3D Off-road Terrain Mapping for Autonomous Ground Vehicle Energy-Optimal Path Planning

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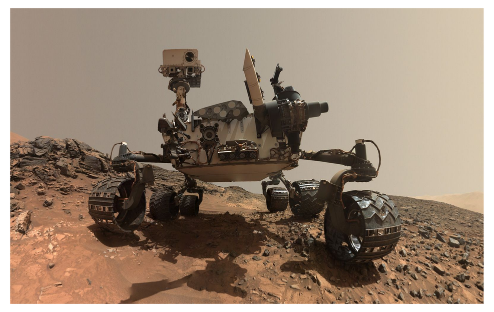
Introduction

- Autonomous ground vehicles (AGVs) are rugged and reliable tools for exploring hard to reach or dangerous areas (underground mines or radiation polluted areas).
- AGVs are also used in precision agriculture, planetary exploration, and military applications.

Source: clearpathrobotics.com

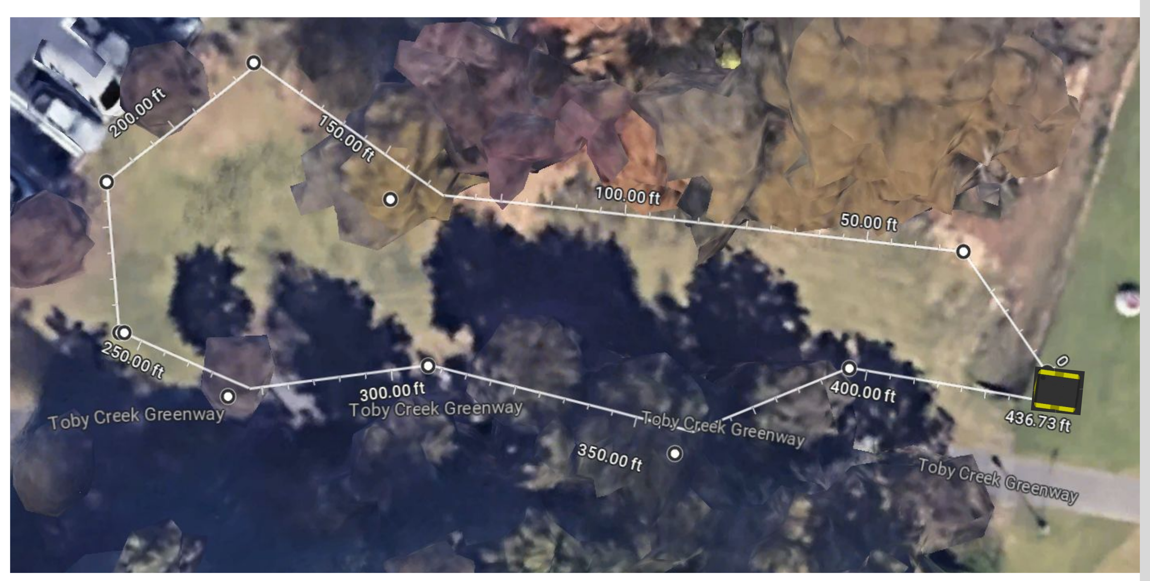


Source mars.nasa.gov

- Path planning for AGVs normally considers 2D maps of the environment that do not account for terrain elevation.
- Collecting and analyzing data to form 3D maps can allow for complex and intelligent maneuvering in difficult terrain.

Objectives

- Implement a method of fusing data collected from multiple AGV sensors on an AGV to generate an outdoor terrain map.
- Develop and test a path planning algorithm that leverages the generated map, ultimately improving the time and energy efficiency of the robot as it travels through the terrain.



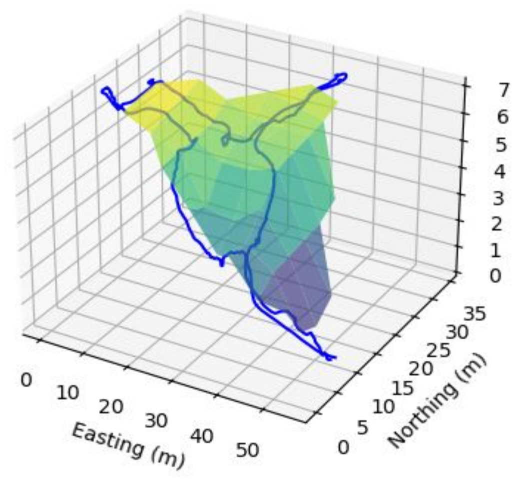
Google satellite image of the terrain for which experimental tests were conducted.

Methods and Data Collected

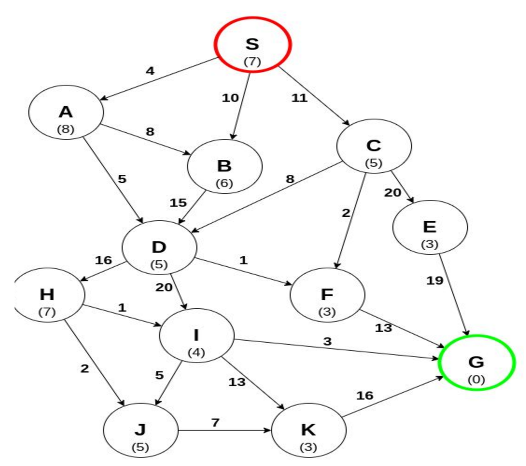
- We used the Clearpath Jackal AGV to collect the data which was used to create the 3D map.

The Clearpath Jackal AGV

- The onboard Robot Operating System (ROS) was used to recording the data of from the IMU, GPS, LiDAR, etc.
- GPS data was post-processed and visualized below.
- Interpolating the UGV's path to create a 3D terrain map that represents the elevation of the terrain.



