High-resolutional topographic survey using small UAV and SfM-MVS technologies in hardly accessible area

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Abstract. Aerial photogrammetry and/or airborne laser scanning with manned light plane are normally used for geomorphological measurement especially in hardly accessible areas. Those methods are, however, relatively expensive and therefore frequent measurement is practically difficult. Additionally, as the manned plane cannot fly at low altitude, it would not measure a correct topography of subvertical features and concave geometries like caves. To solve such problem, the authors have experimented an aerial photography based SfM-MVS (Structure from Motion and Multi-view Stereo) technique on a 'peninsular-rock' surrounded on three sides by the sea at a Pacific coast in Chiba Prefecture. The survey was carried out using UAS (Unmanned Aerial System) combined with a commercial small UAV (Unmanned Aerial Vehicle) carrying a compact digital camera. The three-dimensional model has been constructed by digital photogrammetry using a commercial SfM-MVS software which can generate sparse and dense point-clouds and orthophotographs. Using the 'flight-log' and/or GCPs (Ground Control Points), the software can generate digital surface model with absolute coordinates. As a result, high-resolutional aerial orthophotographs and a three-dimensional model were obtained. The results have shown that it was possible to survey the inaccessible area like free face and deep gorge in detail. This system has several merits: firstly lower cost than the existing measuring methods such as manned-flight survey and aerial laser scanning. Secondly, compared to these other methods, the one the authors have presented also enables frequent measurements. Thirdly lightweight and compact system realizes higher applicability to various fields.

Keywords. UAV, SfM, Sea cliff, Aerial survey

1. Introduction

Recently air borne laser scanning (ALS) and terrestrial laser scanning (TLS) provide high-accuracy and high-density three-dimensional (3D) spatial data (e.g. Stock et al. 2011; Dudzińska-Nowak and Wężyk 2014; Kuhn and Prüfer 2014). However laser scanning method still has the following problems. The ALS is relatively expensive, therefore frequent measurement is difficult and high-resolution temporal analysis of topographic change cannot be detected (e.g. Ružić et al. 2014). In general the ALS is conducted from high-altitude and to a downward direction, therefore data density at steep slope becomes relatively low and high-resolution spatial analysis of 3D properties is difficult or impossible. Observation point of the TLS is limited on the accessible ground, therefore measurement from the air is impossible and topographic data in difficult-to-access place cannot be acquired.

To solve such problems the present study applied Structure from Motion (SfM) photogrammetry measurement with small Unmanned Aerial Vehicle (UAV) to quantify inaccesible coastal cliff geometry. Specifically, 1) the authors have experimented multiple UAV-SfM photogrammetry on a peninsular-rock surrounded on three sides by the sea; and 2) topographic change volume and rate are calculated using the difference between 3D topographic data.

2. Study Area

A case site is located in the center part of the Taitosaki in the east of Chiba prefecture, Japan (Fig. 1). The peninsular-rock named Suzumejima has circular shape with a diameter of 50 m and a height of 30 m. The cliffs are formed in alternation of sand and mud. The area is exposed to waves from the east. Cliff erosion of several meters is identified by comparison of the existing aerial photographs from 1974 and 2005 (Fig. 2).

