Remote Monitoring of Post-eruption Volcano Environment Based-On Wireless Sensor Network (WSN): The Mount Sinabung Case

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Abstract. An accurate information can be useful for authorities to make good policies for preventive and mitigation after volcano eruption disaster. Monitoring of environmental parameters of post-eruption volcano provides an important information for authorities. Such monitoring system can be develop using the Wireless Network Sensor technology. Many application has been developed using the Wireless Sensor Network technology, such as floods early warning system, sun radiation mapping, and watershed monitoring. This paper describes the implementation of a remote environment monitoring system of mount Sinabung post-eruption. The system monitor three environmental parameters: soil condition, water quality and air quality (outdoor). Motes equipped with proper sensors, as components of the monitoring system placed in sample locations. The measured value from the sensors periodically sends to data server using 3G/GPRS communication module. The data can be downloaded by the user for further analysis. The measurement and data analysis results generally indicate that the environmental parameters in the range of normal/standard condition. The sample locations are safe for living and suitable for cultivation, but awareness is strictly required due to the uncertainty of Sinabung status.

1. Introduction

Mount Sinabung (3.17°N, 98.39°E) is one of 130 volcanoes in Indonesia, lies on Pacific Ring of Fire — an arc of volcanoes and fault lines encircling the Pacific Basin. On 2010, the stratovolcano type with summit elevation 2460 m (8071 ft) erupted after dormant for more than 400 years. Since then the volcano intermittently erupting. The volcano dormancy more or less same as mount Pinatubo at the Philippines, which has a potentiality for massive magmatic eruption.

The eruption caused an impact in three sectors: economic, social and environmental. Volcanic ashes and hot cloud have ruined the resident houses and farms. The authorities reported until the end of 2014, for the productive economic sector, has lost about 896.64 billion rupiahs. At least 16 lives have dead according to the authorities. An estimation counts from the authorities showed more than 29000 residents from 32 villages had moved to safety locations. The authorities have defined the hazard area with 3, 4, 5 and 7 km radius from Sinabung crater. Unfortunately, the uncertainty of Sinabung condition pushed some of them back to their home and farms, which is unnecessary and disobeyed a warning noticed from authorities. Water resources and environment around Sinabung could be contaminated by hazardous materials produced by eruptive activity,
which is not being noted by the residents.

To avoid unnecessary casualties, accurate information about the environmental (soil, water, and air) condition should be available for the authority accordingly as well as for other stakeholders. The information should be easy to access too. Many applications has been built using the WSN technology \[1, 2, 3, 4, 5, 6, 7\].

This paper describes the implementation of the environmental remote monitoring system in mount Sinabung area. The sensors for monitoring the water quality, soil and gasses in the air were placed at the pilot points. Then, the information gathered by the sensors send to data server using GSM/3G channel communications and presents it in the application web. Finally, authorities and other stakeholders can access the web via the Internet to get the information. The Open source applications has been used in data analysis \[8, 9, 10\].

2. Methods and Configuration

An Arduino based system was used for processing the signal from sensors. A Waterproof packaging of the mote was required since the sensors will be placed at the outdoor. Smart Water (SW), Smart Agriculture (SA) and Smart Environment (SE) from Libelium Plug&Sense! product has been deployed at sampled locations.

The sensor and motes locations are at Tanjung Merawa, Tiganderket and Perbaji village, Tiganderket residence (Figure 1). Each motes will sense different environment indicators. The Smart Water will monitor the water quality parameters: Oxidation-Reduction Potensial (ORP), water pH, water temperatur, Dissolved Oxygen, and Conductivity. The Smart Agriculture will monitor the parameters related to soil condition, such as temperature (°C), humidity (%RH), atmospheric pressure (kPa), soil temperature (°C), Anemometer (km/hour), Pluviometer (mm/day), Soil moisture (Hz), Vane direction, Leaf wetness (%RH). As the Smart Environment will monitor the presence of certain gases in the air, such as Carbon dioxide (CO₂), Nitrogen dioxide (NO₂), Oxygen (O₂), and Carbon monoxide (CO).

![Figure 1: Motes location for remote monitoring environment in mount Sinabung area](image)

Since the number of equipment is limited, the data collection is done successively at pilot locations. The first location for data collection is at Tanjung Merawa and Tiganderket village, and Perbaji village for the second location.
The SW, SA and SW use GSM/3G as channel communication link. Then, the link connecting the SW, SA, and SE to BTS. Through the Internet cloud, the operator BTS forward the data packets to the data server. The topology of the system show on Figure 2. Periodically, motes activate and run a web service on data server accordingly. This web service then triggers the sensor to sampling the current value of the parameters. Afterward, the sampled value send back to the data server. In data server, a simple table has provided to store the information from the sensors. Each mote has one table to store their record sampled value. A web page has been build to present this data online. To analyze data further, the stored data at online web available for download in CSV format.

