FASTNAV

"Multi-range Navigation for Fast Moon Rovers"

ESA Contract No 4000142767/23/NL/RK/gf

Final Review – Final Presentation

17/09/2024

ESA ESTEC / MS Teams

INNOVATING SOLUTIONS

Agenda

[09:45 – 10:45 CEST]: Final Presentation
- FASTNAV Activity Overview & Objectives
- Architecture & Component Design
- RAPID Platform Upgrades
- Test Campaign & Results
- Conclusions
- Q&A

[10:45 – 11:00 CEST]: Follow-On Activity Discussion
- Main Objectives & Outline Plans
- Timelines

[11:00 – 11:15 CEST]: Coffee Break

[11:15 – 12:45 CEST]: Final Review – Detailed Review of Test Report

[12:45 – 14:00 CEST]: Lunch Break

[14:00 – 15:30 CEST]: RIDs Discussion & AOB

FASTNAV Activity Overview & Objectives

FASTNAV Activity Overview

The goal of FASTNAV is to increase the average rover traverse speed, through the development of a new multi-range and multi-mode rover navigation strategy in a continuous drive paradigm approach, compatible with the class of fast Moon rovers currently being developed in Europe.

De-risking activity to build upon the achievements of the RAPID

FASTNAV aims to establish a rover GNC system which is multi-range and multi-mode, meaning that different navigation strategies can be switched, based on the perceived environment.

Two primary navigation modes:

1. FASTER: Drive faster in benign terrain with minimal path replanning to avoid sparse obstacles
2. RAPID: Conservatively manoeuvre in areas of high obstacle density.

Final Field Tests and Demonstration in representative environment in Bardenas, Spain.

Key Technical Requirements

System Requirements

FASTNAV Requirements were consolidated to complement the achievements of the RAPID activity, but not to duplicate them

FNAV-REQ-FU-0010	FASTNAV GNC Architecture
The FASTNAV GNC Architecture shall accommodate multiple GNC modes for different surface operation conditions	

FNAV-REQ-FU-0020	FASTNAV GNC Function Management
The FASTNAV GNC system shall implement the following GNC management functions: - a function to coordinate the execution of all GNC functions, including management of the internal state of the GNC components - a function to implement GNC mode management to handle GNC mode switching based on global and local data - a function to supervise the execution of all GNC components which acts independently, and is able to react to detected faults during runtime	

FNAV-REQ-FU-0030	FASTNAV GNC – RAPID Mode
The FASTNAV GNC system shall reuse the RAPID GNC system as one of its modes, to be used in challenging surface conditions with high obstacle density	

FNAV-REQ-FU-0040	FASTNAV GNC – Additional Mode
The FASTNAV GNC system shall include at least one additional mode, to be used in benign surface conditions with low obstacle density	

Key Technical Requirements

Performance Requirements

FNAV-REQ-PE-0010	Average Traverse Speed – Benign Terrains
The FASTNAV GNC system should allow the rover to traverse with an hourly average speed of at least 1.0 m/s in benign terrains with low obstacle density	

FNAV-REQ-PE-0020	Average Traverse Speed – Complex Terrains
The FASTNAV GNC system should allow the rover to traverse with an hourly average speed of at least 0.7 m/s in complex terrains with high obstacle density	

FNAV-REQ-PE-0030	Ensuring Safe Traverse
The FASTNAV GNC system shall ensure that all planned paths are safe to be traversed, avoiding all obstacles in all terrain conditions	

FASTNAV GNC Architecture & Component Design

Initial Technology Review & Solution Analysis

- **An initial review of the RAPID activity solution was performed to identify areas for FASTNAV to dedicate effort to build upon.**

- **Coordinator Nodes**
  - Guidance Action Server: control the execution flow and coordinate the nodes states
  - Supervisor Node: check executables states
  - Guidance Mode Manager: handle guidance modes

- **RAPID Nodes Improvements**
  - Unified state machine
  - ROS Services based interfaces
  - Improved ROS integration: TF, ROS parameters, debug outputs, RVIZ visualisation

- **Re-imagined Far Obstacles Perception**
  - Create new Obstacle Detector based on the State of the Art
  - Develop a new Far Obstacle Detection concept that can directly apply detections to local path repairing or local avoidance

- **Adaptive Trajectory Controller**
  - Make crucial parameters such as the linear speed, lookahead distance and turn radius adaptive to the current rover's trajectory

- **FASTER Guidance Mode**
  - Designed to allow faster traverse speed
  - Smoother path with minimal turns
  - Intended to be used when low obstacle density and with sufficient distance from obstacles
  - Fast computation time and lower complexity
  - Safety-driven design to switch back to RAPID mode if needed

FASTNAV Architecture

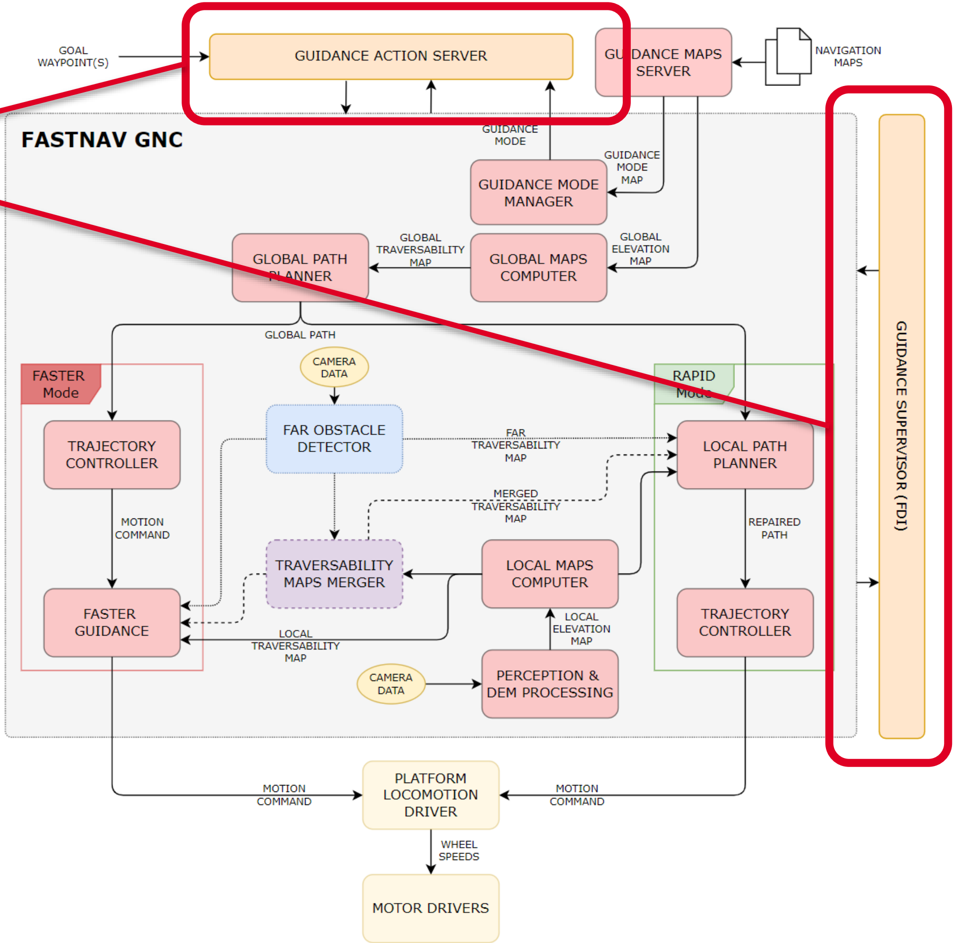
GNC COORDINATION

GUIDANCE ACTION SERVER

- Handles the execution flow of goals
- Coordinates all guidance nodes states
- Provides goals interface and feedback to the operator

GUIDANCE SUPERVISOR

- Provides FDI functionality in the event of a hard-error
- Gracefully terminates the FASTNAV GNC at the application-level if an unrecoverable error occurs

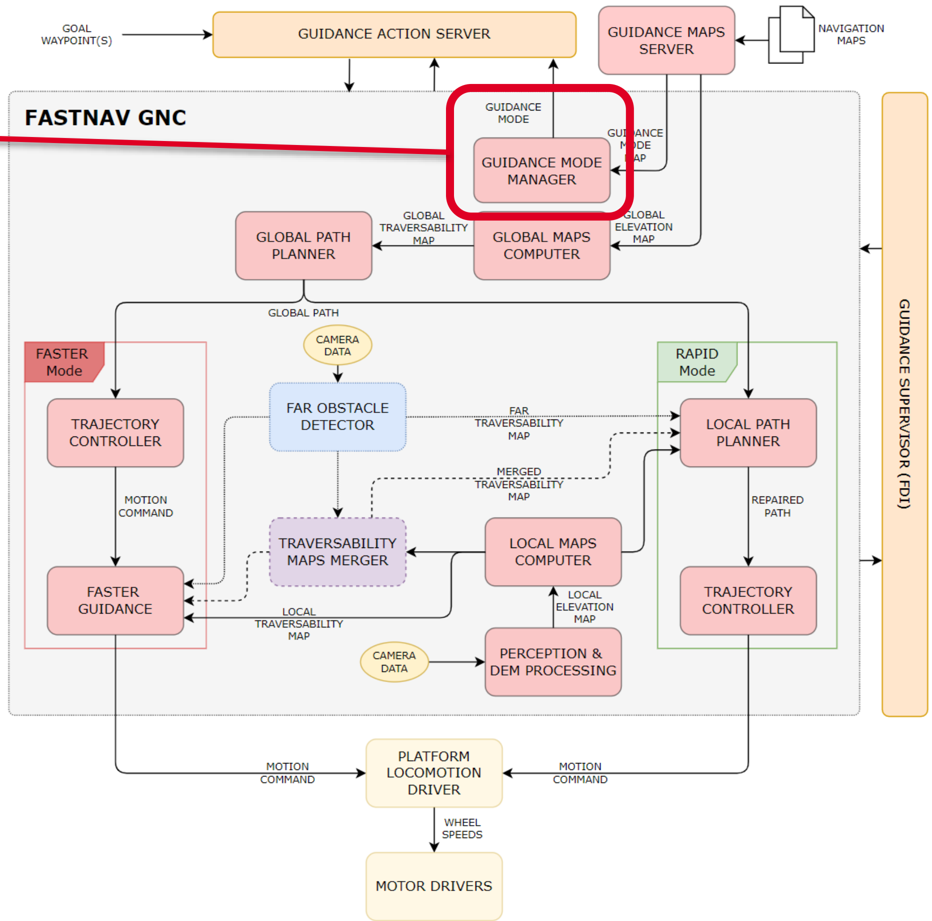


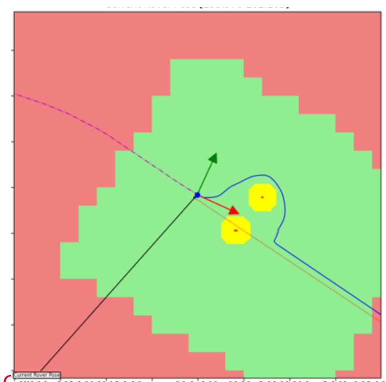
FASTNAV Architecture

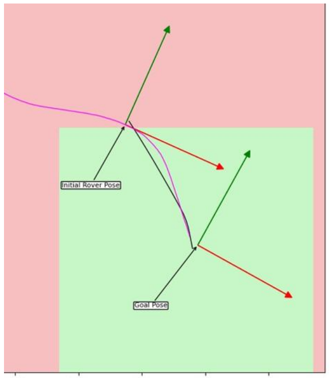
MODE MANAGEMENT

GUIDANCE MODE MANAGER

- Periodically checks that the system is in the correct GNC mode, according to the Guidance Mode Map
- Interfaces with the GAS to handle mode switching
- Provides functionalities for "Overriding" a Guidance Mode and setting "Goal Areas"







