TRL 6 DEMONSTRATION OF THE SFR MISSION MOBILITY CONCEPT ON A LEON4 PROCESSOR

Anthonius Daoud-Moraru[(1)], Duncan Hamill[(1)], Ben Brayzier[(1)], Chris Barclay[(1)], Warren Hamilton[(1)], Róbert Marc[(1)], Piotr Weclewski*[(1)], Michael Dinsdale[(1)], Max Braun[(1)], J. Ricardo Sánchez Ibáñez[(1)]

[(1)] *Guidance Navigation and Control Department, Airbus Defence and Space Ltd., Stevenage, SG1 2AS, UK*
*Corresponding Author - piotr.weclewski@airbus.com

ABSTRACT

At the end of 2022 and beginning of 2023, a series of tests were conducted to demonstrate the TRL 6 readiness of Guidance Navigation and Control (GNC) algorithms developed by Airbus Defence and Space (ADS) for the Sample Fetch Rover (SFR) mission.

These tests consisted of executing algorithms on a space-qualified-representative flight processor, mounted on a breadboard rover which performed an SFR-mission representative Mobility operation at the ADS Mars Yard in Stevenage. In particular, two use cases were addressed. For the first use case the rover autonomously drove almost 20 metres while avoiding obstacles. For the second one the rover approached a location with a certain heading, as if entering a depot area where a sample to fetch would be located. This paper details these tests and presents not only the steps followed to prepare for them but also the successful results obtained as well as some conclusions.

1. INTRODUCTION

During September of 2022, a series of field trials were performed as part of the Integrated Breadboard 2 project (IBB2). They served to test and validate the functioning of multiple GNC and localisation algorithms on the Field Trial Rover System (FTRS). The implementation of these algorithms run on an on-board computer that is not an SFR mission representative. The main reason behind this decision in those trials was to focus on the functionality rather than on their performance. The latter was assessed in simulation to close TRL 5 [1].

Therefore, the natural continuation to mature the technology was to achieve TRL 6. To do this, a mission representative processor was used to investigate the performance of the implementation. For this, as can be seen in Fig. 1, a LEON4 development board (Cobham Gaisler GR740) was physically installed on FTRS.

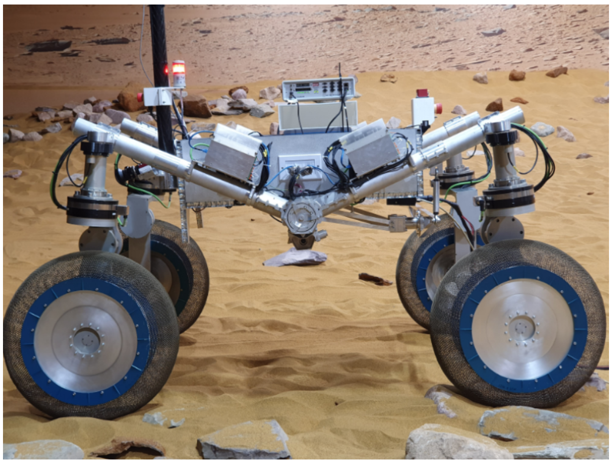

Figure 1. LEON4 development board, mounted on Field Trial Rover System (FTRS)

The enhanced autonomy algorithms in question were developed during SFR A/B1/2 study phases. They included heritage Autonomous Navigation (AutoNav) algorithms integrated with new components: Absolute Global Localisation (AGL) and the integrated Perception algorithm supplied by CNES, all structured in new operating modes developed for SFR mission context. Moreover, the lower levels of the SFR design "GNC-stack" (dedicated to driving and localisation) were already mature and extensively reused from the Rosalind Franklin Mission - Rover (RFM-R, previously known as ExoMars Rover), which have been validated for flight (TRL 8).

The tests, 4 in total, were organised according to the perception system used (in-house from Airbus or the Airbus CNES Autonomous Navigation (ACAN) CNES system) and the mission operation performed (AutoNav traverse or depot approach using AGL). The AutoNav tests consisted of commanding the rover to autonomously drive to a target 18 metres in front of it. A mock-up of a rock was placed in the middle of this line, so the rover had to autonomously detect it, assess it as

