Micro-topographic survey on the block slope using UAV-SfM method: a case study on the west face of Mount Higashi–Nupukaushi, Shikaribetsu volcanic group, Hokkaido, Japan

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In the topographical analysis, it is definitely effective to employ the conventional methods such as total station combined with transit and laser ranger, for their systematized procedures with a high degree of precision. However, in hardly accessible areas, it is often difficult to survey using such above equipment. Instead, aerial photogrammetry and laser scanning with manned flight are normally used for surveying. But this method is too costly for independent researches to implement. In the last few years, SfM (Structure from Motion) based on photographs taken from UAV (Unmanned Aerial Vehicle) has attracted an interest for the creation of DSM (Digital Surface Model) and other morphometric products, as a much less labored and less expensive method than the above. There are a number of reports to testify the method in various environmental settings, showing enough accuracy to be discussed from a viewpoint of micro-topography. This presentation shows a result to have surveyed the block slope on the west face of Mount Higashi-Nupukaushi, Shikaribetsu volcanic group, using UAV-SfM method. Although it is conventionally considered that block slope has been formed under periglacial conditions, there are circumstances when it makes sense to understand the involvement of rapid mass movements in some cases. Anyway, detailed surveying has not been carried out in almost all block slopes on the steep mountain slopes. In a survey conducted by the authors in September 2015, 1124 airphotoes were obtained by a UAV (Phantom3, DJI), producing DSM (Digital Surface Model) and an ortho-image for a detailed, high-definition topographic mapping of characteristic landforms.

Keywords: UAV-SfM method, block slope, Shikaribetsu volcanic group

A survey for the larger block distribution on the block slopes around the summit area of Mount Tateshina, central Japan: an application of combined on-site measurements with UAV-SfM method providing clues as to the understanding of block slope development

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There are a number of studies concerning the “block slope”. Some studies indicate that the block slopes are formed by material transport due to rapid mass-movements such as slope failures and landslides, while the others conclude that the periglacial processes are highly involved to their formation. However, in fact, the conclusive or clear-cut idea has not been presented. The block slopes generally develop in the relatively inaccessible sites, with steep slopes around and larger than 30 degrees. Besides, large blocks occasionally over meters in diameter are unsteadily scattered and numerous gaps among them are sometimes unfilled by topsoil. In such circumstances, the topographic survey with commonly used tools, such as theodolite or totalstation, requires the greatest time and energy. It must be now requested the more sophisticated measurement techniques to realize the higher degree of understanding of the formation processes of the block slopes.
In this study, we carried out an on-site measurement investigation how located the larger blocks on the block slopes, around the top of Mount Tateshina, central Japan. At the same time, in order to recognize the panoramic surficial characteristics of the studied block slope, aerial photographs of the south part of the summit area were obtained by a UAV (Phantom3, DJI), producing DSM (Digital Surface Model) with an orthophoto by SfM software. These were used for validation with field data to testify the usability of this new remote technique. In the field, we established two line transects along the west and south slopes of Mount Tateshina from near the mountaintop to the lower altitudinal parts. On-site measurements along these transects were accomplished for major axis length, its azimuth orientation, and the relative degrees of weathering of selected block surface. The tentative results are as follows, though more detailed investigations will be planed in the near future.
1) Larger blocks are generally distributed in the lower altitude in both slopes, which is also recognized by the areal photos (orthophoto) by UAV. The major axis direction of the larger blocks is roughly parallel to the maximum slope direction. Based on the produced DSM, it becomes much clear the direct relationship between topographic condition (slope, direction and so on) of the block slope and the alignments of surficial blocks on the slope.
2) A possible process of block slope formation is a bit complicated. Firstly, a large number of blocks were produced and concentrated in the lower part of slopes, probably due to the rapid mass-movements after the emergence of summit dome of Mount Tateshina (ca. 40 ka). After that, the major axis direction of such larger blocks was arranged parallel to the slope orientation by a strong periglacial process perhaps during the LGM. Distal end of the block slopes has the tongue-shape with a small cliff, indicating that the periglacial process had likely to played an initiative role as a formation factor of the studied block slopes.