![Network topology remote environment monitoring system](image)

Figure 2: Network topology remote environment monitoring system

### 3. Result and Discussion

#### 3.1. Soil Condition Monitoring

The Smart Agriculture sensor measured soil moisture in frequency unit (Hz), therefore the conversion is needed to represent it in soil moisture percentage unit. After calibrated the sensor, the maximum frequency $F_{\text{max}} = 7986$ Hz, while the minimum frequency is $F_{\text{min}} = 51$ Hz. This means, for every 1% change in soil moisture, will provide the frequency difference of 39.59 Hz. Soil with high-value moisture percentage represents of high humidity soil. Likewise, soil with low-value moisture percentage represents of dry soil (low humidity soil). The soil moisture and temperature for 25 cm depth sensor shows on Figure 3.

![Soil moisture and temperature](image)

Figure 3: Monitoring result for soil temperature and moisture with 25 cm sensor depth
Measured soil temperature in the range of 23.50°C – 30.43°C, with mean temperature 23.93°C and median temperature 24.08°C. Maximum soil moisture from sampled data is 0.355%, this result inferred that water fraction in soil is very small at 25 cm depth below ground surface.

Although the anemometer recorded maximum wind speed at 24.8 km/hour, but the mean wind speed was about 5.69 km/hour or equal to 1.58 m/s. This is below the minimum wind speed required to turn wind generator plant to produce electricity, which is about 4 m/s. Vane direction showed the most wind direction to South-West (Figure 4).

![Figure 4: Monitoring result for wind speed and temperature with vane direction. Sensor height about 15m height above ground level](image)

3.2 Water Quality Monitoring

Oxidation-Reduction Potential (ORP) parameter measured in negative number. A negative ORP value indicate that a substance is a reducing agent. The lower the value measured, the more anti-oxidizing it is. ORP measured with ±15 cm sensor depth below water surface. The result in range of -1.90 - -0.60 Volts, with mean value at -1.011 Volts (Figure 5). This inferred that the sample water has big reduction potential. A reference ORP with 0 V is at 25°C for hydrogen reaction $2 \text{H}^+(\text{eq}) + 2 \text{e}^- \rightarrow \text{H}_2(\text{g})$. ORP value at 25°C for water ($\text{H}_2\text{O}$) with reaction $2 \text{H}_2\text{O}(\text{l}) + 2 \text{e}^- \rightarrow \text{H}_2(\text{g}) + 2 \text{OH}^-(\text{eq})$ is -0.83 V.

Another parameter to determine the water quality is Dissolved Oxygen (DO), which refers to oxygen (O$_2$) gas molecules present in the water. In real, O$_2$ present as part of a water molecule (H$_2$O), that can not be used directly by animal and plant in the water. The animal and plant depend on dissolved oxygen for respiration. Oxygen sources come from the surrounding air and as a product of photosynthesis from aquatic plants. In general, high levels of dissolved oxygen are best for a healthy water ecosystem.

An alternative expression of DO is in terms of air saturation percentage in water. A DO with 100% of air saturation in water means that the water is holding as many dissolved gas molecules as it can in equilibrium. The maximum percentage of DO from measured sample is 160%. During the process of photosynthesis, oxygen is produced as a waste product. This
Figure 5: Monitoring result for Oxidation-Reduction Potential. Sensor depth about 15 cm below the water surface

adds to the dissolved oxygen concentration in the water, potentially bringing it above 100% air saturation. The DO percentage with temperature depicted in Figure 6. Mean DO value is 89.37%, which is good for plant and animal in the water.

Figure 6: Monitoring result for Dissolved Oxygen. Sensor depth about 15 cm below the water surface

Water conductivity is a measure of the capability of a solution such as water to pass an electric current. This is an indicator of the concentration of dissolved electrolyte ions in the water. It doesn’t identify the specific ions in the water. However, significant increases in conductivity may be an indicator that polluting discharges have entered the water.

The basic unit of measurement for water conductivity is micro-mhos per centimeter (µmhos/cm) or micro siemens per centimeter (µS/cm). It is a measure of the inverse of the amount of resistance an electric charge meets in traveling through the water. Distilled water has a conductivity ranging from 0.5 to 3 µS/cm, while most streams range between 50 to 1500 µS/cm. Freshwater streams ideally have a conductivity between 150 to 500 µS/cm to support diverse aquatic life.

Figure 7 depicted water conductivity with pH and temperature from collected data. Data variation of water conductivity quite diverse, ranging from 0.82 µS/cm to 1149.08 µS/cm, with mean data at 509.59 µS/cm. Conductivity data clustered into three range regions: Region
A for values below 150 $\mu$S/cm, region B for values around 150 $\mu$S/cm and region C for values between 900 $\mu$S/cm – 1200 $\mu$S/cm. Values of pH in region B less than 6.5 with low temperatures have conductivity about 150 $\mu$S/cm. In region C, the water temperature values are about more than 27°C with pH values above 9 have conductivity ranging between 900 — 1200 $\mu$S/cm. Conductivity values in region A are around 0.82 $\mu$S/cm with pH values ranging between 6.5 — 9.