FASTNAV Architecture

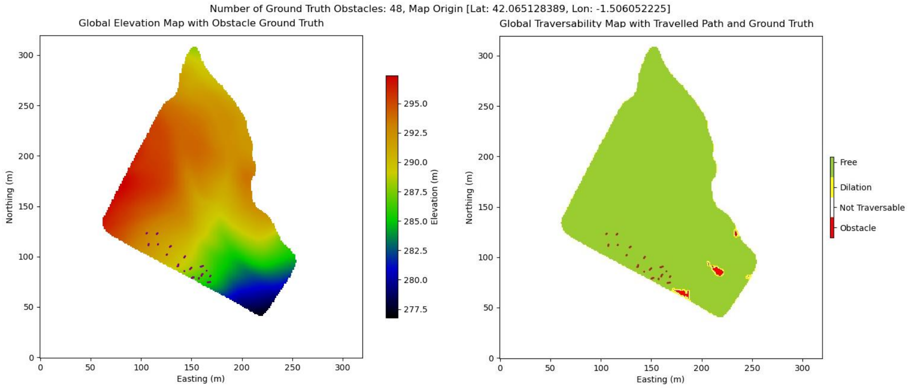
GLOBAL COMPONENTS

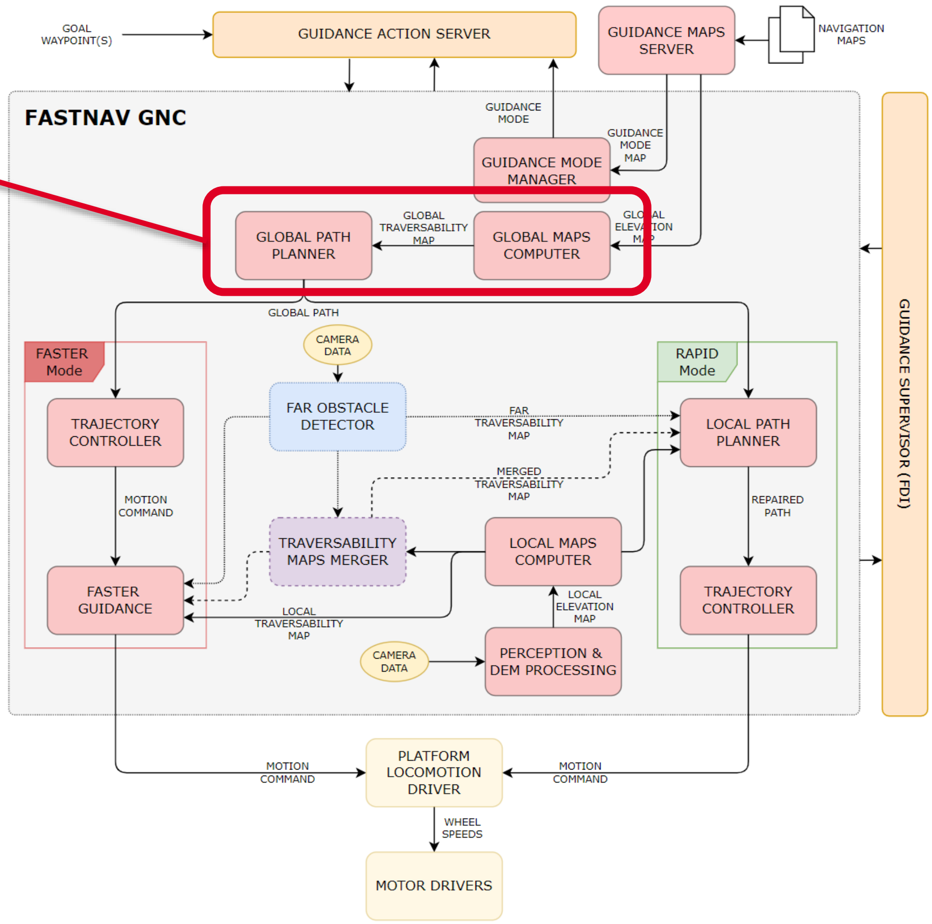
GLOBAL MAPS COMPUTER

- Processes the Global Elevation Map to create a Global Traversability and Global Cost Map based on given Goal Waypoint

GLOBAL PATH PLANNER

- Plans the Global Path using Global Maps



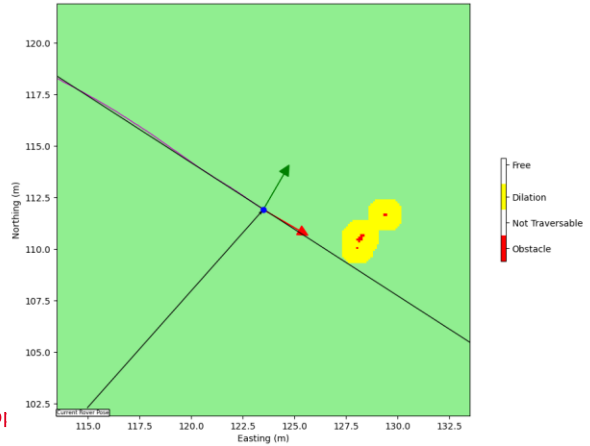


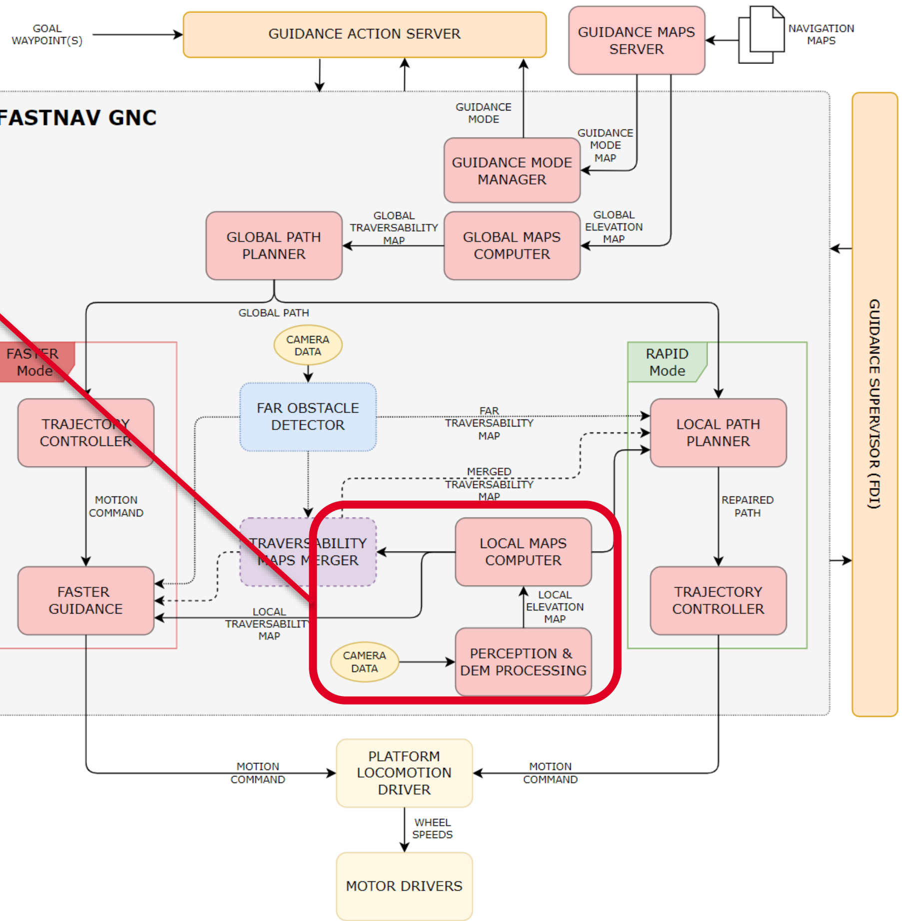
FASTNAV Architecture

LOCAL OBSTACLES PERCEPTION

LOCAL MAPS COMPUTER

- **Generates a Local Traversability Map based on terrain characteristics:**
  - Slope
  - Terrain height compared to wheel radius
- **Traversability Map:**
  - Encodes obstacle areas with dilation





FASTNAV Architecture

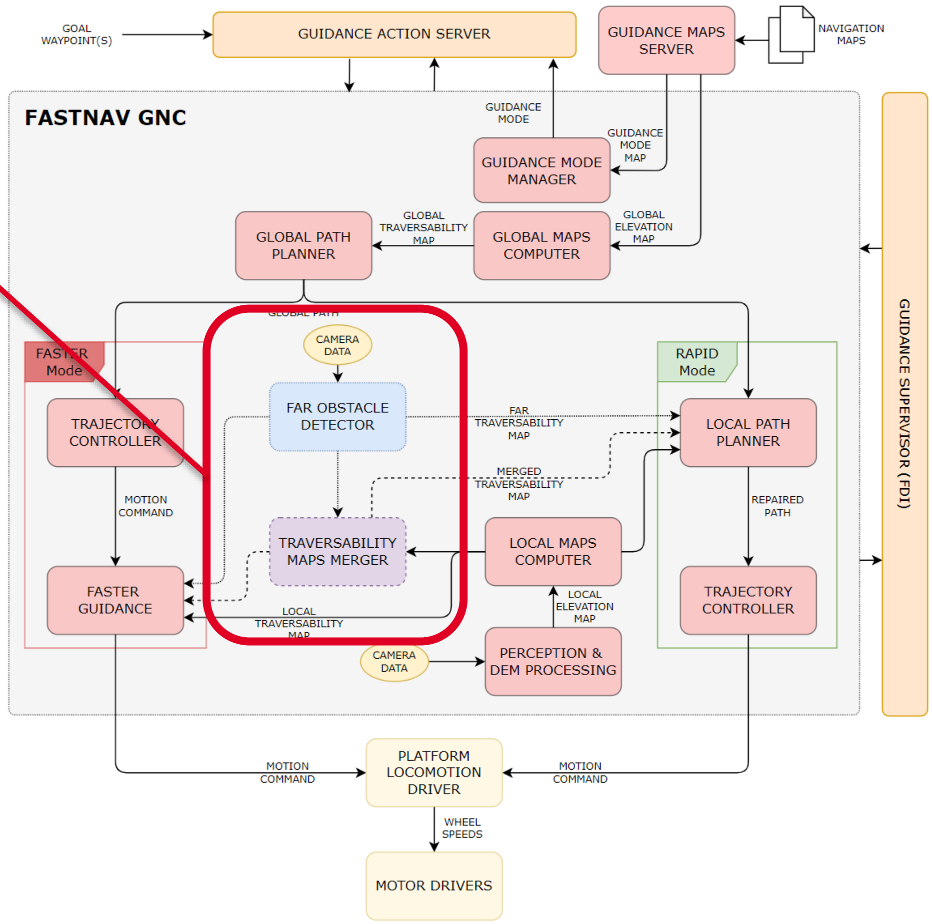
FAR OBSTACLE PERCEPTION

FAR OBSTACLE DETECTOR

- **Detects obstacles from afar for more efficient re-planning**
  - Detector uses Machine Learning Approach to Obstacle Detection based on YoloV8n
  - Detections are then transformed to create Far Traversability Maps using keypoints

