Photogrammetry using Intelligent-Battery UAV in Different Weather for Volcano Early Warning System Application

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Abstract. We have developed a new volcano early warning system based on sensor node, internet of things (IoT) and UAV to overcome some problems in Indonesian volcano monitoring system. Data (monitored by sensor node) transmission and communication is managed by the IoT while UAV is used for remote sensing data to complete the system to predict the geological status of the volcano. An intelligent-battery UAV is needed for this purpose which manage the power utilization for field application. First stage of the remote sensing process is volcano region mapping for constructing an orthophoto before it is combined with field sensor data. Therefore, we have conducted a laboratory experiment to map some region in ITB, Bandung in different weather as real volcano condition. We have constructed day, night, sunny and cloudy maps of ITB after some data collected through flight and control plan as real volcano environment. Some grid flight plans were chosen for expected result as well as battery saving for each 5 meters data collection. A 3D software has been used for modelling of the orthophoto construction and resulted in 0 – 8 meters error of 20000 – 24000 m\textsuperscript{2} monitored area. Therefore, this method could be used in real volcano application.

1. Introduction

Volcano is a geological environment that at any scale is characterized by three elements: magma, eruption and edifice [1]. There are 1544 volcanoes all over the world which are fit with this definition [2]. One of the countries that have many volcanoes is Indonesia. Indonesia has 127 volcanoes (13\% of volcano of the world [2],[3],[4]) and 77 volcanoes [2] have erupted in historic time - the largest number for any volcanic region [4]. These volcanoes have had at least 1171 eruptions, placing Indonesia second (after Japan) for the region with the most dated eruptions [4].

Eruption of volcano is a natural disaster that can cause many loses and chaotic effects [2] in the form of poverty and human: infrastructure, houses, agriculture, animals, and human. Indonesia is one of the countries with highly vulnerable to the eruption. To protect human from this disaster a volcano early warning system should be developed [2].

An early warning system is built to minimize the effect of the disaster, because it gives an extra time before the disaster happen. Hence, activation of automatic responses can be taken to anticipate the effect of the disaster [5].
Volcano monitoring systems is main part of volcano early warning system. Volcano monitoring is designed to detect changes in state of volcano caused by magma movement beneath the volcano. Rising magma typically triggers earthquakes and other types of seismicity, causes explosion and leads to emission of volcanic gases and ashes [6].

For complete monitoring NASA-USGS-WSU has used combination between field sensor and satellite geospatial data since 2008, while other countries still use separated system (field sensor – satellite) [7]. In 2014, the European Space Agency's Sentinel satellite, launched April 3, eventually develop a forecast system for all volcanoes, including those that are remote and inaccessible [8]. The deformation of 165 volcanoes in the world has been also reported by this system. Surface deformation is directly link with the eruption, which can predict the eruption earlier. This research reported deformation of 165 volcanoes using weather analysis around the volcano with about 5 m resolution mapping pictures. [9].

Then UAV technology comes to slowly replace the highly-cost satellite technology for imagery applications, due to its cost compare to the satellite. Therefore, it has been used in some researches for this reason [10], [11], [12], [13], [14], [15], [16], [17], [18], [19].

An agriculture field had been mapped using photogrammetry data and Lidar from an UAV by ROS (Robot Operating System) and Point Cloud Lybrary (PCL) in a cold winter [17]. Meanwhile, a new flight plan has been proposed using GPC (Ground Point Control) compared to the straight-line conventional plan for more accurate images [14]. In the same time, a map has been generated from 200 images captured by a UAV in 60 m of height of a hill in Turk with image vertical accuracy 6,62 m.

Not only in agriculture, geospatial mapping also has been applied in construction site [12]. In the same year, the height of the trees in a forest has been measured using an UAV with 15% error[10].

In volcano application, INGV (Istituto Nazionale di Geofisica e Vulcanologia) Italy has done some researches about the possibilities of a drone to be applied in a volcano by flying a drone (UAV) for monitoring Stromboli volcano. In 2013 they tested the drone in Etna volcano cooperated with aerospace division of Bologna University using multi-rotor hexa-copter drone which monitored an early phase of magmatic accumulation in the volcano [18].

Therefore, in this research we have been conducted a laboratory scale of a geospatial mapping in different weather for volcano early warning system application (in the near future which will be equipped with a Lidar (Light Detection and Ranging also known as Radar) and combined with field sensor array), especially to monitor the surface deformation, so that the eruption can be predicted earlier.

