Sensor head for autonomous planetary exploration. A. Börner[1], D. Baumbach[1], M. Buder[1], A. Choinowski[1], I. Ernst[1], D. Grießbach[1] and S. Zuev[1]. [1]German Aerospace Center, Institute of Optical Sensor Systems, Rutherfordstr. 2, 12489 Berlin, Germany, anko.boerner@dlr.de,

Introduction: Autonomy will be one of the key features of future space exploration systems. There are several reasons to enable machines to perform standalone. First of all, a huge distance to an Earth based ground station can lead to a significant time lapse between command and control. Time critical maneuvers, like descending/ landing or evading/ handling risky situations require autonomous actions. Second, regions on planets, asteroids or comets with no direct line of sight neither to Earth nor to a relay station (e.g. caves, canyons, craters) can be explored by autonomous systems only. Third, system's ability to approach regions of interest without interactions with human operators and even to detect and prioritize spots of scientific value will increase the efficiency of a mission. All these tasks require a reliable and precise navigation technology, which is able to operate with and without a priori knowledge (e.g. via maps, spatial reference). One promising approach to fulfil this requirement is applying an imaging sensor for the navigation system. Since cameras generate data which are very familiar to human being's experience such sensors are predestinated to be used for a navigation system. Additionally, camera images can be used for a large number of other tasks – spatial modelling of the environment, identification of spots of interest, visual inspection of the scenery or the exploration system itself by operators. Cameras are the main sensors of the navigation system IPS. Based on the human perception system, DLR developed a multi-sensor head in the last 10 years. This sensor system acquires sensor data and determines the ego motion and derives a 3D model of the environment in real time. IPS can be a valuable technical contribution to future exploration missions on planets, asteroids and comets.

Navigation system IPS: IPS (Integrated Positioning System) contains several sensors and an onboard computer providing a relative position and a depth map in real time.

Hardware. Main sensors are a stereo camera system and an inertial measurement unit. Other sensors providing information about position and/ or attitude and/ or their derivations can be included. Synchronization of incoming data of the different sensors has to be ensured. Accurate calibration and registration of all sensors is an essential prerequisite. Lighting can be implemented to ensure ability to operate even under dark conditions (see Fig. 1).

Figure 1: IPS sensor head, stereo cameras (left and right) and the lighting system (middle) can be seen. Dimensions: about 30 x 15 x 10 cm³, Weight: about 4kg, depending on configuration

Software. Onboard software consists of different modules for data pre-processing and data processing. Pre-processing has to be applied for noise reduction, defect handling, control of exposure time, auto-calibration and image rectification. This has to be done permanently to make cameras a measuring device. Data processing contains two modules in a base version – localization and 3D modelling. Within the localization module image data are used for feature extraction and tracking. By doing this and by knowing calibration parameters, a relative movement between two consecutive sets of stereo images can be estimated. This information is fused with data from inertial measurement unit by a filter estimating the state vector consisting of position and attitude [1]. Guidance algorithms can be added to fulfil navigation tasks. An adapted version of a standard stereo matching algorithm [2] is implemented into an FPGA and provides depth maps in real time with a maximum frame rate of 10Hz. These depth maps can be converted into 3D point clouds. Additionally, software modules, e.g. for feature detection and inspection, can be implemented.

System validation: IPS was developed as a technological platform for a huge variety of applications on Earth, e.g. indoor navigation and visual inspection. For these applications IPS proofed a TRL 6. In order to verify and to validate IPS, test runs are executed permanently.

