DESIGN AND PLANNING OF FIELD TRIALS FOR THE INTEGRATED BREADBOARD 3 (IBB3): TOWARDS THE DEMONSTRATION OF AN INTEGRATED ROVER SYSTEM IN THE SFR MISSION CONTEXT

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ABSTRACT

As a continuation to the successful Field Trials with the Integrated Breadboard 2 (IBB2) in 2022 [1], the follow-up campaign in September 2023 served to demonstrate end-to-end capabilities for an integrated system including autonomous operations and sample fetching with a robotic arm. The IBB3 Field Trials also constituted a chance to further improve the platform and solutions that were already tested in 2022. The selected outdoors location of this year's tests is an area within the silica sand quarry within the UK.

The functionalities tested covered Sample Fetch Rover (SFR) mission requirements. These include the autonomous traverse of long distances using Absolute Global Localisation (AGL) [2], as well as the autonomous fetch of sample tubes. One major challenge of the IBB3 project was the management of a multidisciplinary team with a varying range of expertise, due to the inherent difficulty in integrating different ways of working. Further, the organisation and logistics proved to have increased in complexity since IBB2. In this paper it is discussed what steps were taken to overcome the challenges and fulfil the objectives.

1. INTRODUCTION

The Mars Sample Return (MSR) campaign is a response to the long-running scientific objective to better understand Mars. By acquiring and returning to Earth a rigorously documented set of Martian samples, scientists will have access to the full breadth and depth of analytical science instruments available in terrestrial laboratories. The resulting investigations of these returned samples will enable breakthrough advances in many fields, such as the search for ancient and/or extant life on Mars, the understanding of the origin and evolution of Mars as a geological system as well as its climate, and the preparation for future exploration missions with human presence.

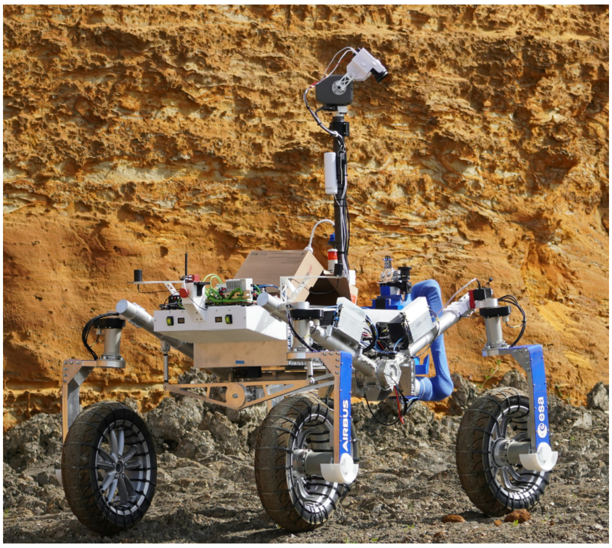

Figure 1. CODI rover during IBB3 field trials

The samples in question shall be selected based on their geologic diversity, astrobiological relevance, and biosignature preservation potential. Besides, the detailed in situ observations acquired at the time of sampling will establish the field context for each sample. In addition to returning up to 30 cached Martian samples to the Earth surface (the exact number is still the subject of ongoing Campaign level trade-offs), the MSR will also include the first ever launch from another planet rather than Earth.

The MSR architecture involves a total of five elements: four flight elements and one ground element. Each campaign element consists of one or more functional elements. The four flight elements are:

- a caching rover mission, developed by NASA-JPL (Mars 2020 project), currently operating on Mars,

- a first Sample Retrieval Lander (SRL-1) mission, consisting of a NASA/JPL developed lander with a Mars Ascent Vehicle (MAV) as well as ESA provided Sample Transfer Arm (STA)
- a second Sample Retrieval Lander (SRL-2) mission, that was supposed to be carrying the Sample Fetch Rover (SFR),
- and an ESA provided Earth Return Orbiter (ERO) mission.

In the context of the MSR campaign, the Integrated Breadboard 3 (IBB3) [3] is a project executed by Airbus Defence and Space (ADS) for the European Space Agency (ESA). Its purpose is to continue development and provide demonstration of an autonomous rover that is representative of the SFR. The development was kicked off in January 2023 to be concluded before the end of 2023. The functionalities agreed with ESA for this project, including autonomous, hybrid and tele-operated sample tube acquisition by a mobile manipulator, were validated through field trials. They were carried out by means of the breadboard rover named Codi (shown in Fig. 1), equipped with four steerable wheels and a robotic arm. Furthermore, the IBB3 includes a prototype of the operator command frontend, provided by Trasys. This software communicates to an emulator of the Mission Management System (MMS), which then commands robotic actions for mobility and robotic arm operations, and provides telemetry back to the operator console.

