Accurate volumetric measurement of tsunami boulders using 3D point clouds

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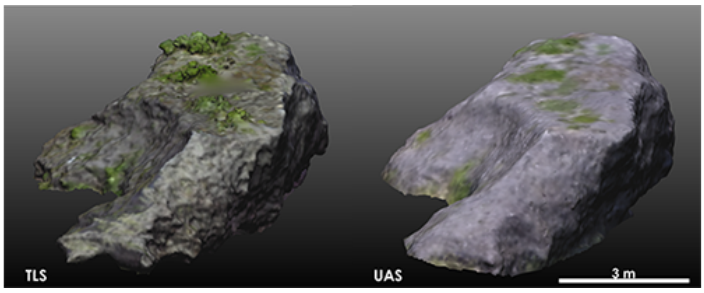
Volumetric measurements of large tsunami boulders have been a challenging issue. Although manual measurements have often been carried out to estimate the size of boulders, the volume may not be directly measured in such a manner because of their complex shape and vegetation covers. Alternatively, three axes (long, medium and short) are often used as representative size parameter of a boulder. However, the accurate measure of the volume is necessary for quantitative assessments of the transport processes of tsunami boulders. Here we perform field measurements of three-dimensional morphology of tsunami boulders in the southern Ryukyu Islands using 3D technologies including terrestrial laser scanning (TLS) and structure-from-motion multi-view stereo (SfM-MVS) photogrammetry either by an unmanned aerial system (UAS) or ground-based camera. The 3D point cloud data obtained by TLS and UAS-SfM are registered and georeferenced, manually filtered to remove vegetation, and converted to 3D mesh data by calculating normal and reconstructing 3D surfaces. The TLS-derived data is used as the reference, while UAS-derived data is utilized for the measurements of widely-distributed tsunami boulders. Although detailed topographic features such as the surface roughness are much better represented in the TLS-derived data, the resultant mesh volumes are nearly the same for both data with <1% difference. The TLS- and UAS-derived volume data are compared with those by manual measurements, showing a good linear correlation. The accurate measure of the volume of tsunami boulders is used for the reconstruction of the potential kinematic energy of tsunami waves, suggesting the presence of higher tsunamis in the southwestern side of the Ryukyu Islands.

Keywords: terrestrial laser scanning (TLS), SfM-MVS photogrammetry, unmanned aerial system (UAS), point cloud, 3D mesh



Quantitative analysis of bedrock weathering at Soya Coast, East Antarctica using the UAV-SfM

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The record of the past ice sheet changes is important for the future prediction of the Antarctic ice sheet melting. The timing of the ice sheet retreat in the southern part of the Soya Coast, East Antarctica, was estimated based on the surface exposure ages at very limited places. However, the ice sheet expansion and retreat history of the ice sheet have been remain unclear. Therefore, it is important to estimate the relative exposed ages based on the degree of weathering of bedrocks in addition to the exposure ages in order to reconstruct detailed ice sheet history in this region.
In this study, we evaluate the degree of rock weathering based on detailed Digital Elevation Model (DEM), which was obtained by an Unmanned Aerial Vehicle (UAV)-Structure from Motion (SfM) analysis in the northern part (West Ongul Island) and the southern part (Telen) of the Soya coast. From these two areas, we sampled the same type of basement rocks and carried out the hardness test using the equotip hardness tester. The field survey was carried out during a December 2015 - March 2016 as a field campaign of 57th Japanese Antarctic Research Expedition. In order to identify the geomorphological characteristics in Telen and West Ongul Island, we applied two-dimensional Fourier analysis and high pass filtering (5.0 m, 1.0 m, and 0.2 m) of them for the obtained DEMs. The result shows that the low frequency component (5.0 m high pass) reflects topographical relief relating to the geological structure. On the other hand, the high frequency component (0.2 m high pass) distributions only near the steep slope. Histograms of the degree of slope for ca. 5.0 cm mesh reveal that Telen has more steep slope (>40˚) areas. These results show that the topographically angular corresponding to knick points are conserved in Telen relative to that of West Ongul Island. In other words, the topographically angular in West Ongul Island is thought to be scraped off due to weathering, suggesting the long time of exposure. In addition, Equotip rebound value (L-value) of Telen was about 1.2 times larger than that of West Ongul Island, and L-value of the sample from West Ongul Island decreases rapidly from surface to inside. These indicate that the degree of the weathering of the rock is significant in the West Ongul Island, which is consistent with the topography features revealed by DEM analysis. Therefore, the difference in topographical characteristics between the northern and southern part of the Soya Coast likely reflects the degree of weathering due to the different exposure time. However, there are various factors, which have to be addressed, such as rock type, inclination, and environment at the bottom glacier. Therefore, further efforts to find out the better approaches are needed for the quantitative analysis of bedrock weathering.

