(4D) Autonomous Navigation

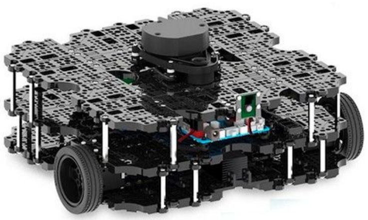
Team Kerbals

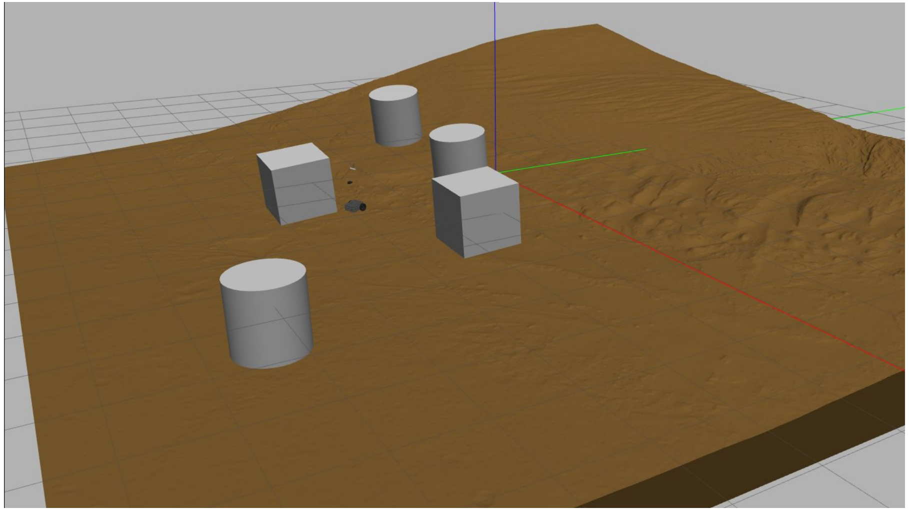
Problem

Design an autonomous navigation algorithm to traverse the rover to a sequence of GPS coordinates that makes use of other parameters including:

- Data from stereo cameras and laser scanner
- IMU Data
- Hall effect sensors in wheels
- External weather conditions