The paper is structured as follows: first, the agreed requirements and use cases are presented. Second, the design and setup of the field tests is described. Third the field trials preparations and planning is summarised, and finally the conclusions are presented.

2. REQUIREMENTS AND USE CASES

The requirements imposed for the IBB3 project were agreed between Airbus and the European Space Agency. They ensure the IBB3 develops the expected functionalities that make it representative of the SFR mission. These include:

- As the main objective to achieve, to perform end-to-end operations with an integrated rover platform working as a mobile manipulator. This shall serve to demonstrate rover navigation and robotic arm manipulation capabilities using SFR mission requirements and scenarios as reference.
- The design shall integrate FTRS with the 3DROCS Mission Control System (MCS).
- The IBB2 GNC software shall be evolved to design, integrate and test in the Field Trial the following additional components:
    - Closed loop Relative Localisation that minimises the localisation error inherent in dead reckoning methods (i.e. fast VO with 0.5 Hz for increased rover speed).
    - Sun Sensing capability integrated with GNC algorithms, to allow the system to reorient itself based on the location of the sun in the sky [6].
    - Smooth transition between autonomous navigation modes with different stereo camera-based perception strategies, i.e. FOPSA, which is further elaborated by Weclewski in [4], and AutoNav.
    - Navigation Corridor width check and automatic avoidance, i.e., the rover should try to continue navigating while staying within the corridor, not just stop when a corridor violation occurs.

The latest requirements shall make the rover capable of autonomously and accurately traversing long distances by using Absolute Global Localisation in Traverse mode (AGL-T) to reduce localisation error. AGL-T is a software component that matches the high precision and limited range maps created from the rover stereo cameras with orbiter-acquired orthonormal rectified images that cover greater areas with lower resolution, built using drones in the frame of the Field Trials. Moreover, the ability of the rover to dynamically transition between different levels of autonomy shall be planned to be exercised as mentioned, with FOPSA and AutoNav. FOPSA comes as a faster version of AutoNav that uses fewer perception operations and is targeted at benign terrains. Should the rover encounter an unexpectedly difficult terrain (e.g. high number of obstacles), it autonomously transitions to AutoNav in order to increase the number of perceptions, increasing the area of assessed terrain to plan more optimal paths as a result.

With the presented requirements in mind, a series of use cases were conceived to address them all.

- **IBB3-UC-1: Long Traverse.** Demonstrate long range autonomous traverse with Autonav and FOPSA performing AGL-T and including transition FOPSA - Autonav due to unexpected obstacles.
- **IBB3-UC-2: Long Traverse Corner Cases.** Demonstrate a subset of corner cases

behaviours, complementing demonstrations of robustness carried out in simulation. These cases include: SFR unable to reach waypoint; SFR unable to find path; AGL unable to find match.

- **IBB3-UC-3: Human Directed Drive.** Demonstrate HDD operations, with CheckPath used to maintain the NavMap but making use of the two options being path checking both enabled and disabled to traverse a complex area.
- **IBB3-UC-4: Pick up multiple tubes autonomously.** Demonstrate autonomous pickup of several tubes following predesignated paths.
- **IBB3-UC-5: Tube Pickup Corner Cases.** Demonstrate drive to alternative depot when tube is not detected in first one, and demonstrate use of paths for both successful and unsuccessful RSTA acquisition.
- **IBB3-UC-6: Human Directed Pickup.** Demonstrate Tube Pickup mixing human directed and autonomous operations for pre-planned HDP, i.e. for a case where Ground assesses in advance that the geometric case does not allow autonomous acquisition.
- **IBB3-UC-7: Sun Sensing at Various Sun Elevations.** Demonstrate accuracy of sun vector based heading corrections at various Sun elevations.
- **IBB3-UC-8: Time Based Operations.** Demonstrate capability of FTRS to support time based operations.

3. DESIGN OF THE SETUP FOR THE FIELD TRIALS

The first challenge was to come up with a setup large enough to successfully execute all the use cases described in the previous section. This setup consists of an outdoors and unstructured test site, large enough given the requirements of some use cases, multiple testing platforms, for not only validate these use cases but also perform some stretch activities, and the infrastructure required to ensure power, safety, data management and logistics.

3.1. Test Site

The test site for the IBB3 shakedown test is the L.B. Silica Sands quarry located in Bedfordshire, England, specifically in the town of Heath and Reach. It consists of a main site entrance with management office and a dirt track leading to multiple quarry areas. Previous quarry tests took place in 2022 during IBB2 trials in suitable areas in the western area of the site. The IBB3 trials were carried out in the North-Eastern part of the quarry, a suitable location identified after a visit in May 2023 made by the Airbus team.

It is an unstructured environment that serves to resemble a planetary/lunar environment, with irregular terrain, rocks, slopes and flat area. Fig. 3 shows the main area scouted for long range traverse tests.