Keywords: UAV-SfM, Rock Weathering

Relationships between coastal sand dune vegetation and landforms: A preliminary analysis using TLS and UAV-SfM photogrammetry in Tottori Sand Dunes

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Coastal sand dunes have been closely related to human activities. In recent centuries, the landward sides of sand dunes have been modified by the creation of farmlands and erosion control forests, as well as the construction of harbors, airports, roads, and residential areas. On the sea side of sand dunes, coastal structures, including revetments and detached breakwaters, have been installed to prevent coastal erosion. By these reasons, the total area of sand dunes has significantly decreased in Japan, and the ecosystem therein has been greatly affected by these changes. The number of endangered species per unit area is particularly large when compared with those in forests and wetlands. These facts encourage the need for the conservation and restoration of sand dunes and their ecosystem.
Meanwhile, investigating sand dunes in the natural state is indispensable for future planning of such conservation planning. This study focuses on the vegetation in sand dunes, which is the primary producer of the ecosystem. In previous studies, it has been suggested that the accretion of sand has the greatest influence on the distribution and survival of vegetation in sand dunes. However, although many studies have explored relationships between coastal sand dune vegetation and environmental factors, effects of landforms on the vegetation growth and distribution have rarely been examined. Here we investigate the spatial relationships between vegetation and landforms in the Tottori sand dunes using high-resolution ground surface information obtained from terrestrial laser scanning (TLS) and unmanned aerial vehicle-based structure-from-motion (UAV-SfM) photogrammetry. Sand dunes vegetation was classified into several communities, and a vegetation map was created based on the orthorectified images obtained by UAV-SfM photogrammetry. We analyzed the spatial correlation between vegetation and landforms. In particular, there is a relationship between the aspect of slope and distribution of vegetation. The distribution of vegetation and landforms is likely affected by the constant wind from the south having a speed of more than 5 m per second, as well as the seasonal winter wind from the northwest having a speed of more than 10 m per second. Because coastal sand dunes are a part of the dynamic ecosystem, it is necessary to further explore the dynamic relationships of vegetation growth with changing landforms, which will be clarified by their continuous monitoring.

Keywords: Coastal sand dune, Vegetation, Landforms, TLS, UAV-SfM

Time series analysis of TLS-derived point clouds for shallow landslides in Aso region, Kumamoto, Japan

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The 2016 Kumamoto earthquake triggered many landslides on steep slopes in the Sensuikyo area near the Aso Volcano in Kumamoto, western Japan. In this research, we use the terrestrial laser scanning to obtain detailed point cloud data of the slopes including landslides before and after the earthquake. We analyze the point cloud data regarding the changes in elevation and topographic profiles. It is observed that new landslides were formed by the earthquake on slopes where landslides formed by the heavy rainfall in July 2012 have already been present. The depth of the earthquake-derived landslides is about 6 m, which is deeper than the past landslides caused by heavy rainfalls. We also found that the longitudinal profiles of the earthquake-driven landslides exhibit different shapes from those of the rainfall-triggered landslides: The former is more curved, while the latter is straight. This suggests that the landslides by the earthquake have occurred along a slip surface deeper than that of the rainfall-derived landslides. Also, further decreases in elevation were partially observed on the ridge, the middle part of the slope, and the valley bottom after the earthquake. This suggests that there were further collapses and erosion possibly caused by a relatively heavy rainfall in June 2016.