TRAVERSABILITY MAPS MERGER

- Merges Local and Far Traversability Maps into single Merged Traversability Map, including Pose Propagation to account for rover motion



FASTNAV Architecture

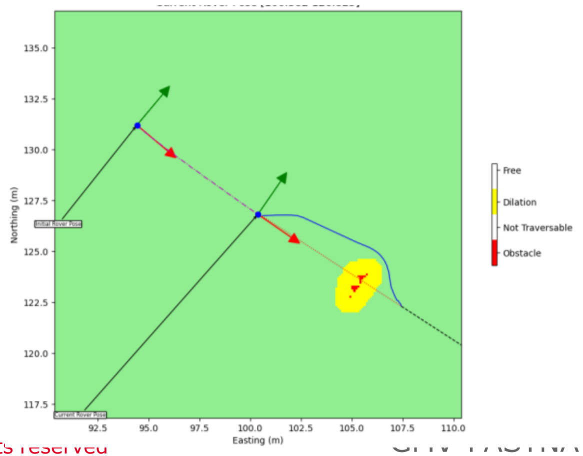
RAPID GUIDANCE MODE

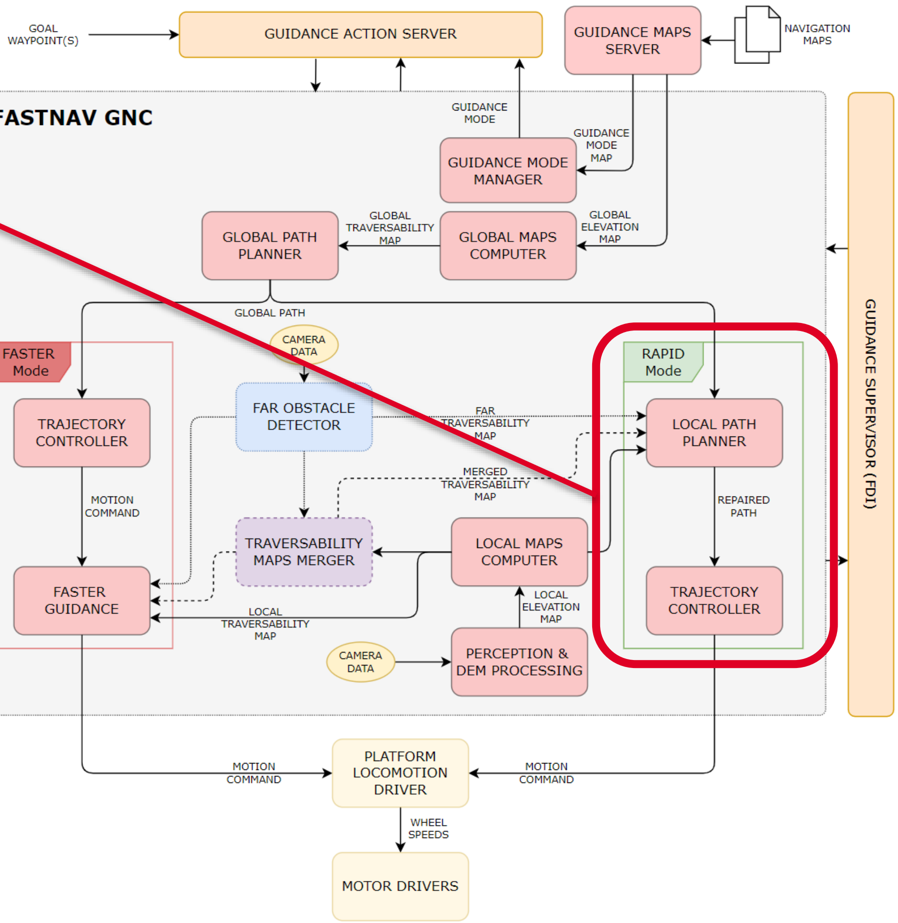
LOCAL PATH PLANNER

- Based on the FMM method
- Adapts the Global Path to find an optimal safe solution around perceived obstacles

TRAJECTORY CONTROLLER

- Based on C-pursuit
- Further extended to adaptively change parameters based on the path's complexity



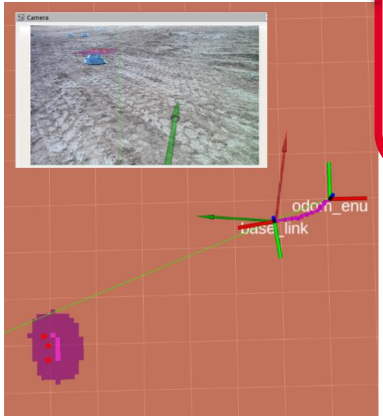


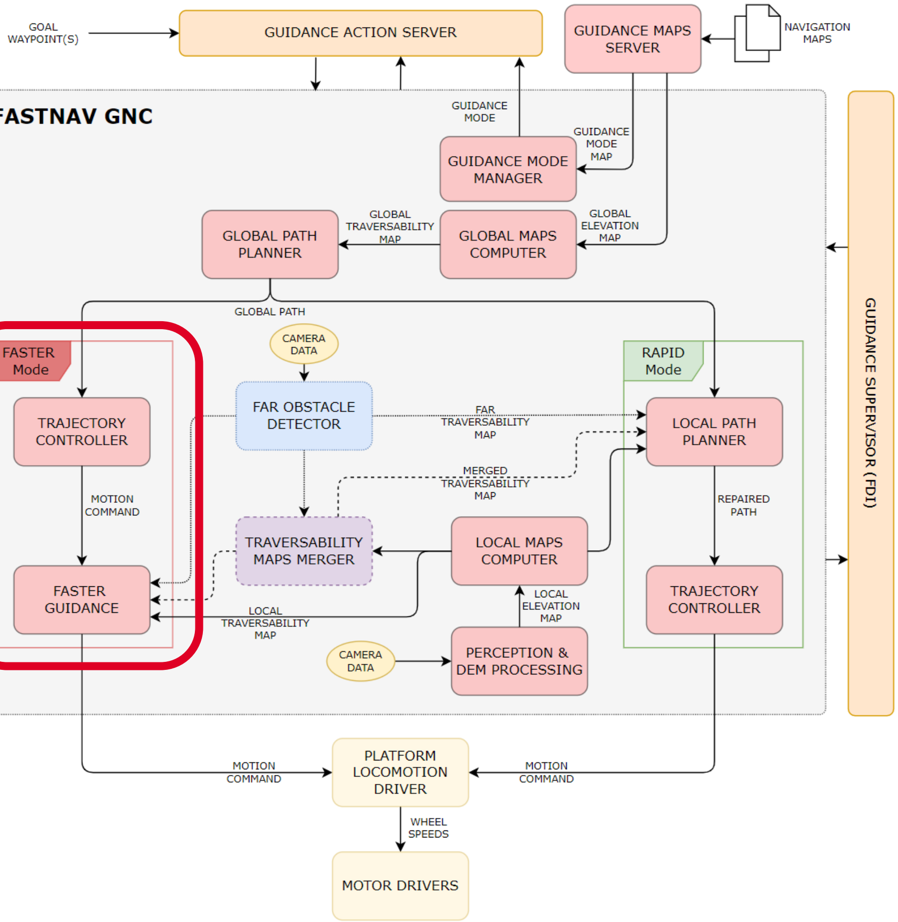
FASTNAV Architecture

FASTER GUIDANCE MODE

FASTER GUIDANCE

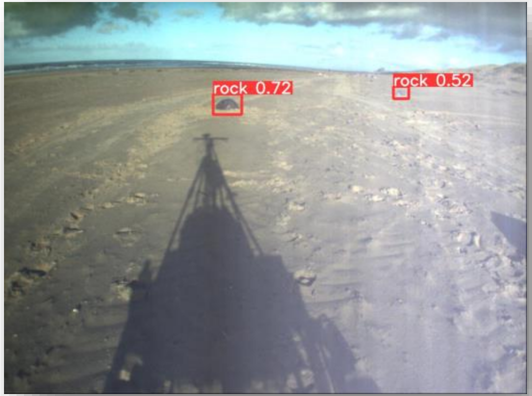
- Based on the reactive approach of Artificial Potential Field (APF)
- Designed for high-speed traverses with low obstacle density
- Receives the command tracking the global path and adjusts it to avoid obstacles
- Automatically detects challenging terrain (based on obstacles density, risk, and proximity) to request an "Override" to the safer RAPID mode

