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Mapping a Volcano Hazard Area of Mount Sinabung Using Drone: Preliminary Results

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Abstract. Mount Sinabung is still active since its first eruption in 2010 and has been declared as national disaster. The persistent eruptions afterward have been lively and affected severely the surrounding villages located within the 5 km from its crater. The purpose of this study is to explore drone technology and its applicability in mapping a volcanic hazard area. The first essential step in this study is to have a well-defined mission flight in order to acquire air photos that can be processed in the subsequent procedures. The following steps including geometry correction and photos stitching were conducted automatically using proper software. It is found that the resulting photo mosaic and 3D map can be obtained in effective and efficient manner and several important interpretations can be made from them.

1. Introduction

Mount Sinabung has been declared active since its first eruption in 2010. Prior to the first eruption it has been inactive and was assigned category B with no official records and literature reports at least since 1600. The persistent and effusive eruptions after that have been lively and affected severely the surrounding villages until now, especially those located within the 5 km from its crater. And Sinabung has been a type A mountain with the highest level of eruption watch (level IV) since then.

Figure 1.a shows one significant incidence of the eruptions. People in the villages located around Mount Sinabung mostly lives and works in the agricultural sector. The eruptions of Mount Sinabung have given destructive impacts on agricultural lands and products that are the main source of living of nearby society. The condition of agricultural land after the eruption of Mount Sinabung can be seen in Figure 1b and 1c.

Figure 1. (a) Mt. Sinabung eruption (2014) (b) and (c) Agriculture product after the eruption

A drone equipped with a lightweight digital camera and GPS can take photos of the land on earth with good quality. These photos can be corrected geometrically so that all images have a uniform scale and same coordinate system. All photos are then combined into a mosaic form that is upright direction (orthomosaics) and become the basis for an accurate map [1].

By using drone, we can produce a variety of maps such as 2D and 3D maps, digital elevation models, NDVI and thermal maps which are normally produced by satellite images for relatively large (Figure 2). The process in producing a map from drone taken photos is actually in line with the photogrammetric mapping process which needs sufficient overlapping among the photos[2].

Two-dimensional map is the most common map produced by the photographs taken by an unmanned vehicle such as drone. The map is basically generated through series of image registration process. There are two main procedures that must be done so that the results in the form of a mosaic can give geometric meaning. The first is the correction of geometry to eliminate distortions in the aerial photos (orthorectified) and to bring them in the same scale and coordinate system. The second is the stitching of the photos based on the same objects found in the overlapping to produce orthomosaics. Next the correction can be conducted using ground control points measured in the field so that we can be sure of the accuracy of the resulting mosaic. The model of 3D maps is now started to be generated by drone technology. The process of 3D map is advanced by software tools. With 3D maps we can visually examine the real situation and analyze the spatial form associated with elevation. One type of 3D map is the digital elevation model (DEM) which represents a terrain's surface. Other type of the maps is thermal map that can be generated by a drone equipped with a thermal camera that captures the earth's surface temperature through wavelength analysis. This type of map can be directly used for example to detect damage in roads, water, and vegetation type (or types of land cover).

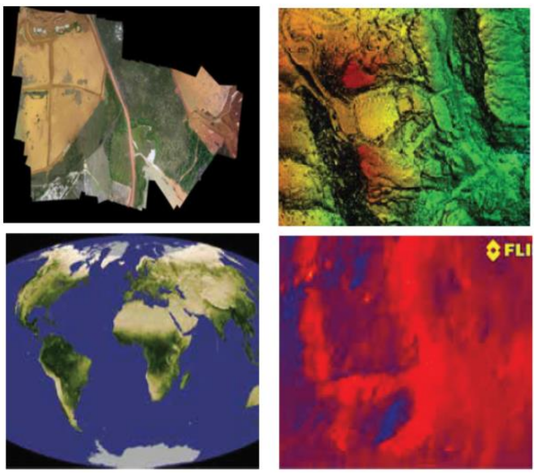

Figure 2. Maps produced by drone (a) 2D (b) digital elevation (c) NDVI (d) Thermal[1]