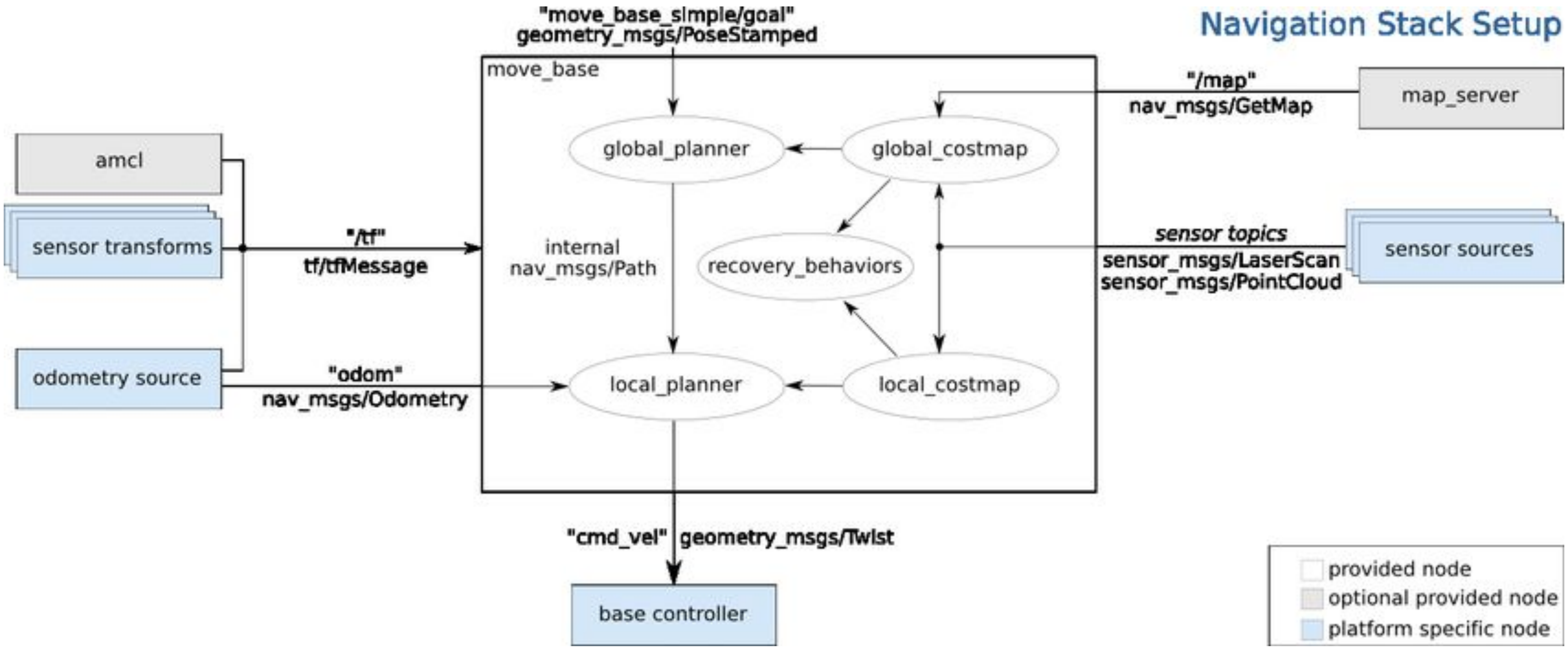
Test Bed: Gazebo-ros simulation

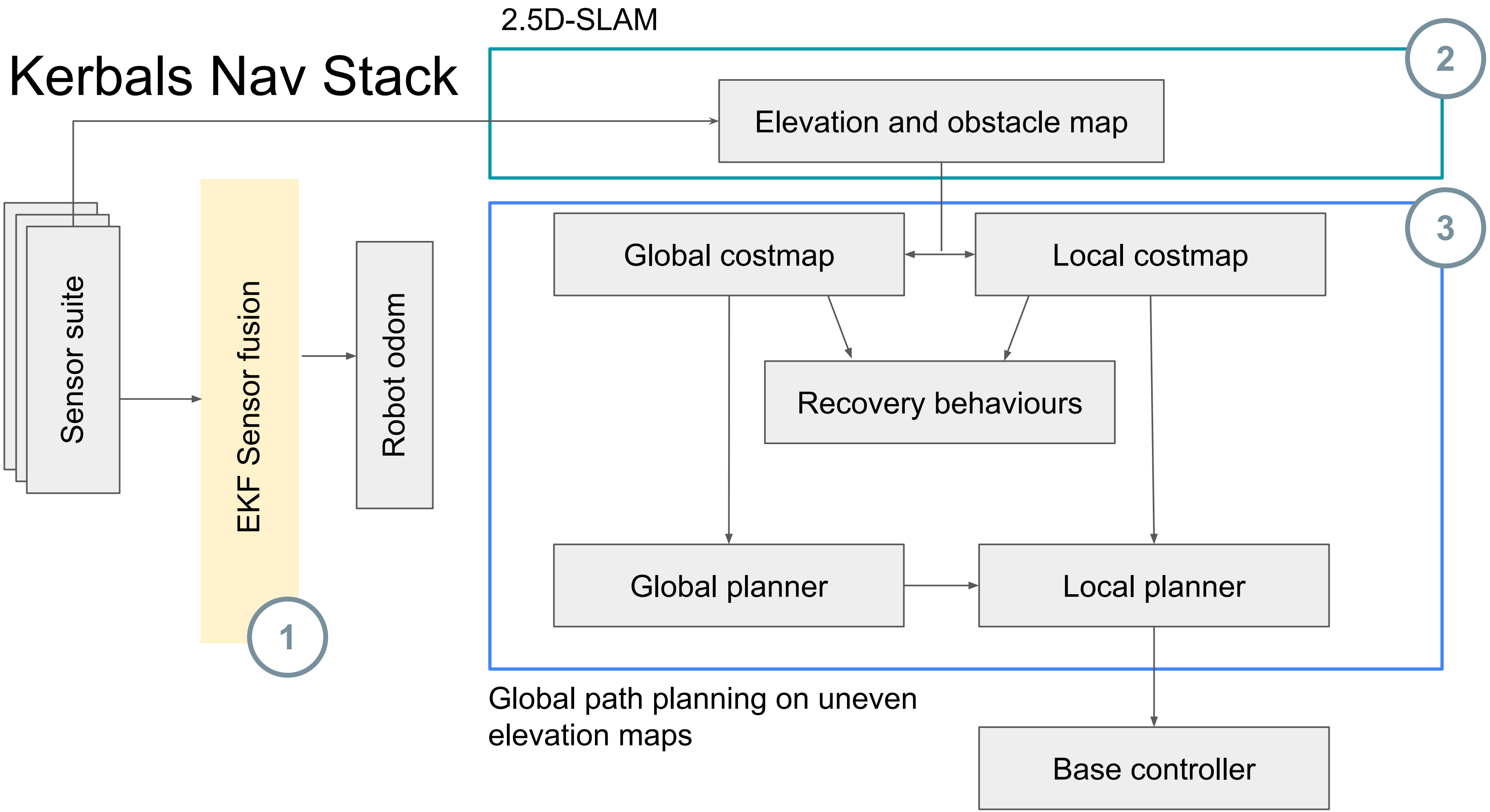




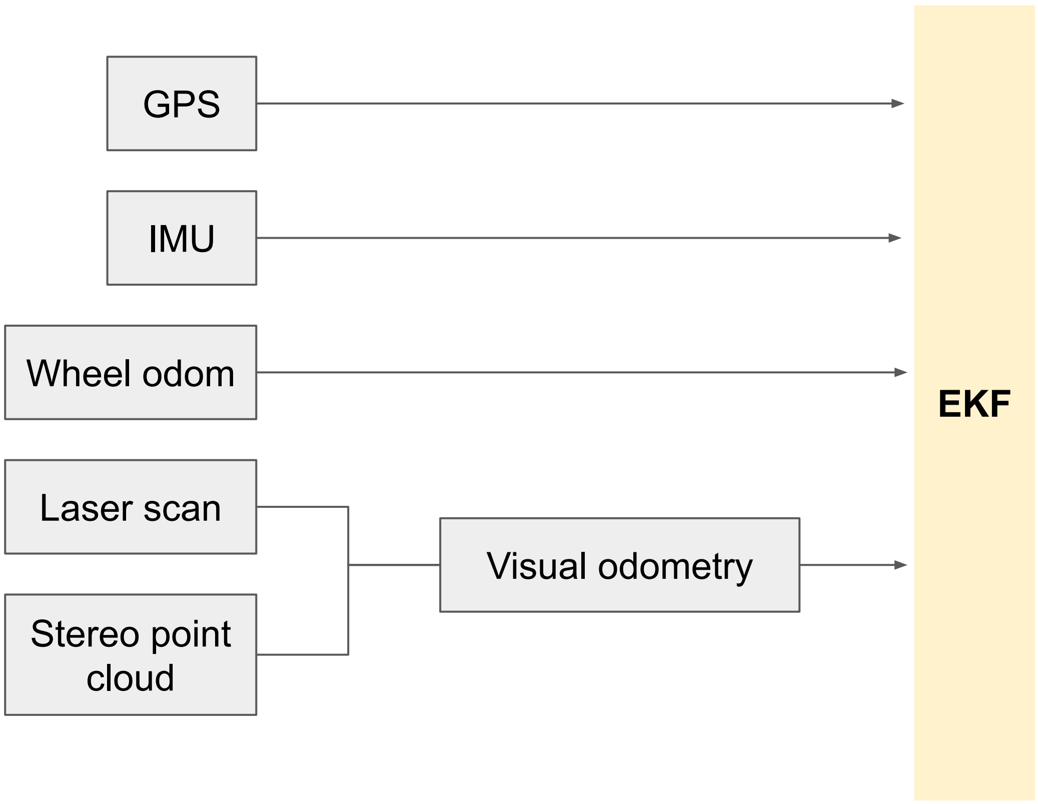
- Open-source Mars terrain map generated from official 3D models of Mars issued published by the NASA JPL itself, based in real martial holography.
- Modified Turtlebot3 Waffle robot model equipped with:
    - R200 RealSense Depth Camera: stereo vision
    - 60 Laser Distance Sensor LDS-01: low-cost 2D laser scanner
    - Replicate low-cost sensors likely to be used on the rover

