AUTOMATIC MAPPING AND LOCALIZATION WITHIN LAVA TUBES.

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This paper presents a fully automatic mapping and rover localization method for planetary sub-surface missions in lava tubes. The work presented in this paper is part of the Biologic and Resource Analog Investigations in Low Light Environments (BRAILLE), a NASA astrobiology analog field research project. BRAILE investigates and documents the geologic and biological variability in a natural lava tube and the impact on science operations while operating a rover. Autonomous planetary lava tube exploration, mapping and localization is challenging due to a set of specific constraints including low illumination conditions, unknown terrain characteristics, reduced on board computational power and energy, lack of Global Positioning System (GPS) signal and reduced or no communicating with ground.

Introduction

Lava tube caves offer protection from surface hazards and may be among the few human- or robot- accessible locations on other planets that could preserve evidence of microbial life. On Earth, they yield access to the subsurface and are natural settings where biology is protected from environmental extremes (surface radiation, thermal variations), geologic history is exposed and preserved, and subsurface resources (water, liquid and solid) may be accessible. It is an austere environment for microbial life, with dramatic changes in light moving inward from the cave entrance. The key science questions concern how abundance and diversity of microbial communities are affected by lava tube ecology, particularly in transition from ambient daylight to aphotic conditions, and whether biological signatures can be detected remotely on cave walls and floors.

BRAILLE investigates a two step navigation approach for lava tube exploration. First, a rover autonomously navigates the lava tube and collects low resolution imagery and 3D data using onboard sensors and an active lighting system. The collected data is used to compute an accurate 3D map of the lava tube. Ground science team determines areas of interest in this map and a path plan is sent to the rover to further acquire high resolution multi-spectral data.

Several solutions for planetary rover mapping and localization have been developed for surface missions. These methods include manual matching of rover camera views and orbital terrain maps (image and elevation) or occasionally be verification of rover location in orbital spacecraft imagery. [1]. A typical approach to automatic mapping and localization registers successive point clouds generated from stereo rover imagery by minimizing their square errors [2, 3] and integrating the relative poses sequentially. To reduce inevitable error accumulation from such incremental pose estimation, [4] most navigation systems take advantage of efficient bundle adjustment techniques [5] and make use of Inertial Measurement Unit (IMU) and wheel odometry measurements [6].

In this paper, we propose a mapping and localization method for **sub-surface missions** using a kinect sensor and a high resolution DSLR camera. A low resolution lava tube map is computed using the kinect sensor data collected during the first traverse. The science team uses this map to determine a location of scientific interest and during the second traverse the rovers localizes itself within this map using high resolution imagery provided by the DSLR camera. The mapping and localization techniques are described in more detail in next section. The experimental results and future work are described in the last section.

Lava tube mapping and rover localization

The mapping method presented in this paper uses 3D imagery provided by kinect 1.0 sensor that captures imagery and associated depth at 1 frame per second. An active lighting module insures that the imagery captured is visible and can be used for visual feature matching as detailed later in this section. The kinect sensor is attached to a moving platform that traverses the interior of the Valentine cave lava tube in Lava Beds National Monument, California. A set of Speed Up Robust Features (SURF) salient visual features are extracted from consecutive images captured with the above system. The descriptors of the salient features are matched using nearest neighbor and outlier matches were removed using the RANSAC algorithm and the fundamental matrix constraint. The resulting matched pixels correspond to matching 3D points at consecutive frames captured by the kinect sensor. The camera pose (rotation and translation) of a frame relative to the previous frame is obtained using Singular Value Decomposition SVD method. Finally the global camera pose is obtained through the concatenation of all previous relative poses to the initial camera location. The global pose transformation is applied to each frame point cloud. The set of the transformed point clouds and their associated pixel values determines the map of the interior of the cave.

In the proposed mission operation, during a second rover traverse, the rover localizes itself in the map determined previously and specifically to an area of interest selected by the ground based science team. The high resolution DSLR camera and active illumination system are used to take high resolution pictures. SURF visual features are extracted from the DSLR imagery and matched against the kinect imagery. Outlier matches are removed using the same technique used in mapping. Following the DSLR to kinect imagery matching, the visual features in the DSLR camera are associated with 3D data available for the kinect images. The DSLR camera pose is obtained from the set of 3D points and their pixel locations using the perspective N point (PNP) algorithm.