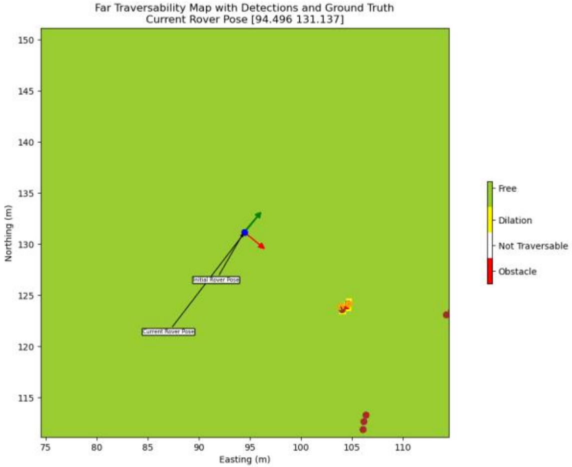




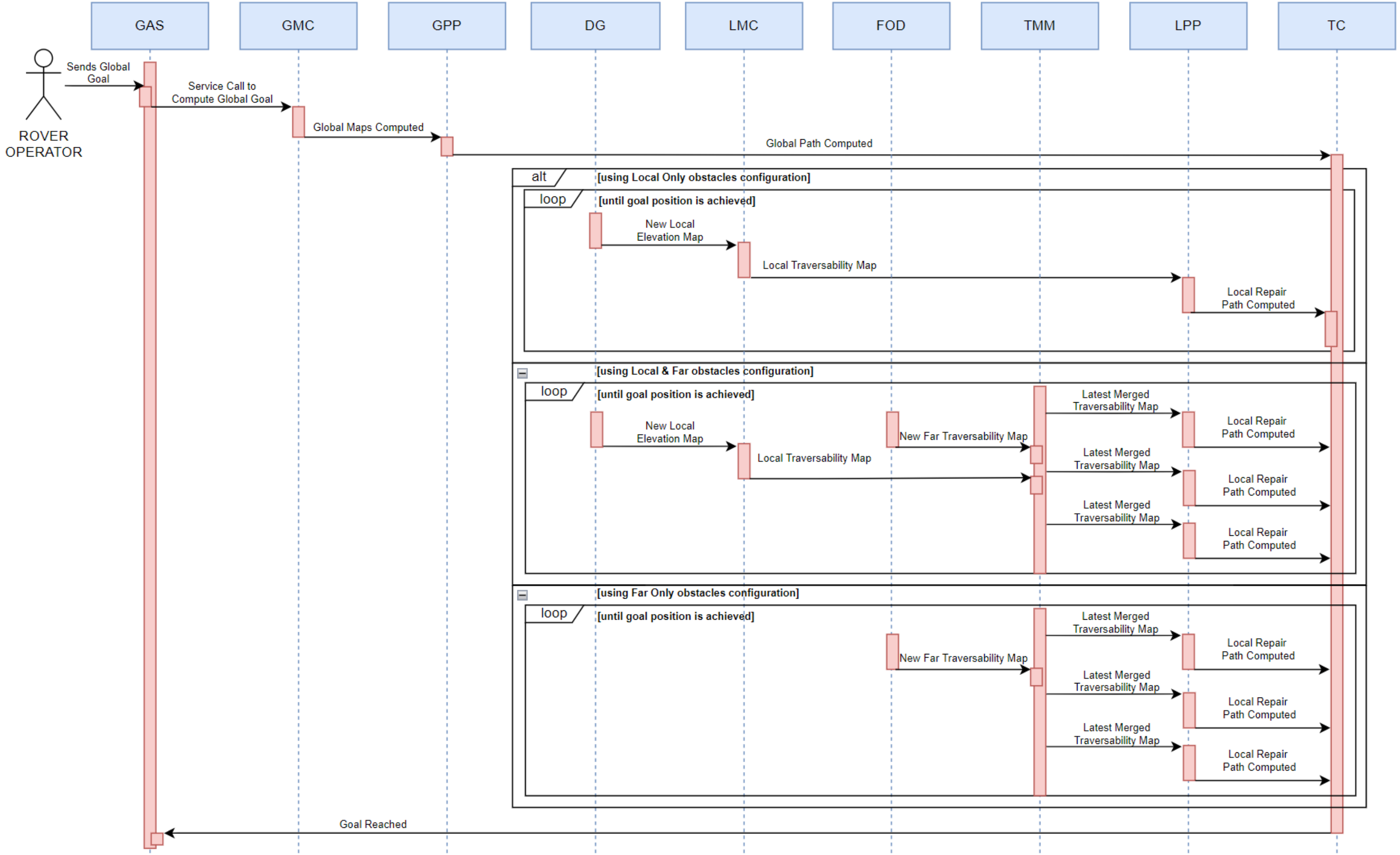
Detector Development & Training

- The selected model for inference is **YoloV8n** (based on speed and ability to run on CPU)
- Various Models trained on labelled data from the Katwjik Dataset, UK Quarry before TRR, and the data collected in Bardenas in week 1 of the Field Trial.
- **Tensorflow model embedded in ROS2 Python Node accessed via Service interface by the Far Obstacle Detector**

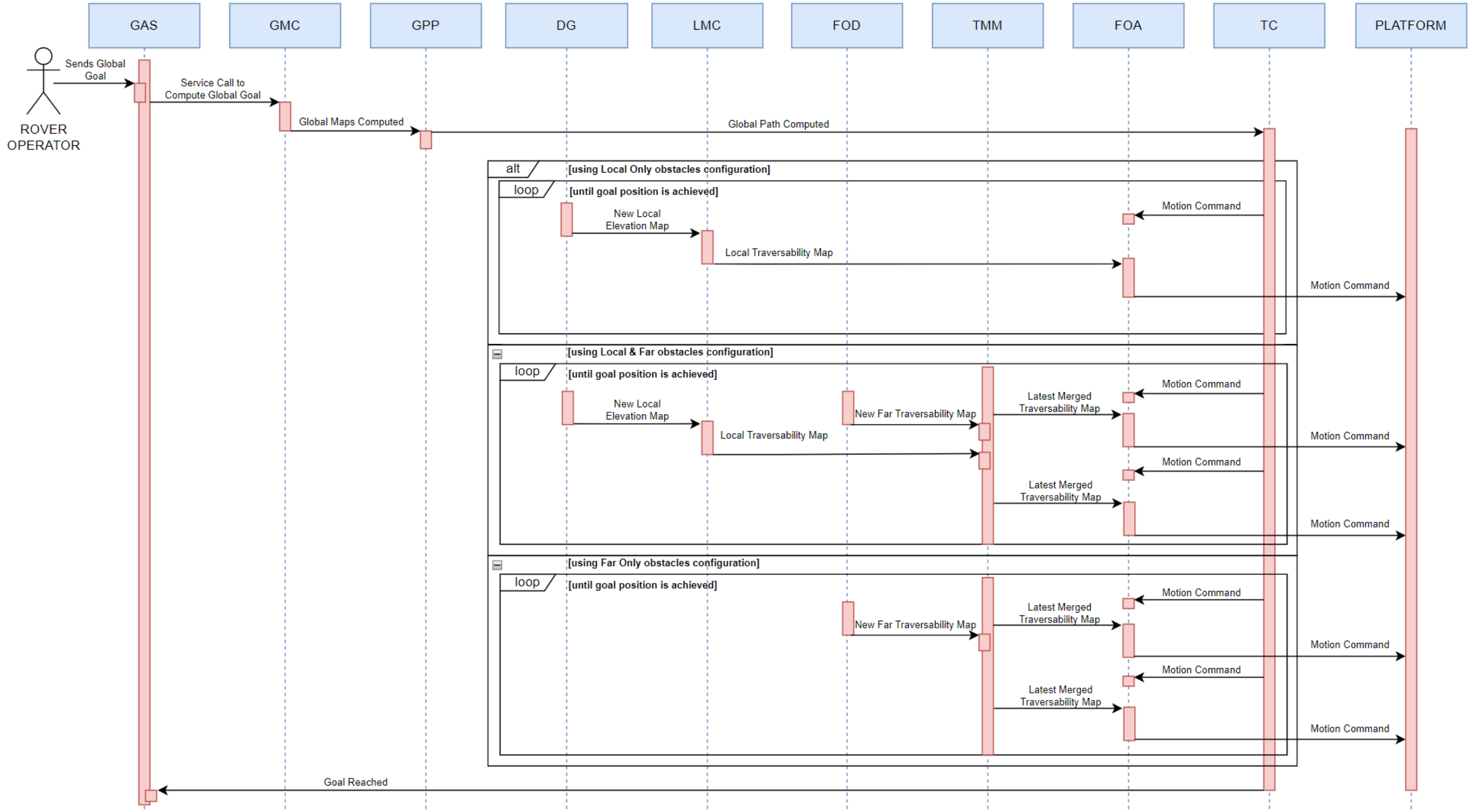




RAPID Mode Description



FASTER Mode Description



RAPID Platform Upgrades

RAPID Platform Upgrades

The RAPID Platform was upgraded in several areas to improve its capabilities in supporting a more demanding Field Trial (effort shared with on-going NAVISP LUPIN activity)

- **Endurance Upgrades (LUPIN):** The FASTNAV activity benefited from upgrades to increase the test duration of the platform, by introducing a “hot-swap” battery changing system, with an Uninterruptable Power Supply
- **Motor Driver / Power System Upgrades:** The existing Motor Drivers were replaced and the Power Systems upgraded to be more robust. Also, a Wireless E-Stop was integrated for safety
- **Networking Upgrades:** A Mesh Networking System from Ubiquiti was installed to provide greater testing range
- **Calibration Upgrades:** Extrinsic calibration based on AprilTag markers

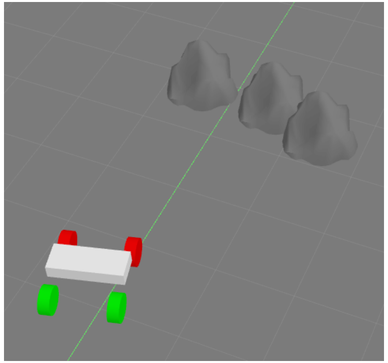
- Sensor Upgrades:
  - **GPS-RTK / IMU (LUPIN):** The SBG Systems Ellipse-D was eventually selected and integrated. This provides ground truth position, and absolute orientation (dual compassing)
  - **NAVCAM:** The NAVCAM from RAPID was upgraded to an OAK-D Long Range (LR), which offered more accurate depth maps with fewer artifacts, and also a longer usable range (~6m)

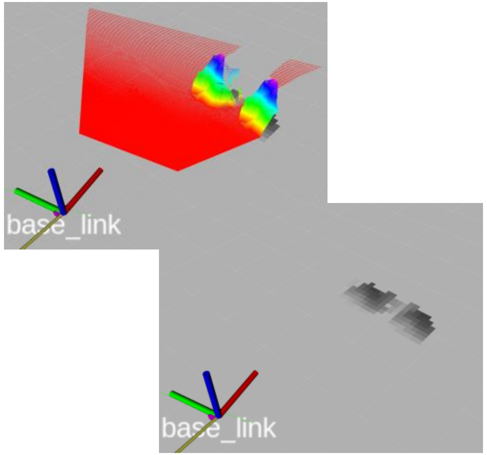
Test Campaign & Results

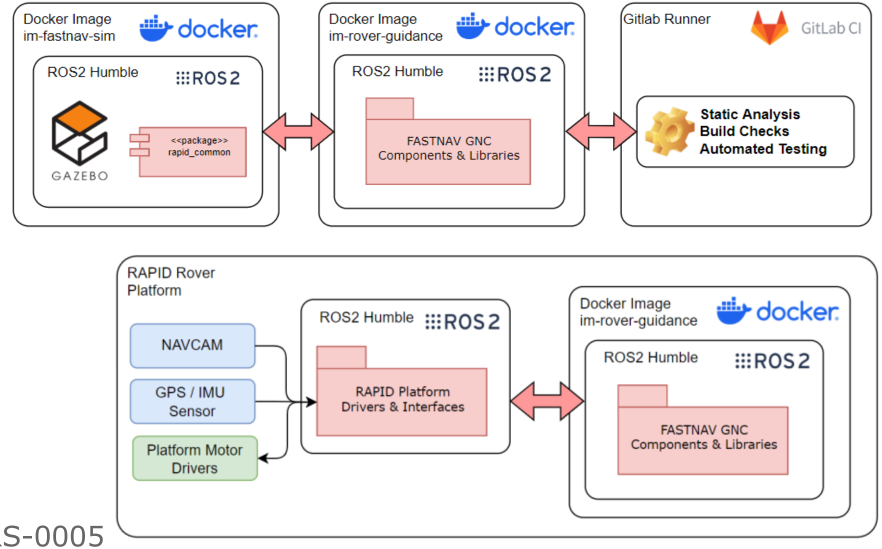
Testing Methodology

- **Containerised Development using Docker greatly simplified development & testing**

- **Unit Testing:** Automated static analysis, build checks, code quality using Gitlab CI
- **Integration Testing:** GNC integration tested thoroughly in simulation using Gazebo Environment
- **Preliminary Field Testing / Shakedown Testing:** Extensive shakedown tests performed on both Harwell Campus and at a local quarry
- **Field Test Campaign:** Analogue test campaign in Bardenas Reales, Navarra, Spain
- **Follow-Up Field Tests:** Further targeted tests performed in local quarry







Preliminary Field Testing / Shakedown Testing

- **Initial Integration Tests performed at Harwell Campus using BUNKER Platform while RAPID upgrades were completed**
- **The integrated RAPID Platform was tested at Upwood Quarry, Oxfordshire, with the help of Hills Group**
- **In total, 7 VERY useful days of Shakedown Tests were performed, combining calibration, tuning, characterisation and initial validation tests of the various GNC configurations**

Some rocks may have been harmed in the development of the FASTNAV GNC…

Field Test Campaign

Field Site Selection & Logistics Plan

- **A Field Site in Bardenas Reales, Navarra, Spain was selected, with a site survey performed in February 2024**

- **The Field Test Campaign was performed between 30/06 and 16/07**
  - A Field Team of 3 GMV-UK Robotics team travelled via Ferry (Portsmouth – Bilbao) under ATA Carnet
  - The Field Team exchanged one person at the end of the first week
  - The Field Team stayed in accommodation around Tudela, Spain, about ~20-minute drive from the field site

- **On-site Infrastructure was minimal (portaloo rented), with the Field Team transporting much of the needed equipment (Shelter, Generator, Table/Chairs etc.,) from the UK**

