Real time volcano activity mapping system using ground based single digital camera

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Commission V, WG V/6

Keyword: Disaster Mitigation, Volcano Monitoring, Real time Mapping, Image Processing, and Edge Matching.

Abstract

Mapping of volcanic activities or events during eruptions such as lava flow, pyroclastic flow, mudflow and etc. at real time basis is very important to monitor and predict movement of these events, and prevent calamity. These events are usually dynamic and occur in short time duration. In this study, a real time volcanic activity mapping system, using single ground fixed digital camera, is developed. An automatic mapping system is designed for real time monitoring. This system produces orthophotos as final outputs from digital landscape images. Once a digital landscape image is obtained, the final output is generated concurrently. A digital landscape photo is rectified into 3D computer graphics to obtain texture image with fixed location and attitude. This 3D computer graphics is created from DEM and is used as a reference image. Rectification is done by skyline matching between the edge of a skyline in the digital landscape image and in the 3D computer graphics. The rectified digital landscape image is converted to an orthophoto map using DEM. Through this system, volcanic activity is automatically mapped as orthophoto on real time basis. This system helps chronological change analysis of volcanic activity, especially for short time period. Volcanic activities mapped by this system would be analyzed by volcanologists to help people escape hazards from volcanic eruption.

1. Introduction

Volcanic eruptions are natural hazards that destroy human properties and lives. Monitoring of volcanic activities is essential to save people from eruptions and related hazards. Mapping of active volcanoes is very important to monitor, document and understand their behavior in detail. It provides information on movement and distribution of lava flow, pyroclastic flow, mudflow, and so on. Eruption events are usually of short time duration. It is important to map movement of lava flow, pyroclastic flow and mud flow at real time basis so that necessary action, most importantly evacuation action is taken place. When a volcano erupts, it is very difficult to obtain data from satellites or aircrafts on real time. It is very important to obtain information of volcanic phenomena or damaged area on real time to predict and prevent calamity. In this paper, a ground-based digital camera is used for mapping and provides information of volcanic activity on real time. Volcanic activity is monitored using a digital camera on the ground instead of satellites or aircrafts from the sky. There are 2 objectives of this study. First is to design a real time volcano activity mapping system, using a ground-based single digital camera for real-time monitoring. Second is to develop a skyline matching algorithm for rectification as a part of the volcano mapping system.

2. Overview of system

There are 4 main steps for mapping volcano activities: data acquisition, reference image creation, rectification, and mapping. Figure 1 shows the over view of the system. In the data acquisition step, landscape images are acquired using a consumer digital camera fixed on the ground. The camera position is measured by GPS, while the summit position is measured in advance from some existing maps. Using the relationship between the camera and summit positions, the camera attitude (ω,ψ, andκ) is approximated. Also, the viewing angle is estimated from the focus length and CCD size.

In the reference image creation step, 3D computer graphics image is created from DEM (digital elevation model) with camera position and camera attitude acquired in the former step. Camera attitude is fixed in the 3D computer graphics image. This 3D computer graphics is used as a reference image for the rectification of the digital camera image.

In the Rectification step, the digital camera landscape image is rectified using the reference image with fixed camera attitudes. Rectification is done by skyline matching. The skyline edge of digital camera landscape image is matched to the skyline edge of reference image by shifting and rotating. Image correlation is calculated to find shifting and rotating parameters. The Pyramid method and mask image are used for reducing processing time.

In the mapping step, the rectified image is converted to orthophoto map as final output in monitoring volcano activity.