Keywords: block slope, photogrammetry, rapid mass-movement, periglacial process

The Application of Unmanned Aerial Vehicle (UAV) for Biotope Monitoring Program

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Nature conservation is carried out at Miyagase Dam area, Kanagawa Prefecture since 1996. Construction work is held in 1992-1994 period for nature restoration works, and its effect is monitored by biotope mapping survey. Observation of living organisms and region temperature at study area are done during 1996-2014 period. In 2014, UAV aerial imaging has been deployed for additional 2D/3D data analysis. The observation used three cameras, e.g. optical camera (Canon S100), Near Infra-Red (NIR) camera (Canon S110 Yubaflex) and a thermal camera (Thermo Shot F30S) board on a Multicopter, which flew with flight altitude of 100m. The 2D/3D mapping products from optical images were derived using Structure from Motion (SfM) method and its results are used for spatial distribution of vegetation and habitat mapping (Fig.1a). Ground moisture and thermal mapping using NIR camera and thermal camera are used in thermal habitat study (Fig.1b, Fig.4). This observation method can be used for monitoring of biotope's environment on the finest scale. In this study, to observe the effect of local temperature changes, we observed the population and habitat of *Poikilotherm*, organisms which have body temperature that can be affected by the surrounding temperature, such as dragonflies.

The observation result shows that the combination of UAV data and field survey data of biotope give a new perspective and good accuracy on 2D/3D data analysis, i.e. 5-31 cm resolution on vegetation and habitat mapping. Normalized Difference Vegetation Index (NDVI) map derived from optical image shows spatial distribution of chlorophyll content which correlates with tree canopy structure (Fig. 2). High NDVI index shows spatial vegetation distribution of Japanese cedar (*Cryptomeria japonica*). Whereas, the distribution of autumn leaves (e.g. konara oak (*Quercus serrata*), etc.) is shown as high normalized index of band red and green ((b2-b3)/(b2+b3)) retrieved from NIR image (Fig. 3a). The analysis of ground moisture level of study area is derived using the normalized difference of green and red band of NIR image. On Fig. 3b, red area shows high moisture level which is habitat preference of dragonfly. Since band math calculation can be affected by tree shade, masking is suggested on preprocessing. Thermal camera captured optical and thermal images simultaneously. Field temperature measurement was held during flight time and its result shows good correlation with thermal map. Although thermal mapping with 31 cm resolution can provide good temperature distribution on observed area, the development of thermal camera sensor is needed for higher accuracy, enable image metadata (Exif) modification for GPS recording to provide 2D/3D thermal mapping using SfM method.

Long term monitoring is useful to detect changes in biotope presence and structure. We observed population increase of species which has strong adaption to high temperature, e.g. Ito Tombo *(Coenagrionidae)*. This species usually lives in or near pond and waterbody without streams, where temperature is warmer during spring to fall compare to the river area. Although few literatures addressed about the change of dragonfly population due to temperature, we conclude that the increase of dragonfly population possibly affected by the increase of temperature at observed area about 1.5℃ during 1996-2014.

Keywords: UAV imaging application, biotope monitoring, optical image, nir image, ndwi/ndvi, temperature rise effect

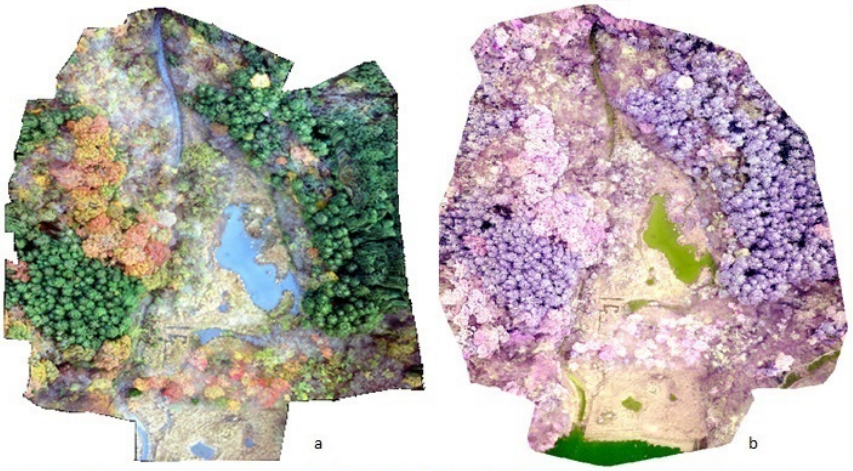

Fig.1 UAV photo result; a) optical image (RGB=123) and b) NIR image (RGB=NIR\R\G). Cooperation with Sagami River Water System Wide Area Dam Administration Office, Ministry of Land, Infrastructure, Transport and Tourism.