Traditional ROS1 MoveIt!



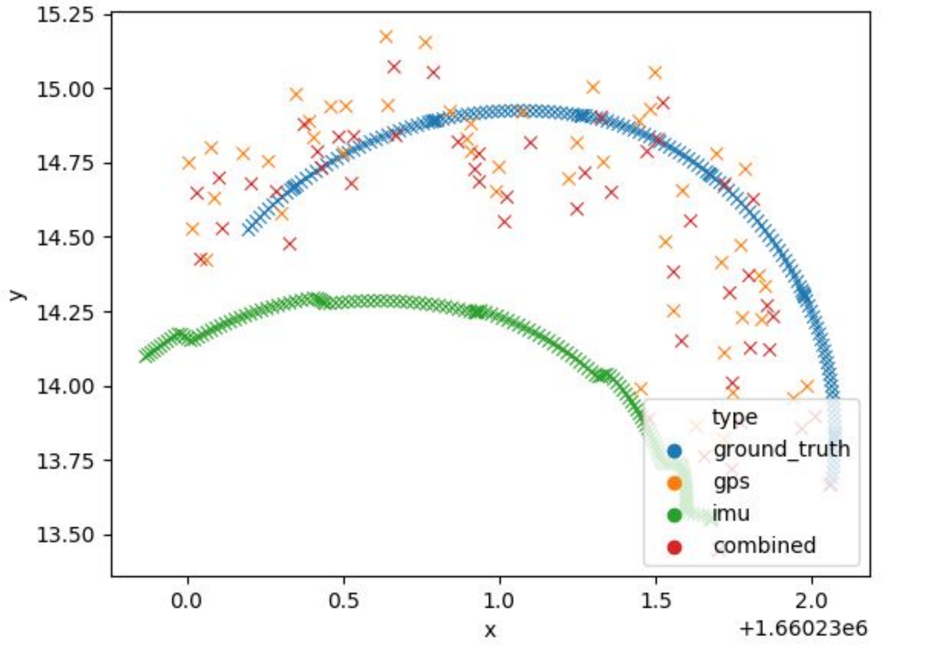

Kerbals Nav Stack
2.5D-SLAM
2
Elevation and obstacle map
3
Sensor suite
EKF Sensor fusion
Robot odom
1
Global costmap
Local costmap
Recovery behaviours
Global planner
Local planner
Global path planning on uneven elevation maps
Base controller

Sensor Fusion with Extended Kalman Filter (EKF) [1]



- **Problem:** Sensor data can be unreliable, especially in adverse weather conditions
- **Solution:** Extended Kalman Filter that uses wheel odometry, visual odometry, IMU sensor and GPS data to estimate the 3D pose of a robot

Sensor Fusion with Extended Kalman Filter (EKF)



- EKF is a variant of the Kalman Filter that works on non-linear functions
- Used in integrated navigation systems which need to combine GPS data with inertial measurements [2]

2.5D SLAM: Terrain Mapping with Elevation Maps [3]