2. Methodology

Our volcano monitoring system consists of temperature and humidity NTC (Negative Temperature Coefficient) type sensor DHT11 which operate from 0-50°C and 20-90% RH; SO₂ MOS sensor TGS2602 with operational range from 0 – 100 ppm; CO₂ sensor MG811 with operational range from 350 – 10000 ppm; digital accelerometer ADXL345 which can detect vibration in x, y and z axis from 0.1-3200 Hz. These sensors are connected to a Wi-Fi module ESP8266 using Arduino pro mini by MQTT protocol. This module based on Internet of Things platform for user friendly application. The volcano also monitored by a quadcopter DJI Phantom 4 Pro for 3D model and photogrammetry of the volcano for volcano parameter monitoring (Fig. 1).

2.1. Sensor module

A 50 W solar cell is supplied the module with 0.5 V voltage (Fig. 2). This cell supplies both Arduino and ESP8266 for Internet of Things. The data in the cloud could be accessed through web-based in the internet by the user using IoT Platform Node-Red Fred as middleware.

2.2. Drone

The drone for this research is a quadcopter DJI Phantom 4 Pro. It has gimbal and camera that can capture 12 megapixels with greater clarity. Moreover, the drone has intelligent flight LiPo-4 cells battery with the capacity of 5870 mAh, 15.2 Volt with the sleep mode to manage the power therefore it can be flight
about 30 minutes, where the information about the battery level, capacity and also current is transmitted to the drone main controller. The drone is controlled by specific phantom 4 pro remote control and having smartphone attached with DJI GO 4 apps installed. The maximum recommended distance between the remote control and the drone is 500 m in a city. Meanwhile, data processing using drone is shown in Figure 3. The pictures of desired earth surface that would be mapped was captured in either figure format e.g. JPEG or GCP (Ground Control Point). These data then be imported to the software (3Dsurvey) to be processed to build a digital model from this surface. Finally, an orthophoto could be generated therefore some analysis such as volume analysis could be performed to this model and orthophoto.

The most important step of the model building is classification [20] in order to calculate the digital terrain model [21]. The process of classification should be defined by the expert. However, it could also be justified using the reference from ASPRS (The American Society for Photogrammetry and Remote Sensing) for geo-spatial data [21].
Generally, the drone is used for photogrammetry data with certain accuracy according to its application as well as its flight height. In this research, it has been used the desired accuracy 1 cm pixel with 60 m height of flight. Before the data acquired by the drone, the flight plan was prepared first (Figure 4).

![Figure 3. Data processing using drone](image)

![Flowchart](image)

**Figure 4.** Flowchart for a typical case of UAV flight planning and control with the application (adapted from [22])

Furthermore, it was also considered some other factors such as wind, forbidden flight area, connection between drone and control station as there is no object would interrupt this connection [23] using the obstacle avoidance mode of the drone. Figure 5 shows an example of the flight plan for geospatial mapping in this research using Precision Flight software where the area captured is 2.3 hectares, 70 m altitude, 3 minutes flight duration and 30 cm/pixel resolution.
3. Result and Discussion
Resolution of the image source (registered) as well as the altitude of the flying drone contribute to the resolution of the model. Therefore, the resolution image source and the altitude of the drone should be known first. Moreover, the point density also represents the accuracy of the model built. In this research, we used DJI FC6310 with 8.8 mm focal length, sensor size about 13 x 8 mm resulted in orthophoto sizes 204 m × 132 m, 159 m × 179 m, 182 m × 201m for Data 1, Data 2 and Data 3 respectively with the size in digital world (pixel size) 2.714 μm, 2.412 μm, 2.714 μm for Data 1, Data 2 and Data 3 respectively (Table 1). According to the image source resolution and ground resolution, the pixel resolution for these orthophoto are 0.015 m, 0.016 m and 0.017 m for Data 1, Data 2 and Data 3 respectively.

Figure 6. Orthophoto for Data 1 with some objects: control station (1), bare soil (2), short grass (3), asphalt (4), building (5), parked cars (6), parked motorcycles (7), trees (8), and moving humans (9)
Figure 7. Orthophoto for Data 2 with some objects: control station (1), short grass (2), asphalt (3), building (4), parked car (5), parked motorcycles (6), concrete surface (7), trees (8), and moving humans (9)

Figure 8. Orthophoto for Data 3 with some objects: short grass (1), asphalt (2), building (3), parked cars (4), parked motorcycles (5), trees (6), and moving motorcycles (7)

All data were acquired in the same place at Institut Teknologi Bandung area from different time with different intensity of light coming to the object and the camera: sunny day, bright night and cloudy afternoon. All data consist vegetated and non-vegetated terrains, including bare soil, short grass, urban
terrain such as asphalt and concrete surface, buildings, trees, moving object such as cars, motorcycles and humans (Fig. 6, 7 and 8). These objects still can be distinguished although there was lack of the light present because of the good resolutions. The map with recognized moving objects shows that this research potentially to be applicated for surface deformation measurement of the volcano.