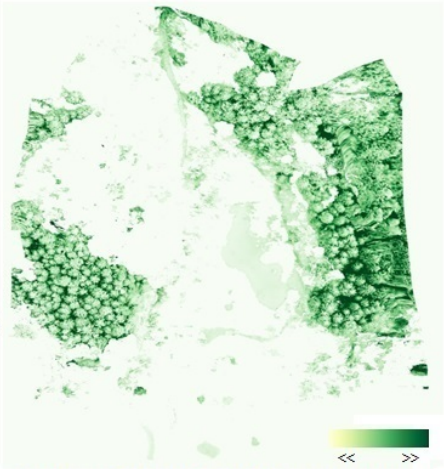

Fig. 2 Chlorophyll distribution of NDVI map (optical image)

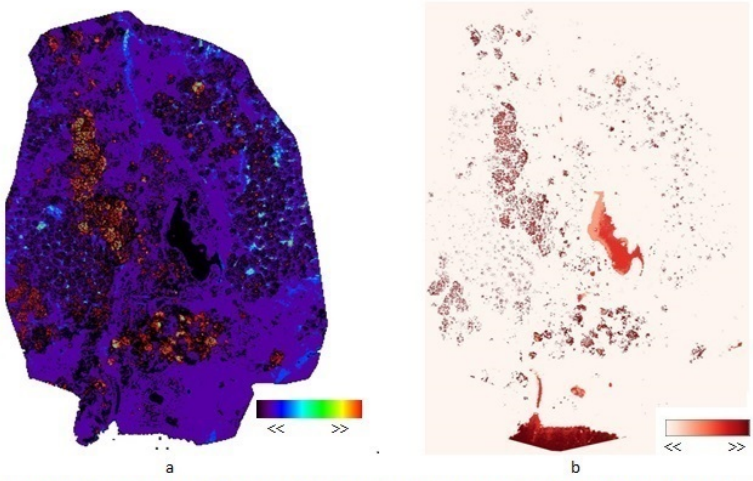

Fig.3 a) Autum leaves map (konara oak, etc.) and b) ground moisture level map (red is habitat preference of dragonfly) derived from normal difference index of green and red band of NIR image.

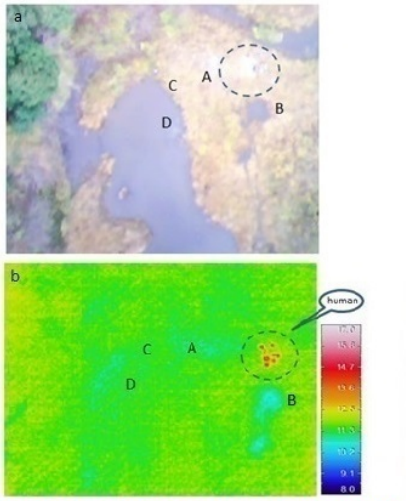

Fig.4 Thermal camera imaging result: a) optical image and b) thermal map. Field temperature measurement (2014/11/28) of A (soil): 10.8 °C, B (grass): 12.3°C, C (near pond): 11°C, and D (pond): 11.5-11.8°C, show good correlation with thermal map.