Problem

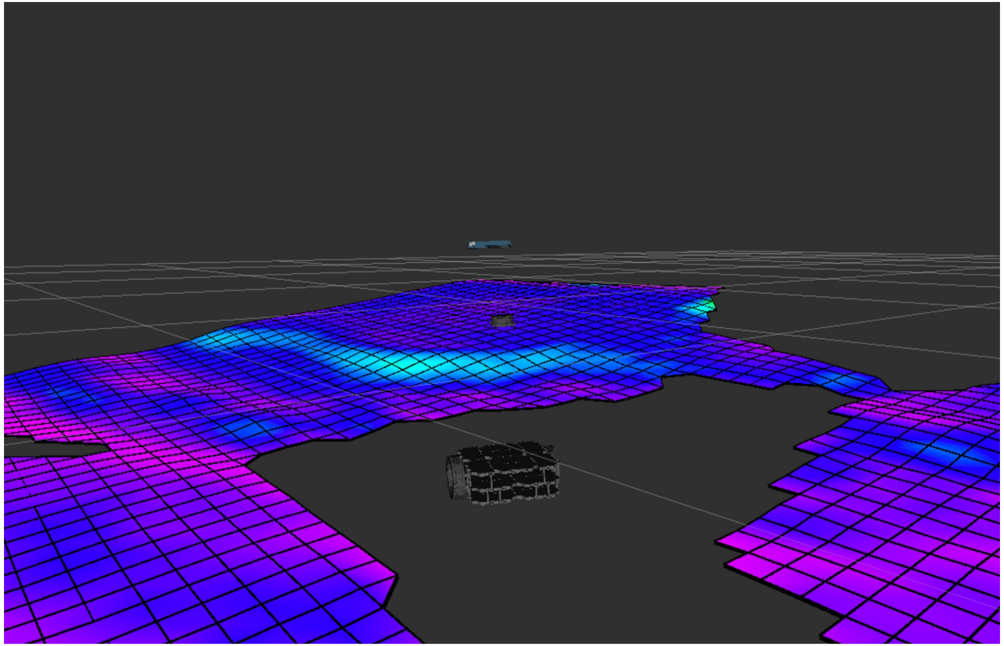
Rugged terrain on Mars means that other than obstacles, terrain elevation is also an important map feature to consider when planning navigation missions to maximise travelling efficiency.

However, full 3D maps are too computationally and memory intensive to maintain for a low-cost rover.