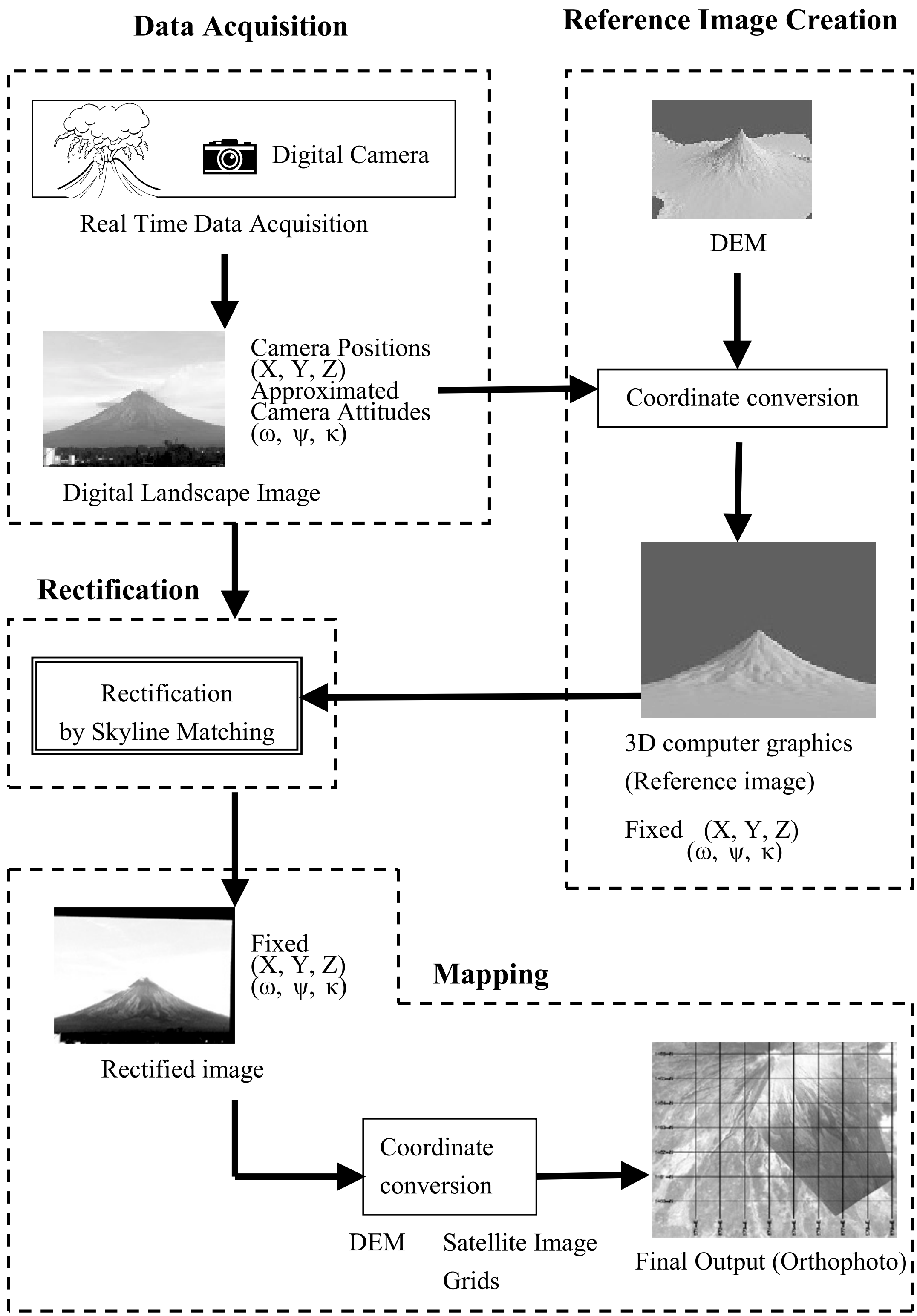


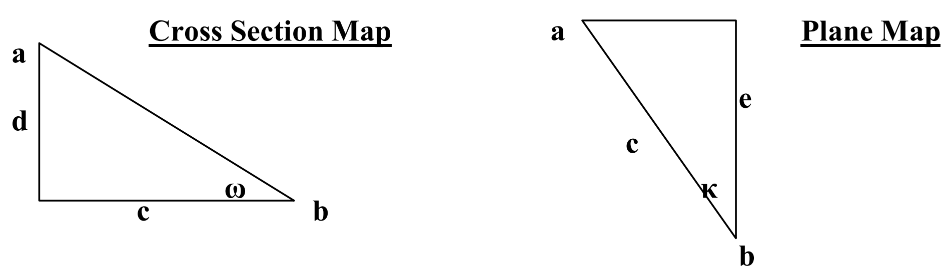
Figure 1 Over View of the System

3. Methodology

3.1. Data acquisition

Digital landscape images were acquired using a consumer digital camera. The use of a consumer digital camera is one of the key points of this study in designing inexpensive and applicable system for variety of fields. Since the number of pixels has increased, consumer digital camera can be used in a variety of photogrammetric fields.