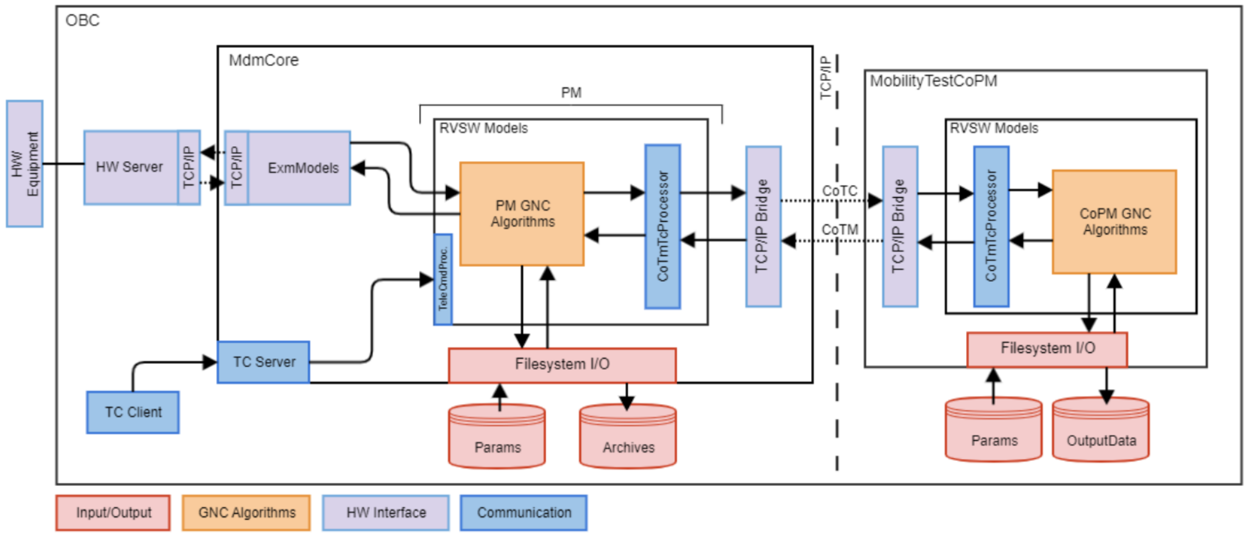

Figure 2. The top level IBB2 PIL architecture [1]

an obstacle and avoid it. The test results showed that the rover successfully completed the traverse avoiding obstacles with AutoNav running on the GR740. The second round emulated a mobility part of the fetching operation in which the rover must approach the location where a hypothetical sample would be located along a pre-planned path. For improving the accuracy in the localisation, corrections were obtained by executing AGL-D (D for "Depot") utilising a priori and rover perspective terrain information.

The results demonstrate that the GNC enhanced autonomy algorithms developed by Airbus Defence and Space are robust enough to be run on space-qualified flight processors. The rover achieved in all cases the imposed objectives of safety and efficiency. Additionally, the rover GNC algorithms are demonstrated to be compatible with different perception solutions. The test review concluded that the SFR GNC autonomy algorithms stack has achieved a readiness of TRL 6.

This paper is organised as follows. First, a quick introduction to architecture is presented. Second, the algorithms under test and use cases are summarised, followed by test setup description. Finally, the test results are presented and conclusions are drawn.

2. ARCHITECTURE

The IBB2 GNC architecture presents the natural evolution of Unitary Bread Board (UBB) and IBB1 developments [1]. The core of the solution comprises the Processor In the Loop (PIL) closed loop test harness, interfacing with the hardware abstraction layer that communicates with the rover hardware. This solution follows a flight-like architecture where the GNC uses the main processor (in flight less capable and more critical OBC, replaced by a commercial-off-the-shelf PC for breadboarding purposes as it is not influencing performance of GNC algorithms) to manage interfacing and schedule execution, and utilises the co-processor for more intensive computations related to navigation stack. The overall architecture is presented in Fig. 2.

With regards to the hardware used, a Cobham Gaisler GR740 development board was used as a representative test processor. This system implements a quad-core LEON4 SPARC-V8 processor running at 250MHz, as well as supplementary functions such as Ethernet I/O for real-time communication with the rest of the system. One of the most challenging obstacles was to configure communications between the COTS OBC (representing the main processor managing the execution of the Mobility system and running a Linux operating system) and the GR740 board (used as co-processor executing absolute localisation and navigation algorithms), running with the RTEMS OS.

3. TARGET ALGORITHMS AND USE CASES

As presented through SFR A/B1/2 study phases, the enhanced autonomy algorithms consist of AutoNav, FOPSA, AGL and the integrated CNES Perception function [1]. It is recalled that the lower levels of the SFR design GNC-stack (dedicated to driving and localisation) were extensively reused from the RFM-R mission GNC, which have been validated for flight (TRL 8).

Tab. 1 lists the use case definitions for the IBB2 Quarry Shakedown. This table encompasses the complete use cases that were envisioned from which the detailed quarry demonstrations test plan was derived. For the purposes of the TRL 6 demonstration of the autonomous navigation stack, covering all integrated system functionalities including CNES Perception and AGL, use case #4 (IBB2-UC-4) and use case #8 (IBB2-UC-8) were selected. Due to the size limitations of the Mars Yard, AutoNav test length was adjusted and AGL-D was reduced to the approach to a single sample tube and the continuation of Mobility operations in the depot, after a hypothetical successful tube acquisition.