Solution

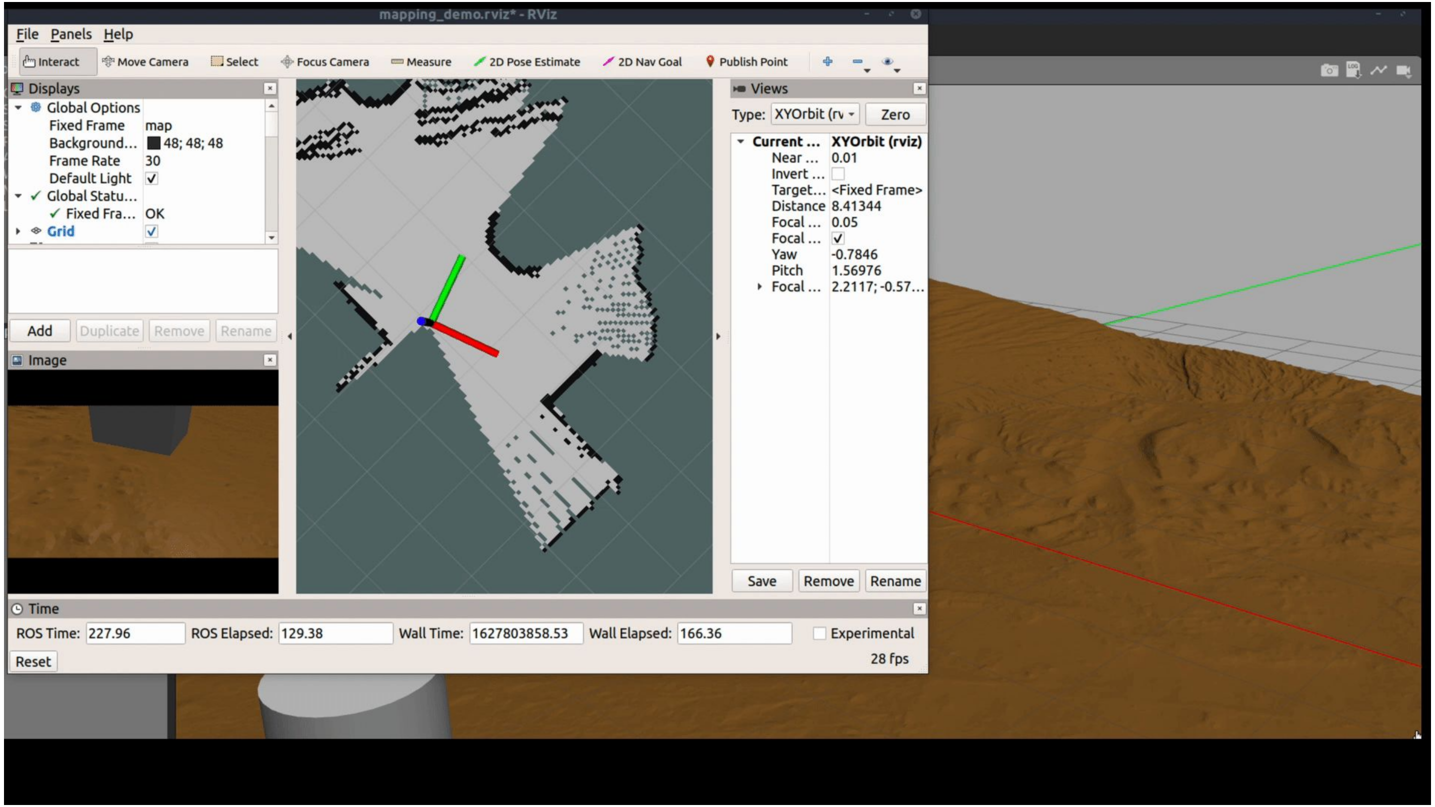
2.5D elevation maps that capture elevation data while remaining computationally efficient.

2.5D SLAM: Terrain Mapping with Elevation Maps [3]



- Discrete mapping approach where each cell represents the occupancy probability, the height of the terrain and its variance
- Cell measurements are updated with a local kalman filter based on RB-D data from hazcams and navcams
- Resolution of the map (size of cells) can be scaled according to computational power available