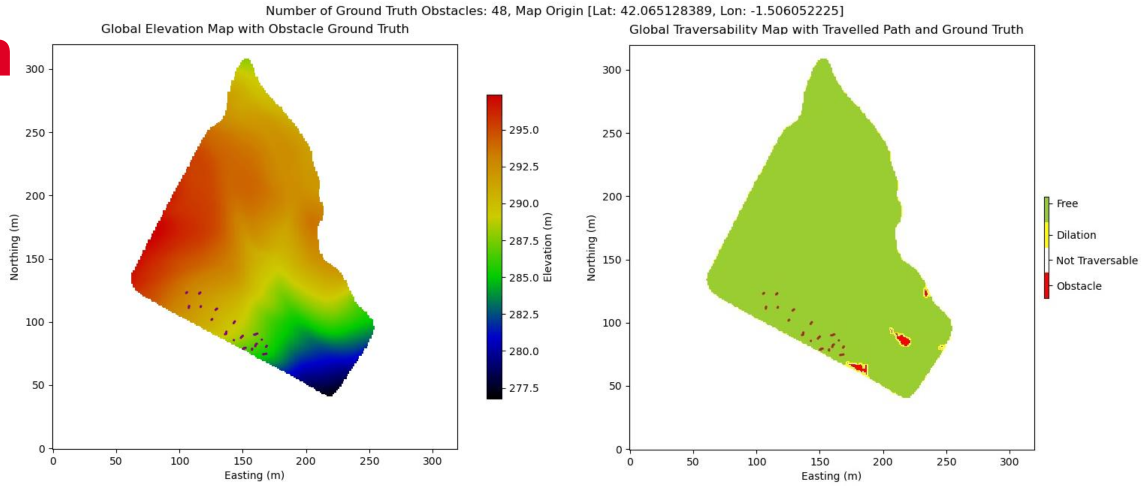
Field Test Campaign

Test Campaign Execution

- The Field Trial Campaign was successful overall, providing the opportunity to demonstrate several test cases

- Identified improvements were applied and a set of Follow-Up Field Tests performed in a Hills Group Quarry near Harwell Campus

- The Field Test Campaign was not without challenges, largely related to hardware failures out of the team's control. Nearly 1 week of testing time was lost waiting for repairs

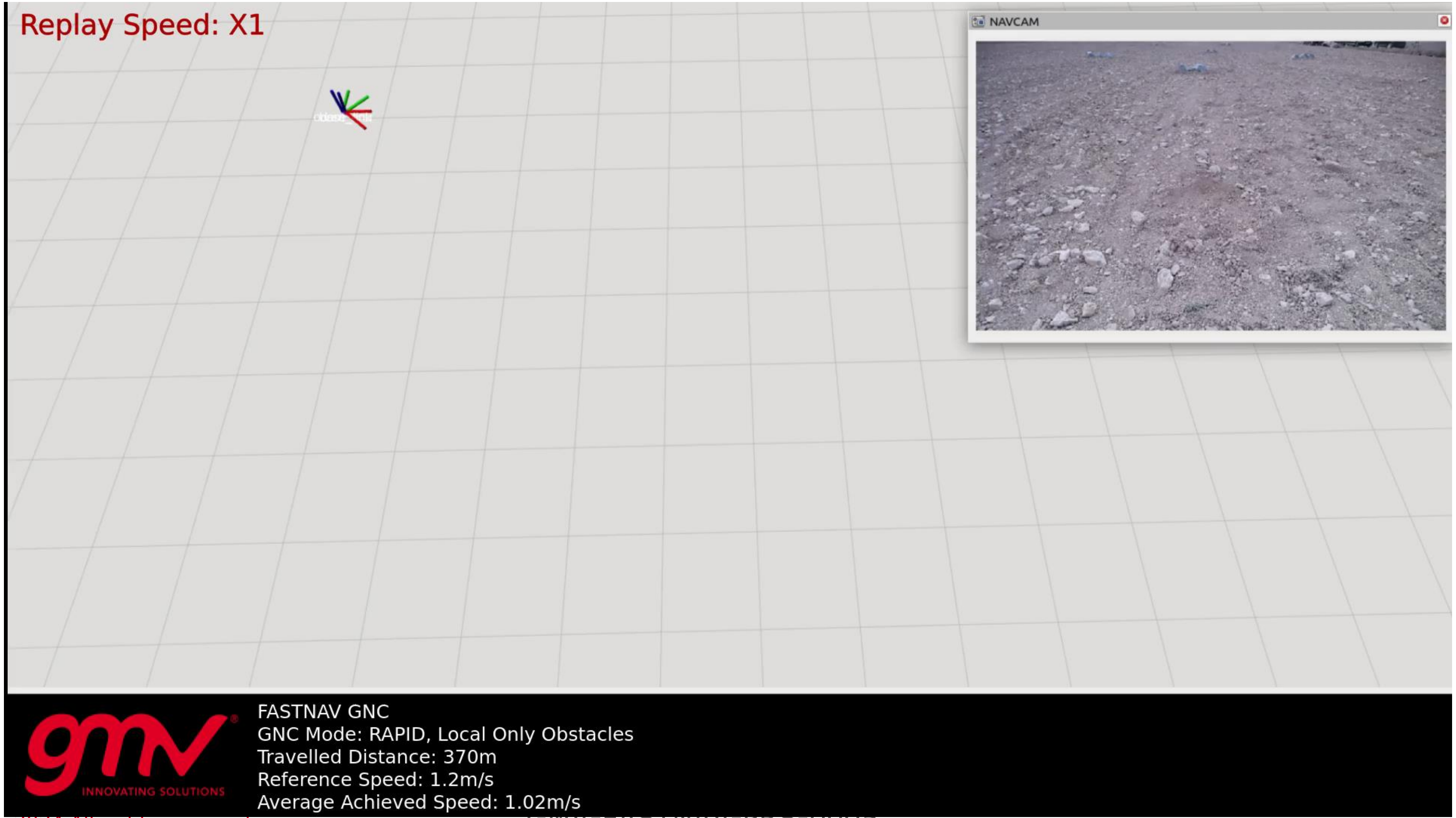


Test Results Summary

Test ID	Test Title	Pass/Fail	Comment
FASTNAV-FT-0010	RAPID Mode, Local Obstacles Only	PASS	Test was performed at MAX speed (1.2m/s) enveloping slower planned speed tests, given a lack of testing time.
FASTNAV-FT-0020	RAPID Mode, Far Obstacles Only	PARTIAL PASS	Test was hampered by hardware issues and eventually abandoned without achieving a Goal Waypoint. Far Obstacles Detection was shown to provide sufficient path repairs
FASTNAV-FT-0030	RAPID Mode, Local & Far Obstacles	PASS	Test was performed at 1.0m/s during the Follow-Up Field Tests
FASTNAV-0040	FASTER Mode, Local Obstacles Only	PASS	Test was performed at MAX speed (1.2m/s) enveloping slower planned speed tests, given lack of testing time.
FASTNAV-FT-0050	FASTER Mode, Far Obstacles Only	PASS	Test was performed at 1.0m/s during the Follow-Up Field Tests
FASTNAV-FT-0060	FASTER Mode, Local & Far Obstacles	PASS	Test was performed at 1.0m/s during the Follow-Up Field Tests

