Space Robotic Systems

Final Exercise
Rovers: Path Planning and Localization

A.A. 2022/2023

The report and the source code must be uploaded on Google Classroom at least two days before the oral exam. To fairly evaluate the exercise, we strongly encourage you to provide a thorough discussion of the results. Figures are not enough to fully address the tasks of the homework. For information regarding the text of this exercise, send an email to simone.andolfo@uniroma1.it, edoardo.delvecchio@uniroma1.it and antonio.genova@uniroma1.it

VIPER

NASA's Volatiles Investigating Polar Exploration Rover (VIPER) is a mobile robot that will explore the South Pole of the Moon, scouting for ice on the Lunar surface. The following data of the rover should be considered:

- Maximum velocity: $V_{max} = 20\ cm/s$;
- Wheel base (*i.e.*, Axles distance): $L = 1.5\ m$;
- Maximum traversable slope angle: $\alpha = 15°$.

Task 1: Navigation

At the initial epoch, the pose of the *VIPER* rover with respect to the station frame (reported in orange in Fig. 1):

$$\vec{P}_0 = \big(X_0, Y_0, \theta_0\big) = \big(-23225\ m, -2815\ m, -45°\big)$$

The rover is requested to reach a desired position defined as:

$$\vec{P}_1 = \big(X_1, Y_1\big) = \big(-4855\ m, -1975\ m\big)$$

by **avoiding the Permanently Shadowed Region (PSR)** (represented in black in Fig. 2) located between the initial and the final positions, represented by the green and the blue spots, respectively (Fig. 1). The requested results are:

- The trajectory of the rover across the map;
- The velocity of the rover as a function of time;
- The heading angle of the rover as a function of time;

- The rate-of-change of the heading angle as a function of time;
- The time required to reach the final location.

