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Computer Vision for a Planetary Service Rover

G. Paar (1), A. Medina (2), K. Furuya, T. Nunner, A. Bauer (1), E. Pensavalle (3)

(1) Institute of Digital Image Processing, JOANNEUM RESEARCH, Wastiangasse 6, A 8010 Graz, Austria, gerhard.paar@joanneum.at, (2) GMV, C/ Isaac Newton 11, Tres Cantos, 28760 Madrid, Spain, amedina@gmv.com, (3) Thales Alenia Space Italia S.p.A., Strada Antica di Collegno 253, 10146 Torino – Italy, Emanuele.Pensavalle@thalesaleniaspace.com

Abstract

The Eurobot Ground Prototype Rover has been developed under ESA contract to demonstrate the abilities of a large planetary rover to support human spaceflight on the Moon and Mars. It contains a stereo vision system on a pan-tilt unit to provide localization and mapping as well as Astronaut supporting functions. We report on the envisaged mission scenario for using the vision system, its functional objectives, important realization aspects as well as development state.

1. Scope

With the success of NASA MER rovers Spirit and Opportunity and newly arising objectives in robotic and human exploration of Moon and Mars in terms of mobility, there is an increase in the interest of Space Agencies for developing new rover prototypes. In this context the **European Space Agency** (ESA) awarded the **Eurobot Ground Prototype** (EGP) Project to an industrial consortium lead by Thales Alenia Space Italia [1]. Within this project, JOANNEUM RESEARCH (JR) developed the Rover Vision System (RVS) in close co-operation with GMV (being responsible of the development of the mobile platform "**EGP-Rover**").
Main focus was to evaluate and prove the abilities of the concept and its individual solutions to be a valid candidate solution for supporting future human and robotic space exploration to Moon and the Planets. Such support actions will include the following tasks:

- Support for Human Landing on Planet / Moon
  - Preparation / Inspection of a Ground Station
  - Support for Human Landing
  - Exploration of Hazardous Environment
- Support for Human Presence
  - Transport of Humans & Equipment
  - Monitoring of Human Tasks
- Inspection of equipment.

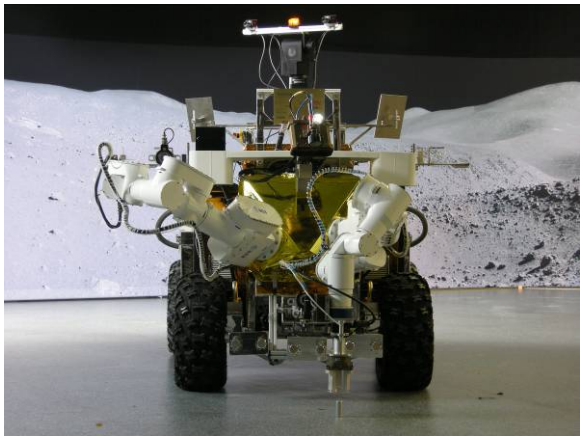

Figure 1: EGP Rover, equipped with vision system (on top) and two Eurobot Arms, in Moon-like environment.

2. RVS Objectives

In order to fulfil the mission requirements (pre-landing, during landing and post-landing of a human crew) the RVS on board of the EGP Rover completes the current suite of robotic vision systems (a robot Head Stereo Camera for human-remotely driven operations, and a set of arm cameras for supporting robot operations such as tool manipulation). It has to perform the following tasks:

- **Mapping of environment:** Generate a high-resolution 3D description of the environment around the expected Crew landing site, using its locomotion abilities, i.e. by Digital Elevation Model (DEM) generation, navigation & localization in the environment and augmenting the DEM. This includes hazard and slope map generation, absolute localization w.r.t. the lander vehicle, and hazard avoidance during EGP motion.
- Autonomously **following an Astronaut** by means of target recognition, localization and tracking

- **Detecting and localizing a spot** on the Planetary surface that has been marked by the Astronaut using a light pointing device

3. Vision System

The RVS consists of a **colour stereo camera set-up** mounted on top of the rover to provide a panoramic stereo view using a pan-tilt unit (PTU).
The RVS Software solution is realized as **independent agent in the Navigation cycle** [3], providing a simple command interface (Table 1) and data exchange by file access.

