GEOLOGICAL CHARACTERIZATION OF ASGUARD ROVER TEST TERRAINS AND CORRELATION WITH MOBILITY ON THE VULCANO ISLAND PLANETARY ANALOGUE ROBEX SITE (ITALY). R. Karimova[1], A. P. Rossi[1], V. Unnithan[1], L. Thomsen[1], J. Schwendner[2], M. Hökelmann[2], A. Pacifici[3], R. Pozzobon[3], (1) Jacobs University Bremen Jacobs University Bremen, Campus Ring 1, 28759 Bremen, (2) German Research Center for Artificial Intelligence (DFKI), Robert-Hooke-Straße1, 28359 Bremen, (3)"G. d'Annunzio" University of Chieti-Pescara, Via dei Vestini, 66100 Chieti CH, Italy.

Introduction: Testing rover equipment on analogue sites on Earth has become crucial for evaluating the performance of rovers on the soil types they might encounter on other planetary bodies [1]. We characterize our test site from a physical analogue perspective, and focus on roughness estimation methods using 3D visualization. These methods could help improve the planning of planetary rover traverses.

We tested the hybrid leg-wheel rover ASGUARD [2], developed by the German Research Center for Artificial Intelligence (DFKI), during a field trip in June, 2015, organized by the ROBEX (Robotic Exploration of Extreme Environments) alliance [3]. Our selected planetary analogue site was the Fossa, the biggest volcanic cone on the Island of Vulcano in Italy. We define roughness as the topographic expression of surfaces at three scales of interest: large (meters), medium (tens of centimeters) and small (centimeters). For large-scale characterization, we created a geomorphological map of the cinder cone from Google Satellite imagery [4]. Medium-scale roughness was analyzed by means of photogrammetric measurements and 3D visualization based on drone aerial imagery using PhotoScan [5] and Pix4D [6] software.

We compared the results of 3D modelling from rover-mounted camera imagery and aerial footage. This allowed us to determine the problems related to the data collection and the limitations of the methods. We also report on the constraints of the rover system and improvements for future test campaigns.

Data collection and methods: Rover test drives were conducted on several terrain settings: boulder field, loose ash, solid duricrust, dry riverbed and a gully. A GoPro Hero4 camera mounted on the rover recorded the video of the path during each drive. A mobile phone GPS application tracked the positioning. Aerial imagery was collected with an aerial drone Phantom 4 over the boulder field. A geomorphological map of the Fossa Cone was created using Google Satellite imagery accessed via OpenLayers plugin in QGIS software. 3D models, orthomosaics, digital elevation models (DEMs) were generated from rover`s video feed and drone images using PhotoScan and Pix4D programs, which use the structure from motion technique to create 3D models from images [7][8]. The DEMs were then used to create roughness maps using the surface derivatives plugin for ArcGIS created by Minin et al. [9].

Roughness on the smallest scale was compared for all rover test settings by manual particle counting from scaled images collected on site. Automatic particle counting was performed on the orthomosaic from drone imagery in ImageJ software [10]. Rover performance was analyzed using the GPS tracks by calculating the average speed on each track, and observations on the field.

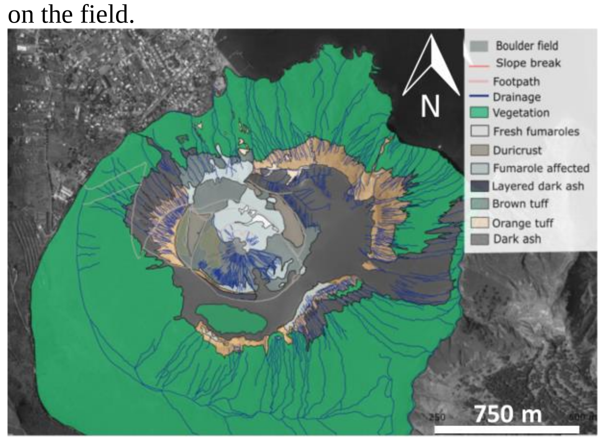

Figure 1. Geomorphological map of the Fossa Cone.

Results and discussion: *Geomorphological map and large-scale roughness:* Geomorphological mapping of the Fossa Cone identified several prominent surface units: pale yellowish orange tuff and loose dark ash on the outer flanks; dusky yellowish-brown tuff, exposed duricrust partly overlapping with two boulder fields, as well as areas visibly altered by the fumarolic activity on the inner part of the cinder cone. The volcanic cone is covered by vegetation on the outer flanks. The Fossa shows a radial drainage pattern, typical for a volcano (fig.1).

