ScuDo

Scuola di Dottorato – Doctoral School

WHAT YOU ARE, TAKES YOU FAR

38th Cycle

Advanced planetary mobility system for exploration and astronaut support

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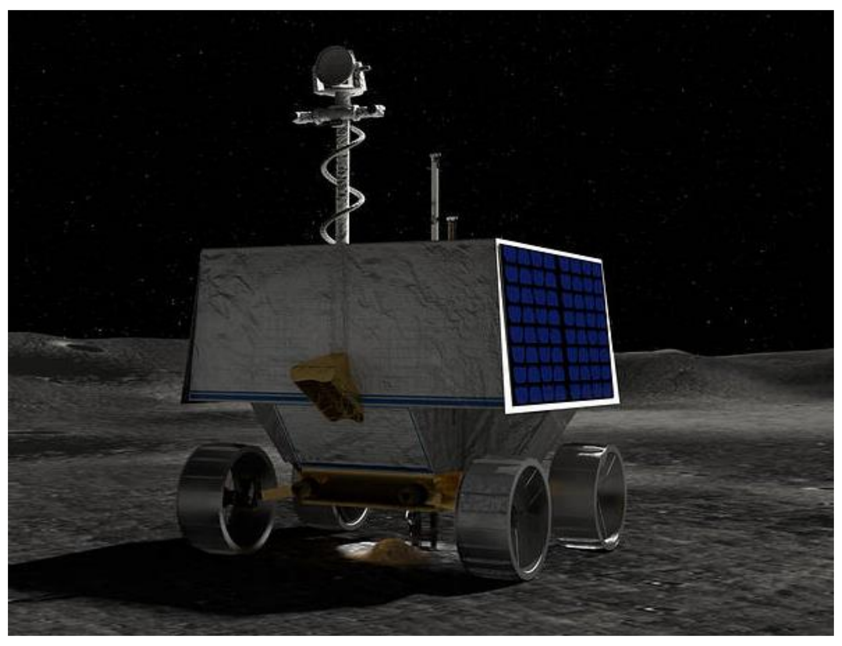
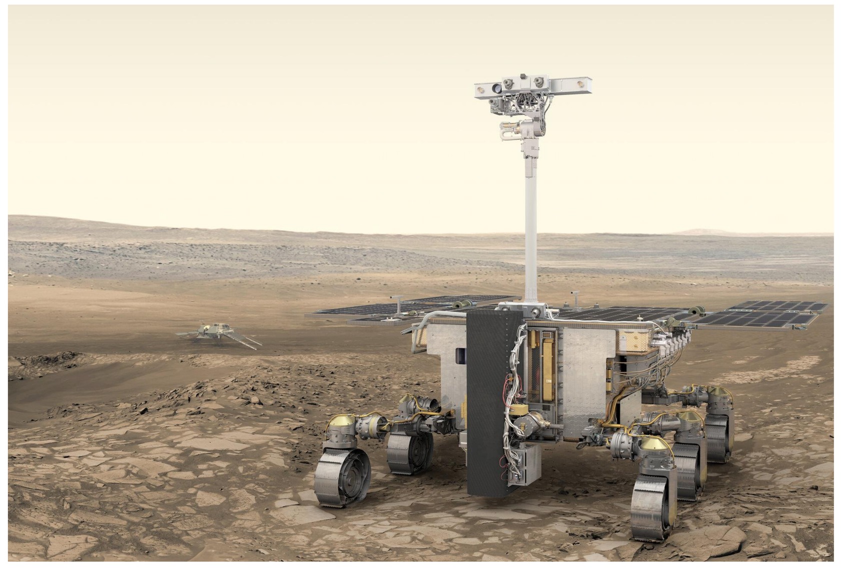
Research context and motivation

- In the last 20 years, there has been a large growth in **development** and **deployment** of **robotic applications for space exploration**, specifically **toward Mars and the Moon**. These robotic assets play a crucial role in paving the way for a future human permanence on extra-terrestrial celestial bodies: by utilizing robots, we reduce the risks associated with human presence in inhospitable environments and enhance our ability to conduct scientific research, establish infrastructure, and prepare for future human missions.
- As we increasingly rely on robotic systems, there is a pressing need for these to be **reliable** and **fully autonomous**. Nowadays, robots need capabilities such as navigation, **localization**, **mapping**, and the ability to continuously learn and adapt to evolving conditions over extended missions. Achieving these levels is essential for ensuring the success and sustainability of long-term space exploration efforts.