Experimental Results and Future Work

Figure 1 illustrates the 3D reconstruction of the Valentine cave entrance in Lava Beds Monument using 300 kinect frames. The map is reconstructed using the method described in Section . The proposed mapping method runs at 2 frames/second which is approximately two times faster than the image acquisition rate. The results show reduced seems between consecutive frames with easy to distinguish cave wall features. Future work will be directed towards computing the accuracy of the map against ground truth. Figure 2 illustrates an example

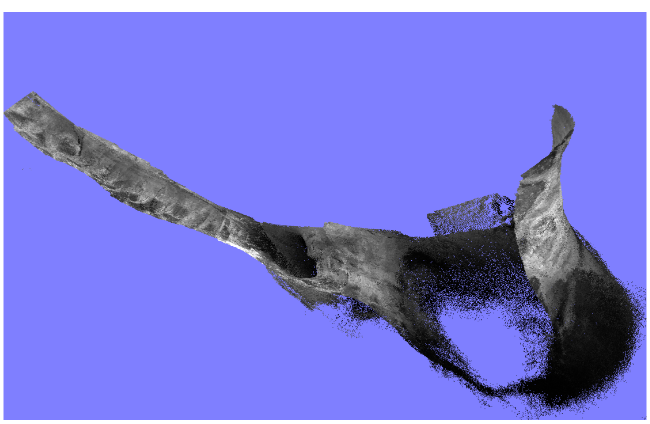

Figure 1: 3D Reconstruction of Valentine cave entrance.

of visual feature matching between a DSLR (left) and kinect (right) image. The horizontal line segments are connecting co-location matching between the two instruments. It can be seen that for a true image match the individual visual feature landmarks are correctly identified and the large number of lines (which reflects the quality of the matching methodology) leads to accurate localization results. In our preliminary experimental results the average localization precision within the map obtained above is less than 2cm. Future work will be conducted towards the validation of these results using ground truth data.

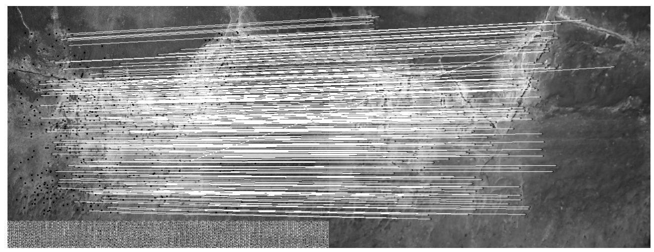

Figure 2: Example of SURF visual feature matches between the down sampled DSLR (left) and kinect images.

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References

[1] Rongxing Li, Shaojun He, Yunhang Chen, Min Tang, Pingbo Tang, Kaichang Di, Larry Matthies, Raymond E Arvidson, Steven W Squyres, Larry S Crumpler, et al. MER Spirit rover localization: Comparison of ground image–and orbital image–based methods and science applications. *Journal of Geophysical Research: Planets (1991–2012)*, 116(E7), 2011.

[2] AJ Stoddart and A Hilton. Registration of multiple point sets. In *Pattern Recognition, 1996., Proceedings of the 13th International Conference on*, volume 2, pages 40–44. IEEE, 1996.

[3] Shinji Umeyama. Least-squares estimation of transformation parameters between two point patterns. *IEEE Transactions on pattern analysis and machine intelligence*, 13(4):376–380, 1991.

[4] Sebastien Gemme, David Gingras, Alessio Salerno, Erick Dupuis, François Pomerleau, and François Michaud. Pose refinement using ICP applied to 3-D LIDAR data for exploration rovers. In *Proc. 2012 International Symposium on Artificial Intelligence, Robotics and Automation in Space*, 2012.

[5] Kurt Konolige and Willow Garage. Sparse sparse bundle adjustment. In *BMVC*, pages 1–11, 2010.

[6] Rongxing Li, Kaichang Di, Larry H Matthies, Raymond E Arvidson, William M Folkner, and Brent A Archinal. Rover localization and landing-site mapping technology for the 2003 mars exploration rover mission. *Photogrammetric engineering and remote sensing*, 70(1):77–90, 2004.