dem-full --region <hor_start> <hor_end> <vert_start> <vert_end> --position <r11> <r12> <r13> <r21> <r22> <r23> <r31> <r32> <r33> <px> <py> <pz> --output <base_filename> --quality <quality value>	<status code> <status string> dem <dem_path> ortho-image <ortho_image_path> hazard-map <hazard_map_path> slope-map <slope_map_path> roughness-map <roughness_map_path>
dem-update --pointing <hor> <vert> --position <r11> <r12> <r13> <r21> <r22> <r23> <r31> <r32> <r33> <px> <py> <pz> --output <base_filename> --quality <quality value>	<status code> <status string> dem <dem_path> ortho-image <ortho_image_path> hazard-map <hazard_map_path> slope-map <slope_map_path> roughness-map <roughness_map_path>
orient --pointing <hor> <vert> --position <r11> <r12> <r13> <r21> <r22> <r23> <r31> <r32> <r33> <px> <py> <pz> --quality <quality value>	<status code> <status string> position <r11> <r12> <r13> <r21> <r22> <r23> <r31> <r32> <r33> <px> <py> <pz>
hazard-start --pointing <hor> <vert> --max-distance <meters>	hazard --hazard-map <hazard_map_path> --slope-map <slope_map_path> --roughness-map <roughness_map_path> --dem <dem_path> --ortho-image <ortho_image_path>
hazard-stop	<status code> <status string>
track3d-detect --region <hor_start> <hor_end> <vert_start> <vert_end> --position <r11> <r12> <r13> <r21> <r22> <r23> <r31> <r32> <r33> <px> <py> <pz> --color <color_value>	<status code> <status string> position <r11> <r12> <r13> <r21> <r22> <r23> <r31> <r32> <r33> <px> <py> <pz>
track3d-start --pointing <hor> <vert> --color <color_value>	track --position <r11> <r12> <r13> <r21> <r22> <r23> <r31> <r32> <r33> <px> <py> <pz> --not-found
track3d-stop	<status code> <status string>

Table 1: RVS Command Suite

For initial detection of the EGP position and pose, it uses artificial (coloured or specially shaped) targets mounted on infrastructure (e.g. the Lander). Initial high-resolution mapping results in a Digital Elevation Map (DEM) [2] and derived products such as slope map, hazard map and roughness map. These maps are analyzed by the navigation system using a cost function which delivers an optimum path (in terms of safety and cost) from the current EGP position to the desired target location. This initial guidance solution is supplied by a path-planning A* algorithm where the rover is modelled as a single point and obstacles are enhanced within the navigational map. The trajectory is refined through cubic splines adjustment in order to avoid rotation on-the-spot mode whenever the trajectory radius is below the minimum Ackerman turn radius.

During EGP motion, the RVS provides near real-time hazard maps (again based on local DEMs). In addition, the RVS updates the EGP position and pose every few meters by visual comparison of the initial DEM texture with the current image ("surface-relative orientation"). This process also refines an existing DEM, resulting in a larger, accumulated DEM version (Figure 1).

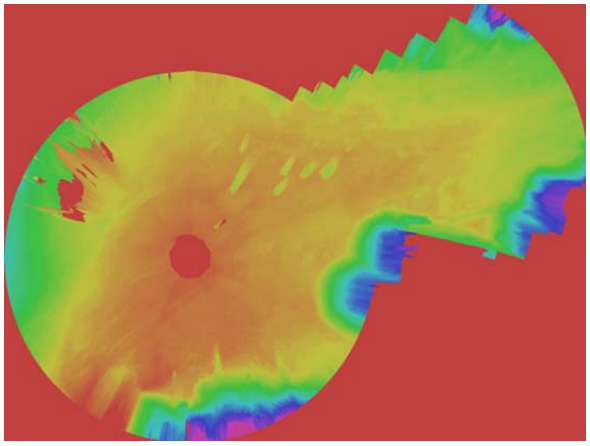

Figure 1: DEM (elevations colour-coded) generated from a panorama (left circular part), and subsequently augmented DEM after Rover motion.

The auxiliary functions for Astronaut Interaction (Astronaut detection, localization & tracking and Light Spot detection & localization) are realized by a simple solution based on colour spot detection (Figure 2).

Figure 2: Colour Spot detection during Astronaut following test, using a yellow target (right image from stereo pair). The wide rectangle indicates the search space determined by pre-search in the left image. A mock-up of the Lander is visible, containing red targets used for RVS absolute localization.

3. Current Status and Outlook

The EGP Rover, equipped with two Eurobot Arms has been delivered to ESA in March 2010, for application in a dedicated Moon-like environment [5]. RVS tests were successful, some minor drawbacks in terms of robustness to varying environment conditions (illumination; albedo & BDRF of simulated Lunar landscape) were gradually removed during intensive testing and refinement [2]. Due to its modular concept and the simple interface, various updates in terms of future sensors to be used (e.g. a 3D- Time-of-Flight camera could replace the stereo capability) and more enhanced target recognition concepts can be implemented without major effort.

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