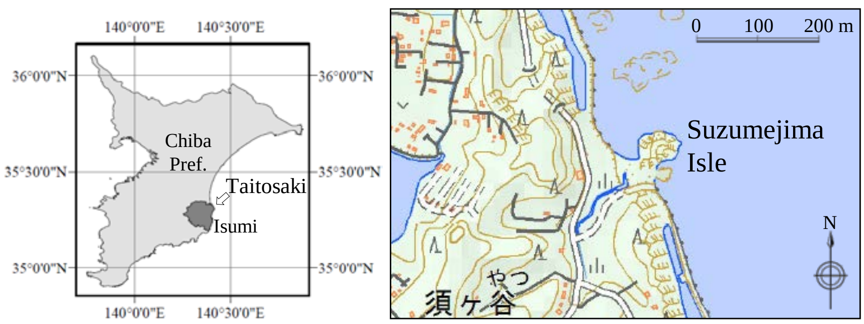
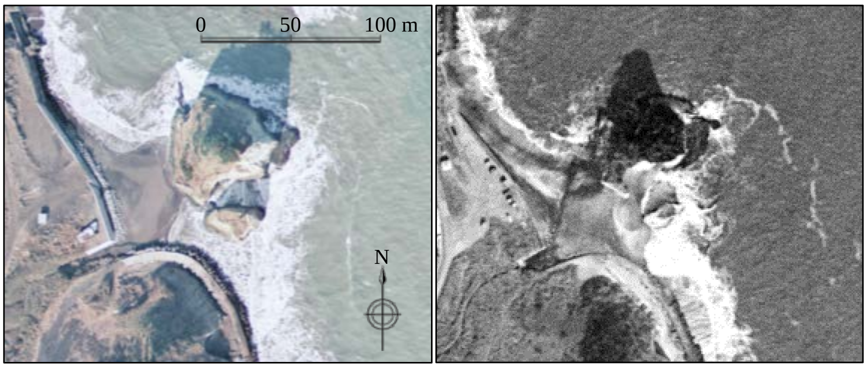


Figure 1. Study site.



Date taken:	Dec. 31, 1974	Nov. 5, 2005
Original scale:	1/8,000	1/30,000

Figure 2. Aerial photos. (taken by Geospatial Information Authority of Japan)

3. Aerial Survey using UAV

The survey was carried out using a commercial small UAV (DJI Phantom 2) carrying a compact digital camera (NIKON Coolpix A) (Fig. 3). The three-dimensional model has been constructed by digital photogrammetry using a commercial SfM photogrammetry software (Agisoft Photoscan Professional) which can generate sparse and dense point-clouds and orthophotographs. Using the ‘flight-log’ and/or GCPs (Ground Control Points), the software can generate digital surface model with absolute coordinates. In this study, positional data of each photo recorded by GPS unit on the camera were used as GCPs of 3D model. For more details and earlier work on this method, the reader is referred to Obanawa et al. (2014a, 2014b).

Figure 3. Small UAV with compact digital camera and GPS unit.

Aerial photography using the small UAV was conducted twice by one person on 24 June and 31 October 2014. The photos were taken from various elevations and angles to cover all slopes including vertical and partially overhang cliffs. The number of photos was 1,217 at the first survey in June and 1,279 at the second survey in October.