Addressed research questions/problems

SLAM for planetary rovers

- Development of a complete module for concurrent real-time environment map generation and robot localization in planetary scenarios, where no GPS and prior knowledge of the surroundings are available, thus enabling the ability to fully explore both scientific and possibly resource rich sites, with particular focus on the Moon south pole.

Front-end: tracking and robust place recognition

- Efficient perception pipeline for robot and landmarks pose tracking with high frequency in real time.
- Achieve perception robustness to the space environment, characterized by severe visual aliasing due to the scarcity of recognizable features and extreme lighting conditions, to perform place recognition and loop closures detections.

Back-end: graph building and optimization

- Light and efficient SLAM back-end optimization to achieve high localization and mapping accuracy, while dealing with strict power consumption constraints and limited memory/computational power budgets, as typical of space systems.

Novel contributions

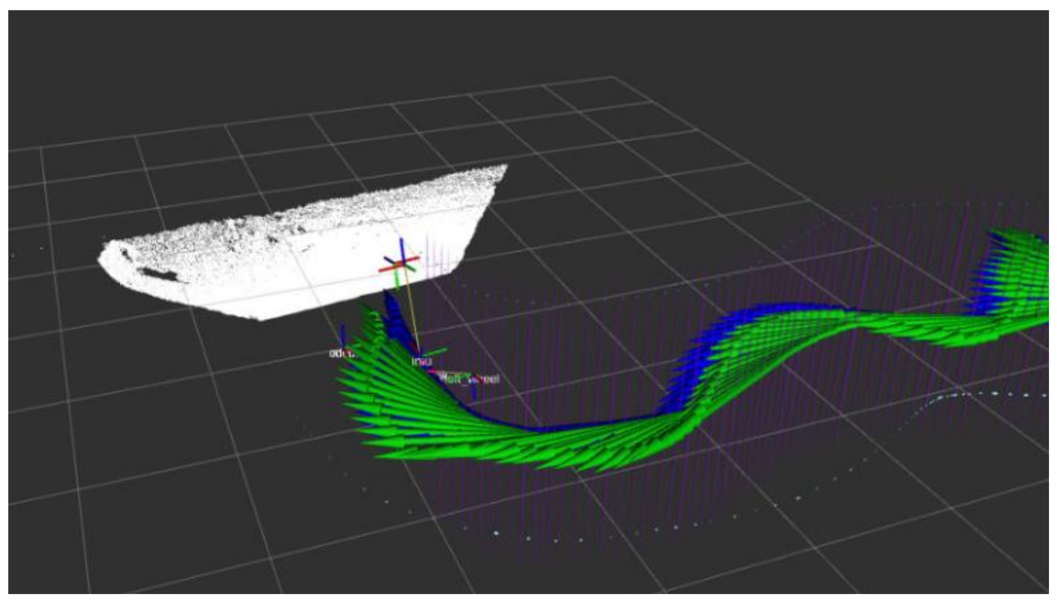
- **Robust place recognition** and **loop closure detection** in visually aliased environments with high dynamic range.
- High frequency **local robot localization** and **pose covariance estimation** based on efficient pointclouds registration.
- SLAM back-end based on **factor graphs** and **on-manifold optimization** to achieve real time capabilities with low on-board resources availability.
- Software development based on **SpaceROS** to achieve safety, reusability and modularity requirements, enabling generalization for different missions and favour transitions to higher flight qualification standards.