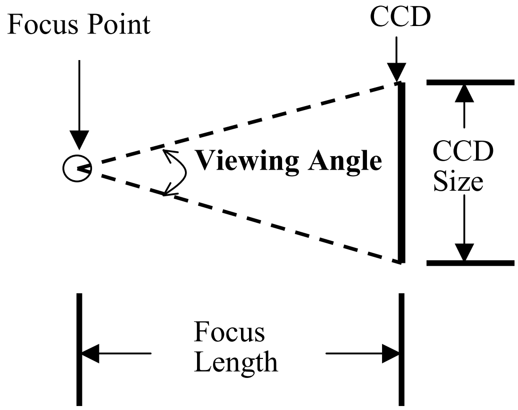
In digital landscape images, camera position is measured by GPS. The summit position is measured in advance from topographic maps. The camera attitude is approximately estimated using the camera and summit positions (Figure 2). The top of the mountain was supposed to be the center of the digital landscape image. This digital landscape image is assumed to be level, that is, ψ is 0°. ω is measured by $\tan^{-1}$ using the cross section map. On the other hand, κ is measured by $\cos^{-1}$ using the plane map. The parameters ω, ψ, and κ are only approximates. The viewing angles are calculated using the following step. There are two viewing angles: one in the X direction (horizontal) and the other in Y direction (vertical). The CCD size is 6.4 mm for X direction and 4.8 mm for Y direction. Figure 3 shows the method of estimating viewing angles.



$\omega = \tan^{-1}(d / c)$ $\kappa = \cos^{-1}(e / c)$

a. Summit
b. Camera Position
c. Distance from Summit to Camera Position
d. Height of mountain form Camera Position
e. Distance from Longitude of Summit and Camera Position

Figure 2. Approximation of Camera Attitude



$$VA = (\tan^{-1}(a / b)) \times 2$$

VA = Viewing Angle
a = 1/2 of CCD size
b = Focus Length

Figure 3. Viewing Angle

3.2. Reference image creation

In this study, a 3D computer graphics image is used as reference image for the rectification of digital camera image. Camera position and attitude acquired from previous step are used to create 3D computer graphics. Also, the viewing angles and image size must be set the same as that of the digital camera landscape image. The magnitude for elevation is set at 1.0. The shading effect is considered. The 3D computer graphics image, used as reference image, has fixed camera attitude (ω, ψ, κ), while the camera attitude of digital camera image are only approximates.

3.3. Rectification

The 3D computer graphics image, created from DEM, is used as reference image for the rectification process. Rectification is done by matching the skyline edges of the digital camera landscape image and the reference image. The skyline edge image of the 3D computer graphics is called reference edge image, and the skyline edge image of the digital camera image is called original edge image. There are some advantages in matching skyline. In this method, any ground control targets do not need to be setup, but only the skyline is needed for the rectification. The whole skyline is not necessary for the matching. Even though some parts of the skyline is covered by cloud or smoke, it is possible to obtain image matching. Here, this method is called skyline matching. As stated in the later part of this paper, this matching process can be applied to thermography image as well.

(1) Skyline edge detection of reference image
Skyline is detected by gradient-based Sobel filter operation method (Figure 4). The reference edge image is shown in Figure 5. The 1/2 and 1/10 size of reference edge images are prepared for pyramid processing method which is mentioned in this section. All of these images are converted to binary images using appropriate threshold value.

$$Hx = \begin{matrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{matrix} \qquad Hy = \begin{matrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{matrix} \qquad Vxy = \sqrt{(Hx^2 + Hy^2)}$$

Figure 4. Gradient-Based Sobel Filter Operation

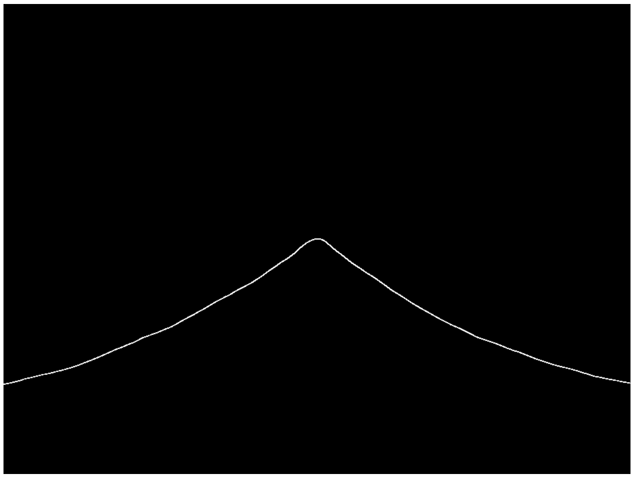


Figure 5. Reference Edge Image

2) Skyline edge detection of digital landscape image

The skyline of digital landscape image is also detected by gradient-based Sobel filter operation method. It was found that gradient-based Sobel operation method is most effective for skyline detection. In the digital camera landscape edge image, the skyline edge and edges of houses, trees, and other objects are extracted. Also, skyline is not one continuous line because cloud and smoke cover the skyline. Edge images with the size of 1/2 and 1/10 of original images are prepared as same as reference edge images.