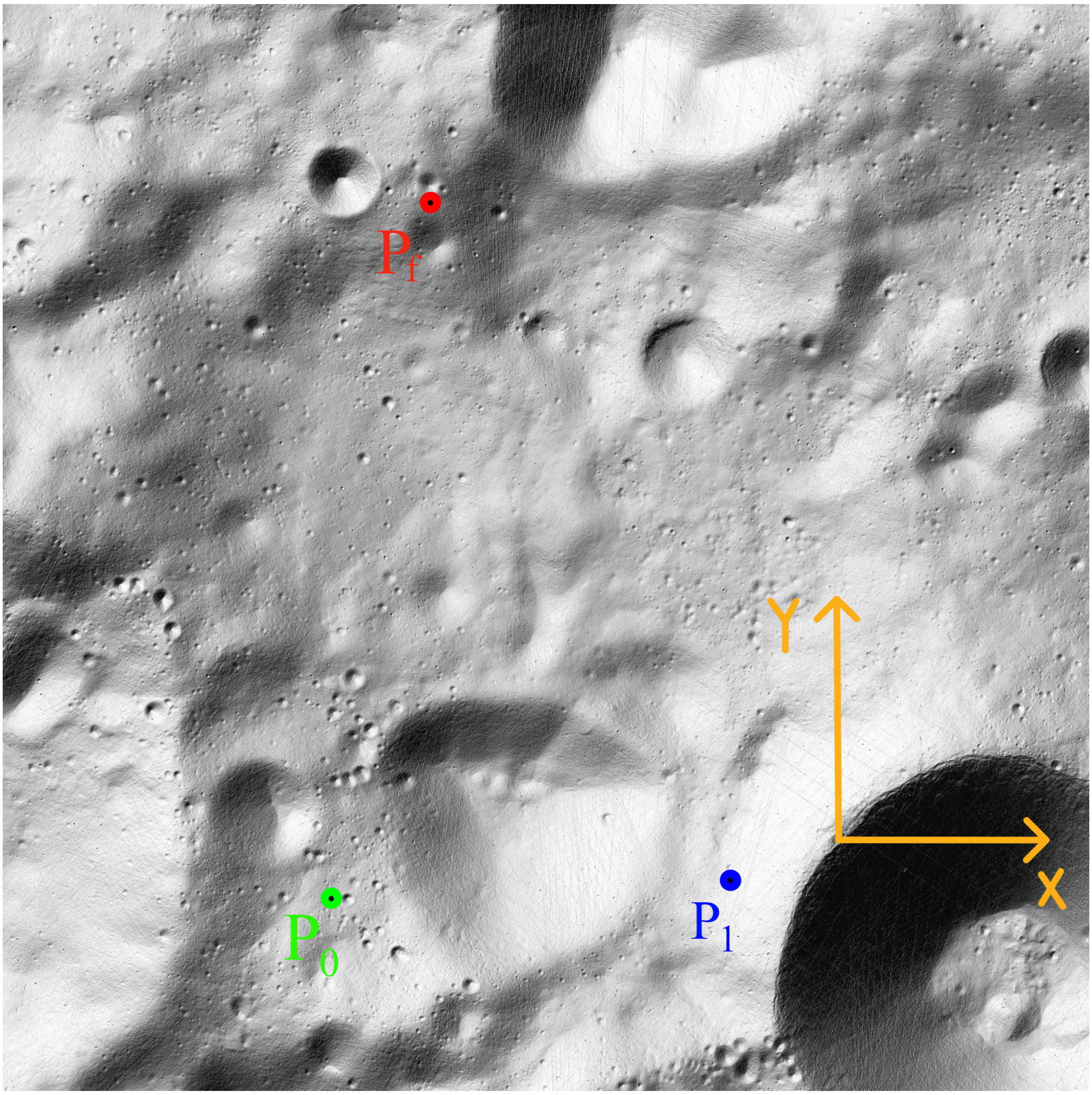

Figure 1: Map of the operational environment

Task 2: Path Planning

After completing its first journey, the rover is requested to reach the target position (red spot) defined as:

$$\vec{P}_f = \big(X_f, Y_f\big) = \big(-18660\ m, 29200\ m\big)$$

The path should be planned by resolving the *pathfinding problem* (**minimum distance path**), implementing the A* algorithm in an **8-way grid**. The provided map has a resolution of 5 m/px and each pixel should be considered as a node of a squared graph. The location of the nodes are provided in the .MAT file as X and Y coordinates.

The rover must avoid the steep slopes and the Permanently Shadowed Regions, represented by red and black contours, respectively (Fig. 2). An *obstacleMap* is hence provided in the .MAT file. It is a grayscale image (a 2D matrix containing values ranging from 0 to 255) where the edges of the steep slopes regions are represented through white pixels (255 value), while the edges of the Permanently Shadowed Regions are represented through black pixels (0 value). This means that all the nodes corresponding to white or black pixels should be considered as **obstacles** by the A* algorithm (*i.e.*, an infinite value should be given to the cost function at these nodes).

The requested results are:

- The length of the planned path given by the A* Algorithm;
- The planned path across the map;
- **[OPTIONAL]** The length of the planned path given by the A* algorithm, with the constraint on the maximum slope angle α, and the planned path across the map.

The Digital Elevation Model (DEM) of the operational environment is provided in the .MAT file for the resolution of the optional task.

Task 3: Rover Localization

Dead Reckoning

By assuming that the trajectory planned in the first task is perfectly performed by the rover (*i.e.*, there are no errors in both position and orientation), the objective is to test the accuracy of an onboard autonomous localization system that uses **odometry data only**. The path of the rover has to be reconstructed by using the *dead reckoning* method (with a measurement acquisition rate of 1 Hz), considering the following odometer noise:

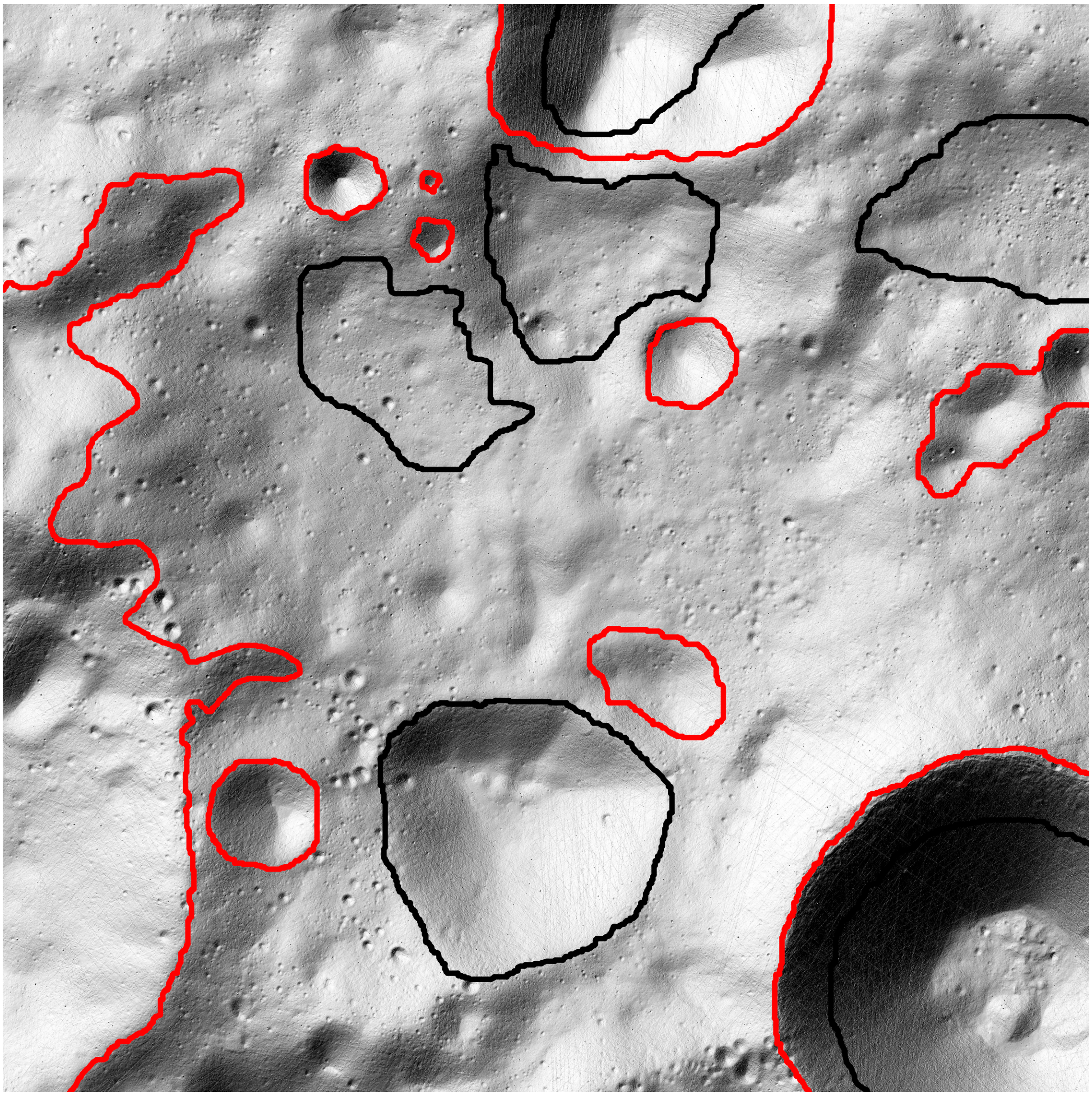

Figure 2: Edges of the steep slopes regions (red) and permanently shadowed regions (black) in the operational environment.

- $\sigma_d = 5\ mm$ on traveled distance
- $\sigma_\theta = 0.05°$ on heading angle

and assuming the following covariance matrix for the initial conditions:

$$\Lambda = \begin{bmatrix} \sigma_x^2 & 0 & 0 \\ 0 & \sigma_y^2 & 0 \\ 0 & 0 & \sigma_\theta^2 \end{bmatrix}$$

where $\sigma_x = \sigma_y = 10\ cm$ and $\sigma_\theta = 1°$.

Localization with a Map

To enhance the reconstruction of the path of the rover, data from **odometer and on-board LIDAR** terrain mapper can be combined. The LIDAR provides the relative distance of the rover with respect to known features in the operational environment (*landmarks*, Fig.3) with a rate of 1 Hz. For this task, the implementation of the Extended Kalman Filter (EKF) is required. The following noise on the LIDAR measurements should be considered:

- $\sigma_r = 5\ cm$ on range;
- $\sigma_\beta = 0.3°$ on bearing angle;

The LIDAR can only detect *landmarks* at a **distance lower than 250 m** and has a **Field of View (FOV) of 360°**. The location of the *landmarks* with respect to the station frame are defined by (x_{LM}, y_{LM}). These vectors are provided in the .MAT file.

