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Philae locating and science support by robotic vision techniques

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A B S T R A C T

The ROLIS, CIVA-P and OSIRIS instruments on-board the Philae lander and the Rosetta orbiter acquired high-resolution images during the lander's descent towards the targeted landing site Agilkia, during its unexpected rebounds and at the final landing site Abydos on comet 67P/Churyumov–Gerasimenko. We, exploited these images, using robotic vision techniques, to locate the first touchdown on the surface of the comet nucleus, to reconstruct the lander's 3D trajectory during the descent and at the beginning of the first rebound, and to create local digital terrain models and depth maps of Agilkia and Abydos sites. Using the ROLIS close-up images we could also determine the actual movements of the lander between the beginning and the end of the First Science Sequence and we propose a new lander's bubble movement command meant to increase the probability for a successful drilling during a hypothetical future Long Term Science phase.

1. Context

CNES Rover Navigation Team has been working for over two decades on vision-based navigation algorithms for rover missions such as MARS-96, MSR and Exomars. Computer vision, 3D reconstruction and visual locating techniques derived from previous robotics work were therefore adapted to Rosetta [1] case to help solving some of the operational and scientific issues raised by Philae landing(s).

2. Philae's landing position determination

Philae's descent trajectory towards Agilkia landing site at the surface of the 67P/Churyumov–Gerasimenko comet was designed to be ballistic after the separation from Rosetta. Due to the high landing uncertainties and the spinning of the lander around its yaw axis, the illumination on the solar panels could significantly vary depending on the final position and attitude of the lander inside the 500 m-radius nearly circular landing zone. To issue lander's bubble rotation and elevation commands that would ensure the optimal battery charging during the LTS (Long Term Science) phase, the FD (Flight Dynamics) team needed to know, within three hours after the touchdown, Philae's landing position on the comet with a precision better than 50 m.

It was planned that after Rosetta's arrival at the comet, OSIRIS (Optical Spectroscopic Infrared Remote Imaging System) [2] images would be acquired both for scientific purposes and for the landing site selection process and that the LAM (Laboratoire d'Astrophysique de Marseille) and DLR-PF (DLR Institut für Planetenforschung) would

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use them to generate a DTM (Digital Terrain Model) with sub-metric accuracy of the selected landing site. Also ROLIS (Rosetta Lander Imaging System) instrument on-board Philae was expected to acquire several descent images during the final landing phase that would be transmitted to the SONC (Science Operation and Navigation Center) via the orbiter a few minutes after the touchdown.

A computer program named PLW (Philae Locating Workshop, workshop meaning "place with tools" in this context), was therefore developed for the purpose of accurately determining Philae's landing position at the surface of the comet, by registering ROLIS descent images with OSIRIS images of the landing site mapped on the comet's DTM (Digital Terrain Model). For the record, image registration is the process of geometrically aligning two or more images whose pixels represent the same features.

PLW's human–machine interface is composed of two windows: the 3D viewer and the image registration window. The 3D viewer's aim is to simultaneously display the lower-resolution comet's global DTM and the high-resolution landing site local DTM and to give the operator the possibility to navigate at the surface of the comet using a 6-degrees-of-freedom 3D mouse.

NavCam (Navigation Camera) lower resolution images and OSIRIS high-resolution images were used for "colorizing" the 3D models through the projective texturing technique (see Fig. 1). The displayed 3D model of the comet was consequently more realistic and contained more details that the operator could use to register ROLIS images on the comet surface. Projective texturing consists in mapping a textured image on a scene as if it was projected by a slide projector. This technique allows to dynamically move the slide projector and update the comet texturing at runtime.

As, due to the time shift between acquisitions, the lighting conditions could have been significantly different between ROLIS and OSIRIS images, strong visual inconsistencies were expected despite the same location being observed. To mitigate this effect, real-time shadow projection was implemented to help the operator to deal with possible visual inconsistencies. The real-time computing of the shadow of the comet on itself at any given time was implemented into the 3D viewer by the shadow mapping technique. This 3D rendering technique can be summarized in two steps. First, the scene is rendered with an orthographic camera from the vantage point of the sun and the depth of each fragment is computed and stored in a "shadow map". Then the scene is rendered from the vantage point of the camera as usual with a perspective camera and if a fragment is further away from the light source, once projected in the orthographic camera, than the value in the shadow map at this point, then the fragment is colored (in green in PLW to help differentiate dynamic-computed shadow from natural shadows in the images).

The second window in PLW is dedicated to the image registration (see Fig. 2). The chosen locating method was to let the operator manually associate geological features from the ROLIS image (e.g. boulders) to the corresponding features in the previously described texture-mapped DTM (virtual comet). By precisely associating elements in the ROLIS image with elements on the virtual comet, a relation could be made between the 2D space (ROLIS image) and the 3D space (virtual comet nucleus).

The images being processed on-ground, the choice of putting an operator in the loop for associating features in the images instead of developing a fully-automatic process was natural taking into account the high effectiveness of human brain for pattern recognition and its adaptability to the unforeseen.

Computing the location of the ROLIS camera was then a problem of minimizing the distance between a 2D element and the projection on the image plane of its 3D associate,

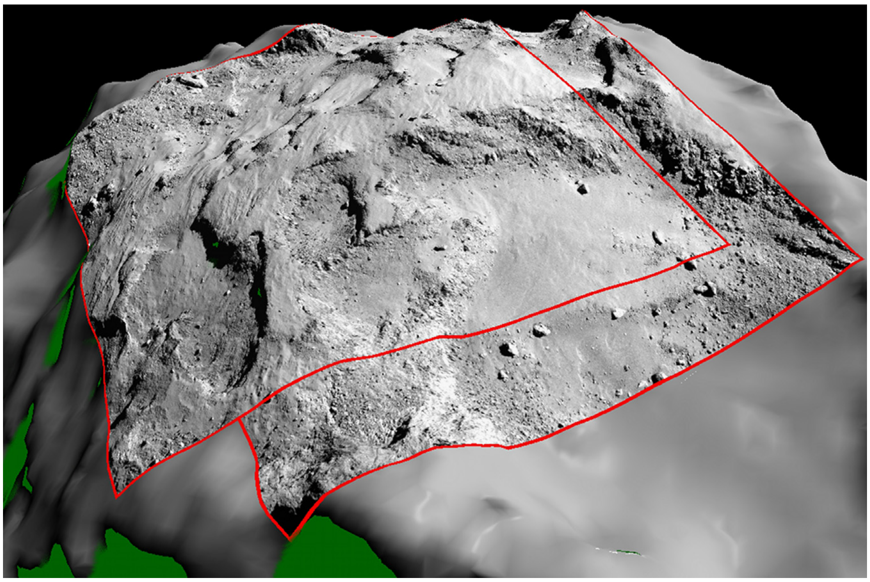

Fig. 1. Agilkia landing site with OSIRIS images mapped on the comet DTM.