CONSTRUCTION AND ACCURACY EVALUATION OF THE LOCAL DIGITAL ELEVATION MODELS OF THE ASTROID RYUGU. Yuta Aikyo[1], Tomokatsu Morota[1], Seiji Sugita[1,2], Yuichiro Cho[1], Naru Hirata[3], Tatsuhiro Michikami[4], Rie Honda[5], Eri Tatsumi[1,6], Naoya Sakatani[7], Shingo Kameda[8], Manabu Yamada[2], Yasuhiro Yokota[7], Moe Matsuoka[7], Chikatoshi Honda[3], Toru Kouyama[9], Hidehiko Suzuki[10], Masahiko Hayakawa[7], Kazuo Yoshioka[1], Kazunori Ogawa[11,12], [1]Univ. of Tokyo (7-3-1 Hongo, Tokyo, Japan, aikyo@eps.s.u-tokyo.ac.jp), [2]Chiba Inst. Tech., [3]Univ. of Aizu, [4]Kindai University, [5]Ehime University, [6]Univ. of La Laguna, [7]JAXA/ISAS, [8]Rikkyo University, [9]National Institute of Advanced Industrial Science and Technology, [10]Meiji Univ., [11]JAXA/JSEC, [12]Kobe Univ.

Introduction: The local digital elevation models (local DEMs) of a few regions on asteroid Ryugu have been constructed by a structure-from-motion (SfM) method from high-resolution images obtained during descending operations for both selecting candidate landing sites of Hayabusa2 spacecraft [1-3] and investigating morphology of artificial crater on Ryugu [4,5]. Such high-resolution local DEMs have great potentials for studying the morphometries of boulders and small craters.

However, the accuracy evaluation of local DEMs is not easy and has not been sufficiently conducted despite their scientific and exploratory importance. In particular, the vertical accuracy of local DEMs cannot be directly evaluated due to the absence of ground truth.

In this study, we constructed local DEMs from high-resolution ONC-T [6] images of Ryugu's surfaces and evaluated the accuracy of the local DEMs by comparing to the topographic information directly obtained from the images. We investigated the relationship between the parallax among images and the accuracy of boulder height measured from the local DEMs. In the local DEM construction, we adopted Agisoft Metashape [8]. Agisoft Metashape is a well-known SfM software and has been used in various fields in Hayabusa2 mission: global shape measurement of Ryugu [10,11], local DEM construction [1-5], and shape measurement of returned sample particles [12,13].

Local DEM construction procedure: Local DEMs were constructed with the following procedures: 1) Image preparation, 2) Constructing dense point cloud, and 3) Generating DEM from dense point cloud.

Image preparation. ONC-T L2c image data available in DARTS [9] (Fig. 1) were used to construct the local DEM. The SfM method was applied to high-resolution ONC-T images taken successively (usually in sets of 7 images) during low-altitude descents to Ryugu.

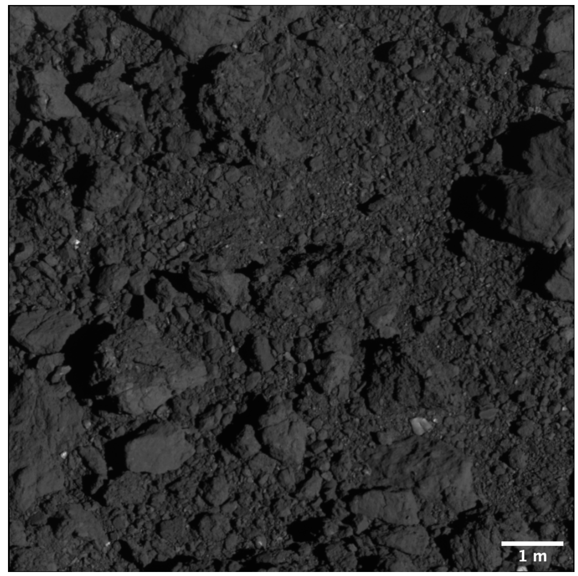

Figure 1: High-resolution image example. The image used in the construction of local DEM is shown here (hyb2_onc_20190711_003036_tvf_l2c).

Construction of dense point cloud by SfM method. In the SfM method, three-dimensional shape of an object was estimated based on the parallax between multiple images. Feature points were searched from images and their position and camera positions were simultaneously estimated based on feature point matching (called alignment). Camera positions were used to construct dense point cloud. During the alignment process, no information about camera position was inputted to Metashape.