FASTNAV-FT-0010

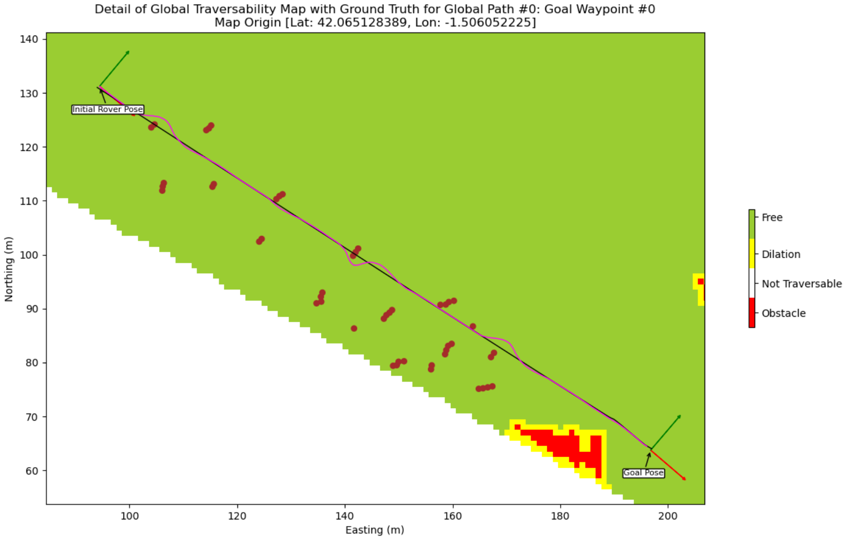
RAPID Mode, Local Obstacles Only

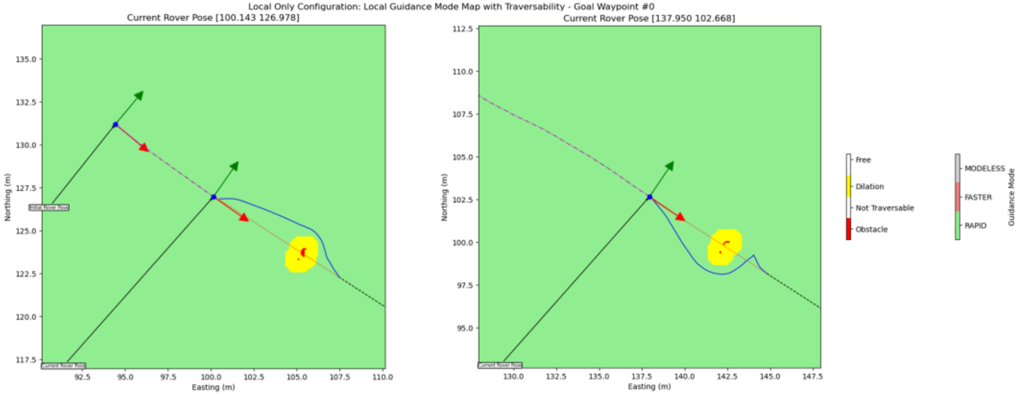


FASTNAV-FT-0010

RAPID Mode, Local Obstacles Only

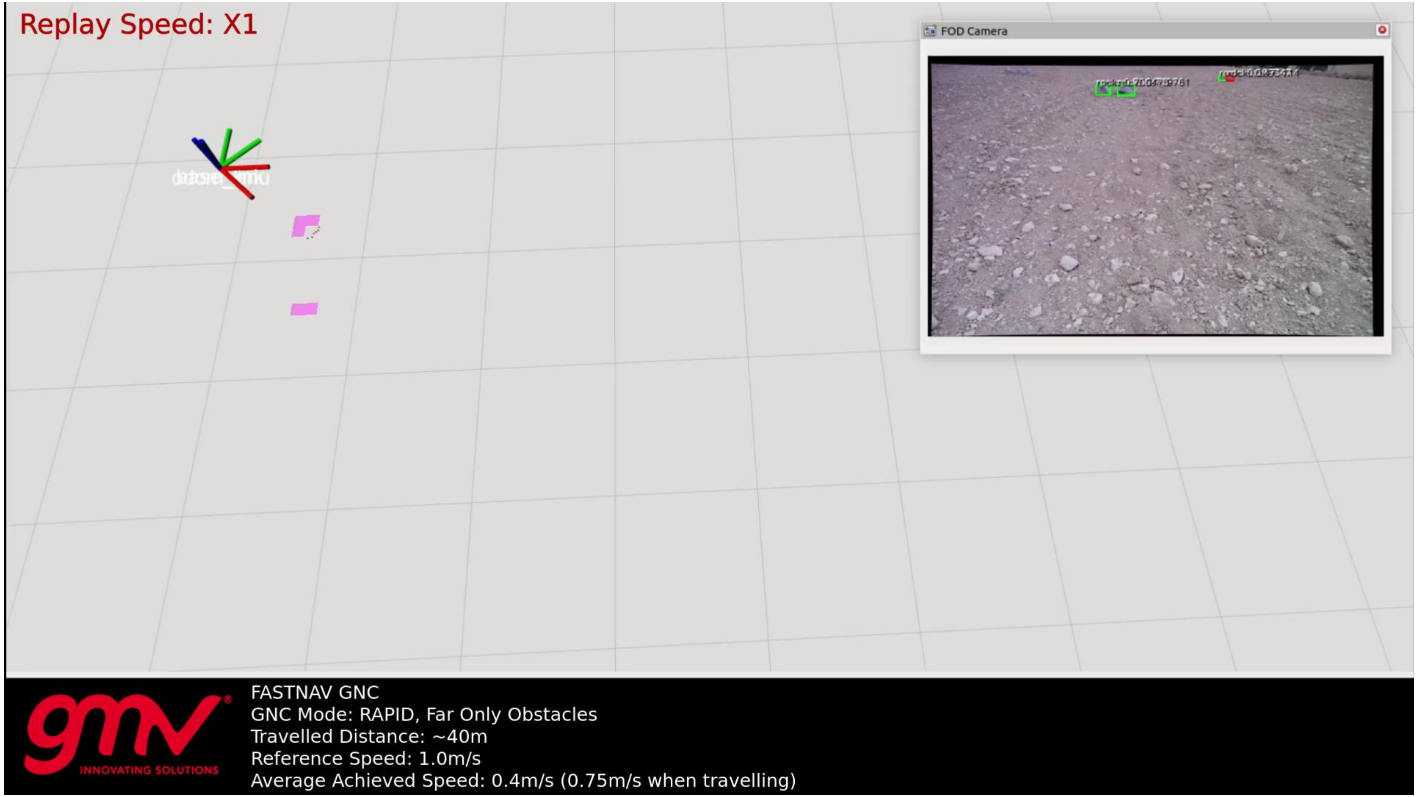
- **Total traverse of ~370m**
- **Average speed of 1.022m/s**
  - Considerable improvements thanks to the Adaptive TC
  - Between 2% and 8% across goals spent in Point Turn
- **3 waypoints successfully and safely reached, with several path repairs**
  - Local Path Planner sometimes flips side of the repair, forcing a point turn





FASTNAV-FT-0020

RAPID Mode, Far Obstacles Only



FASTNAV-FT-0020

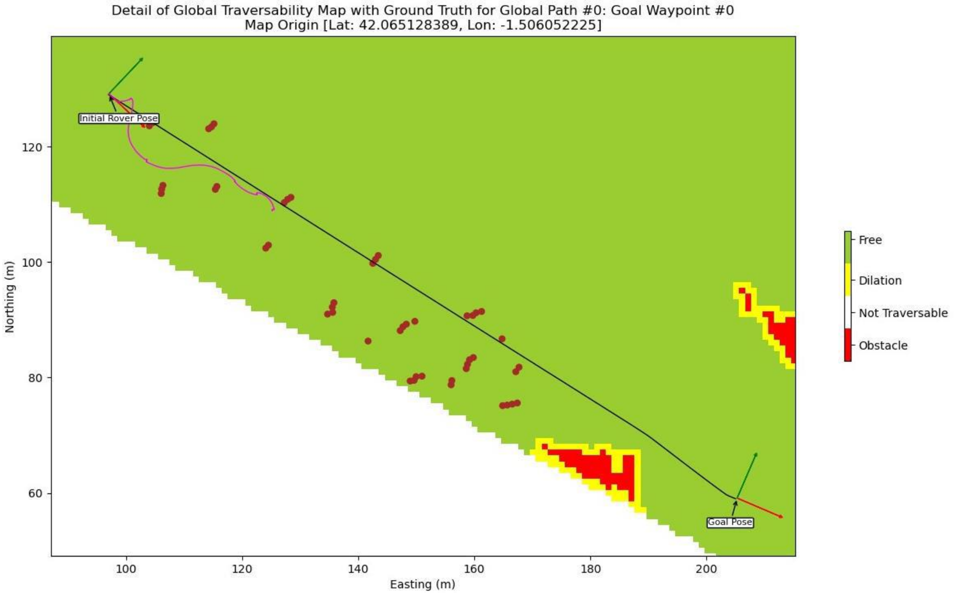
RAPID Mode, Far Obstacles Only

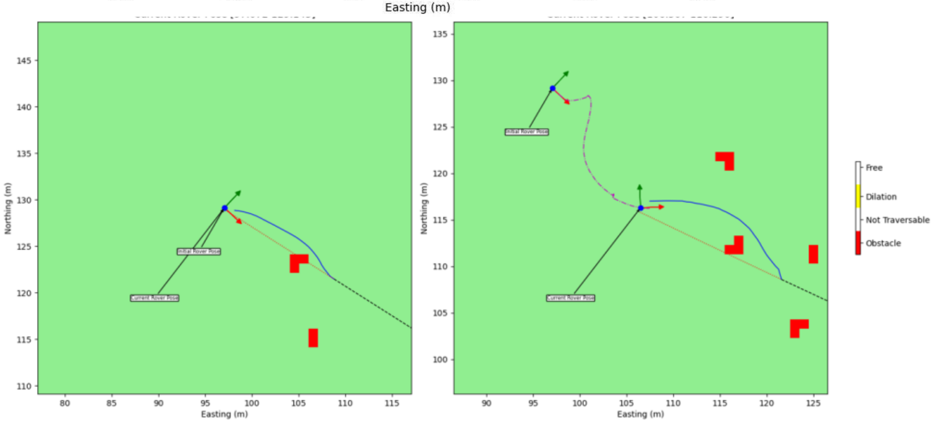
- This test case was significantly hampered by Camera driver problems, which made the rover stop often. Eventually it was abandoned after a few less-than-optimal avoidances

- This test case was not re-run in the Follow-Up Tests as FASTER Local+Far and Far Only were prioritised in the limited time available

- Overall, 40m distance was covered, with an average speed of 0.4m/s (due to the stop/start from camera restarts)

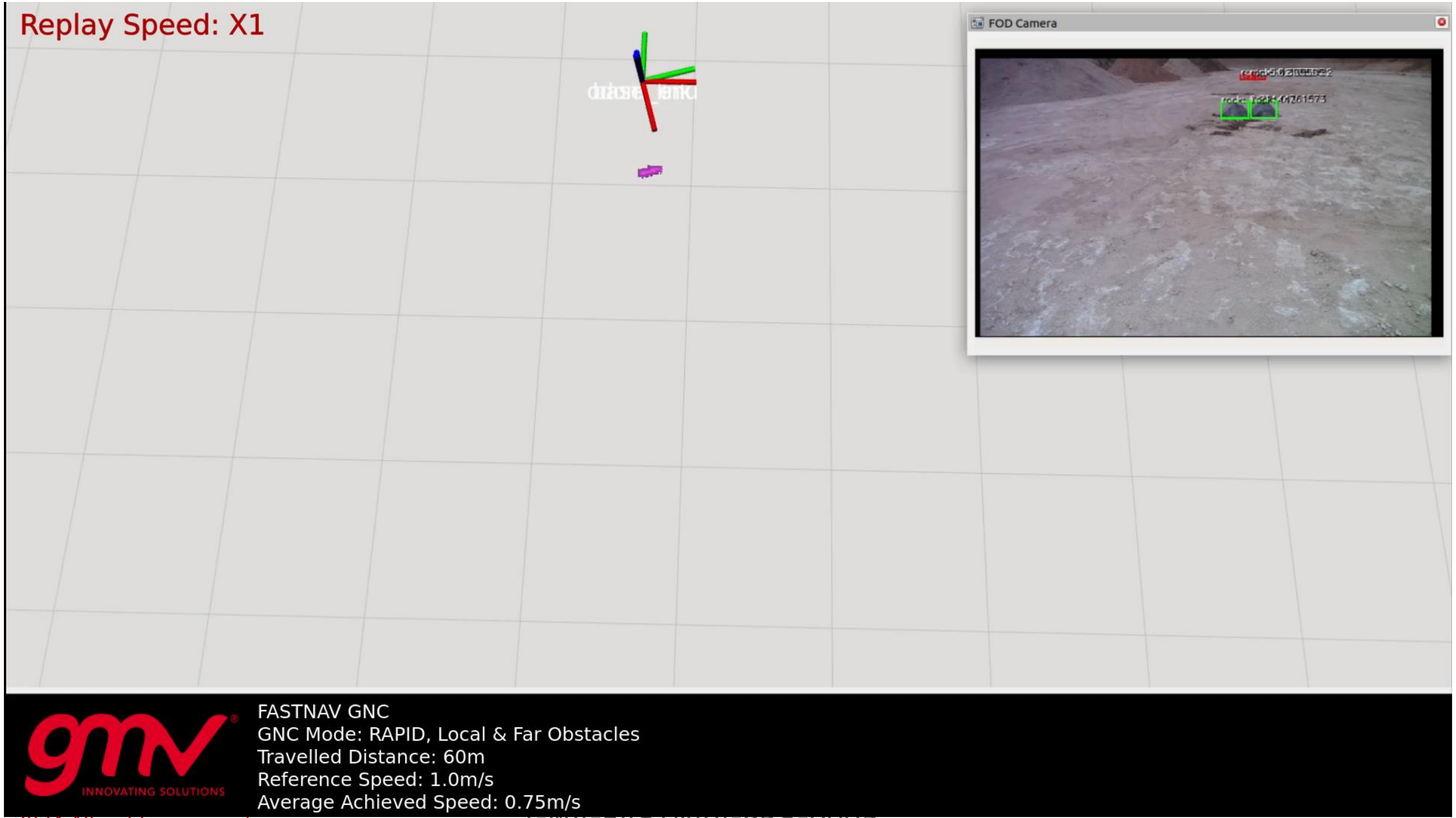
- The overall concept of Far detections however is better captured in RAPID Local & Far and the equivalent FASTER tests