Aerial model and medium-scale roughness: 3D models generated from aerial imagery over the boulder field provided an extensive coverage at excellent resolution of 1cm/pixel (Pix4D) and 2cm/pixel (PhotoScan) (fig.2). Apart from point clouds and textured models, both programs allow creating orthomosaics and DEMs that could be used for further terrain analysis. We found the mean square error (MSE) of elevation surface derivative map the most useful in outlining separate boulders that the rover could not cross, in our case, boulders larger than 25 cm. Derived slope maps were essential in visualizing channels, gullies and slope breaks [9]. In combination, these maps allow assessing medium-scale terrain roughness, and could be used in rover traverse planning. The aerial orthophotos could also be used for automated particle (boulder) counting in ImageJ software when quantitative information on the boulder size-frequency is needed. Minor errors with edge recognition were observed while using this method on areas with bright colored material, formed due to sulfur precipitation from the fumaroles.

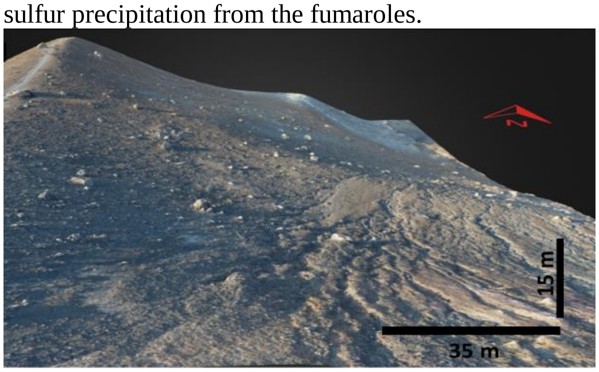

Figure 2. 3D model of the boulder field from aerial images, northward view.

Oblique models and small-scale roughness: 3D models were also generated from imagery recorded by the rover-mounted GoPro camera. The models in many cases were distorted, due to the instability of the camera and the rolling shutter effect [11], which produced blurry images. Some of the models were not usable for roughness estimation due to the lack of scale within the field of view. Automated particle counting on the oblique orthophotographs produced large errors visible on the ImageJ count mask outputs. Due to the camera angle, boulders on large areas of the image were not recognized by the software. Manual counting had to be performed for the correlation of the boulder size-frequency distribution with the rover speed.

The test site with the largest average particle size was the gully, with average grain size of 4 cm, while the boulder field, the rocky river bed, and the loose soil on the outer flank of the cone had average particle sizes around 3.5 cm. However, the boulder field had the largest frequency of rocks almost twice as much as the other soils with similar particle sizes.

Rover performance: Observations on the field showed that the rover could easily overcome obstacles below ~25 cm, which is approximately the diameter of its wheels. Crossing of larger boulders depended on the boulder shape. We use 25 cm as the maximum crossable obstacle, as boulders up to this size were driven over regardless of their shape.

The speed of the rover was larger on downslope than on upslope or flat terrain. Slope had a significantly larger effect on the rover speed than roughness. Steep slopes of ~25-30° combined with loose soil proved the most challenging for rover mobility. The rover`s wheels could not get sufficient grip on these soils, while similar slopes on rocky terrain did not present difficulty for movement.

Conclusions: Geomorphological mapping identified several tuff units and deposits of volcanic ash on the surface of the Fossa Cone. Areas with large boulder concentration, fumarole altered soil, as well as exposed duricrust were identified.

Aerial imagery based 3D models, orthophotographs and DTMs provided extensive coverage and excellent resolution for roughness assessment. Combined use of MSE and slope maps derived from the DTMs could be used for rover traverse planning. However, imagery from the other test sites, apart from the boulder field are needed for the comparison of medium-scale roughness.

Oblique (rover based) images presented challenges with scaling and distortions of the 3D models, which further complicated roughness assessment. This could be avoided in the future test campaigns by using a camera with a global shutter, which exposes all the pixels on the image sensor simultaneously, allowing to image a fast-moving scene without artifacts [12].

The rover showed satisfactory performance on complex rough terrain. The slope had a larger effect on mobility than the roughness. Steeply sloping loose soil presented the largest challenge to the rover mobility due to the insufficient grip this soil provided to the rover`s wheels. Using a differential GPS (DGPS) or a real time kinematic (RTK) GPS device on the rover in future campaigns could provide more accurate positioning and elevation data. Additional sensors on the rover, e.g. engine current sensor, could considerably improve the performance data.

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