The price of drones, cameras and digital memory is now getting cheaper. Drone has an ability to capture a relatively large area in a relatively short time, making drone now becoming an alternative mapping technology that is considered to be effective, inexpensive, and safe, especially when used in a disaster prone area [3, 4]. The use of drones to surveying and mapping is still in an initial step that is being developed in various parts of the world. The drone technology with fixed-wing aircraft Sensely Bee has been used in Tanzania to map the buildings and the results are quite satisfactory and can complements existing maps [5]. In Indonesia, the drones are used by the Dayak in Kalimantan to create a map in order to defend their ancestral lands from mining activities [1]. The use of drone in disaster managements itself had been reported in previous study such as natural disaster in Carribean [6], Australia [7] as well as in India [8]. Specific use of drone for mount eruption was discussed in some study cases like mount Etna [9], mud activity of Paterno Italy [10], Colima Volcanoes Latin America [11] and lusi project surrounding Arjuno-Welirang volcanic in East Java Indonesia [12].

The usage of drones to map volcanic hazard areas of mount eruption would help relevant parties (government and NGO) to assess the risk and damages in the areas in an efficient and effective manner [3, 4, 13]. The resulting maps may become the inputs in formulating disaster management actions and policies, including emergency responses, rehabilitation and reconstruction. The purpose of this study is to explore drone technology and its applicability in mapping a volcanic hazard area in the spirit of disaster relief and management.

2. Methodology

2.1. Flight plan

Before we set the drone to fly, the area to be photographed was first analyzed carefully. The important things to be checked for were ground surface relief, high trees and existing poles, power lines and cables attached, and all sorts of objects that might impede or hinder the flight. These were checked through direct surveys on land, but first we check also through Google map (google). Information with regard to volcanic activities was of considerable importance in planning the flight so that image acquisition could be carried out without interruption from eruption; information on local weather was a second important matter to be checked [14].

Several considerations need to be taken before deciding whether the flight is done automatically or manually, or even in hybrid (a mixture of automated and manual). But mostly in this study, since the photographing can be implemented systematically to generate a map of the study site, the automatic flight control was selected. The manual flight control was carried out when we tried to capture the whole picture of the area under study before the automatic mode was carried out. Also, we changed from automatic to manual mode when the drone was about to land during the time of returning home.

2.2. Flight route

After reviewing the flight plan, the flight route was made. Things to be considered for the flight route were as follows:

a. Transect lines, i.e. parallel lines that describe the flight patterns
b. Waypoints, i.e. coordinate points which guide the transect line
c. Flying height or elevation of drone
d. The overlap between the images and the number of photos
e. The software used to design and monitoring (pix4d Capture)

The items *a* to *d* were actually governed by the capacity of the battery used.

During the flight mission, we, using a hand phone display, were able to monitor the flight data such as the status of the position of drones, GPS, battery and signal ground. Figure 3 shows example of flight route. We found that a successful mission of flight is dependent upon the success of flight plan and flight route. This is the essential first stage that must be well defined and prepared before the drone is set to fly.

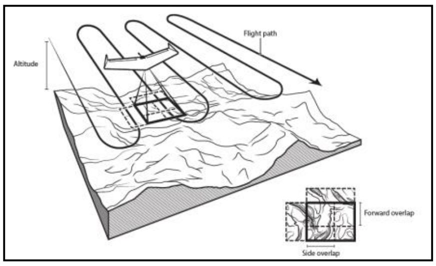

Figure 3. Example of Flight Route [1]

2.3. Sensors
The one sensor mounted on drones was camera. The camera was a lightweight camera that was programmed to take pictures with predefined time intervals on regular distances. It supports remote control and has internal GPS function to enable tagging function during image acquisition on the planned waypoints. Gimbal mounting was installed for the camera to produce stable shooting [15]. Here we use 1/2.3" CMOS camera with possible resolution of 4000x3000 and FOV 94^0 20mm. The camera can provide pixel with size up to 12.4Mpix.