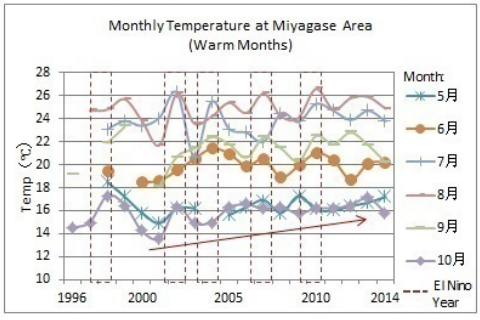

Fig. 5 Monthly temperature at Miyagase area during 1996-2014 period

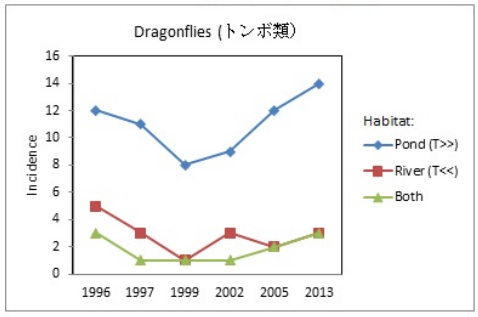

Fig. 6 The incidence index of dragonflies in various habitats during 1996-2013 period

Measurment of snow distribution using small UAV

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Recently aerial photography using small UAV (Unmanned Aerial Vehicle) carrying a compact camera and SfM (Structure from Motion) technique has been carried out in many areas. As one of the advantages of the small-multicopter survey it can closely shoot and measure the mountain slope where the existing manned airplane cannot survey enough because its flight height is relatively high and so it cannot come close to the object. In addition, because running cost of the small UAV survey is far less and its operation is relatively easy, repetitive measurements are easier than the existing methods such as aerial photogrammetry and laser scanning with a manned airplane. We have carried out the topographic measurements using the above advantages at snow covered area in Niigata Prefecture, Japan. By the repetitive UAV measurements we have constructed the multi-temporal 3D models of the surfaces of the ground and snow field and could quantitatively clarify the snow distribution with higher spatial and temporal resolutions. The snow-depth values estimated by the UAV surveys corresponded reasonably well with the actual data measured by snow probe. The UAV-SfM technique has a great potential for a wide range of application, because of its high data accuracy, low initial and operational costs, allowing high spatial and temporal data recording.

Keywords: UAV, SfM, snow distribution

Using an unmanned aerial vehicle to examine influence of topography on development of debris flows in a initiation zone of Ohya landslide, Japan

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In debris flow initiation zones, flows alter the topography of deposited sediments through their development by entrainment. Although it is possible that such topographic changes influence the magnitude of subsequent debris flows, this influence is not well understood because of the difficulty in conducting a temporal series of high-definition topography measurements. Therefore, to examine how topography affects the development of debris flows, we carried out structure-from-motion (SfM) photogrammetry from aerial shoots by an unmanned aerial vehicle (UAV) in the Ichino-sawa subwatershed of the Ohya landslide, in central Japan. Debris flow occurrences and rainfall were monitored using interval cameras and a rain gauge. In the gully in the hillslope, the sediment discharge was dominated by entrainment due to the deposited sediments that were gradually discharged by storm rainfall events. In comparison, deposition several meters thick typically occurred in the main channel. Consequently, the topographic changes in the main channel were more complex than those of the gully. Furthermore, in the main channel, the trends in the changes regarding the amount of sediment differed in the upper and lower parts of the confluence of the gully. In the upper part of the main channel, sediment entrainment and deposition occurred repeatedly after each debris flow, whereas entrainment by such flows dominated the topographic changes in the lower part. Consequently, deposited sediment supplied by a previous debris flow in the upper part contributed to the development of the subsequent debris flow. The results indicate that the magnitude of the debris flow was affected by the topography of the main channel created by previous flows, including flows from the gully.

Keywords: Debris flow, Deep-seated landslide, SfM-MVS, UAV

Machine Learning Algorithm for impact crater extraction from high resolution DEM derived from SfM data in Vanuatu