2.5D SLAM Demo



Global Path Planning over Elevation Maps

Problem

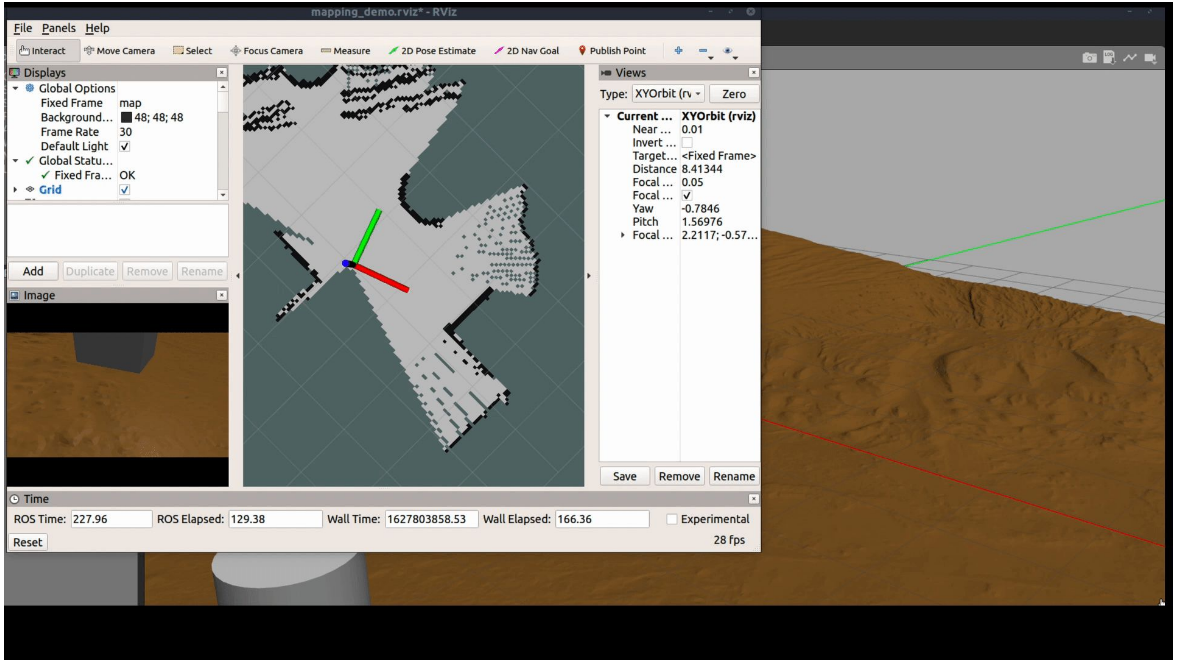
Rugged terrain on Mars means that other than obstacles, terrain elevation is also an important map feature to consider when planning navigation missions to maximise travelling efficiency.

Adverse weather conditions (e.g. rain) makes increases the cost of travelling over uneven terrain due to slip.

Solution

Custom path planning algorithm that performs minimisation over 2.5D elevation maps, and a dynamic cost calculation that accounts for adverse weather conditions.

Global Path Planning over Elevation Maps



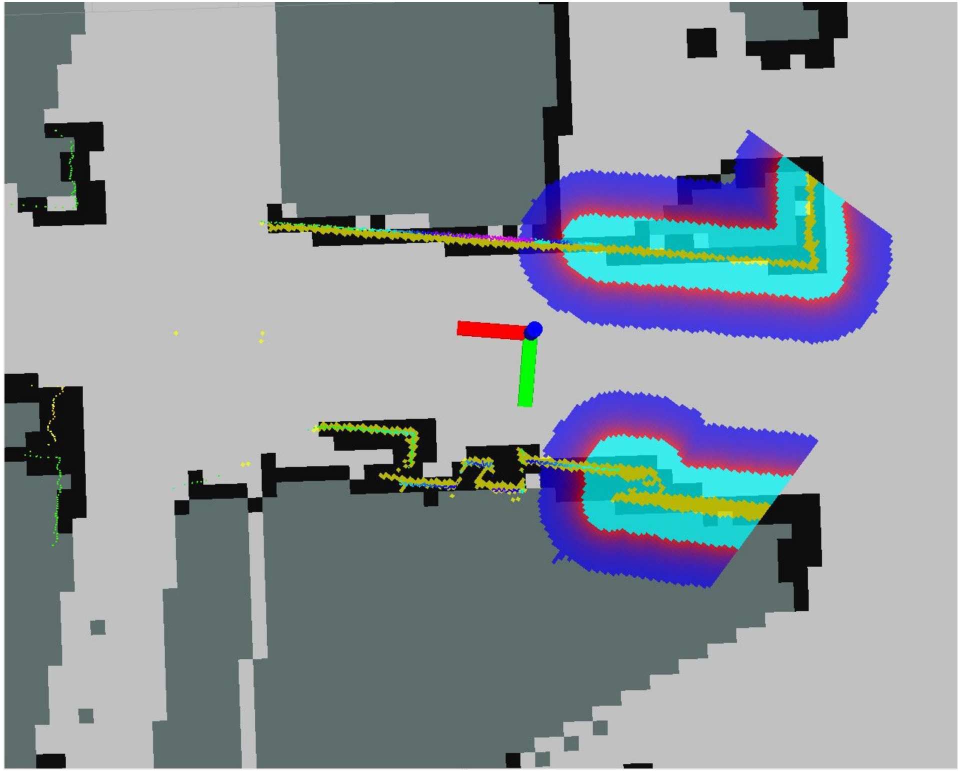
Problem

Rugged terrain and extreme weather conditions (e.g. rain) affect the cost of travelling.