Keywords: The 2016 Kumamoto Earthquake, Terrestrial laser scanning, Point clouds, High-definition topographical data, Landslides, Time series analysis

Quantitative assessment of tree trunk inclination and topographic conditions using multi-temporal point cloud data in a hilly catchment

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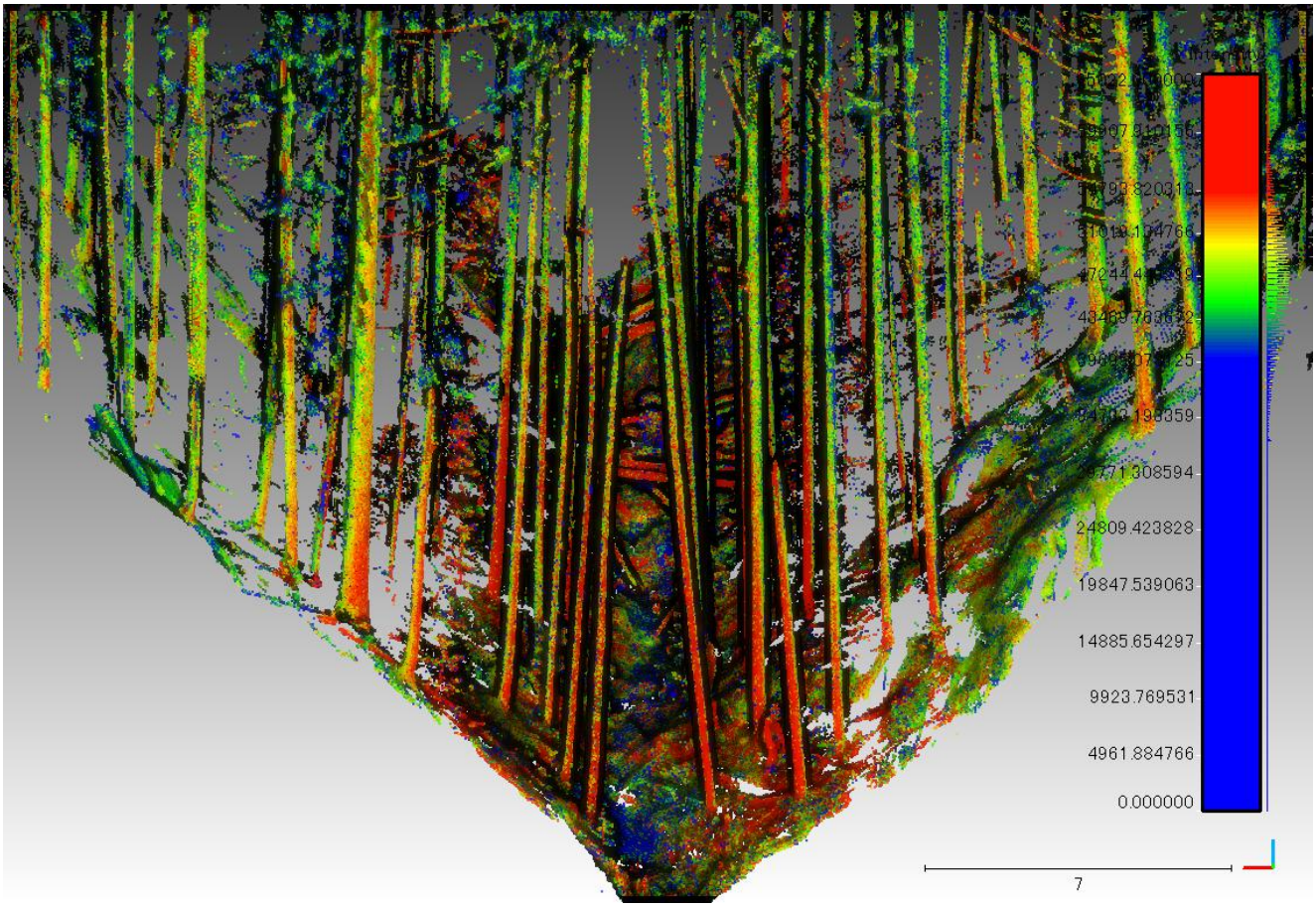
Recent advances in the measurement approaches using terrestrial laser scanning (TLS) have enabled quantitative evaluation of forest environments with three-dimensional (3D) point cloud data. Several issues, including estimation of biomass, light transmission through canopies, and hierarchical structures of forests, have been investigated by point cloud analysis. However, the 3D structures of individual trees, as well as the relationships among such vegetation characteristics and topographic conditions, remain to be further examined. In this study, we examine the inclination of tree trunks, as a representative shape parameter of forest vegetation, in a small hilly watershed using 3D point cloud data. The effects of topographic conditions on the vegetation shape are further investigated. We use multiple time series of point cloud data obtained by TLS in 2005 and 2016, which enable us to detect decadal changes in the vegetation and topography in the study site. Spatial distribution of the tree inclinations shows topographic controls on the vegetation shape: for instance, more inclined trees are found around the valley bottom where slopes tend to be steep due to the channel incision. Comparisons of the multi-temporal point cloud data reveal the changes in both vegetation shape and topography. In particular, gradual erosion and deposition of sediments on the order of decimeters to meters are found to have occurred around the valley bottom following the occurrence of the debris flow in 2005. In the last decade, the sediment accumulation was domant in gentle reaches along the channel, while the erosion occurred on the steep side slopes. Such the change in topography seems to have affected the tree trunk inclinations, probably due to the soil creep toward the steepest descent of the catchment slopes. Also, it is suggested that the tree crown have grown asymmetrically toward the sunlight that is more available in the forest gap around the valley bottom, leading the tree trunk more inclined toward the gap due to its unbalanced weight. This kind of analysis will also contribute to the disaster prevention issues in mountainous or hilly areas with forests.