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As the 2015 Ontake eruption unfortunately reminded us, volcanic balistic impacts are serious threats to humans and infrastructures alike. To improve disaster risk management, probablisitic and physical models calibration, data on the spatial distribution of ballistic impacts are essentials. Investigating this issue, the present contribution explains the usage of a crowd-sourced high-resolution close-range photogrammetric technique (Structure from Motion), which was used to collect 3d Data of impacts in Vanuatu around an active volcanic vent, and for which a machine-learning algorithm was developed.
The dataset used in this presentation was collected using a GoPro3 camera, which was chosen as it is easy to operate and relatively low-cost, with the goal to simulate a crowd-sourcing exercise. For the present experiment, a student with no experience of SfM and to whom only simple information was given, collected the data at 12 different sites. Out of 12 investigated sites, 8 provided images of sufficient quality, number and overlap.
Using half of the 8 succesfull survey sites as training sites and the other half as test sites, the developed algorithm detects the lowest point in a depression and try to determine whether it has been created by a volcanic bomb or whether it is an unrelated depression. This choice is based on a comparison with an existing dataset of angles of curvatures of the radii of the depression.
The algorithm is meeting some success, increasing the information productivity - which is often an issue in post-disaster management - although its scalability remains to be proven at other volcanoes.

Keywords: close-range photogrammetry, Structure from motion, Machine learning, Vanuatu Volcano

Comparison of DEMs derived from simultaneous airborne LiDAR survey using two types of laser scanner

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Airborne Light Detection and Ranging (LiDAR) survey provides geomorphic information with fine details even for forests; thus, it is being increasingly used in measuring landscape. Recently, the survey was operated sequentially for rivers to evaluate geomorphic changes from the difference of elevation, by using digital elevation models (DEMs) derived from each survey. However, it is difficult to apply the difference of DEMs to hill slopes as it often presents unrealistically large values. This is due to errors of DEMs, which can be expected to be higher for hill slopes, considering that denser vegetation cover and steeper slopes prevent the laser beams from the scanner from reaching the ground surface and less ground points are used to produce the models. In addition, it is difficult to estimate the error ranges of DEMs for hill slopes as there are fewer ways to crosscheck the values. To examine the ranges, this study conducted airborne LiDAR survey in four locations in Hokkaido by using two types of laser scanner, old and new version of SkEyes Box (SkEyes Unlimited), and compared the DEM products. One site was located on a volcano fan while three were on mountain slopes that were prone to landslides and covered by trees. The survey was carried out on the same day in each site in October 2015. The laser scanner was mounted on an unmanned helicopter (YAMAHA RMAX G1), which made it possible to operate the survey twice in a day. After ground data was extracted from the survey data, DEM of 1 m, 2 m, 5 m and 10 m sizes were produced for each case. When comparing between DEM values of the same location, finer DEM sizes showed less elevation difference in all the sites. However, 10 to 20% of the 1 m DEM sets presented more than 0.7 m of difference in each site. They were likely to appear along stream banks, slope breaks, and the rim of the survey areas. In addition to elevation, the slope angle was obtained on ArcGIS software using the DEMs and was similarly compared for each site. The larger DEM presented a better agreement for the values at the same locations, although 5 m DEM was considered to be better for analysis to avoid losing the information of fine geomorphic features. In this case, 10 to 20% of the DEM sets in each site presented a difference larger than 5 degrees. These analyses suggested that the DEMs for hill slopes contained the degrees of errors, which were difficult to use for volumetric evaluation from a sequential survey. However, the difference of DEMs from the survey could be still useful to extract the locations of moving slopes as the information of change in the ground surface should be reflected in a group of DEMs on those hill slopes.

Spatial pattern analysis of wall surface modification by weathering in Yoshimi-Hyakuana cave using terrestrial laser scanning

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Detection and quantitative evaluation of actual changes in rock surface morphology are crucial for understanding weathering processes. Repeated measurements by terrestrial laser scanning (TLS) were performed at test sites in the Yoshimi-Hyakuana cave in Saitama Prefecture, central Japan. Six time series of point clouds were obtained in 3 years, and those point clouds were finely aligned to each other at millimeter-scale accuracies applying the ICP algorithm for unchanged domains. Digital elevation models (DEMs) were then produced by projecting the point cloud on a vertical plane at a resolution of millimeters. Centimeter-scale changes in the wall surface were successfully detected. Such changes are particularly active at a wall close to the outlet of the cave, and are found to be concentrated on a certain height above ground. This indicates that the rock surface modification is actively induced by salt weathering where groundwater evaporation is favorable. In contrast, walls located more inside of the cave show less or almost no changes in their surface. The air temperature and humidity monitoring at the wall surfaces supports this fact, suggesting the decreasing effects of environmental fluctuations which are higher around the cave entrance but lower in the inner side. This study is supported by JSPS KAKENHI Grants (20312803, 25702014).