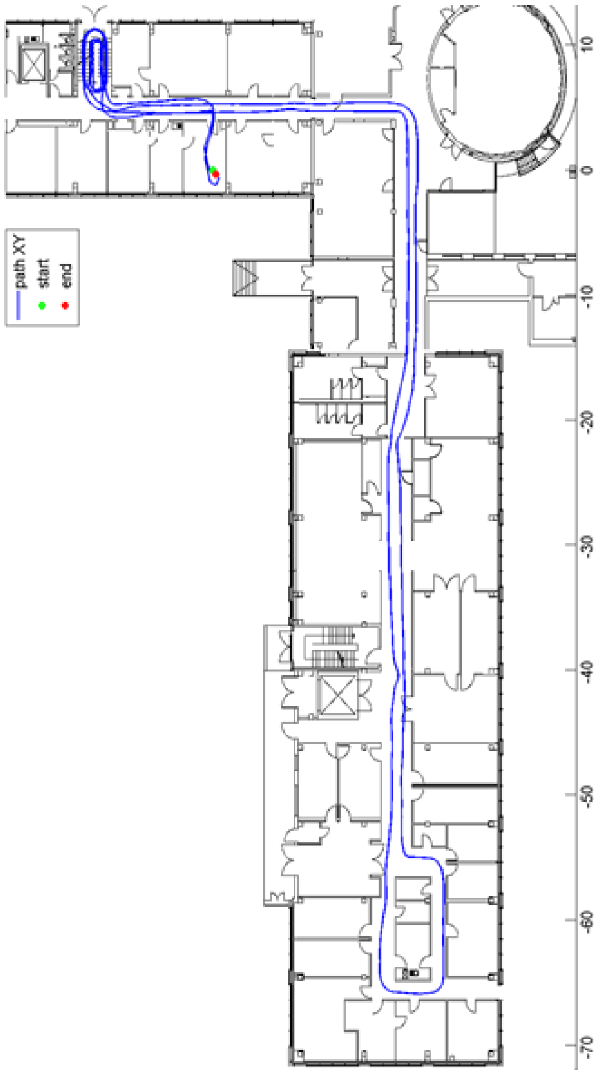

Figure 2: Indoor trajectory (blue) of a test run performed with IPS plotted into a floor plan of DLR building.

Standard test field is an indoor scenario, in which a human operator carries IPS through a building performing a closed loop walk. This setup was used since it is a kind of worst case – lighting conditions change, texture is missing or self-similar, motion model is almost unpredictable. IPS reaches an accuracy of 2m/ sqrt(hr) meaning that a walk of one hour will result in an positioning error of 2m. For planetary exploration, IPS has to be mounted on a suitable platform (rover, crawler) and tests have to be applied in an appropriate test bed. Fig. 3 and 4 illustrate the 3D capability of IPS.

Figure 3: Image seen by one camera in an indoor test setup. Lighting conditions are difficult, regions without any texture occur.

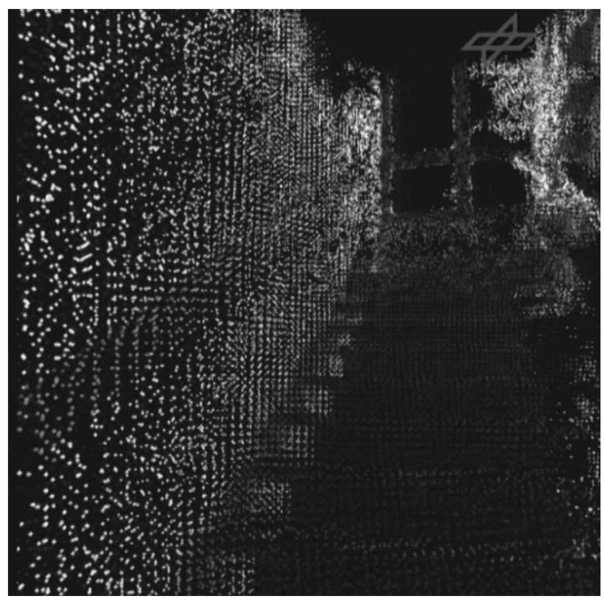

Figure 4: 3D point cloud corresponding to the image shoen in Fig. 3

References:

[1] D. Grießbach et al. (2013) *ISPRS Acquisition and Modelling of Indoor and Enclosed Environments*

[2] H. Hirschmüller er al. (2012) *ISPRS Ann. Photogramm. Remote Sensing*