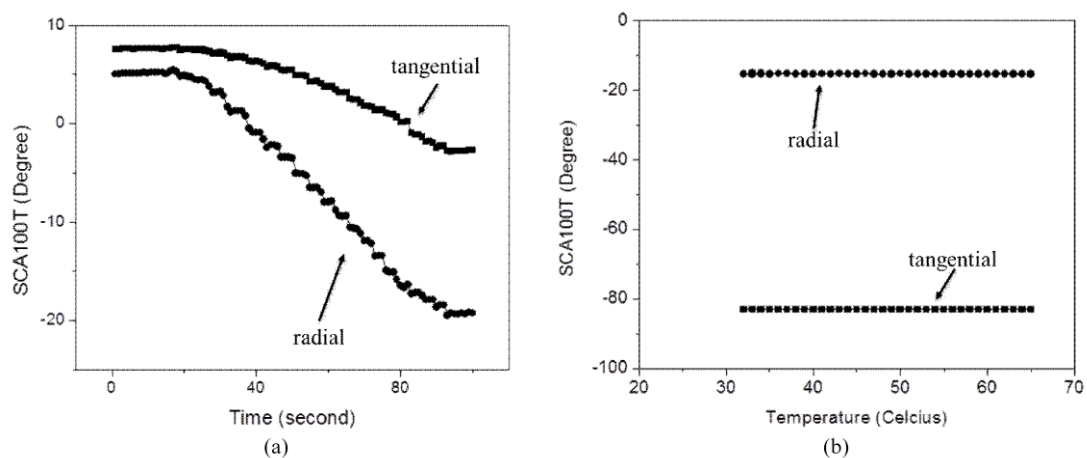


Figure 5. Simulation data (a) deformation and (b) durability.

Figure 5.(a) is the data taken from the deformation simulation. The simulation of deformation was done by pumping balloon below the ground starting from free of gas until fully expanded using a hand pumping. The curve is identical with the curve from the Mogi model [10]. Therefore, the sensor worked really well in measuring data. The data for GPS was described elsewhere. Figure 5.(b) shows the sensor output from the SCA100T D02 in condition when the chamber temperature was raised from room temperature till 65°C. The data shows that the sensor has high stability when there is temperature change. The sensor is therefore proven to be powerful to be implemented in a high temperature environment such as volcano.

4. Conclusion

The system for monitoring volcano based on deformation has been developed. The system can show data from the tilt meter and GPS very well. Simulation of ground deformation has been experimented and it was shown that the data measurement was identical with the Mogi model proving that the measurement data were valid. Therefore, the node worked very well in measuring data from simulation of ground deformation.

Acknowledgments

This work was supported by “Riset Unggulan ITB 2015” research grant in the fiscal year 2015.

References

- [1] Tilling R I 1989 *Rev. Geophys.* **27** 237–69
- [2] Tilling R I 2008 *Adv. Geosci.* **14** 3–11
- [3] Lowenstern J B and Hurwitz S 2008 *Elements* **4** 35–40
- [4] Rix M, Valks P, Hao N, van Geffen J, Clerbaux C, Clarisse L, Coheur P F, Loyola D G R, Erbetseder T, Zimmer W and Emmadi S 2010 *IEEE J. Sel. Top. Appl.* **2** 196 – 206
- [5] Nishi K, Hendrasto M, Mulyana I, Rosadi U and Purbawinata M A 2007 *Earth Planets Space* **59** 151–6
- [6] Larson K M, Cervelli P, Lisowski M, Miklius A, Segall P and Owen S 2001 *J. Geophys. Res.* **106** 1–12
- [7] Dzrusin D, Westphal J A and Johnson D J 1983 *Science* **221** 1381–3
- [8] Acocella V 2007 *Earth-Sci. Rev.* **85** 125–60
- [9] Abidin H Z, Andreas H, Gamal M, Hendrasto M, Suganda O K, Purbawinata M A, Meilano I and Kimata F 2004 *J. Global. Position. Syst.* **3** 16–24
- [10] Wright T L and Klein F W 2014 *Two hundred years of magma transport and storage at Kilauea Volcano, Hawai‘i, 1790–2008* (U.S. Geological Survey) p 240