Table 1. IBB2 field trials use cases

ID	Use Case	Primary Objective
IBB2-UC-1	FollowPath	Demonstrate FPath functionality
IBB2-UC-2	HDD (Human Directed Drive)	Exercising CheckPath as applicable for both difficult traverse, plus nominal in depot driving operations
IBB2-UC-3	FOPSA	Demonstrate FOPSA functionality
IBB2-UC-4	AutoNav	Demonstrate AutoNav functionality
IBB2-UC-5	Waypoint Navigation	Demonstrate GNC to follow defined waypoints
IBB2-UC-6	Traverse Driving	Demonstrate AGL-T functionality
IBB2-UC-7	Mock SRL Approach	Demonstrate GNC in the presence of a mock-up SRL structure
IBB2-UC-8	In Depot Driving	Demonstrate AGL-D functionality

4. TEST SETUP

After successful field trials concluding TRL 5, the TRL 6 tests were performed at the ADS Mars Yard out of practicality, namely extended time necessary to perform the tests. The system was presented in similar (adapted) use cases, but execution of them took much longer due to the limited computational resources of the mission target processor.

The scenario for the test is an adaptation of IBB2 Use Case #4 and #8, but is constrained by the size of the Mars Yard. AutoNav was performed as a regular run through the middle of the Mars Yard, with a single obstacle present, as shown in Fig. 4 and Fig. 5. Depot driving was specified in relatively flat terrain with no obstacle present, thus the same region of the Mars Yard was used with the AutoNav obstacle removed and the full width of the yard used (Fig. 8).

To enable AGL-D testing, reference data (Ortho-Rectified Image (ORI) and Digital Elevation Model (DEM)) needed to be supplied [2]. Those data products were produced in a similar process than during the real mission, by visiting and mapping the area by the rover's navigation system. As in the relevant mission scenario, depot operations were supported only by specific cut-offs of this information called Islands.

5. TEST RESULTS

This section introduces the results obtained from the tests carried out with FTRS in the Mars Yard. As previously introduced, two tests were performed: use case #4 (AutoNav) and use case #8 (AGL-D).

5.1. TRL 6: AutoNav

The first test consisted of commanding the rover to perform an autonomous traverse of 18 metres forward. Fig. 4 and 5 showcase the initial and final positions of the rover respectively, as well as a rock placed between them.

Figure 4. Start of the TRL 6 test with AutoNav

Figure 5. End of the TRL 6 test with AutoNav

Fig. 6 shows the resulting Navigation Map (NavMap). Here, the axes correspond to the local reference frame, centred on the initial position and with the initial orientation of the rover. Fig. 7 depicts an ORI of the Mars Yard, using its own reference frame, as well as the traverse made by FTRS.

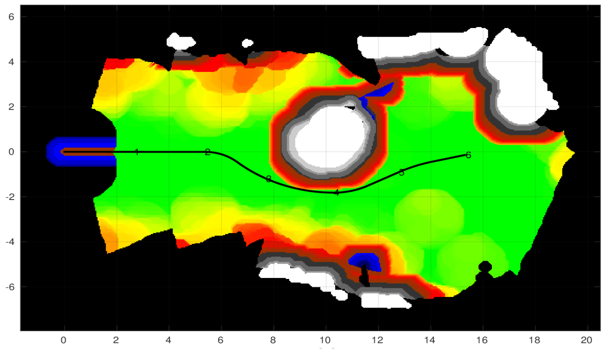

Figure 6. NavMap resulting from the AutoNav test. The reference frame is local

The test took almost 1.5h (including data archiving and systems overheads). The rover executed a 16.6m path as expected (stopped within 5m tolerance radius). Eight navigation stops were performed, and no replanning events were recorded.

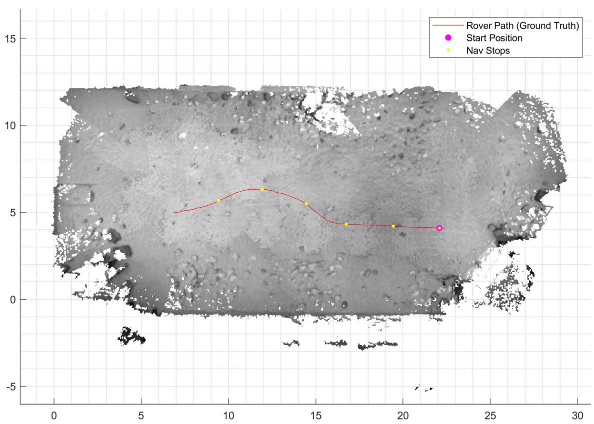

Figure 7. Test results presented on an orthonormal Mars Yard image (note the difference between reference frames compared with Fig. 6)

5.2. TRL 6: AGL-D

The second test included driving a predefined path using CheckPath mode [1] with AGL-D enabled. The drive sequence was supplied by the operator using a depot operation planning tool which is designed to maximise accuracy of depot operations and thus safety of the sample. The drive sequence, presented in Fig. 9, included two segments: tube location approach and final approach (last 0.5m of straight path executed with minimal speed). After a hypothetical successful tube acquisition, the rover continues the drive out of Island. Initial rover position is purposefully set in the system with ~20cm of error. Due to the size of a typical island as well as the high accuracy of the relative localisation over small distances, additional errors were added to the relative localisation estimations to let AGL-D work in more realistic conditions.