Generation of local DEM. Local DEMs (Fig. 2) were generated from the dense point cloud. We constructed five dense point clouds for each image set, and the point cloud consisted of the largest number of points was adopted for DEM generation. Before generating a DEM, the dense point cloud was scaled by inputting the image resolution-based distance between two points into Metashape. The shape of shadow region was not obtained by the SfM method, but it was interpolated during the DEM generation process.

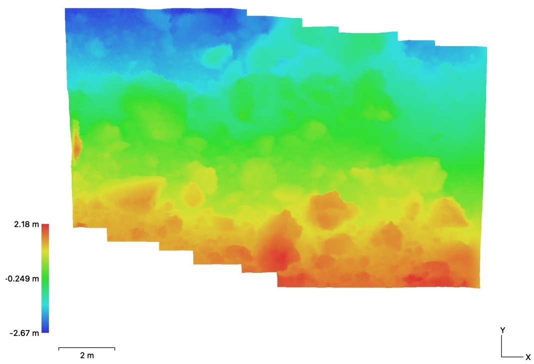

Figure 2: An example local DEM of Ryugu's surface. In this local DEM, elevation is valid only as relative values.

Boulder height measurement: Slope angle was calculated by QGIS from the local DEM. For each boulder, four elevation and slope profiles were obtained at approximately 45-degree azimuthal intervals on the DEM, and the points where the slope angle met certain conditions were connected to form the baseline of the profile (Fig. 3). The boulder height was measured from the elevation profiles after subtracting the baselines.

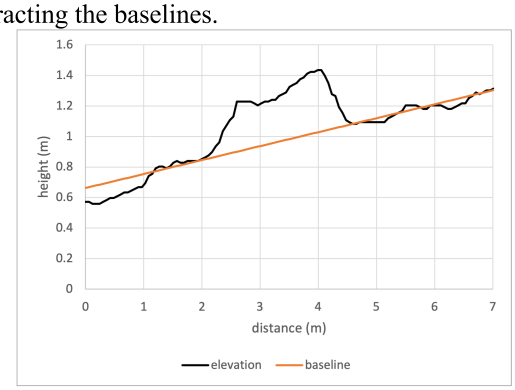

Figure 3: An example of the elevation profile. Both boulder topography (black) and baseline defined by the surrounding terrain (orange) are shown.

Evaluation of local DEM accuracy: The horizontal accuracy of local DEM was less than 10% and mainly constrained by errors that occur during the scaling of dense point cloud. On the other hand, the vertical accuracy of local DEM could not be evaluated directly as noted above. Therefore, we measured the height of the boulders using their shadow length [7] and compared to the height measured from the local DEM. The accuracy of boulder height based on shadow measurement has been evaluated previously [7]. Comparison was made in four areas (resolution 0.8 - 5 cm/pix) and the height of three boulders were compared in each area.

Accuracy evaluation result: The vertical accuracy of local DEMs was dependent on the amount of parallax between images (Fig. 4). Generally, the boulder height was measured more accurately as the parallax increased.

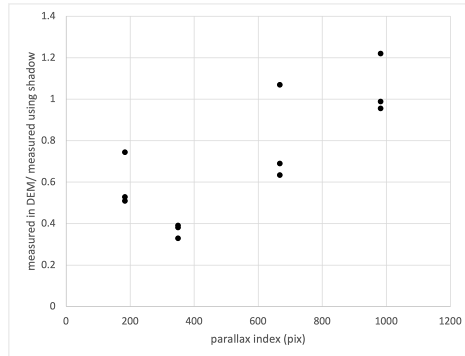

Figure 4: Comparison of measured boulder height. The vertical axis shows the boulder height measured by the local DEM divided by the same boulder height measured from the shadow length. Each point represents the measured boulder. Parallax index was derived from the shape of the local DEM and characterizes the area on images covered by local DEM.

Discussion and conclusions: We found that the vertical accuracy of local DEMs depends on the amount of parallax of the image set. The parallax between images is mainly caused by the rotation of Ryugu, so the images taken at lower altitude have larger parallaxes. Our results suggest that images taken at an altitude of about 100 m have enough parallax (~1000 pix) to construct high vertical accuracy DEM. Such low-altitude images were obtained at several locations during the asteroid proximity phase. Most of those images were not suitable for the boulder height measurement by shadows [7] because of their small solar phase angle, but the construction of local DEM will make the measurement possible.

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