spaceROS

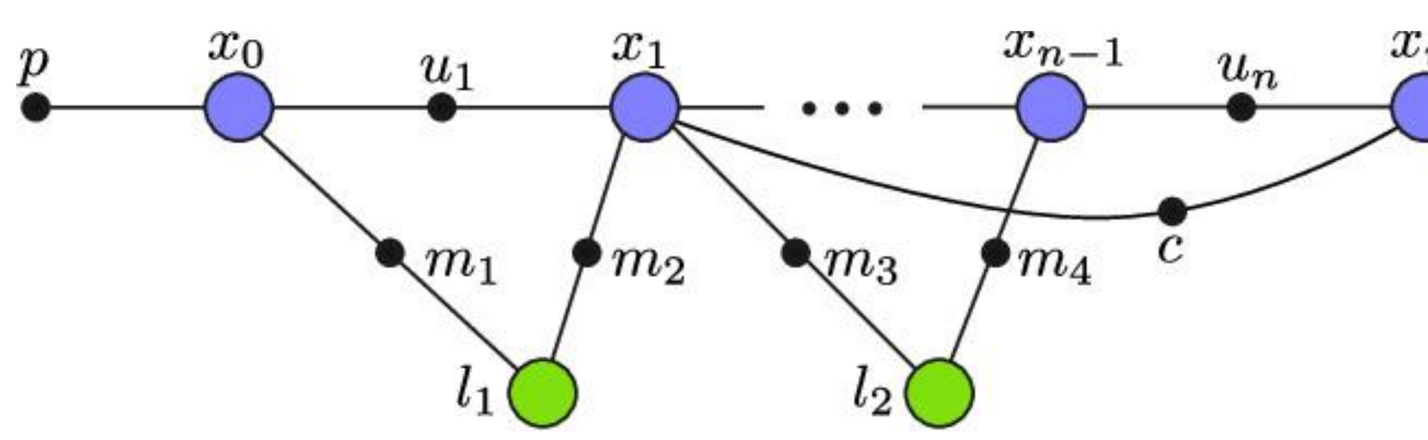
Publications

Adopted methodologies

- **Local tracking:** inputs from visual sensors, such as stereo cameras and time-of-flight cameras, will be used in a sensor fusion approach along with data from IMUs to estimate the robot trajectory in real time. Estimation is performed by incrementally building a factor graph with robot poses connected by odometry constraints computed from sensors measurements. The pose graph is optimized at high rate by computing poses which minimize the constraint costs.
- **Odometry covariance estimation and propagation:** in the proposed approach, robot odometry data are computed from registration of point clouds extracted from camera inputs. Registration is performed with an algorithm based on Iterative Closest Point. A Kalman filter has been used to estimate the output transformation covariance matrix, while an optimized and lightweight C++ library to propagate pose covariances in time and through datatypes conversions has been developed.



- **Global tracking and mapping:** the pose graph optimized by the local tracking module will be wrapped in a higher-level global graph, which will include loop closure detections as well as tracked landmark locations. The global graph models the mapped environment and the corrected robot trajectory. Graph optimization will take place in a dedicated thread at a lower rate or triggered by a loop closure detection.



Future work

During this first year of Ph.D., efforts have been focused in developing the foundational framework for the research project. Looking ahead, the future directions to be pursued are the following:

- **Generalization to 3D sensors and motion models:** to increase the localization accuracy and be compatible with other kind of robots, the state of the art ROS2 Fuse package on which the SLAM module is built needs to be extended to include 3D sensors and more complex motion models. This will enable our system to operate in with different robots in generic three-dimensional environments.
- **Adaptive and reliable place recognition module:** one of the most important goals is to develop a place recognition module which is able to adapt to harsh and variable environmental conditions, to efficiently detect correct loop closures and be robust with respect to outliers.
- **Compatibility with SpaceROS framework:** develop software following guidelines to be standardized with SpaceROS framework, enabling easy integration with other robotic systems and knowledge sharing within the community.

Collaborations

The research project is carried out in collaboration with the Robotics and Mechatronics Group at **Thales Alenia Space Italia**.

ThalesAlenia Space

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Finanziato dall'Unione europea NextGenerationEU

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