FASTNAV-FT-0030

RAPID Mode, Local + Far Obstacles



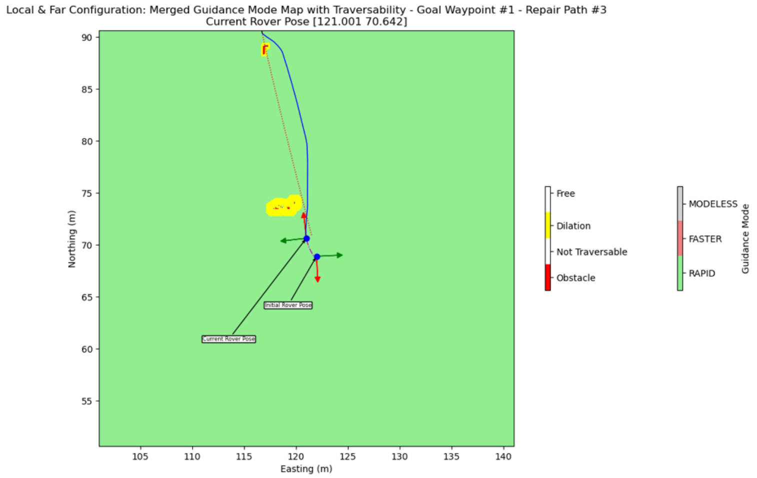
FASTNAV-FT-0030

RAPID Mode, Local + Far Obstacles

- **Total traverse of ~61m**
- **Average speed of 0.81m/s (ref 1m/s)**

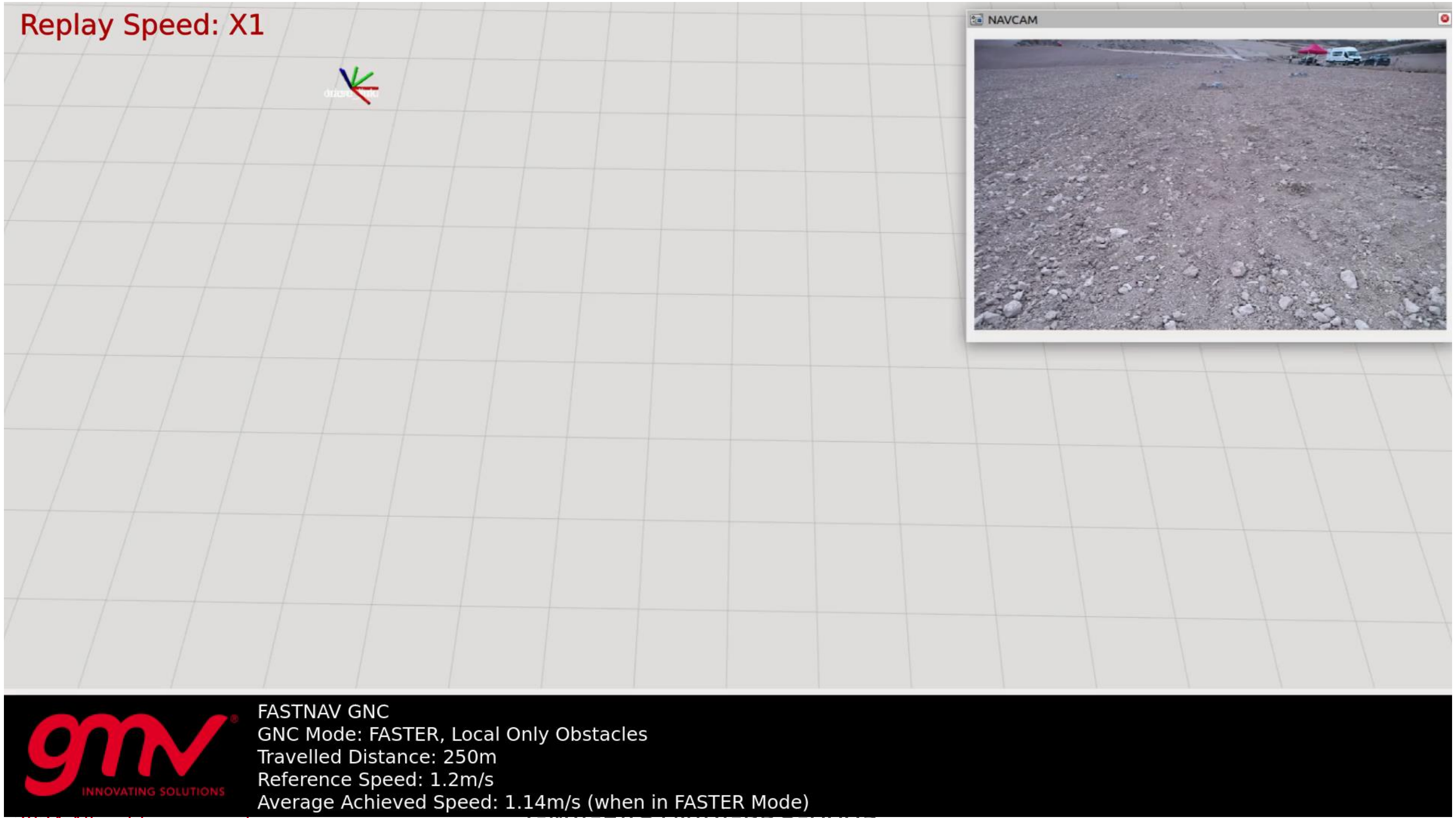
- **Successful test overall**
- The Merged Traversability Map at 0.1m resolution improved the stability of the system

- **Showcase the advantage of using both local and far obstacles**:
  - a far detection (~18m range from rover) as well as a local detection (~3m range from the rover) both intersect the global path, with the LPP computing a repair path which avoids both set of obstacles within a single, efficient repair path.



FASTNAV-FT-0040

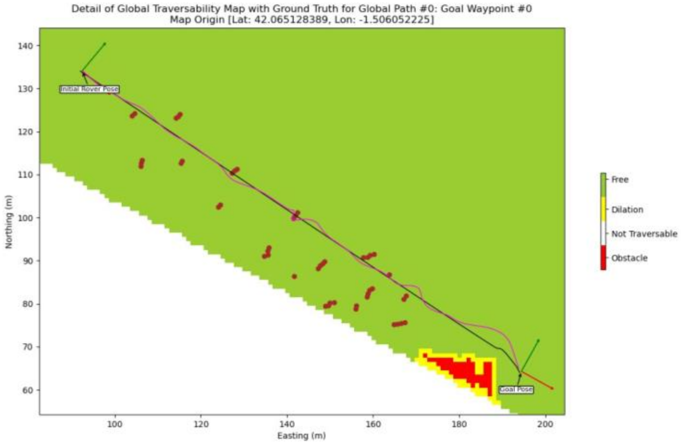
FASTER Mode, Local Obstacles Only

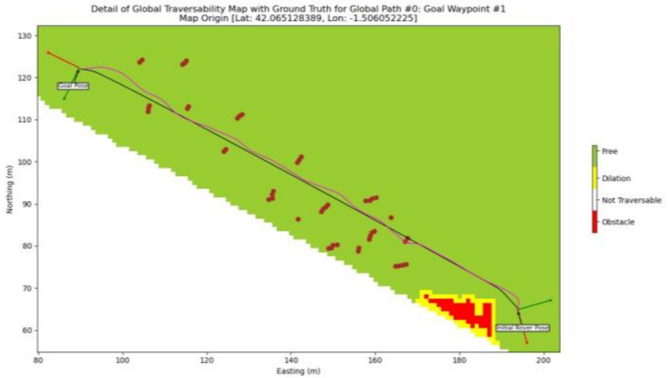


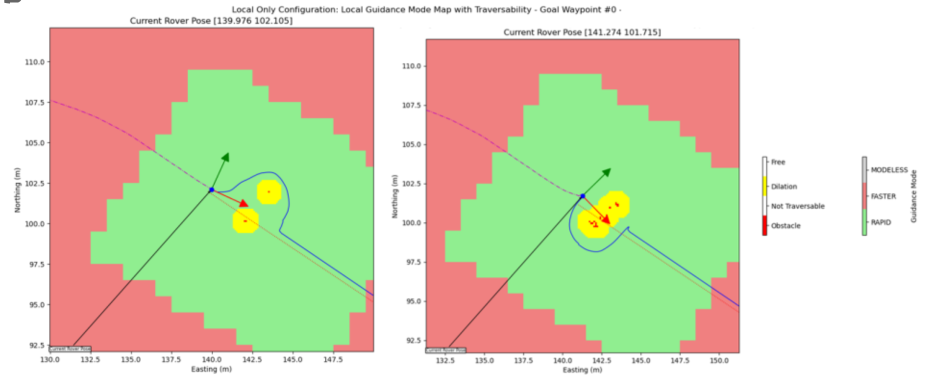
FASTNAV-FT-0040

FASTER Mode, Local Obstacles Only

- **Total traverse of ~240m**
- **Average speed in FASTER of 1.14m/s**
  - Compared to 1.02m/s of the RAPID local only test
  - Mainly thanks to the lower time spent in point turn (0.068% of the time opposed to the 8.295% in the RAPID test)
- **3 successful RAPID overrides during the 2 goals**