2.4. Altitude
The altitude is an important factor because it affects the flight safety and the resolution of the images. Lower altitude was imlemented to produce the images with higher resolution and consequently better accuracy. However, it should be noted that low flying would present higher risk of possible obstruction by objects. Higher altitude was implemented to produce the images with a broader scope, so it was used to evaluate the whole picture of the study site. Since the area under study is far away from a non-flight zone, there was no concern of interference with conventional aircraft.

2.5. Camera Angle
There were two types in taking the photos: nadir and oblique. Nadir photos, taken with the camera facing perpendicular to the earth's surface, were used in the single grid mission. Oblique photos, taken with a certain angle, were used in the doule grid mission. The most common technique used as standard for 2D mapping is a photograph nadir. The oblique photograph gives ability to analyze different perspective to provide a more integrated view for 3D mapping. In this study we have tried both techniques with different altitude; lower altitude with smaller area for double grid mission. In the double grid mission, the camera angle was set up using the software and was not changed too often to avoid complication during the image processing [16].

2.6. Ground Control Points and Geo-references
Control points on the earth surface with known coordinates were used to control the points in the photograph (Figure 4). It usually requires 3-5 control points to obtain good accuracy. We conducted a ground survey to measure 4 control points using a total station. It is impotant to note that the control points were marked so that they were clearly identified in the aerial photos captured by drone [17].

Geo-referencing is a coordinate system that we use for control points and in turn for the entire points on the photo. The selected coordinate system is important when we want to associate or to integrate maps we produce with other maps, making it compatible when processed in a GIS. Usually in Indonesia, the coordinate system used by many surveyors is the UTM with WGS-84 ellipsoid. The study site is located in the UTM zone of 47 N.

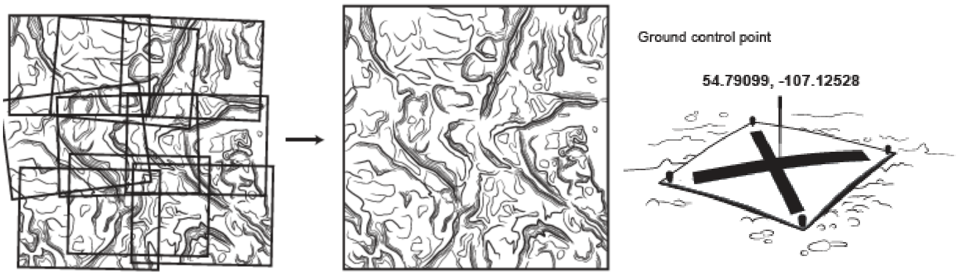

Figure 4. Image overlapping with references [2]

2.7. Research Data
In this study, the photos were processed digitally using a software and the results were described qualitatively. The research data can be divided into three groups:

a. The photo images that captured by the drone.
b. Ground control points measured in the field.
c. Visual observation and terrestrial photos taken during the survey.

The selected area under study is the area of Guru Kinayan village, Payung district, Karo regency.

3. Results and Discussions
In this stage of study, we presents only a preliminary result of data processing. Further analysis would be presented in the next stage of the study. We have acquired actually more than 400 images during the survey over the study site. Here we demonstrate only the first part of photos which were taken using double grid mission with average flying altitude 75.5 m and a coverage area of about 0.1 km^2.

3.1. Survey data
From 166 images processed in this stage, about 917,041 tie points were generated with 2,684,807 projections giving resolution of 3 cm per pixel (re-projection error 1.3pix). The images overlap spanned from 1 to 9 overlapped images in a pixel. Figure 5 and 6 show camera locations and image overlap and the error estimation, respectively.