Keywords: terrestrial laser scanning, weathering, point cloud, digital elevation model

A Diversified Approach to Generate High-Resolution Topographic Data on the Maunakea Summit, Hawai‘i Island

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The Maunkea summit (3200-4205 m) of Hawai'i Island is a unique aeolian-driven stone alpine desert ecosystem created by late stage volcanism and glaciation. The summit area geomorphology contains steep cinder cones, scoria, and glacial moraines and erosional features, producing a somewhat complicated pattern of surface mineralogy. The summit is also home to the world's most advanced constellation of telescopes and numerous endemic or rare plants and arthropods. Surprisingly, little high-resolution topographic data exists over much of the area, which are needed to further understand summit erosional processes and to better conserve and manage endemic species habitat. To rectify this situation, we used a VZ 400 Riegl terrestrial laser scanner to collect a high-resolution lidar dataset (33 pts/m^2 average) over ~15 km^2 across the summit area in 2014. The lidar coverage contained occlusions due to environmental obstacles and perspective issues. To 'fill' two of the largest/important occlusions (36,081 m^2 within the interior crater of a cinder cone and a 256,485 m^2 exterior slope of another remote cone) we generated new topographic datasets vie Structure from Motion (SfM) by taking photos of the missing areas from ground and airborne (unmanned aerial vehicle) camera campaigns. The lidar and SfM-derived point clouds were then merged together to create a blended and continuous topographic dataset. Vertical errors from the ground-based photo campaign were generally higher than for the UAV survey, ranging between +3.76 & -1.75 m, though after geoprocessing the average vertical errors for both datasets was <0.05 m. Lessors learned include the importance of creating enough overlap between the raw lidar and SfM point cloud datasets to be able to register them together, instead of solely relying on differential GPS coordinates for ephemeral ground control points. The merged dataset will be compared to future topographic survey campaigns to detect areas of active geomorphic change and quantify contemporary erosion rates. These data are also being used to define quality habitat for the endemic wekiu bug and serve as a template for habitat restoration following future telescope decommissioning.

Keywords: UAVs, Geomorphic, Lidar

Estimation of dip angles of faults near the surface in Toyama by eigenvalues and eigenvectors of the gravity gradient tensor

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The Toyama prefecture, central Japan, hosts several active faults, including the Kurehayama fault, the Isurugi fault, the Takasyouzu fault, and the Kurobishiyama fault. Many researchers have studied these faults, with investigations having been performed into their morphological, geological, and geophysical characteristics.
Numerical simulations of intense ground motion caused by fault activity play an important role in planning how damages can be mitigated in the event of an earthquake. In such simulations, the length, width, and dip angle of a fault are important parameters. Fault dip angles would usually be estimated by geophysical techniques, such as seismic and gravity exploration. Seismic needs large expense. Although gravity exploration does not need so large expense, this exploration needs seismic exploration data because the gravity is a function of density and structure (distance) and the gravity exploration can't determine unique solutions from gravity anomaly data only.
A new method for estimating the dip angle of a fault using eigenvalues and eigenvectors of the gravity gradient tensor has recently been developed by Beiki and Peterson (2010: Geophysics), Beiki (2013: Geophysics), and Kusumoto (2015: Butsuri-tansa). This method relies upon the maximum eigenvector of this tensor being parallel to the orientation of the causative body, from which the dip angle of a fault or structural boundary can be estimated without supplemental geophysical and geological data.
A gravity gradient tensor can be obtained via gravity gradiometry, which measures the gradient of a gravity field in multiple directions. Three gravitation components (g_x, g_y, and g_z) form around a causative body, with the combined set of x-, y-, and z- derivatives of each forming the gravity gradient tensor. This tensor is known to be symmetric, with its diagonal components summing to zero in order to satisfy Laplace's equation. Thus, the gravity gradient tensor consists of five independent components, which can be obtained for any subsurface structure using gravity gradiometry at a single observation point. By contrast, a conventional gravity survey can only identify one out of three gravitational components, which must then be used to estimate the nature of any subsurface structures. A gravity gradiometry can thus obtain five-times as much information as a gravity survey can.
Since no gravity gradient surveys have yet been undertaken in Toyama, we derived gravity gradient tensors by calculations based on the study of Mickus and Hinojosa (2001: Jour. Appl. Geophys.). The method described therein estimates a gravity gradient tensor as follows: (1) a Fourier transformation is made of a gravity anomaly, (2) an estimation of gravitational potential is made by integration of the gravity anomaly in the Fourier domain, (3) calculation of gravity gradient components is achieved by calculating second-order derivatives of the potential in each direction, and (4) the acquisition of all components of the tensor in the spatial domain is performed by applying Fourier inverse transformation.
We applied this technique to the Kurehayama fault, Isurugi fault, Takasyozu fault, and Kurobishiyama fault, and estimated that they have dip angles in the range of 45-60°. Our results are consistent with dip angles obtained by surface geomorphological and geological surveys.