![Graph](image)

Figure 7: Water conductivity and pH with water temperature. Sensor depth about 15 cm below the surface

3.3. Gasses monitoring in air

The gasses monitored by Smart Environment mote are: O$_2$, N$_2$O, CO$_2$ and CO. As default features, the temperature and relative humidity monitored as well. All of the gasses measured in voltage unit, the unit conversion to percentage or parts per million volume unit is required. Although WaspSensorGas_v20.h and WaspSensorGas_v20.cpp provide the function to convert the measured voltage unit into percentage or ppm, but none of the function was implemented. Only the function to read the data from sensors implemented. The conversion to percentage or ppm unit calculated manually. The specific equations [11] are used for conversions.

The mean O$_2$ from data collected is 17.18%, ranging in 16.51% - 18.40%(red dashed line at Figure 8). Which is below to expected atmospheric concentration i.e: 21%. Like other motes, Smart Environment mote equipped with small solar PV module and battery. The mean battery status of the mote is 83.28%, which is good enough for supplying the mote in normal operation. The Formula 1 used to approximate the percentage concentration of O$_2$ in air, where $V_{read}$ is the voltage read by the sensor.

$$O_2 \% = \frac{V_{read} - 0.45}{0.318}$$

Two steps needed to convert voltage value read by CO$_2$ sensor into ppm concentration. First, calculate the $\Delta$EMF (equation 2). Then applying estimated ppm concentration CO$_2$ using calculated $\Delta$EMF as parameter (equation 3). Others parameter are $EMF_1$ as baseline voltage reading for 350 ppm CO$_2$, and $EMF_2$ as voltage reading from sensor. The GAIN parameter setup at 100. The conversion result depicted on Figure 9, which showed the CO$_2$ mean concentration at 485.8ppm.
\[ \Delta EMF(mV) = \frac{EMF_1 - EMF_2}{GAIN} \times 1000 \]  
\[ CO_2(ppm) = 10^{\left( \frac{\Delta EMF + 163.4}{64.25} \right)} \]  

Figure 8: O₂ monitoring result from Smart Environment

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Figure 9: CO₂ monitoring result from Smart Environment

The NO₂ sensor has typical air resistance \( R_O \) 2200 Ω with configured power supply \( V_{cc} \) at 1.8 volts and 2000 Ω load resistance \( R_L \). To calculate the NO₂ concentration in ppm, first calculate sensor resistance using the equation 4

\[ R_S = \frac{R_L}{V_{cc} - V_{read}} \times V_{read} \]  

The approximation of NO₂ concentration in ppm, calculate with equation 5. Figure 10 depicted the NO₂ concentration (ppm) calculation result in mote battery status (%) with temperature and relative humidity. The concentration of NO₂ ranging from 0.02006 - 0.03044 ppm, which is below of significant harm level (US EPA Guidelines) at 2.0 ppm. Mean NO₂ concentration is 0.02465 ppm, while the mean of temperature and humidity are 23.70 °C and 80.48% respectively.

\[ NO_2(ppm) = 10^{\left( \frac{\log\left( \frac{R_S}{R_{NO_2}} \right) - 2.702}{1.865} \right)} \]  

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Estimation of CO concentration in ppm, calculate using Equation 6. The CO gas concentration ranging in 11.37 - 24.12 ppm, with mean value at 22.62 ppm.

$$CO (ppm) = 10^{(0.09721 - 10^8 \frac{R_S}{R_O})^{0.6483}}$$ (6)

Figure 11: CO monitoring result from Smart Environment

4. Conclusion
The small scale remote environment monitoring have been implemented using motes equipped with small solar PV module and 3G/GPRS module. Three environmental aspects have been measured, i.e: soil condition, water quality, and air quality. The WSN methods provide an alternative technic for measurement of environmental parameters with acceptable accuracy. The availability of 3G/GPRS operator BTS infrastructure helps to implement the motes in the rural area.

The occurring cost in this system mostly for 3G/GPRS SIM card which has to be "top up" regularly in order to keep it working. Another maintenance need is a replacement for battery, roughly once in a year. Hybrid communication between motes and BTS can be studying further to solve the single point of failure issues and building resilience system. Another further study based on WSN such as landslide detection could be done as a continuation of this research.

The measurement results, generally indicate that the environmental aspects after mount Sinabung eruption outside the "red zone" is safe for living. Awareness is strictly required, failure to obeyed authorities warnings could be harmful.
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