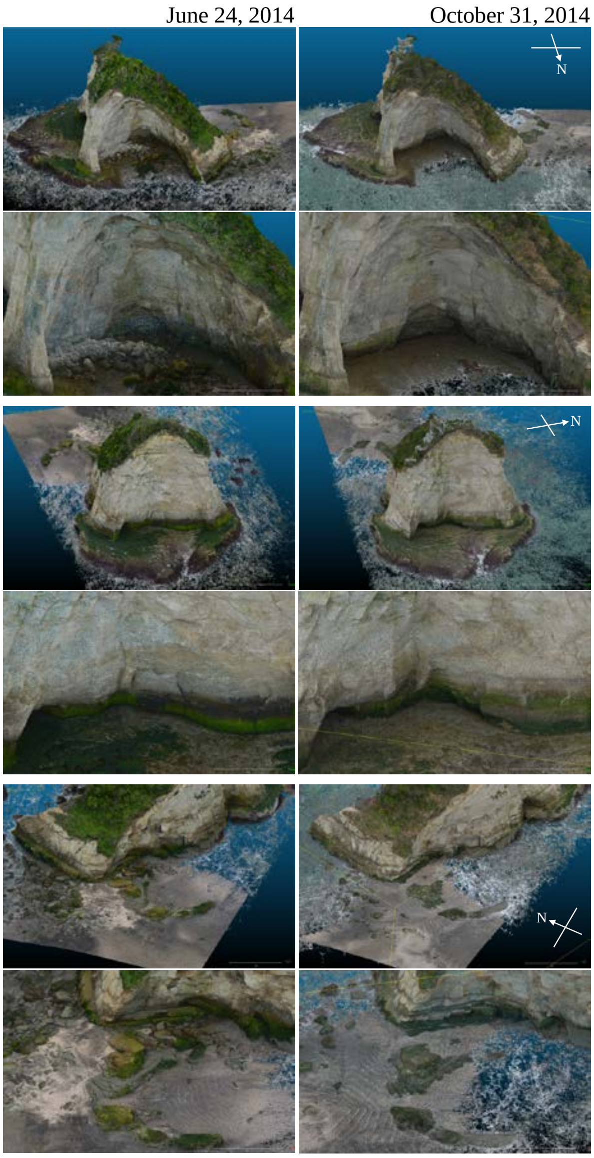


Figure 4. 3D textured models.

The photos were processed using the SfM photogrammetry software and the 3D point clouds and textured models were derived (Fig. 4). Point densities are about 1,700 points/m^2 in the case of June and about 1,000 points/m^2 in October respectively. Each point of the 3D cloud has x, y, z coordinates as well as colour (RGB) enabling further qualitative analysis. In the present case, aerial photogrammetry using UAV took about 2 hours and computer processing took about 24 to 48 hours respectively.

4. Measurement of Topographic Change

Three extracted profiles which are derived from 3D point cloud (each of 30 cm width) are shown in Fig. 5. The vertical cliff, wave-cut bench and sea cave including ceiling portion are clearly visible. East part of the island has the vertical big cliff with a height of 30 m and flat bench with a width of 40 m and a depth of 24 m. North part of the island has the big cave with a height of 18 m, a width of 29 m and a depth of 10 m.

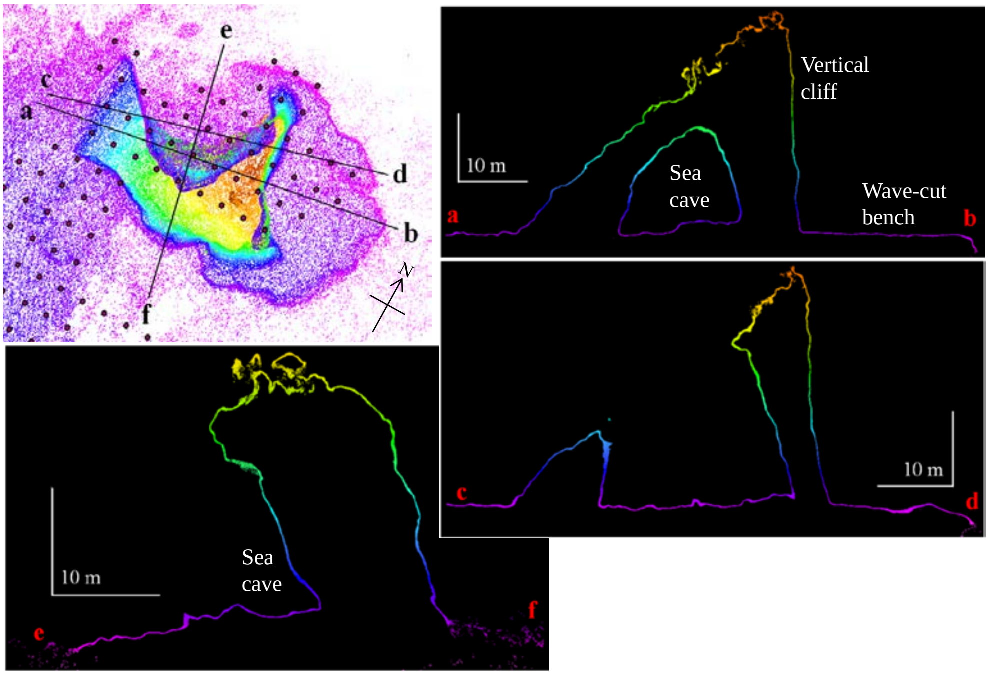


Figure 5. Topographic profiles in June 2014.

To detect the temporal change of the island quantitatively, firstly 3D models were geo-referenced. Because of errors of GPS data of the camera, 3D models of the different periods do not completely overlap. Therefore the secondary data in October was aligned to the first data in June through manual identification of three fixed points in the point cloud and the computation of an appropriate transformation using a 3D point cloud processing software CloudCompare.

