Self-learning SLAM (Simultaneous Localisation And Mapping) solutions in resource-constrained environments applied to space exploration:

Martian and Moon rovers/in-orbit servicing/in-orbit manufacturing

Following the International and European Roadmaps for space exploration, the future European space exploration rovers will have to deal with the harsh lunar environment as well as interact with a dynamic environment (as defined below). Both those characteristics are impacting significantly the guidance systems.

First of all, the lunar environment is complex to manage for navigation systems due to two main differences with the Martian environment:

- The lack of atmosphere on the Moon creates shadows that are particularly sharp, thus difficult to differentiate from a rock from a computer vision point of view. More generally, specific lighting conditions (Figure 1) on the Moon are expected to be complex to manage for GNC systems, particularly near the Moon poles (e.g. Shackleton Crater), which are areas of high scientific interest.
- The dust can also be a difficulty for guidance systems created by dust, which only slowly falls due to the lower Moon gravity and lack of atmosphere. Dust is thrown up by the rover itself and will be a problem also near other rovers or moving astronauts. This persistent dust can disturb the interpretation of the rover perception by the guidance systems.

Figure 1: View of lighting conditions over Shackleton crater at lunar south pole (credit: ESA/Space-X)

Secondly, future space exploration rovers on the Moon will have to deal with a very dynamic environment in comparison to Martian missions. Indeed, from deployable parts on the lander around which the rover is operating, to other rovers operating simultaneously (cooperatively or not), or an astronaut working in the rover's vicinity, requires the rover to adapt its guidance to this moving environment to interact safely and efficiently. Moreover, the map could also change due to surface regolith processing or surface forming operations, as expected from the upcoming In-Situ Resources Utilization missions.

In the European space exploration sector, industrial development of rover guidance systems has been mostly driven and focused by the Martian environment and European mission profiles. Hence, those systems have been optimised in order to efficiently manage (<u>with a frugal processing power</u>) the guidance of the rover, isolated on the Martian surface, in a static environment with specific lighting and terrain conditions. Adding the necessity to extensively verify and validate those algorithms, past trade-offs have led to the development by industry of state-of-the-art systems optimized for Mars that use deterministic computer vision methods, characterized by their limited flexibility and limited robustness to non-ideal conditions (i.e. lighting conditions, terrain conditions, ageing sensors).

To address the challenges of future Moon missions, existing rover navigation systems are lacking:

- Robustness to non-ideal conditions generated by the dust and lack of atmosphere which are expected to significantly disturb those guidance systems, preventing them from generating navigation maps and hence relevant paths from the exteroceptive sensory data.
- Moving in a static environment by design, those systems are not able to operate in the vicinity of moving elements, being a rover, a lander, or an astronaut, in a collaborative form or not (Figure 2), ensuring its safety.

Figure 2: Artist rendering of one of the Artemis missions. This highlights the need for the rover to drive around a lander with movable objects (crane, other rover, astronauts) and deploying various payloads on the Moon surface, while ensuring operational safety. (credit NASA)

While other industries (automotive) have pushed for it, advanced methods to solve those issues are still an open problem, in particular guiding a robot in a dynamic environment (SLAM). Moreover, those methods have not been adapted and tested yet to the specificities of the space environment and space hardware (i.e. very low processing power). Hence, we would want to fine new solutions to address the following topics:

- Generate rich and stochastic navigation maps able to identify and follow moving elements in the rover environment, which are adapting to changes in the environment, in terms of terrain, set-up, lighting, etc. Fusing data from several sensors and timescales in a memory-efficient way, those navigation maps are believed to be the cornerstone of increased safe autonomy for space exploration rovers.
- Take into account the environmental dynamics, adapting path checking and guidance systems to ensure safety of the assets and humans in the rover vicinity: e.g. having identified and followed moving elements in the navigation map, the path planning systems need to be able to anticipate future movements to ensure safe distance.