Development of an Internet of Things Based Volcano Monitoring System

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Abstract. Indonesia has the highest number of active volcano all over the world. There were 63 eruptions with more than 70000 casualties from last year eruptions. To minimize the effect of this disaster, we have developed a volcano early warning system for Indonesia volcano. The main part of the system is volcano monitoring system. A system based on Internet of Things (IoT) has been developed to monitor some activities of a volcano. The physical parameters of these activities are indicated by the changing of temperature, gases (sulphur dioxide and carbon dioxide) concentration, vibration and landslides. The system consists of these parameter sensors, a microcontroller, a solar cell and a Long Range Radio (LoRa) for data transmission to the base station. The system has been tested in laboratory environment for the solar cell, sensors and radio communication. The solar cell could generate 18.81 Volt voltage and 0.23 Ampere current. The temperature sensor has been calibrated for until 51°C measurement (volcano normal condition), while the gas sensor could properly detect the gas until 8 ppm according to the calibration result. After Fast Fourier Transform (FFT) analysis the vibration sensor detected almost zero frequency with 0.168 m/s², 0.0168 m/s² and 1.125 m/s² X, Y and Z axis zero offset respectively. In addition, the landslide had maximum about 4° degraded land slope error. Moreover, only 4% (maximum) percentage error rate (PER) shown by the radio for about 400 m data communication. Furthermore, the physical parameter data acquired then be real-time displayed using Node-red dashboard which can be accessed by the user or other parties who need the information.

Keywords: volcano, internet of things, gas, temperature, vibration

1. Introduction

There are 1544 volcanoes all over the world. Indonesia has 177 volcanoes with more than 1000 eruption, resulted in fatalities, infrastructure damage as well as farmland. Livestock and etc. Hence, it is needed a volcano early warning system to predict when the eruption will happen, hence the evacuation and automatic response can be carried out immediately [1–10]. The main part of this system is monitoring system to monitor some parameters of volcano’s characteristics such as seismicity, temperature and gases [10]. Because of the importance of these data and hazardous environment for human, it is needed a real-time yet robust volcano monitoring system.
Therefore, in this research we have developed a volcano monitoring system for energy characteristics: vibration (kinetic energy), temperature and gases (thermal energy), landslide (potential energy), which has high-fidelity operation, real-time data acquisition and robustness, tested in laboratory and display the result in Node-red dashboard of MQTT (Message Queueing Telemetry Transport) with short program command, which easily to be implemented in various network for dual communication without packet loss [11].

2. Methodology

2.1 The System

Generally, the system is divided into two parts: client for the parameter measurement will be sent to the second part (server) which will process the data and connect to internet network through MQTT protocol (Figure 1)

![Figure 1. The system: client (green rectangle) and server (red rectangle), where data line indicated by solid line while power supplying by dashed line](image)

In client part, there are 5 sensors ((SO2 sensor TGS 2602, CO2 sensor MG 811 (will not be explained in this paper), temperature sensor DHT 11, vibration sensor ADXL 345, and gyroscope MPU 6050 for landslide measurement) connects with microcontroller Arduino D1 for receiving, processing and sending the data to server through WiFi ESP 8266 and LoRa-02, supplied by a solar cell for the battery charger through a controller which connected with the microcontroller.

In server part, there is Raspberry Pi 3B (Prosesor 1,2 GHz 64-bit quad-core, ARMv8, Videocore IV 3D graphics core GPU, and 1 Gigabyte RAM) featured by Node-red dashboard for displaying the real-time data and MQTT broker for client-server communication and fuzzy logic for defining the warning system status.

After each parameter of volcano (divided into thermal energy activity (SO2, CO2 and temperature), potential energy activity (landslide) and kinetic energy activity (vibration), in for level: normal, waspada (alert), siaga (standby) and awas (watch out)) acquired, these data then be processed by fuzzy logic using fuzzy rule. However, this logic will not be discussed in this paper.

The real-time data and their analysis are shown in InfluxDB which suitable for database time series for measurement application through Node-red dashboard of IoT [12]. For each database utilization, user could rename this process, while for each data recall process, user parse the data for data specification to be processes in the next step.

2.2 Laboratory testing

Reading the output of voltage and current of power supply is the first testing held for this laboratory testing to know how much energy degenerated by the solar cell and the time for charging this battery (Figure 2), where
Temperature sensor was tested inside a temperature controlled room where a reference Hg thermometer reading the temperature simultaneously with this sensor (Figure 3). For 1 °C decrement of thermometer, sensor measured the temperature in the same time. The numbers were compared to get a calibration curve for next real measurement.

Meanwhile, the gas sensor is placed inside a chamber with certain concentration of gas where analog voltage as the output represents the gas detected by the sensor (Figure 4). In this test, gas only available at 0-8 ppm. Therefore, a graph of voltage and gas detected also represented for only 0-8 ppm.
Furthermore, landslide testing is indicated by ground surface slope. The sensor is placed on a protractor (Figure 5). Then a surface which the slope can be varied is measured by the sensor and protractor in the same time.

Moreover, the vibration sensor is tested to know its zero offset. The output of this sensor is read to know the offset when there are no external forces applied (except gravitational force) [13-16] when the sensor is placed in a flat surface. The first test is where X axis is parallel to gravitational force, while Y and Z axis are perpendicular (Figure 6). The next is where Y axis is parallel to gravitational force, while X and Z axis are perpendicular, then Z axis is parallel to gravitational force, while X and Y axis are perpendicular. The result also presented in frequency domain using Fast Fourier Transformation (FFT) from time series domain.