Normally the topographic change is calculated by comparing raster data of two periods with GIS software. However there is overhang slope like sea cave at the study site and such concave structure cannot be expressed by a raster format data because in the XY plane each coordinate can have only one data as an altitude value. In other words, in the case of 3D structure which has three altitude values at a same XY coordinate like a cave, only surface topography of the island can be expressed in raster data such as Digital Surface Model (DSM) and the topographic data of inside cave is removed.

To solve such problem firstly the 3D model was subdivided into four segments: a flat area such as the wave-cut bench and floor portion of the sea cave; b vertical cliff on the east side; c slopes on the south and west sides; d ceiling portion of the sea cave (Fig. 6). Secondly target slope was formed on the top face by rotating the 3D model adequately for each segment. Lastly the target area was clipped appropriately and topographic change was evaluated by comparing raster data of two periods.

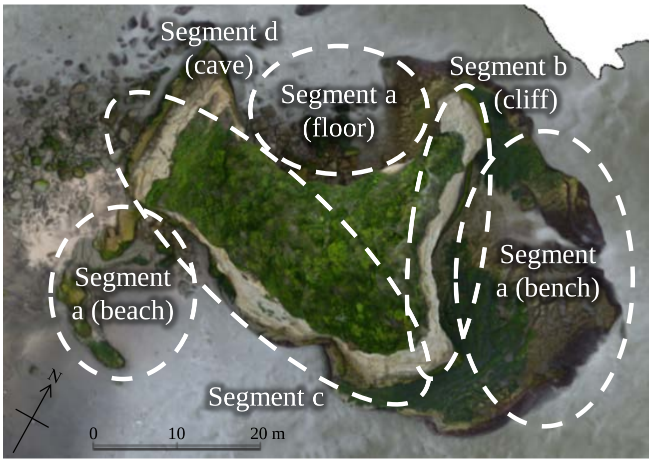


Figure 6. Segmentation of the slopes.

As shown in Figs. 7 and 8 at the beach area (segment a) on the west side of the island the difference between the geo-referenced 3D rasters is up tp 110 cm and total erosion volume is 26 m³. At the floor portion of the sea cave (segment a), the maximum erosion depth is 230 cm and total volume of the topographic change is 146 m³. However this volume change is not an erosion of the island bedrock but a removal of the fallen rocks on the floor because according to the aerial photos taken on 28 October 2013 using UAV as a preliminary study there was no fallen rocks on the floor of the cave so these fallen rocks of 146 m³ is thought to be produced from the ceiling portion of the sea cave during the period of October 2013 to June 2014. At the segment b small erosion is recognized at the base of the cliff which depth is up to 130 cm and volume is only 12 m³. At the segment c relatively small topographic changes are recognized at some parts of the slope and that total volume is only 9 m³. At the segment d large collapses were occurred on the ceiling portion of the sea cave which total volume is 64 m³.