Keywords: tree trunk inclination, topographic , TLS



Verification and Possibility on the Operation of Gravel Bed River Measurement using UAV and SfM-MVS

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Recently, it is possible to acquire high spatial resolution information by UAV (Unmanned Aerial Vehicle) and SfM-MVS (Structure from Motion –Multi-view Stereo). Terrain surveying by UAV and SfM - MVS has the advantage that it is possible to acquire terrain information of high spatial resolution at low cost. Further, there is an advantage that the survey designer can freely measure at the timing at which data is desired to be acquired. As a result, it became possible to acquire topographical information with higher temporal resolution than conventional aerial photographs.
Utilizing the merit of acquiring terrain information of high spatiotemporal resolution, We have the ultimate purpose of monitoring the topographic change of the gravel bed river. First, the resolution of DSM (Digital Surface Model) that can be generated by UAV and SfM - MVS is about 10^0 ~10^1cm, and can grasp riverbed gravels one by one. Also, the gravel bed river in Japan has a steep gradient and a large flow rate, so the flow velocity is fast. However, in the existing research, there are many researches that analyzed the target site based on data once captured with high spatial resolution. In this research, through verification experiments and on-site survey experiments, verification is performed on the surveying of the gravel bed river, proposing the analysis process, and giving issues to calculate the topographic variation.
First, we measured the bricks size assuming riverbed gravel using UAV and SfM - MVS and verified how accurate the actual bricks size are.
It is the GCP (Ground Control Point) that is given at analysis time to give the most influence on the accuracy of the DSM. GCP should be placed on the xy plane of the object to be surveyed from the end to the end, the highest point and the lowest point in the z direction, and interpolate the object.
We actually tried to measure the gravel bed river. The target area is the Tedori River, Ishikawa Pref., Japan, which is a first-class river with a source in Mt.Hakusan. We shot riverbed using UAV at a frequency of about once every two weeks. At that time, it flew at the altitude of 30m according to the aerial law. The GCP set the reference point using temporary survey data (here, taken for 8th December 2016) and used it for data of other periods and used it. The resolution of the DSM was 2.5cm.
As a result, we were able to capture the actual gravel (Fig.1). The size of the gravel that could be caught was about 50cm. In addition, we could express the shape of gravel by drawing contour lines. We tried to measure the transportation / deposition situation of gravel by extracting this difference from DSM at other time. As a result, a horizontal error of about 45cm occurred, and it was impossible to extract the difference by gravel size. The horizontal accuracy of GCP is about 5cm, whereas the systematic nature which was not noticeable also in error of DSM was not seen. Therefore, rather than using GCP using relative coordinates, it is possible to use precision surveying such as GNSS (Global Navigation Satellite System) and RTK (Real Time Kinematic).
In continuing this research it is possible to connect the development process of the gravel growing with the conventional geomorphological research results for the first time by solving this problem. By capturing the change of micro topography with DEM, it is possible to simulate the terrain development process of hundreds of thousands of years scale, realize the terrain development simulation. In the Tedori River, the outflow of gravel has been actively carried out since the construction of the dam, and the bed change is intense even for decades. In the future, we would like to estimate the topography development on the scale of hundreds of thousands of years, and think about deepening the consideration of river channel