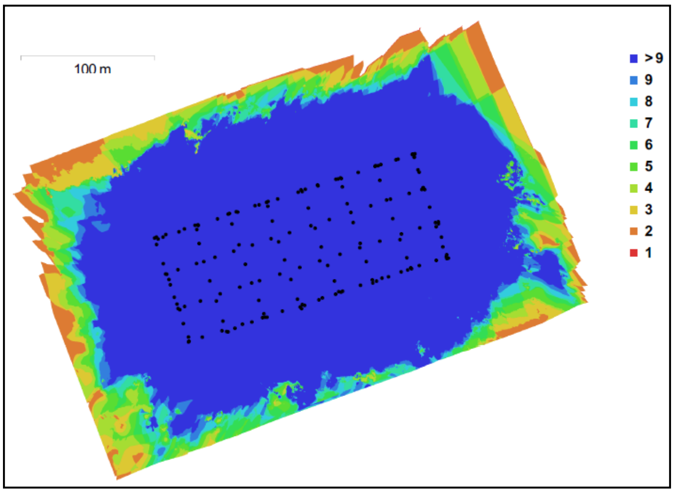

Figure 5. Camera location and image overlap

The errors produced by using the measurement of ground control points were about 10.8m for X-axis, 14.1m for Y-axis and 5.5m for z-axis. Plane error reached at 17.8m and total error was 18.6m. Figure 6 shows the error estimation over the all mapping zone. In Figure 6, Z error is represented by ellipse colour, and X-Y error is represented by ellipse shape, whereas estimated camera locations are shown in black dot. It should be noted that this relatively large errors are due to the fact that coordinates used for the ground control points are not absolute coordinates. The errors would significantly be reduced if distance controls were used in the image processing instead of ground control points.

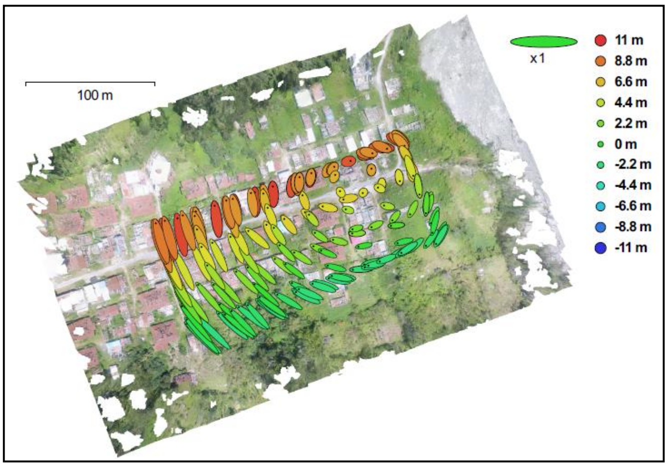

Figure 6. Error estimation and camera location

3.2. Digital Elevation Analysis

The digital evolution model reconstructed was in the range of height 1020 m to 1100 m. The height resolution is 11.7cm per pixel and point density is 72.5 points/m2. The reconstructed digital elevation model is shown in Figure 7.

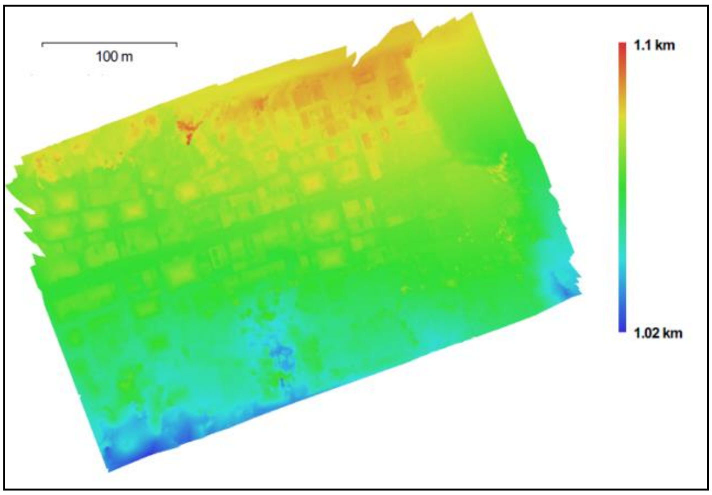

Figure 7. Reconstructed digital elevation model

The size of digital elevation model was 3,843 x 3,197 pixels with mesh source data and interpolation method used. The processing of digital elevation model took 16 seconds.