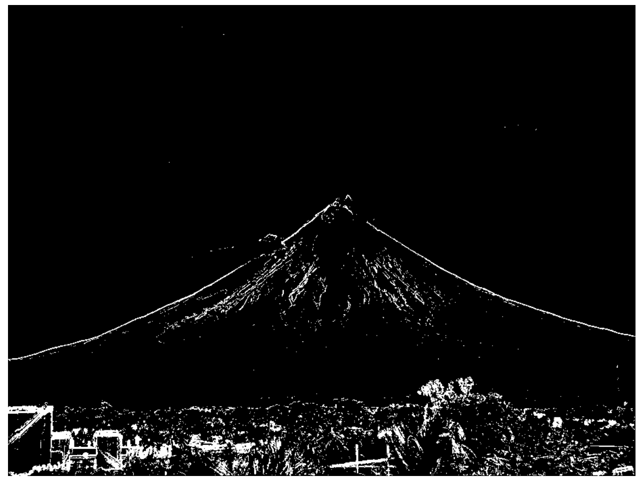


Figure 6. Original Edge Image

(3) Skyline Matching

The reference and original images do not match because of the error of camera attitudes estimation. For the reference image, camera attitude are fixed, but for the original image, camera attitude are only approximates. Thus, the original edge image is shifted and rotated to match into reference edge image to obtain texture image with fixed camera location and attitude. Image correlation is calculated to obtain image matching between the reference edge image and the original edge image. Image correlation is well known and widely used in image matching. It provides satisfactory accuracy for skyline matching.

(4) Pyramid method

Pyramid method is applied to reduce calculation time (Figure 7). The 1/10, 1/2, and 1/1 scales of edge images are prepared as mentioned above. At first, the 1/10 scale reference edge image and original edge image are roughly matched, followed by the 1/2-scale edge images. Finally, the 1/1 scale edge images are matched exactly by calculating image correlation.

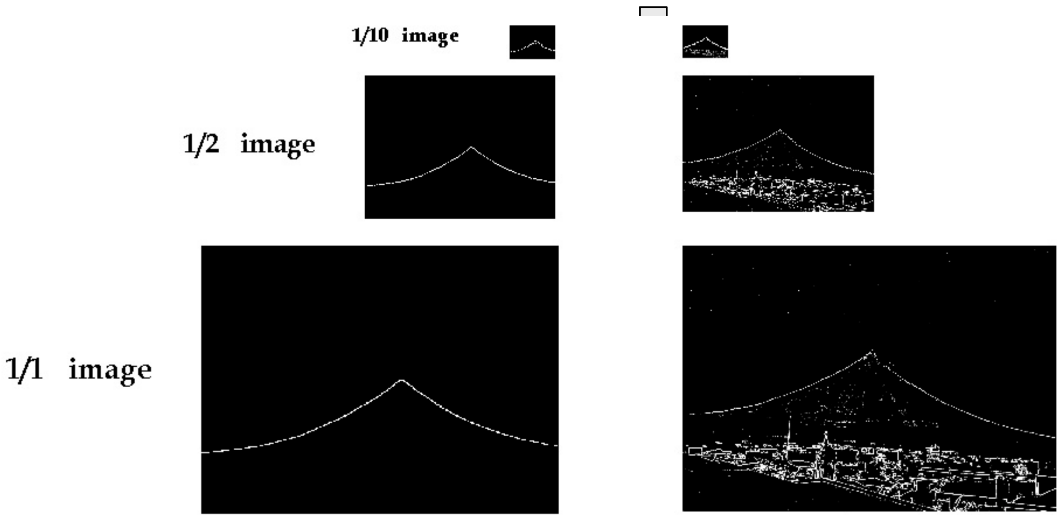


Figure 7: Pyramid method

(5) Limitation of Calculating Area

To save calculation time, a mask of skyline is used to avoid calculating correlation for the whole image. Image correlation is calculated only inside of limited area of the mask. The mask is prepared by mathematical morphology of dilation using the reference edge image. Mask image is applied to all steps of pyramid method. The size of masks is 4 to 8 pixels wider than the reference edge.

(6) Applying rectification

Finally, rectification is carried out by applying the shifting and rotating parameters to the digital camera landscape image. Shifting and rotation parameters are obtained by skyline matching algorithm. These parameters have the shifting and rotation values for maximum image correlation. The rectified image created through this matching process is shown Figure 8. Black parts, located at the top and left side of the image, show shift and rotation.

Figure 8. Rectified Digital Camera Image

(7) Flow chart

The flow chart of skyline matching algorithm is shown in Figure 9.