change and environmental change.

Keywords: Topographic measurement, High-definition Topographic Data, Grabel bed river, Digital Surface Model(DSM)

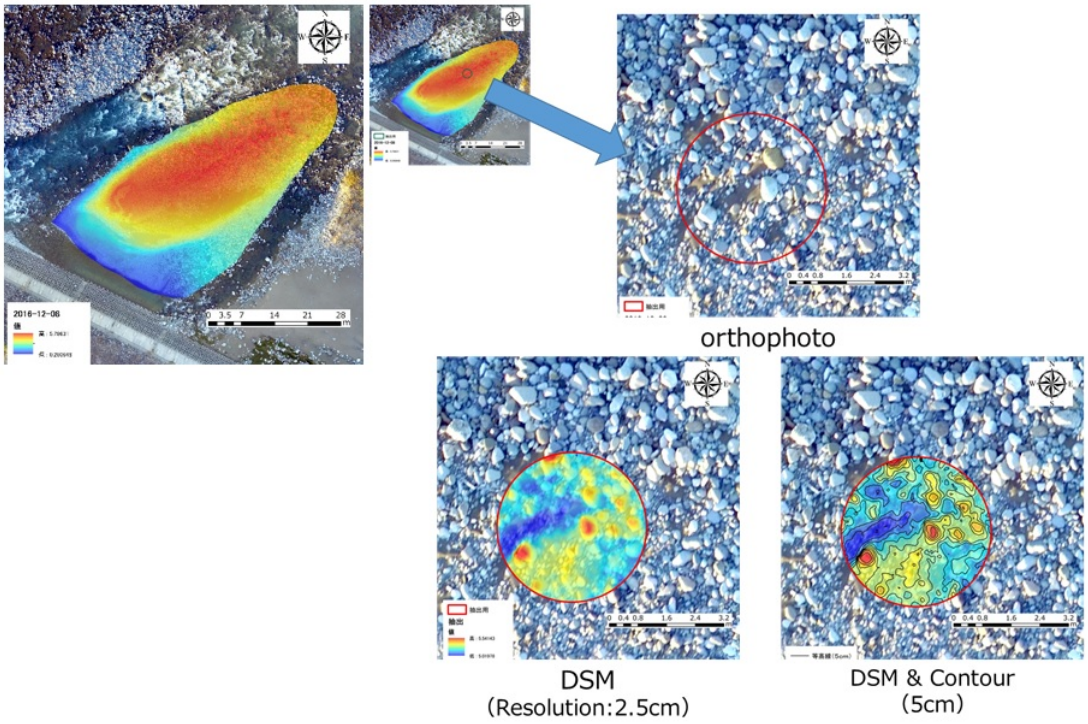

Fig.1 DSM and Orthophoto of the gravel bed river generated by UAV and SfM-MVS

Application of Structure-from-Motion Multi-View-Stereo Photogrammetry to the extraction of vertical deformation caused by an inflated magma chamber in an analogue experiment

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In recent years, SfM MVS (Structure-from-Motion Multi-View-Stereo) photogrammetry has become widespread in the Earth sciences. Although this technique has been applied mainly to topography measurement, it has been expected to have applications in the analysis of data from analogue experiments (model experiments).

In this study, we attempted to verify whether or not the SfM MVS technique could extract displacement of a sub-millimeter order when applied to a small analogue experiment. We employed an analogue experiment on surface deformation caused by inflation of a magma chamber, because this type of experiment has often been conducted and discussed for the purpose of understanding caldera formation, and excellent results have been obtained. In addition, the requisite knowledge for obtaining a good result has been accumulated.