Figure 8. Setup of the AGL-D test with the rover at the starting position

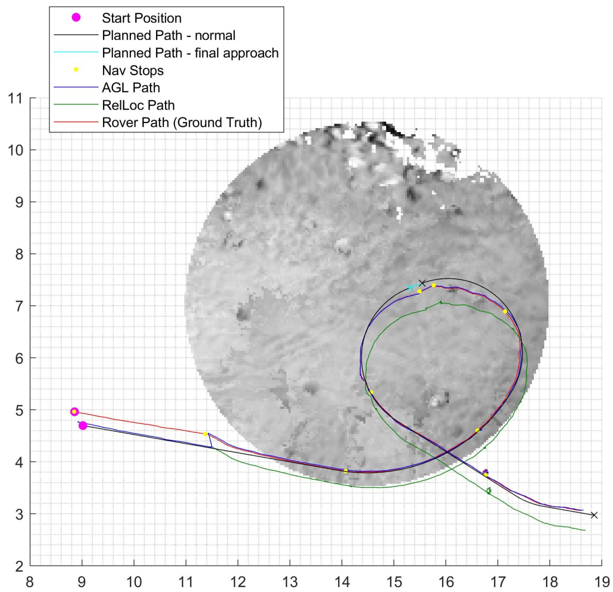

Figure 9. Traverse information on top of an orthonormal island around the location of RSTA

This test took a little over 2h (including data archiving and systems overheads). The overall path was 21.07m including 9 navigation stops.

As one can observe, when the localisation jumped at the second navigation stop (Fig. 9), AGL-D successfully fixed the initial rover position error and continued correcting relative localisation errors (with added error).

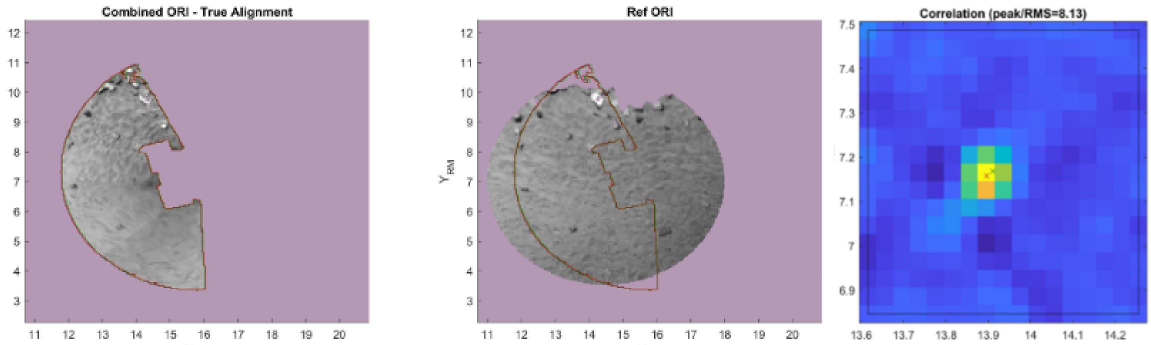

Figure 10. Example of successful AGL-D correlation: left - rover local data, middle - reference Island, right - cross-correlation (red "x"=measured peak, green "x"=ground truth expected peak)

Example of successful correlation of AGL-D is presented in Fig. 10. Test success was indicated by arriving at the sample location within +/- 10 cm as required.

6. CONCLUSION AND OUTLOOK

The ADS GNC robotics team has demonstrated TRL 6 on all selected use cases, for realistic exploration mission scenarios, in conditions which - for the algorithms - are flight representative; specifically the algorithms executed in real-time on a GR740 development board featuring LEON4 processor, integrated onto the FTRS (IBB2 configuration) while driving within the ADS Mars Yard.

The use cases include both autonomous driving (exercising full navigation stack in AutoNav mode) and 'in Depot' driving (exercising CheckPath + AGL-D) scenarios. Performance of the presented system has been satisfactory to continue the developments of the overall mission.

The fact that the test campaign used CNES supplied perception algorithms demonstrates an additional robustness of the ADS rover GNC autonomy stack, being capable of executing successfully on a flight like processor with different perception solutions.

7. ACKNOWLEDGEMENT

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