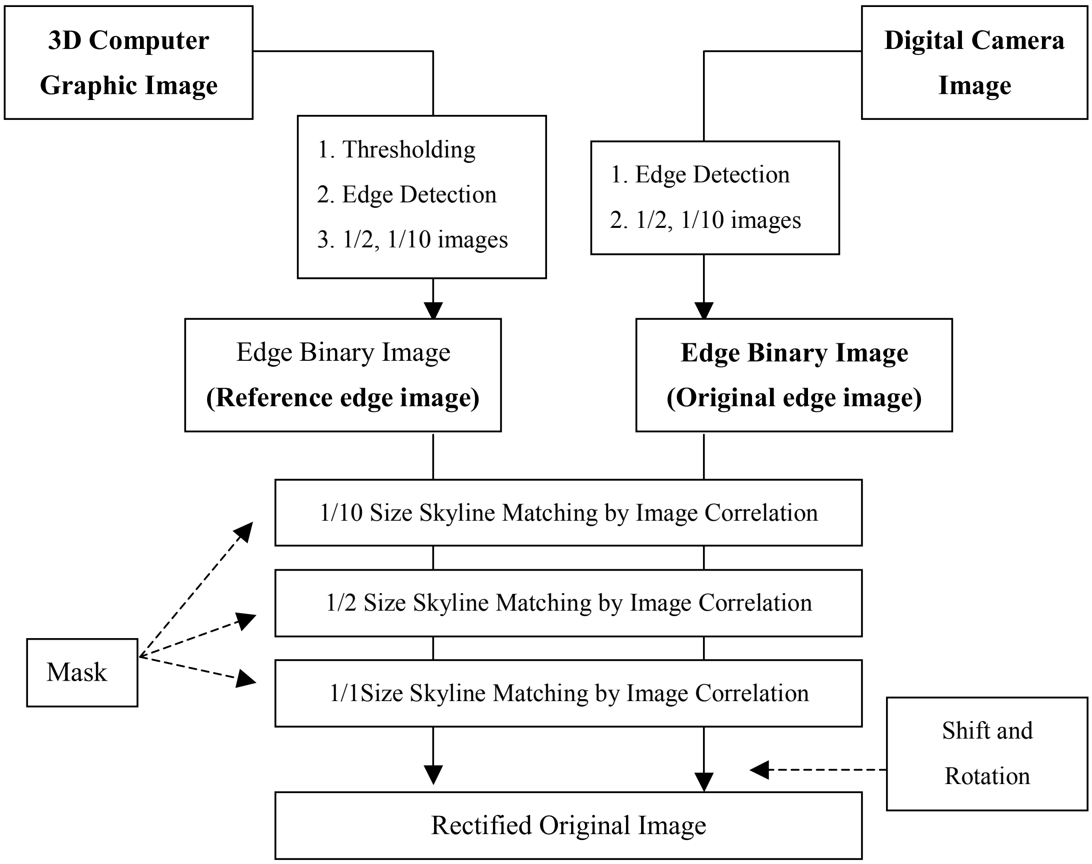


Figure 9. Flow Chart of Skyline Matching Algorithm

3.4. Mapping

An orthophoto is created from the rectified digital camera landscape image as the final out put in this volcanic activity mapping system. The coordinate and attitude of camera are used in coordinate conversion. Satellite image is set as a background image for better visualization. Also, grid line is applied over the orthophoto map to identify the positions of lava flow, pyroclastic flow and mud flow easily.

4. Result

4.1. Orthophoto map

The orthophoto is geometrically corrected for displacements caused by terrain and relief. Because the digital images are geometrically corrected, they can be used as map layers in geographic information system or other computer based manipulation, overlaying, management, analysis, or display operation. Orthophoto is helpful to know exact location of volcanic activities such as vulnerable areas, lava flow, pyroclastic flow, mud flow, debris flow and so on. Overlaying vectors on imagery immediately draws one's attention to areas of change.

Figure 15 below, shows an orthophoto map automatically created on real time basis, using this volcano activity mapping system. This orthophoto map, created from landscape image, can be used to measure the position of lava and pyroclastic flows. If orthophoto maps are created chronologically, the speed of lava and pyroclastic flows can be estimated. This orthophoto map (Figure 10) will show the people the exact location of damaged area caused by volcanic eruption, and will help people to evacuate from danger or hazard zones.

4.2. Processing speed

After acquiring real time data by digital camera, orthophoto automatically comes out through this system. For the first image, the total calculation time is about 2 minutes by using Pentium IV personal computer. Succeeding images takes only 3 seconds to map, because rectification value has been already calculated in the first image. It is not necessary to again create a 3D computer graphics and perform skyline matching. Therefore, in this mapping system, image is updating every several seconds. The break down of calculation time for each steps is shown in figure 11.