We made an experimental apparatus using an aluminum tube (diameter 60 cm), a small balloon, a bicycle pump, and rice powder. We conducted experiments and analysis according to the following procedures. (1) We fixed the balloon (radius 2.0 cm) at the center of the base of the tube, and covered it with rice powder. The base is 19 cm below the top of the tube. The scale of this model experiment was 1/20,000, and the fracture strength of the material was estimated using the Coulomb-Mohr criterion for model experiments. (2) We took photos (80 pictures) of the non-deformed surface as an initial state, from various directions and distances. We employed a RICOH GR II digital camera to take the photos. (3) We inflated the balloon radius from 2.0 cm to 4.5 cm in 0.5 cm increments, and we took photos (80 pictures) of the deformed surface caused by the inflated balloon at each stage. (4) We analyzed these photos using PhotoScan software, and constructed a DEM (Digital Elevation Model). (5) We detected net surface deformations caused by inflations of the balloon by subtracting the DEM data obtained at an arbitrary stage from the DEM data obtained at the other stages, using QGIS software.

We repeated this experiment more than ten times, and found that vertical deformations of more than 1 mm could be extracted without conspicuous noise. In addition, we found that inhomogeneity of illumination affected the extraction of the net deformation field, when we attempted to extract vertical deformations of less than 1 mm. The effects of this inhomogeneity appeared as systematic noise or error, appearing like a shadow in the results. This systematic noise appeared in the results even if we illuminated the experimental apparatus using strong LED lights. From the occurrence pattern of the noise, we found that the ceiling lights were causing inhomogeneity of illumination. When we conducted the experiments without the ceiling lights, we were able to detect vertical deformation of 0.2 mm without conspicuous noise.

From these results, we can conclude that the SfM MVS technique can extract vertical deformations of 0.2 mm when the technique is applied to model experiments of the scale of 1/20,000.

Keywords: Structure-from-Motion Multi-View-Stereo Photogrammetry, analogue experiment, inflated magma chamber

3D modeling of a damaged Sabo dam with a combination of a DSM and near-surface geophysical survey data

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We conducted an integrated analysis of high-resolution digital surface model (DSM) and detailed geophysical survey data obtained on the rear wall of a sabo dam, which had been damaged by a huge debris flow occurred in July 9, 2014. An orthophotograph and a DSM of the rear wall of the dam were reconstructed from a set of surface digital photo images at a spatial resolution of 1.2 cm using commercial multi-view stereo (MVS) software (Agisoft Photoscan). The debris flow swept away the top 5 m part of the dam, and segmented the dam body into several blocks associated with horizontal cracks. Estimated surface dislocation was at most 20 cm. Our DSM covered the right half surface of the dam (left bank side), about 30 m wide and 20 m high. We also carried out GPR measurements on the surface, 10 m wide and 15m high, by hanging and moving up the tool along the surface from the top of the dam. A total of 50 lines was scanned at 20 cm intervals. In addition, high-resolution seismic measurements were conducted along 5 survey lines set horizontally on the surface. Piezoelectric type accelerometers were pasted on the surface at 20 cm intervals, and manual hit using rock hammer was employed for generating high-frequency signals.
Because the dam surface was too steep and too high to place a number of GCPs by hand, only 3 points were set on the surface at reachable distances. Then we built a DSM projected on the inclined plane defined by these 3 points. Detailed GPR measurements successfully imaged fractures at the shallow depths up to 1 m, and high-resolution seismic survey detected dipping fractures extending into the deeper portion in the body up to 8m. In addition, photogrammetric analysis clearly mapped blocked deformation. Finally, we combined these planes to create a 3D model with aid of a 3D modeling tool named Voxler provided by Golden Software. In conclusion, joint interpretation of geophysical survey results with the photogrammetric analysis was quite helpful to interpret the dislocation process of the dam body. GPR and high-resolution seismic survey results also demonstrated their applicability for the delineation of internal fracture in large concrete structures.

Keywords: Orthophoto, DSM, Sabo dam, GPR, Fracture Imaging