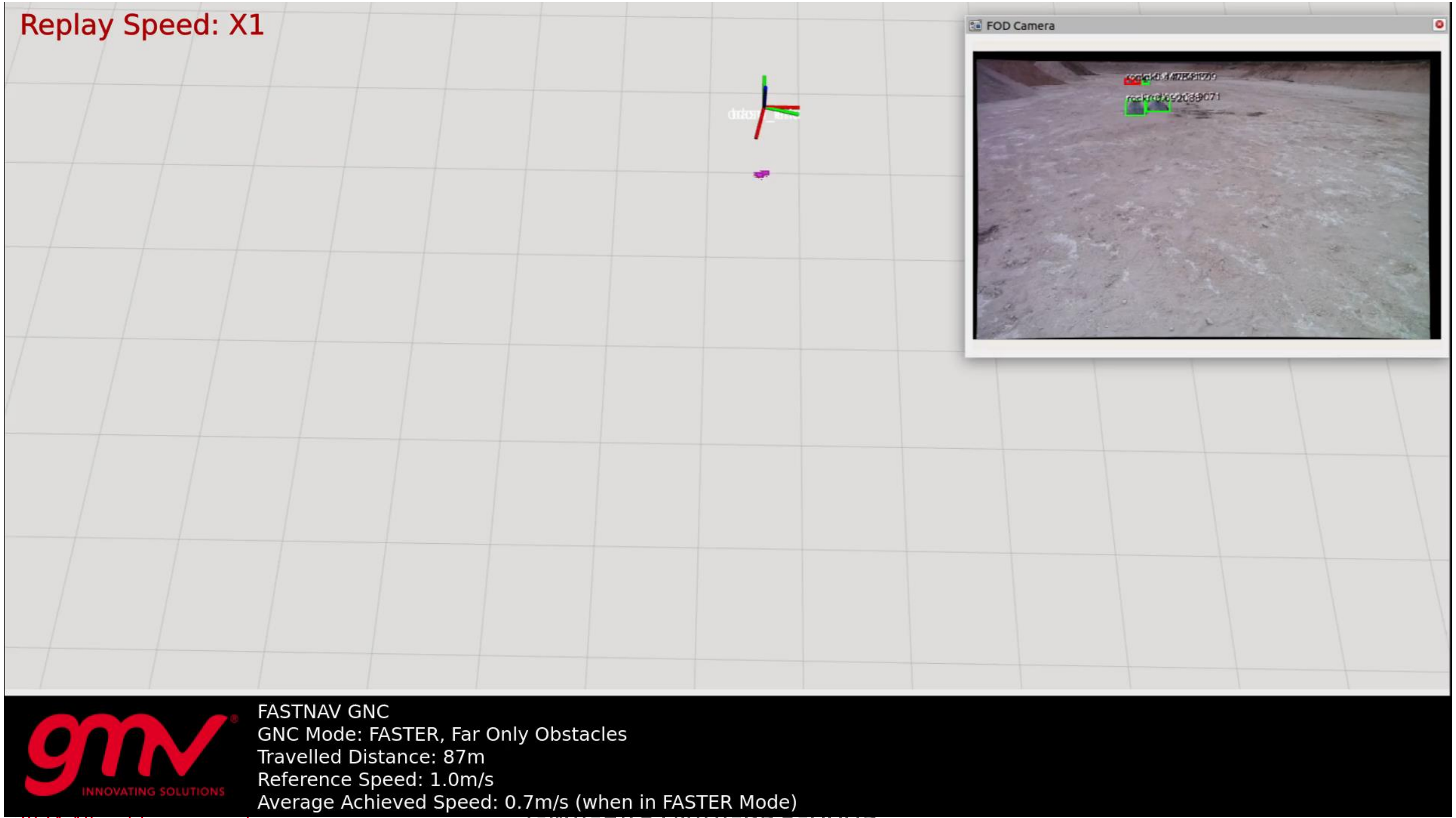






FASTNAV-FT-0050

FASTER Mode, Far Only Obstacles

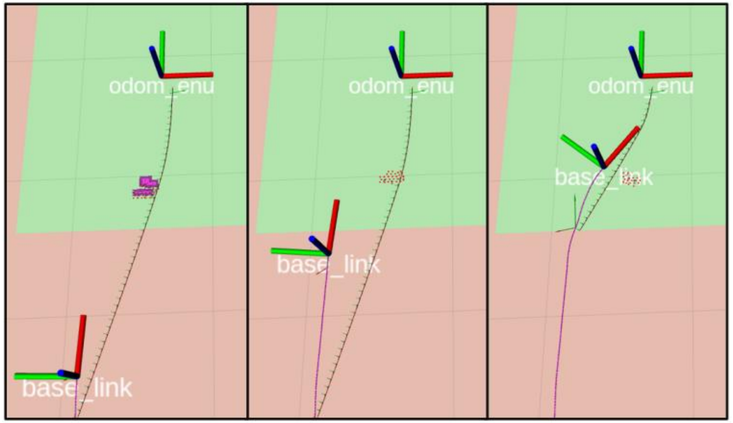


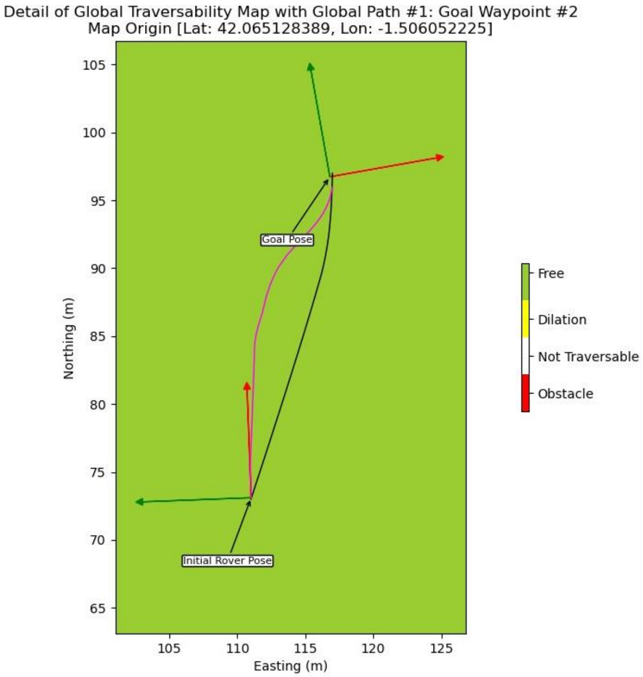
FASTNAV-FT-0050

FASTER Mode, Far Only Obstacles

- Shorter traverse of ~87m
- Average speed in FASTER of 0.94m/s (ref 1m/s)

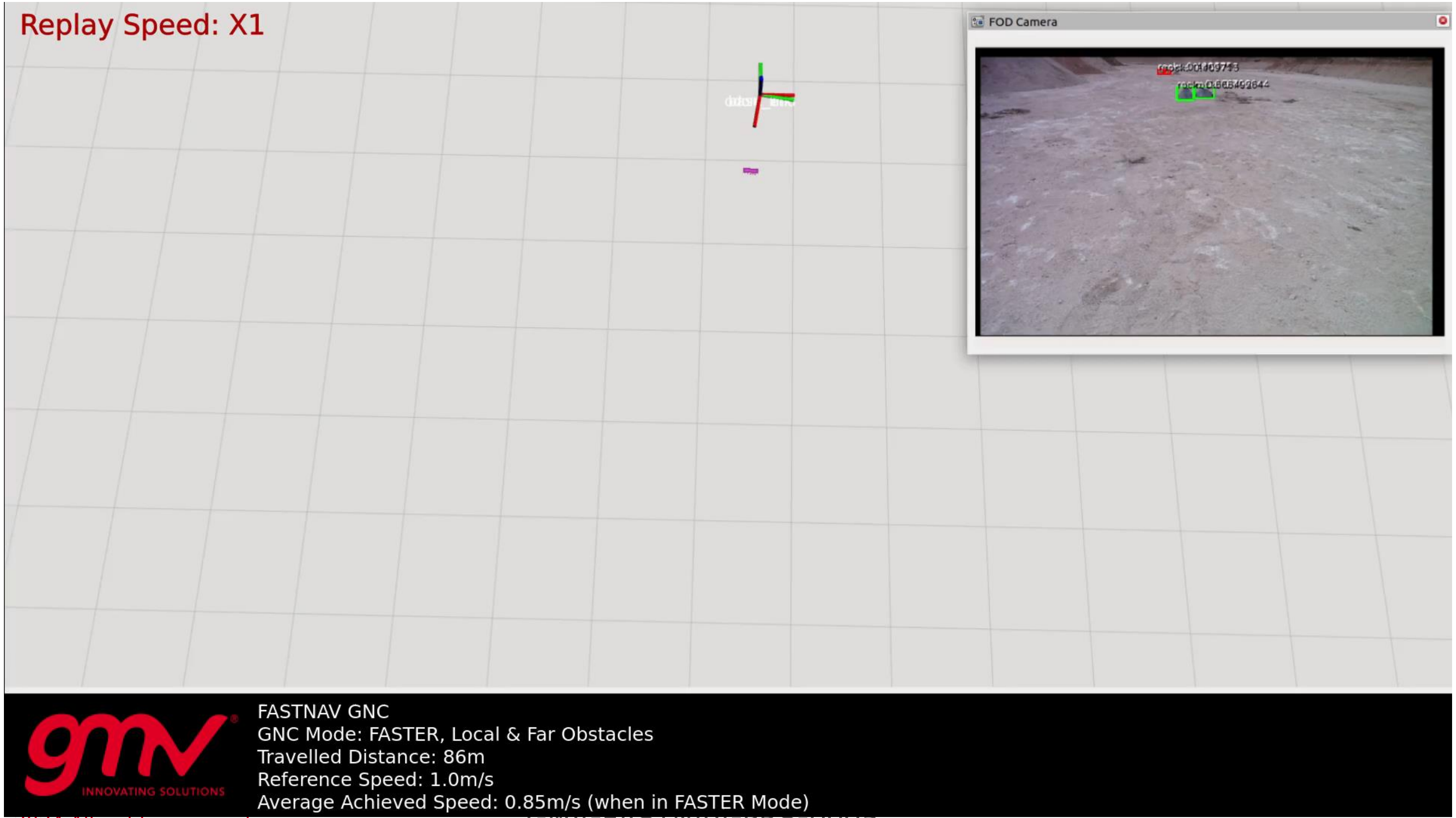
- During the 3rd waypoint it shows detected obstacles at ~17m with a smooth repaired path





FASTNAV-FT-0060

FASTER Mode, Local & Far Obstacles



FASTNAV-FT-0060

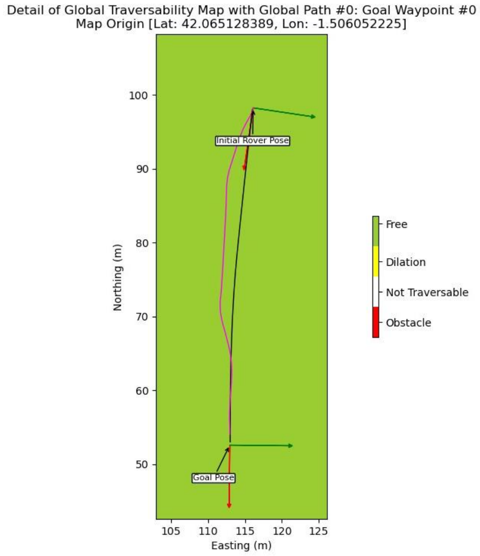
FASTER Mode, Local & Far Obstacles

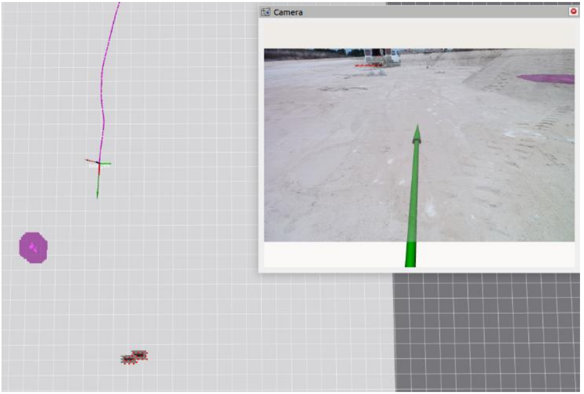
- **Total traverse of ~90m**
- **Average speed of 0.86m/s (ref 1m/s)**
- **100.0% of the time spent in skid-steering**

- This traverse showcases the advantages of using both Far and Local Obstacles. FOD detects a far obstacle and the FOA then starts applying a small correction from a distance of ~15m

- A local obstacle is detected closer to the rover, the FOA applies a stronger correction to avoid it

- After clearing the local obstacle, the FOA applies corrections to finish avoiding the first obstacle and reaches the goal smoothly





Conclusions

Conclusions

- **A new Multi-Range and Multi-Mode Rover GNC has been developed in the continuous drive paradigm, successfully combining both Local (up to 6m) and Far (up to 20m) Obstacle Detection strategies**

- **This new “FASTNAV” GNC System includes a refactored mode using locally optimising path planning as well as a newly developed reactive Artificial Potential Fields (APF) mode, selectable based on global knowledge and local determinations**

- **The RAPID Platform has been upgraded to provide significant improvements for planned and future field trials, allowing us to gather ever better data and improve flexibility in how we can make use of the platform**

- **Thanks to these developments, the FASTNAV GNC System was demonstrated through a series of representative analogue tests to achieve (and surpass in some cases) the challenging performance requirements:**
  - RAPID Mode (Target 0.7m/s): Achieved 1.02m/s (RAPID Local Only)
  - FASTER Mode (Target 1.0m/s): Achieved 1.14m/s (FASTER Local Only)

GSTP Follow-On Discussion

Main Objectives & Outline Plans

While there are many things that could be identified as Future Work, we are basing follow-on plans around the objective of eventual productization of this GNC solution through industrialisation → implying first a programme of Technical Maturation & Optimisation

This Technical Maturation & Optimisation (TRL 5) may consist of:

- **Further consolidation, maturation and optimisation of the algorithmic and software implementation of the FASTNAV GNC solution using extended breadboarding, including OBSW development plans**
- **Definition of clear Mission Scenarios and Detailed Requirements Specification → Expansion of Use Case analysis, CONOPS refinement and Technical Roadmapping**
- **Analysis of further potential technical extensions, including:**
  - Integrating aspects of High-Level Planning / Decision Making to further increase the levels of on-board autonomy
  - Addressing the need for Navigation to enable Fast Lunar Rovers
  - Terrain-Aware and Risk-Aware GNC Concepts
  - Exploring further ways to harness AI/ML for on-board tasks
  - Ground Segment
- **More expansive Analogue Field Testing, focussing on challenging operational scenarios and use cases with a view to improve robustness and resilience**

GMV intend to prepare a GSTP Follow-On (Phase 2) submission at the earliest possible opportunity late 2024

Thank you

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INNOVATING SOLUTIONS