The requested results are:

- The trajectory of the rover from P_0 to P_1 reconstructed through the dead reckoning and the ellipses of uncertainties along the path;
- The trajectory of the rover from P_0 to P_1 reconstructed through the combination of the odometer and the LIDAR measurements and the ellipses of uncertainties along the path;
- The evolution of the square root of the determinant of the covariance matrix in both cases.

The reconstructed trajectory and the associated ellipses of uncertainties should avoid the steep slopes and permanently shadowed regions.

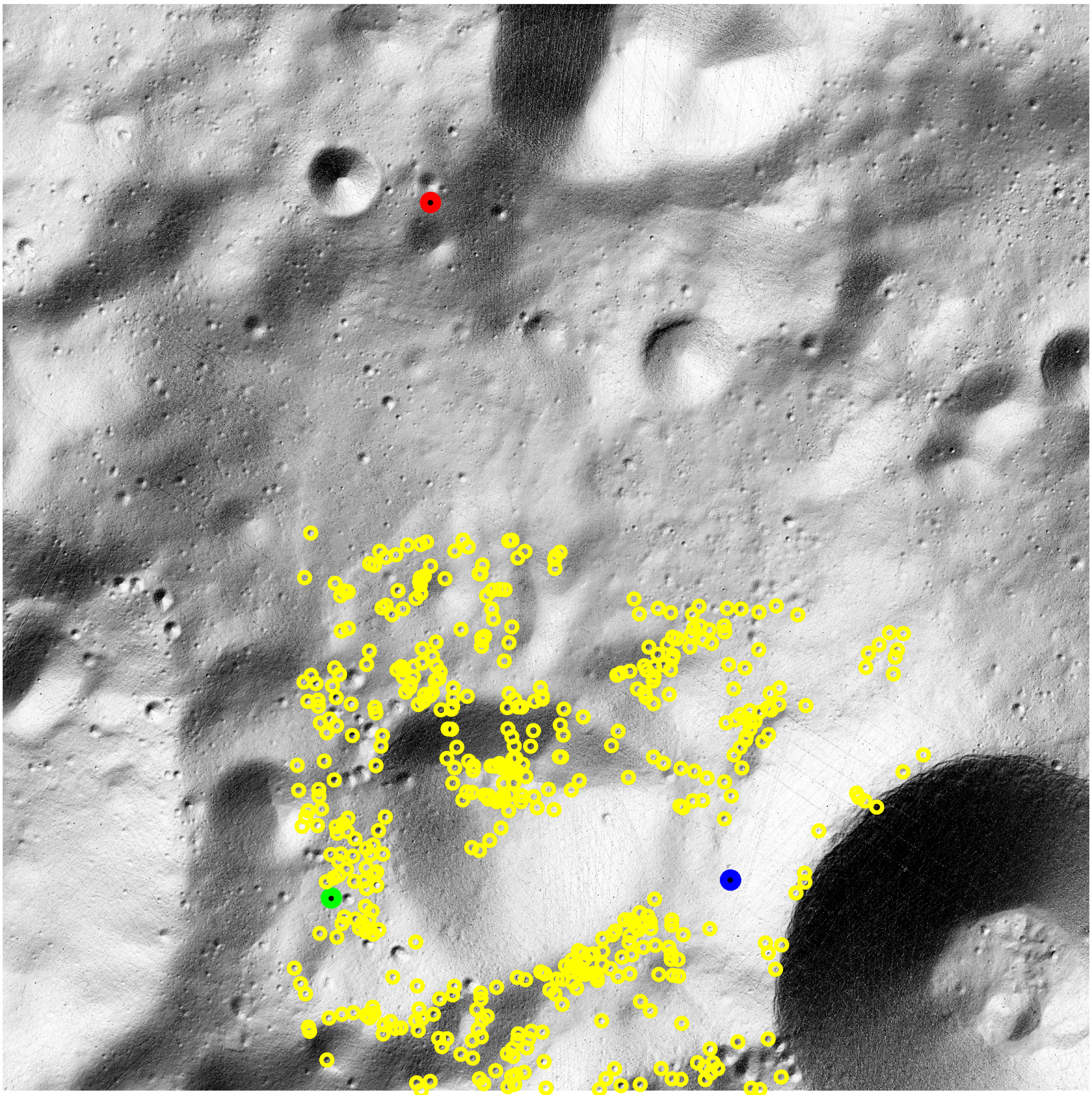

Figure 3: Landmarks location in the operational environment.