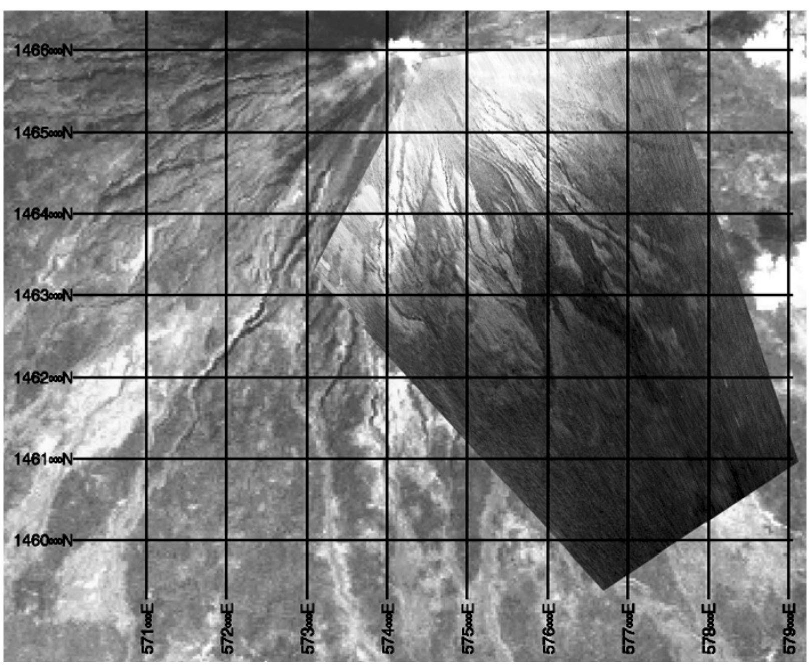


Figure 10. Final Output, Orthophoto

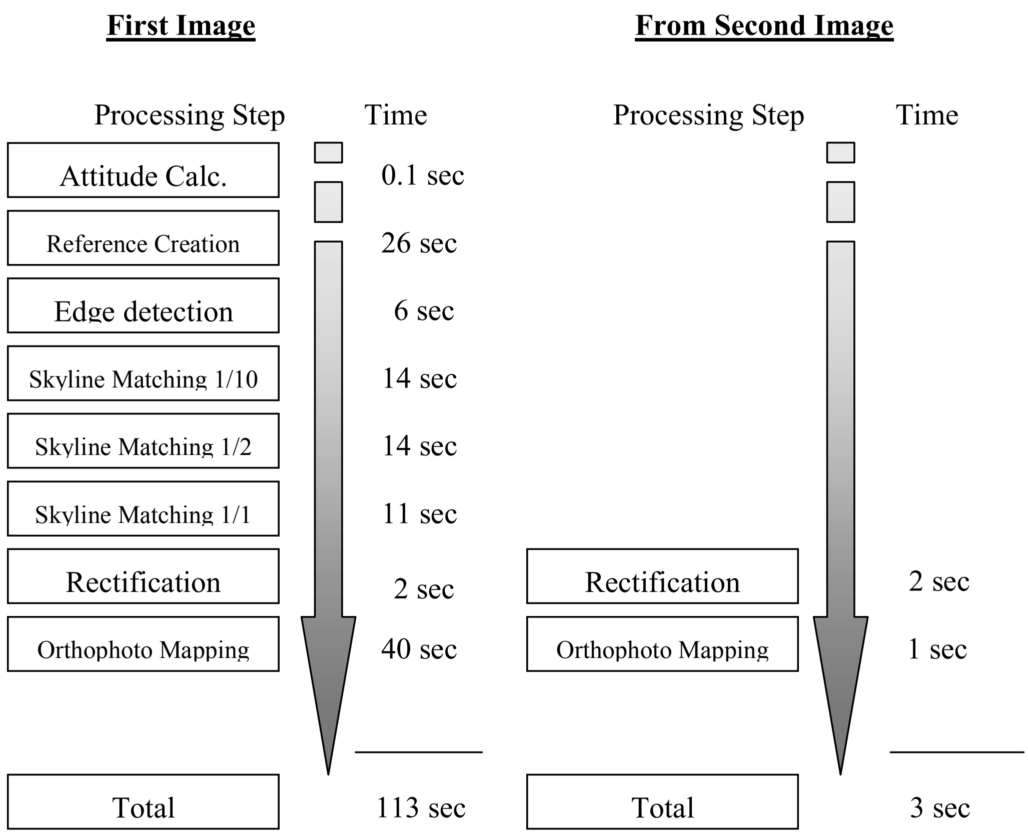


Figure 11. Processing speed

4.3. Use of Thermography for night time monitoring

Thermography image can be used in this volcano activity mapping system. A thermography is very effective for night time monitoring. Lava and Pyroclastic flow can be monitored even though night time because the temperature of these objects are very high.