![Figure 4. The Gas sensor testing mechanism](image)

![Figure 5. The Slope sensor testing mechanism](image)

![Figure 6. The Vibration sensor testing mechanism](image)
The last testing is LoRa RA02 testing without external antenna [17]. The Percentage Error Rate (PER) (ratio between error packet number in receiver per time unit with the packet received) is acquired for different distance. The distance was varied until the data could not be obtained (indicated by its signal strength RSSI - received signal strength indicator).

3. Result and Discussion

Power consumption of the system could be seen in Table I, where Battery capacity is 12 V and 7 AH. Therefore, Battery lifetime for this power consumption is 7 aH/(2.26 W/12 V), or 37 hours.

| No | Sensor      | Power Consumption (mW) | Information          |
|----|-------------|------------------------|----------------------|
| 1  | TGS 2602    | 15                     | Circuit              |
|    |             |                        | 280                  |
| 2  | ADXL 345    | 0.4719                 |                      |
| 3  | LoRa RA-02  | 396                    | Client               |
| 4  | DHT 11      | 1.5                    |                      |
| 5  | MPU 6050    | 13.53                  |                      |
| 6  | MG 811      | 1200                   | Heater and circuit   |
| 7  | Node MCU v3| 350                    | Fully operating      |
|    | Total       | 2,256.5019             |                      |

Solar cell (17.6 volt, 0.58 A) is used for battery charging. The output voltage and current for morning, midday and afternoon testing can be seen in Figure 7 and 8. It is assumed that the solar cell received energy for 12 hours. The average voltage (morning, midday and afternoon) is 18.81 V (Figure 7) and the average current is 0.229 A (Figure 8). Therefore, battery charging is 7 AH/0.229 A or 30.48 hours (Eq. 1 and 2).

![The Output voltage of solar cell for morning (start from 08:50), midday (start from 11:25) and afternoon (start from 15:00)](image_url)

Figure 7. The Output voltage of solar cell for morning (start from 08:50), midday (start from 11:25) and afternoon (start from 15:00)
Figure 8. The Output current of solar cell for morning (start from 08:50), midday (start from 11:25) and afternoon (start from 15:00)

Furthermore, there is only slight different result (maximum 0.7°C) for the temperature sensor and Hg thermometer comparison (Figure 9), because at this point/measurement response time is more than 2 s, the sensor could not obtain the proper data [18].

Figure 9. The Temperature measurement of the sensor DHT 11 (blue graph) and Hg thermometer (red graph)

Meanwhile, the sensor gas was tested until up to 8 ppm of controlled SO\textsubscript{2} concentration. The output voltage form straight lines with the slope 0.5 for 0-2 ppm (Figure 10), 5.91 for 2-4 ppm and 27.36 for 4-8 ppm (Figure 11). The voltage shows the concentration detected by the sensor.
Moreover, the slope sensor’s offset could be detected from the first measurement (0°), the sensor shows the -0.6° (Figure 12). Therefore, all the data seems slightly different.
Hereinafter, the following are the result from vibration sensor testing. The average zero offset from X and Y axis are almost 0, while Z is almost 1 m/s$^2$. However, it still in the range of operation [24]. Moreover, Z axis is designed to be parallel to the earth gravitational force, hence it shows wide deviation (10%) (Figure 13) from gravitational acceleration in Bandung (9.676 m/s$^2$) [19]. Moreover, these data were transformed into frequency domain by Fast Fourier Transform (FFT). This transformation is processed on board the microcontroller (Atmega 3281 dengan memori 32 KB). The data then be sent to the server as the input for fuzzy logic system. The data shows that there is no vibration in X, Y and Z axis detected by the sensor (~0 Hz) (Figure 14).

**Figure 12.** The Slope measurement of the sensor MPU 6050 (blue graph) and the protractor (orange graph)

**Figure 13.** The Vibration in form of acceleration for X axis parallel to the earth gravitational force (blue graph), Y axis parallel to the earth gravitational force (orange graph), Z axis parallel to the earth gravitational force (grey graph)
Figure 14. The Frequency domain of vibration of X (top), Y (middle) and Z axis (bottom)

These all data were sent by LoRa RA-02 from client part to the server part. LoRa characterized by its error ratio between the data sent by the client and received by the server (PER). In this test, the data packet error receive by the server is 2.87% (on average) (Figure 15) for 4 different distance with 100 measurements for each distance until LoRa shows very weak signal (under -102 dBm) of RSSI (Received Signal Strength Indication) in 400 distance m (Figure 16).
Figure 15. The Percentage Error Rate (PER) for 100 times measurement for each 100 m test

Figure 16. The Received Signal Strength Indicator (RSSI) for 100 times measurement for each 100 m test

All measured data are real-time displayed on Node-red dashboard (Figure 17) where the address of the data has the same name both in client and server parts.
Figure 17. The Node-red dashboard of sensor data: vibration of Y axis (Ay), Z axis (Az) and X axis (Ax) (top); X axis (Angle X) and Y axis (Angle Y) of slope (top); temperature and SO$_2$ (bottom), while humidity (top) and CO$_2$ (top) are explained in this research

4. Conclusion

It has been developed a volcano early warning system equipped with temperature, Sulphur dioxide, landslide and vibration sensors based on Internet of Things. The temperature has been tested for up to 51°C where only 0.7°C deviation when the measurement exceeded its response time. Sulphur dioxide sensor successfully detected the gas until up to 8 ppm as well as the slope sensor which has 0.6° zero offset. Furthermore, the vibration sensor detected almost zero frequency in normal condition test. Hereinafter, the real-time rapid measurement is displayed on node-red dashboard. In the near future, the system will be tested in a real volcano.
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