Evaluation of TWI-Derived Soil Depths and DEM-Assisted Terrain Slopes in Tainan Mountain Areas

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The study is aimed at evaluating the soil depths from topographic wetness index (TWI) method, and the terrain slopes from a 5m resolution digital elevation model (DEM) in Tainan mountain areas, located in southern Taiwan. The field surveys (field work) for validating the results have been being implemented in recent months. During the field surveys, a soil auger and a Nikon laser rangefinder are used for obtaining the soil depths and terrain slopes, respectively. The related methodologies for obtaining TWI-derived soil depths and DEM-assisted terrain slopes (office work), and the comparison results for office and field works will be well described in this paper. We hope that the research is able to determine the accuracies of the TWI-derived soil depths and the DEM-assisted terrain slopes in Tainan mountain areas.

Keywords: TWI, DEM, Soil Depth, Terrain Slope

Interpretation of Terrain Features by Self-Developed Red Relief IMAGE MAP

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We produce the Red Relief Image Maps (RRIMs) to aid terrain feature interpretations, especially in potential landside areas. RRIM is generated based on openness and slopes derived from a digital elevation model (DEM). In this study, we use software of Fortran and generic mapping tools (GMT) to produce the Self-Developed RRIMs. The related programs and theories are being constructed and are going to be completed. All kinds of terrain features will be well chosen and analyzed in the following tests. The purpose of this research is to develop a new visualization of topographic maps to provide subtle and useful terrain information and further bring contributions to the regions of disaster prevention, soil and water conservation, environmental monitoring, and resource exploration.

Keywords: RRIM, DEM, GMT

Shallow water bathymetry derived from visible satellite image: toward application to the waters around Japan

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Hydrographic organisations and their affiliated institutes are stepping up development of the technology of Satellite Derived Bathymetry (SDB).
In SDB, water depths are estimated from visible satellite images based on the basic principle of exponential attenuation of light. In practice, however, the intensity of light detected by the satellite sensor is affected by various local conditions; for example, attenuation rate in water varies with the water quality, and reflection rate on the seabed differs according to the types of sediment and benthos.
Toward the application of SDB to the waters around Japan, we have been developing and verifying the technology of SDB based on the methods by Lyzenga (1978) taking into account of the environmental characteristics of Japan. We analyse the images obtained by WorldView-2, equipped with optical sensors of eight bands (six of them are visible bands) at 1.8m of horizontal resolution, which are available since October 2009. We expect SDB will be a rapid and cost-effective solution for surveying shallow water topography and navigational obstructions, producing dense bathymetric dataset for tsunami simulation, etc.
In our presentation, we show the recent analysis results of SDB in several sea areas around Japan, as well as the evaluation of the results by comparison with multibeam or LiDAR surveys. Based on that, we will discuss the future utilisation of the SDB data.
Acknowledgement: Part of this study is financially supported by the Nippon Foundation.

Keywords: bathymetry, shallow waters, satellite imagery, visible bands