Thermography image is usually very difficult to rectify, because it is nearly impossible to set control points in thermograph image. However, skyline matching method which has been proposed in this paper can be applied to rectify thermograph images. Temperatures of the sky and the mountain are very different at night time that allows easy detection of skyline.

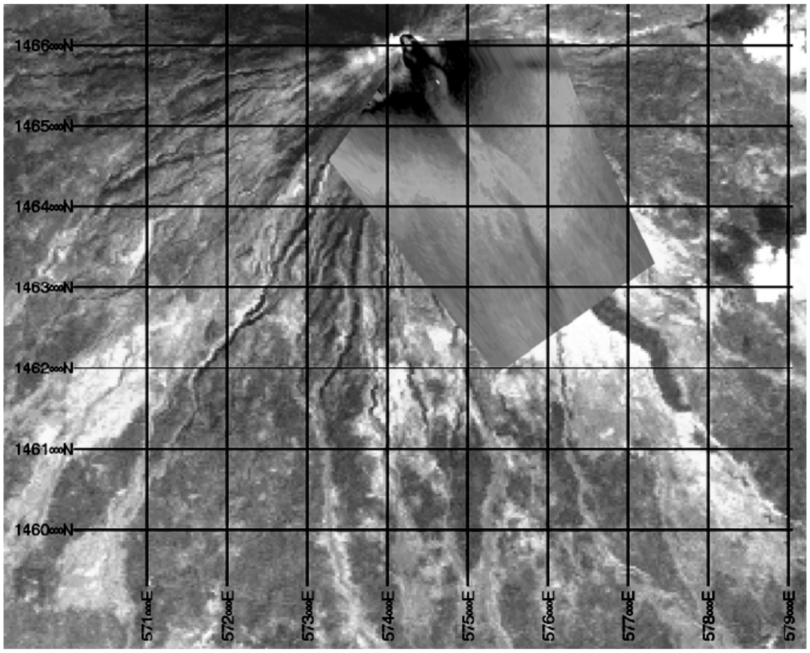


Figure 12: Night-time Ortho-Thermograph Map (Lava can be still identified after several months of eruption)

5. Accuracy assessment

5.1. Camera Calibration

Ideally, camera calibration should be done before surveying. Kunii and Chikatsu have done some experiments. According to their experiments, the accuracy for the consumer digital camera has improved with the increase in the number of pixels. Digital cameras with more than 3 mega pixels have the same accuracy value. High-resolution consumer digital cameras are usable for this study. In this study, camera calibration was not performed but as mentioned later, the result gives enough accuracy for practical application.

5.2. Accuracy assessment

Mayon volcano geomorphological map is used to assess the accuracy. Lava flows and some gullies are clearly recognized in both geomorphological and orthophoto maps. Four feature points, which are available in both geomorphological and orthophoto maps, are chosen. The positions of these feature points are compared between the geomorphological map, and orthophoto map. Digital camera landscape images are taken from three positions and three focus lengths (viewing angles), and orthophoto maps have been produced from each images. Details of each location of digital camera are shown in Table 1. Accuracy is checked from three different locations (A, B, and C). Accuracy is also checked by three different focus lengths (C1, C2, and C3) with four feature points. A total of 5 orthophoto maps are created in different position and focus lengths for accuracy assessment. In table 2, there are (-) values. It means those feature points cannot be observed from that camera position. From the Table 2, the maximum difference is 102m and the minimum difference is 18m. Therefore, the accuracy of this map is between 18 to 102 m. This accuracy value is practically acceptable for real time monitoring.

Table 1. Camera Position

	Location Date	Camera Position North/East/Altitude	Distance form Summit	Focus length
A	Cagsawa Sep. 14th, 8:53am	N: 1,455,730 E: 575,814 A: 84m	10,419m	12.4mm
B	PHIVOLCS Sep. 13th, 9:43am	N: 1,455,249 E: 578,886 A: 179m	11,744m	14.4mm
C1	Albay Hotel Sep. 13th, 6:30am	N: 1,454,403 E: 581,311 A: 53m	13,615m	11.7mm
C2	Albay Hotel Sep. 13th, 6:39am	N: 1,454,403 E: 581,311 A: 53m	13,615m	18.3mm
C3	Albay Hotel Sep. 13th, 6:46am	N: 1,454,403 E: 581,311 A: 53m	13,615m	21.7mm