Figure 9. Survey data for Data 1 (a), Data 2 (b) and Data 3 (c)

From Figure 9, it can be seen the camera position and number of registered images over the area observed, marked by little circles on the pictures. This data also consists of the information about external orientation of images of their position known as telemetry data. This information together with the rotation and scale of photogrammetric model is simultaneously georeferenced by the UAV. Not only the position in planar coordinates, the data also consists of the height of that position. This data which is called digital elevation data (Fig. 10) could define the horizontal accuracy and eventually this data could define the accuracy class for digital orthophoto from the same aerial triangulation (Eq. 1 and 2) [21].

$$\text{Accuracy} = \frac{2.4477}{1.4142} \text{CMSA} = \frac{2.4477}{1.4142} \left(\frac{2.1460}{1.4142}\right) \text{RMSE}$$ (1)

$$\text{Class} = \frac{\text{RMSE}}{\text{Pixel size}}$$ (2)

Where CMSA is Circular Map Accuracy Standard and RMSE is Root Mean Square Error defining the accuracy how the map matches the actual real world.

Figure 10. Digital elevation model for Data 1 (a), Data 2 (b) and Data 3 (c)

According to Equation 1, accuracies are 3.0151 cm, 3.4794 cm and 2.9111 cm for Data 1, Data 2 and Data 3 respectively. According to the data from ASPRS, the model has 95% level of confident for combination of non-vegetated and vegetated area including the area where the ground is not visible. In addition, horizontal data accuracy class according to Equation (2) are: 423018, 549279 and 408423 for
Data 1, Data 2 and Data 3 respectively. These accuracies are not directly correlated with resolution of the source imageries and final pixel resolutions (0.015 m, 0.016m and 0.017m for Data 1, Data 2 and Data 3 respectively). The resolution depends on DSM (Digital Surface Model) cell size of selected DSM and the flight height.

**Table 1.** Report and processing parameter using 3Dsurvey for Data 1, Data 2 and Data 3

| Report                | Data 1          | Data 2          | Data 3          |
|-----------------------|-----------------|-----------------|-----------------|
| Resolution            | 4864 × 3648     | 5472 × 3078     | 4864 × 3648     |
| Focal Length          | 8.8 mm          | 8.8 mm          | 8.8 mm          |
| Sensor Size           | 13.2 × 9.9 mm   | 13.2 × 7.4 mm   | 13.2 × 9.9 mm   |
| Pixel Size            | 2.714 μm        | 2.412 μm        | 2.714 μm        |
| Orthophoto Size       | 204 m × 132 m   | 159 m × 179 m   | 182 m × 201 m   |

**Processing Parameter**

| Bundle adjustment statistics | Data 1 | Data 2 | Data 3 |
|------------------------------|--------|--------|--------|
| Images                       | 70     | 100    | 54     |
| Registered images            | 48     | 79     | 54     |
| 3D tie points                | 12192  | 5071   | 8389   |
| RMS reprojection error       | 1.14807| 1.32486| 1.10846|
| Max reprojection error       | 4.97263| 11.5323| 4.8471 |

**Optimization camera parameters**

| Focal length               | 4652.14 px | 4615.31 px | 3739.13 px |
| Principal point X          | 2455.15 px | 2752.87 px | 2428.06 px |
| Principal point Y          | 1832.95 px | 1555.82 px | 1836.66 px |
| Radial distortion (k1)     | 0.016472   | 0.017472   | 0.009902   |
| Radial distortion (k2)     | -0.060345  | -0.026631  | -0.023426  |
| Radial distortion (k3)     | 0.10503    | 0.046722   | 0.02682    |

**Dense points cloud**

| Number of points           | 230628 | 5071  | 132621 |

**DSM (Digital Surface Model)**

| Grid cell size             | 1 m    | 1 m   | 1 m    |
| Number of triangles        | 53856  | 56922 | 73164  |

**Orthomosaic**

| Pixel resolution           | 0.015 m | 0.016 m | 0.017 m |

4. Conclusion and Future Work

The mapping has shown such satisfy resolution orthophoto about 0.01 m which classified as high-resolution pixel size, with total error ranging from about 1 – 4 meters for 20000 – 30000 m² of monitored area for different weather condition. Moreover, the RMS Error indicated about 3 cm horizontal accuracy with 95% confident level according to the standard. With this resolution and error, we are confident that this method could be used for surface deformation monitoring of a volcano which requires such a high-resolution image for data analysis.

In the future, we will test our UAV in a real volcano with more challenging environment than in laboratory scale space. Furthermore, we will combine the drone-Lidar with field sensor array using internet of things technology for better monitoring system.

Acknowledgement

We would like to say thank you to ITB for supporting our research through Riset ITB 2018 research program.

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