Interpolated 3D terrain from the trajectory of the robot (blueline)



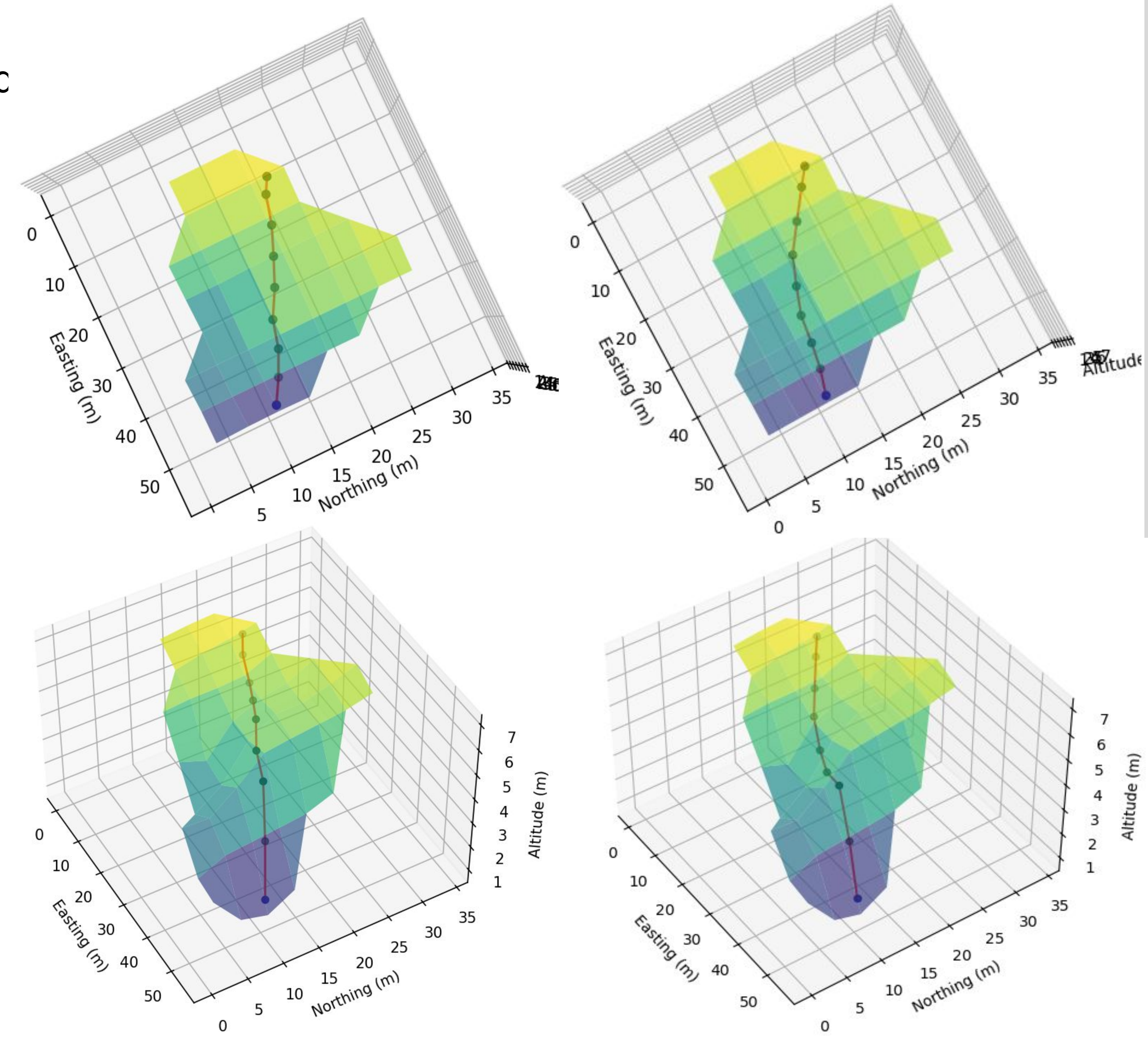
A* visualization.
Source: Code Academy

- We used the A* algorithm path planning on the 3D graph with nodes generated with the probabilistic roadmap method.
- To calculate distance in 2D between all the randomly generated nodes we used,
  $D\ (distance) = \sqrt{X^2 + Y^2}$
- With the cost function between nodes
  $Cost = (1 + \exp(\alpha \cdot \Delta Altitude)) \cdot D$

X: Easting distance between nodes.
Y: Nothing distance between nodes.
α : The parameter reflects energy's importance in our optimal path.

Results

- The algorithm successfully plannec an optimal path between a start and end point. The (red) connecting line connects the best nodes (black dots) from the sample of 20000 random nodes fitted to the terrain curve.



Top: Top view. Bottom: Front View Left: The graph only consider distance (α = 0). Right: The graph considers energy efficiency (α = 1).

Discussion

- Interpolation using cubic splines from the GPS data provides a reasonable representation of the terrain for robot path planning.
- The probabilistic roadmap approach is computationally efficient making it suitable for future integration of this method onboard the robot.
- The results shown that the shortest straight line path is not necessarily optimal

Conclusion and Future Work

- A method was developed that allows terrain-mapping from prior GPS data collected.
- Follow-on work may involve fusing additional data sources in to the terrain mapping algorithm to enhance accuracy (e.g., IMU and LiDAR data). Other aspects such as energy consumption, terrain type, obstacles may also be encoded in the map.
- Future works aims to enable the robot to perform the mapping and path planning tasks autonomously in real-time.

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