N = Northing, E = Easting, A = Altitude by UTM 51 / Datum LUZON 11 / Projection TMPHIL 4

Table 2. Position of each Feature Points and Accuracy

Camera Location	**Feature Points**	**Northing**	**Easting**	**Distance (m)**	**Distance from average position**
Geo-	1	1,463,950	574,400	-	-
Morphological	2	1,463,150	576,500	-	-
Map	3	1,464,350	576,250	-	-
	4	1,461,600	577,450	-	-
A	1	1,463,860	574,445	101m	94m

	2	-	-	-	-
	3	-	-	-	-
	4	-	-	-	-
B	1	1,463,950	574,365	35m	28m
	2	1,463,115	576,485	38m	10m
	3	-	-	-	-
	4	-	-	-	-
C1	1	1,463,975	574,355	51m	55m
	2	1,463,100	576,465	61m	20m
	3	1,464,315	576,305	65m	17m
	4	1,461,745	577,495	64m	19m
C2	1	1,463,910	574,365	53m	19m
	2	1,463,165	576,490	18m	50m
	3	1,464,280	576,325	102m	23m
	4	1,461,690	577,465	18m	48m
C3	1	1,463,930	574,355	49m	22m
	2	1,463,090	576,460	72m	31m
	3	1,464,305	576,310	75m	6m
	4	1,461,775	577,475	79m	38m

Northing, and Easting by UTM 51 / Datum LUZON 11 / Projection TMPHIL 4

6. Conclusion

Volcanic activity is mapped on real time basis using a newly developed volcano activity mapping system, with ground fixed consumer digital camera. Every part of the mapping techniques is done automatically. The skyline matching algorithm was developed for automatic rectification without setting ground control point on the slope. Once a digital camera landscape photograph is obtained, an orthophoto map, which is the final output, is automatically produced concurrently. This volcano activity mapping system should help people evacuate from hazards in case of volcanic eruption on real time.

The advantages of the real time volcanic activity mapping system are listed below.

(1) Orthophoto map is created from landscape image taken from the ground which makes it possible to monitor volcanoes continuously. Landscape image were being used for just observation purposes in former times. However, in this system, landscape image can be used both for visual observation

and measurement purposes. Orthophoto maps created from landscape image, can be used to measure the position and speed of lava and pyroclastic flows, damaged area, and others.

(2) The use of consumer digital camera is one of the key points in designing inexpensive and applicable system for a variety of fields. Also, it allows real time imaging possible. With the number of pixels increased, consumer digital camera can be used as variety of photogrammetric fields with good geometric accuracy and stability.

(3) Observation is done safely. The camera position is far from volcanic activity. In this study, the camera position is set about 10 to 14 km far from the summit. The observing position is safe enough. Usually, in case of volcanic eruption, the hazardous area is within 10 km from the crater.

(4) Clouds do not affect the monitoring of volcanic activity because the landscape image is taken from the ground. If volcanic activity is monitored by satellite, the presence of clouds always influence the quality of optical image acquired. However, clouds do not always have an effect on landscape image because most of the clouds are located at higher altitude than the mountain's summit. Therefore, volcanic activity can still be mapped during cloudy days if clouds are located at higher altitudes.

(5) Rectification is done by skyline matching. In usual photogrammetry, control points are required for rectification. Setting of control points is one of the hardest works and takes at least few hours to days. In this system, only the summit and camera positions are required for rectification. Using the skyline matching algorithm, rectification is done automatically with very short processing time. This matching method has been speeded up to practical level by introducing pyramid method and edge mask image.

(6) The presence of clouds or smoke does not affect to rectification. Even if some parts of mountain are not visible because of cloud or smoke, skyline matching algorithm is still possible to apply by just using visible part of skyline.

(7) Orthophoto maps are produced real time in pretically. For the first image, it takes 113 seconds to produce orthophoto map. After first image, it just takes 3 seconds to produce orthophoto map.

(8) This mapping system is not only applicable to optical camera images but also thermography images. The implication is that volcanic activities, such as lava and pyroclastic flows, can be observed even at nighttime.

(9) The accuracy of orthophoto map is practically acceptable. Comparing with the geomorphological map, the accuracy is between 20 to 100 m. This accuracy value is practically acceptable for real time monitoring. The standard deviation of mapping position is about 10 to 30 m, meaning mapping stability is good.

Acknowledgement

The authors would like to express deep appreciation to PHIVOLCS (Philippine Institute of Volcano logy and Seismology) for their support during the field survey. Their support was very valuable in our research development. The authors also would like to extend deep appreciation to Keio University

for the use of thermography equipment.

Reference

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