

## High-resolution spatio-temporal topographic survey in hardly accessible sea cliff

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The present study applied Structure from Motion (SfM) photogrammetry measurement with small Unmanned Aerial Vehicle (UAV) to quantify inaccessible 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. A case site is located in the center part of the Taitosaki in the east of Chiba prefecture, Japan. The peninsular-rock named Suzumejima has circular shape with a diameter of 50 m and a height of 30 m. Aerial photography using the small UAV was conducted twice 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 photos were processed using the SfM photogrammetry software and the 3D point clouds and textured models were derived. Point densities are about 1,700 points/m<sup>2</sup> in the case of June and about 1,000 points/m<sup>2</sup> in October respectively. Each point of the 3D cloud has x, y, z coordinates as well as colour (RGB) enabling further qualitative analysis. Extracted profiles which are derived from 3D point cloud show the vertical cliff, wave-cut bench and sea cave including ceiling portion clearly. To detect the temporal change of the island quantitatively, 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. 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. At the beach area (segment a) on the west side of the island the difference between the geo-referenced 3D rasters is up to 110 cm and total erosion volume is 26 m<sup>3</sup>. 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 m<sup>3</sup>. 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 m<sup>3</sup>. At the segment c relatively small topographic changes are recognized at some parts of the slope and that total volume is only 9 m<sup>3</sup>. At the segment d large collapses were occurred on the ceiling portion of the sea cave which total volume is 64 m<sup>3</sup>. 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, 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.

Keywords: UAV, SfM, photogrammetry, sea cliff