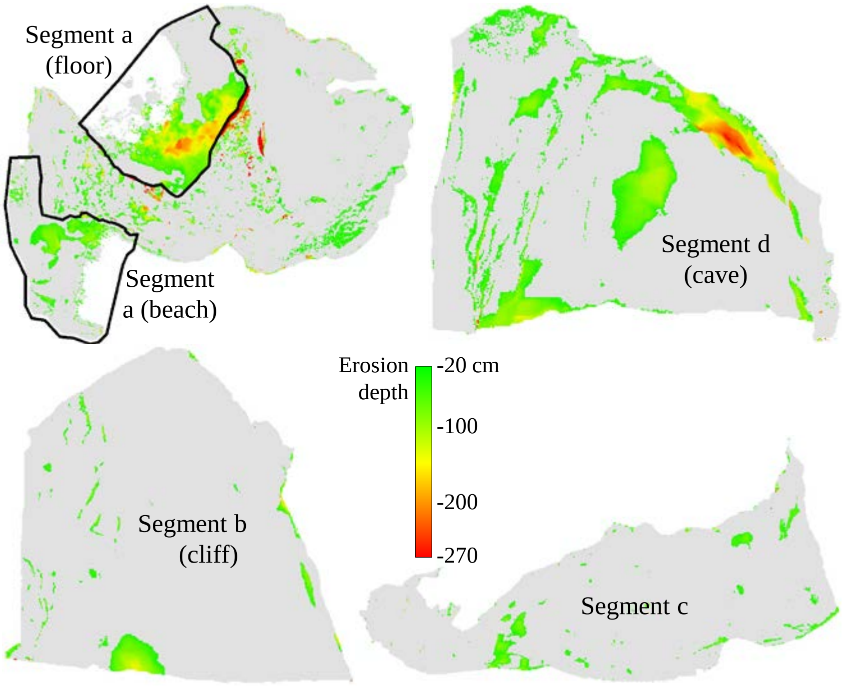


Figure 7. Topographic changes.

Average erosion rate of the cliff, i.e. segments b, c and d, is about 4.5 cm/4 months. According to the previous study using topographic maps with a scale of 1/1,000 in 1960 and 1966 by Horikawa and Sunamura (1967), erosion rate of the Taitosaki sea cliff is about 1 m/year on average. The erosional rate estimated from the present study is rather small in comparison with the previous one. However as the target period of the present study is very short, the continuous monitoring in the future will make it possible to evaluate the erosion rate of the sea cliff more accurately including seasonal and/or annual variations.

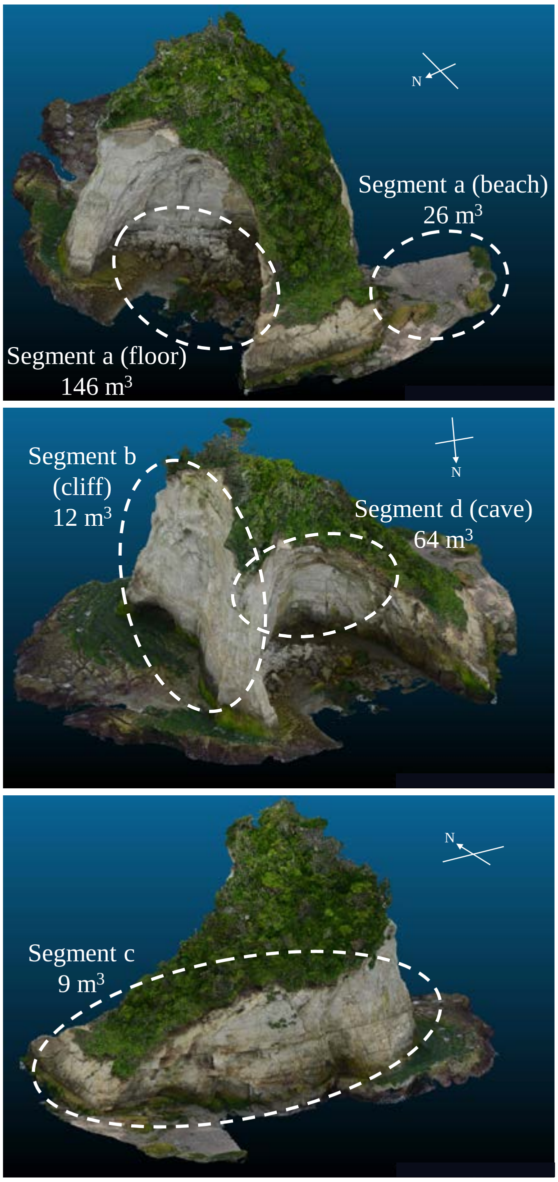


Figure 8. Erosion volumes.

5. Conclusion

This work demonstrates the high potential of the SfM photogrammetry using small UAV in quantitatively monitoring the geometric change of complex and inaccessible cliff faces including undercuts and overhangs which are difficult to measure with the existing methods. Due to easy application and low cost, this method is highly suitable for continuous measurements over short time periods such as earthquake and storm as well as long term monitoring.

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