3.3. Ground Control Points

We utilized 3 control points out of the total 4 for the current stage of analysis. Figure 8 shows the locations of the ground control points (GCP), while the estimated errors are given in Table 1. Based on the results shown in Figure 8 and Table 1, it can be stated that the orthophoto mosaic and the digital elevation model produced were satisfactory in terms of relative accuracy. It is noted that as mentioned before the absolute accuracy would be satisfactory as well if the control points were used as distance controls in the image processing.

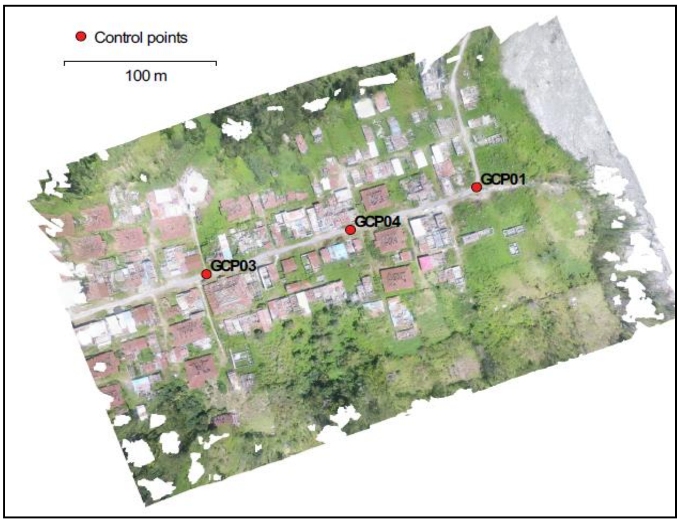

Figure 8. GCP Locations

Table 1. Control Points

Labels	X error (cm)	Y error (cm)	Z error (cm)	**Total (cm)**	Image (pix)
GCP01	3.14181	-1.19733	0.229636	**3.37006**	1.948 (38)
GCP03	2.79259	-1.18884	0.221465	**3.04317**	0.700 (41)
GCP04	-5.88977	2.34602	-0.434794	**6.35470**	2.085 (42)
Total	**4.17767**	**1.66841**	**-0.311355**	**4.50927**	**1.693**

3.4. Field and Image Interpretation

Based on the data obtained during the field survey and results of image processing, the following preliminary interpretation can be made:

- Although it is no longer safe to reside, Guru Kinayan village has survived from prolonged eruptions. This can be deduced from the fact that most of the roads and houses of the village do still exist whereas the eastern end of the village has been buried by the volcanic material. Hence the village demarcates between the total destruction zone and the relatively sheltered zone as depicted in the resulting mozaic.
- The survival of the village can be attributable to indigenous wisdom of the local founders of the village in selecting the proper location. Had they selected the position of the village more toward the east, Guru Kinayan village would have been wiped out by the volcanic material, as the case of three villages (Simacem, Bekerah, and Sukameriah) located east of Guru Kinayan.
- The morphology of the village may likely be a major factor that prevents it from total destruction. Although we could not reason this from the images obtained in this stage of study, this interpretation can be drawn from field observation in the context of a big picture of the volcano. More coverage of drone images would be necessary to depict the morphology setting.

While there is no indication that the eruption would soon end, the people of Guru Kinayan who are currently displaced in temporary settlements still retain the faith that they may someday hopefully return to the village. This could materialize when the volcanic activities of Mount Sinabung reduce significantly and consistently to a near inactive level.

4. Conclusion

In this study, we have explored drone technology and its applicability in mapping a volcanic hazard area, i.e. Guru Kinayan village. The first fundamental step in this study is to have a well-planned mission flight in order to acquire air photos that can be processed in the subsequent procedures. The following steps including the photos correction and stitching were conducted automatically using a proper software. It is found that the resulting ortho mosaic and the ensuing DEM were satisfactory in terms of relative accuracy, meaning that the map produced could be reliably used as a source of geospatial information to assess the volcanic disaster in the village level. Better absolute accuracy may be gained with GCP used as distance controls. Over all the resulting, meaaningful photo mosaic and 3D map can be obtained in an effective and efficient manner, and several important interpretations can be made from them.

Acknowledgements

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