Solution

Custom path planning algorithm that performs minimisation over 2.5D elevation maps, and a dynamic cost calculation that accounts for adverse weather conditions.

Global Path Planning over Elevation Maps



- Generate costmaps by fusing 2.5D elevation maps from RGB-D data with 2D occupancy maps from laser scan data to compute a 2D cost map [4]
- Costs assigned is dynamically calculated with information on weather conditions
- D* path search minimises cost to obtain optimum path [5]

Global Path Planning over Elevation Maps

Key consideration: Energy efficiency

Energy available is limited on Mars, hence energy efficiency in travel is key

Consider nodes X and Y with elevation h_X and h_Y

Traditional cost between adjacent nodes: $\boldsymbol{\lambda_1 * \mathrm{euclid}_2(X, Y)}$ - 2d euclidean distance

Elevation map cost: We consider gravitational potential energy required to go from X to Y

Energy used = mass of rover * gravitational acceleration * $(h_x - h_y)$

→ Additional cost: $\boldsymbol{\lambda_2 * (h_X - h_Y)}$

Global Path Planning over Elevation Maps

Weather cost: Rain

- Rain increases wheel slip, more wheel rotations needed to travel the same 3d distance between X and Y
- Rain cost:

$$\lambda_3 * \mathrm{euclid}_3(X, Y)$$

dynamic lambda parameter scales according to heaviness of rain

Weather cost: Wind

- Moving into strong winds on Mars increases energy needed to travel
- Wind cost:

$$\lambda_4 * \mathrm{dot}[\ \mathrm{vec}(X, Y), \mathrm{unitvec}_{wind}\ ]$$

dynamic lambda parameter scales according to magnitude of wind

Global Path Planning over Elevation Maps

Key consideration: Energy efficiency

Total modified cost for D* search in rover exploration:

$$
\begin{aligned}
\mathbf{c(X, Y)} = \quad & \lambda_1 * \mathrm{euclid}(X, Y) \\
& + \lambda_2 * (h_X - h_Y) \\
& + \lambda_3 * \mathrm{euclid}_3(X, Y) \\
& + \lambda_4 * \mathrm{dot}[\ \mathrm{vec}(X, Y), \mathrm{unitvec}_{\mathrm{wind}}\ ]
\end{aligned}
$$

References

[1]M. I. Ribeiro, ‘Kalman and extended kalman filters: Concept, derivation and properties’, Institute for Systems and Robotics, vol. 43, p. 46, 2004.

[2] E. Wan, ‘Sigma-Point Filters: An Overview with Applications to Integrated Navigation and Vision Assisted Control’, in 2006 IEEE Nonlinear Statistical Signal Processing Workshop, Sep. 2006, pp. 201–202. doi: 10.1109/NSSPW.2006.4378854.

[3] S. Kohlbrecher, J. Meyer, T. Graber, K. Petersen, U. Klingauf, and O. von Stryk, ‘Hector Open Source Modules for Autonomous Mapping and Navigation with Rescue Robots’, in RoboCup 2013: Robot World Cup XVII, Berlin, Heidelberg, 2014, pp. 624–631. doi: 10.1007/978-3-662-44468-9_58.

[4] Choi, S., Jaehyun Park, Eulgyoon Lim, & Yu, W. (2012). Global path planning on uneven elevation maps. 2012 9th International Conference on Ubiquitous Robots and Ambient Intelligence (URAI). doi:10.1109/urai.2012.6462928

[5] A. Stentz, ‘The D* Algorithm for Real-Time Planning of Optimal Traverses’, Apr. 2011.