Cameras for navigation and 3D modelling on planetary exploration missions

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Abstract

Mobile exploration systems on planetary missions require technologies for navigation and 3D modelling. Both are mandatory prerequisites for any interaction in an unknown environment. Since GNSS will not be available, technical alternatives have to be developed. In this paper, a sensor system will be introduced which contains a stereo camera and an inertial measurement unit. Data of both sensors are fused to achieve a precise 6DoF ego-pose in real-time. Image data can be processed to depth maps optionally. Trajectories and 3D models are essential for path planning of the robots, for identification of scientific regions of interest and for spatial referencing of the scientific payload data. The paper gives an overview about the technology, the approaches for navigation and 3D modelling, an end-to-end software simulator and a planet like test campaign.

1. Integrated Positioning System

DLR has developed an Integrated Positioning System (IPS) during the last 10 years. It copies the human perception system by applying a stereo camera and an inertial measurement unit (IMU). Additional sensors providing position or orientation data or their derivatives can be considered. No external reference data (e.g. GPS) are needed, but they will be used if they are available.

1.1 Navigation

By detecting features in images (e.g. natural landmarks such as edges and corners) and tracking them over time, an ego-trajectory can be estimated. These data will be fused with rotational and translational measurements of an IMU which delivers angle velocities and accelerations. After integrating these signals once and twice, respectively, the position and orientation ('pose' refers to both quantities) can be obtained building a 6DoF trajectory. IMU offsets and noise lead to drifts and random walk, which can disturb the 6DoF information very fast (within seconds) if not compensated. By the combination of camera data and IMU data, the influence of the drifts can be minimized. Applying such a technology requires detailed knowledge about the system and its components. Sensor data need an unambiguous assignment w.r.t. time, a precise calibration (e.g. interior orientation of the camera) and information about the spatial co-registration between different sensors [1]. IPS can deliver a real-time 3D position with an accuracy of $2m/\sqrt{hr}$, e.g. 1m after 15min.

1.2 Environment modelling

IPS's stereo data can be used to retrieve a 3-dimensional model of the environment. The choice of the matching algorithm, which is the most demanding software part w.r.t processing time, will depend on the mission and the resources being available. A broad spectrum of algorithms has been implemented (sum of absolute differences, normalized cross correlation [2], semi-global matching [3]). The coordinates of the matched pixels and the knowledge about camera calibration can be used to estimate the 3D position of each matched object point resulting in a (dense) point cloud.

1.3 Simulation

The evaluation of an IPS like system (software and hardware) is demanding, since generating ground truth data is very difficult. DLR decided to develop an end-to-end simulator to estimate the performance of IPS, to evaluate data processing steps and to optimize system parameters. The simulator generates image data and IMU data in a virtual world based on a defined trajectory and based on known auxiliary data (e.g. calibration). These data will be processed with IPS's standard processing chain. The resulting 6DoF information will be compared with the ideal trajectory. By doing this, single sources of errors can be detected and sensitivity analyses can be performed (e.g. how does the system behave if the cameras will have low SNR).

1.4 Validation and test

IPS was developed for several terrestrial and space applications in commercial and research projects. For mining applications IPS was further developed to an industrial product in cooperation with partners, for this application the development cycle from an idea (technology readiness level TRL1) to a product (TRL 9) was completed [4]. In order to test IPS in an environment being more relevant for planetary science, in 2018 a geological measurement campaign at island Vulcano [5] was joined. The images and results shown below are taken at this campaign.

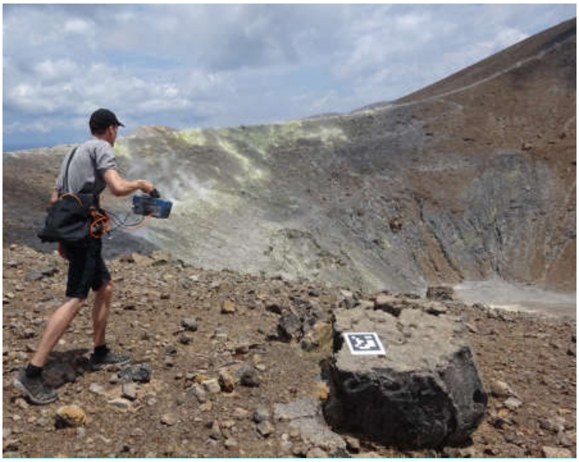

Figure 1: IPS experiments on island Vulcano

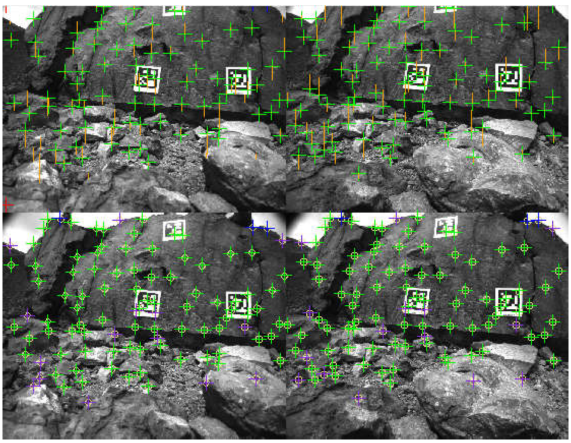

Figure 2: IPS stereo images with detected/ tracked features

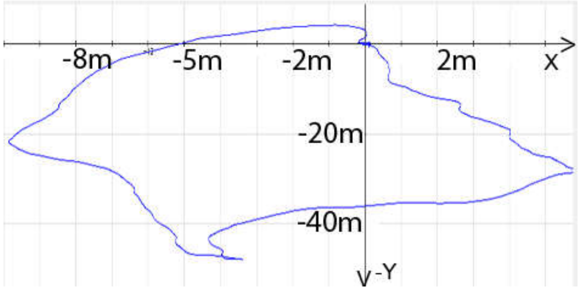

Figure 3: Trajectory derived from IPS data

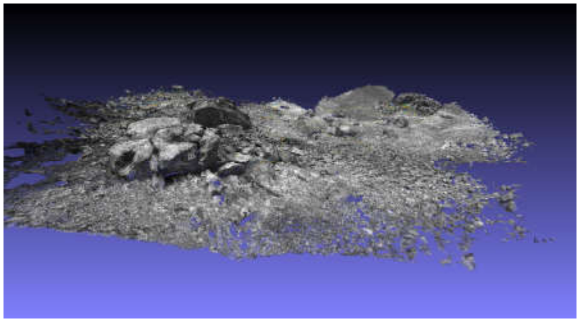

Figure 4: 3D model derived from stereo data

2. Summary and Conclusions

DLR developed a positioning system which determines its ego motion on camera data and IMU data. DLR is able to offer this technology for space applications, e.g. exploration or on-orbit servicing. Team's experience, the transfer to an industrial product and the availability of a simulator enables DLR to apply for a space mission.

References

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[4] https://www.dmt-group.com/en/products/geo-measuring-systems/dmt-pilot-3d.html

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