Figure 3. Test area scouted in May 2023

The characteristics of this area, which includes rough unstructured terrain, are adequate for the kind of tests planned for IBB3. This location allows for long autonomous drives as it covers a surface of around 10,000 m^2 of clay and 900 m^2 of sand and long continuous straight drives of around 200 metres.

Figure 4. Location chosen to perform the long traverse test during IBB3 field trials - aerial view

Being part of an active quarry, the area in question slightly changed in September 2023 and it was as shown in Fig. 4. It contained a flat area with clay and scattered rocks, suitable for long traverse testing. Two blue gazebos were set up and can be seen in the same figure, placed along the small pond which accumulates rain water. The gazebos served not only to cover equipment that must be close to the testing area, but also as a protection measure for the observers against harsh conditions, such as the prolonged exposure to the sun. As it is an active sand mine, the testing team was granted the sole access for this area.

3.2. Testbed platforms: Codi and Charlie

The IBB3 physical platform, shown in Fig. 5, presents notable changes from its IBB2 counterpart. The development concentrated on three pillars:

- The RSTA Acquisition System (RAS) integration (see Fig. 6) from a mechanical and electrical standpoint.
- The substitution of the existing legs with an updated version.
- The improved accuracy of the GNSS subsystem.

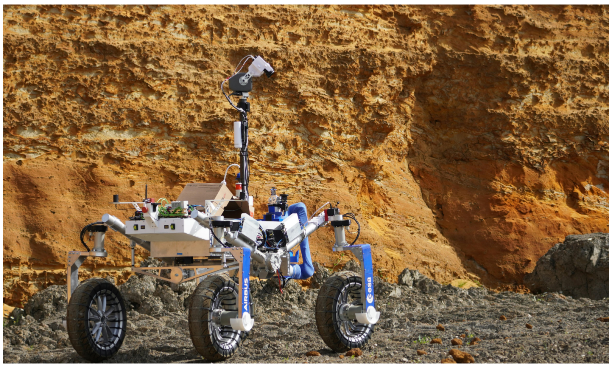

Figure 5. CODI: the IBB3 rover platform

In order to secure the RAS to the rover, a robust attachment point on the front of the main tub has been produced in the form of a milled aluminium plate that spans the width of the tub. The arm is linked to the batteries via a 24V rail and is protected by a 3A circuit breaker. On the other hand, the gripper electrical interface is more complex, as it features a control box provided by AVS. This includes an amplifier, a position controller, an Ethercat bus, and the PLC units for the gripper control. Power is supplied to the gripper electronics via the 24V rail and through a 5A circuit breaker. The voltage to the arm and the gripper electronics is jointly controlled by a 24V voltage regulator.

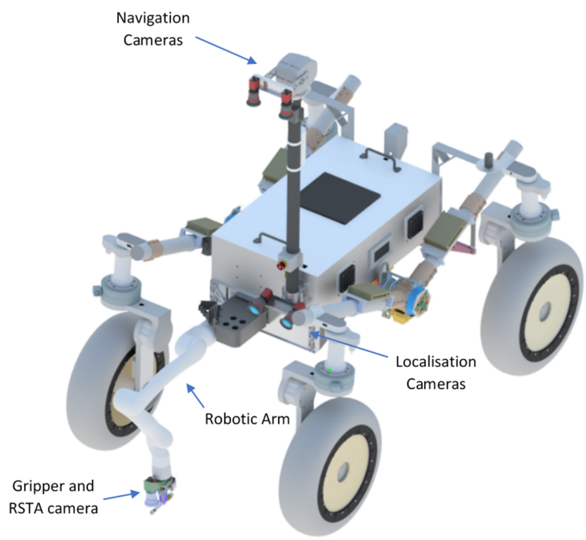

Figure 6. CODI: 6 DoF robotic arm integrated into the FTRS platform

The leg re-design activity resulted in four major advantages. First, the ability to swap interchangeably between mesh and rubber wheels, ensuring tests can be carried on a tarmac surface. Second, the removal of four unutilised force-torque sensors, shedding almost 10 kg overall. Third, the enlargement of the usable workspace for the RAS operations, achieved by flipping the legs outwards (compared to IBB2). Lastly, the elastic deformation of the legs themselves has been considerably reduced, by stiffening the mechanical design in key areas around the motor hub. These four advantages have been accomplished by a three-piece design, where the triangular joining plates can be rotated to swap between the different wheel configurations.

Figure 7. Charlie rover

While Codi was used for testing the formal IBB3 use cases, Charlie (shown in Fig. 7) was used for gathering data on the feasibility of RADAR and LIDAR sensors for object detection. More information on the Charlie prototype can be found in [5].

3.3. Infrastructure

The infrastructure and setup for the IBB3 field testing was designed with efficiency in mind. This was translated into placing all the important facilities close to each other, leaving maximum testing capability for the various rovers.

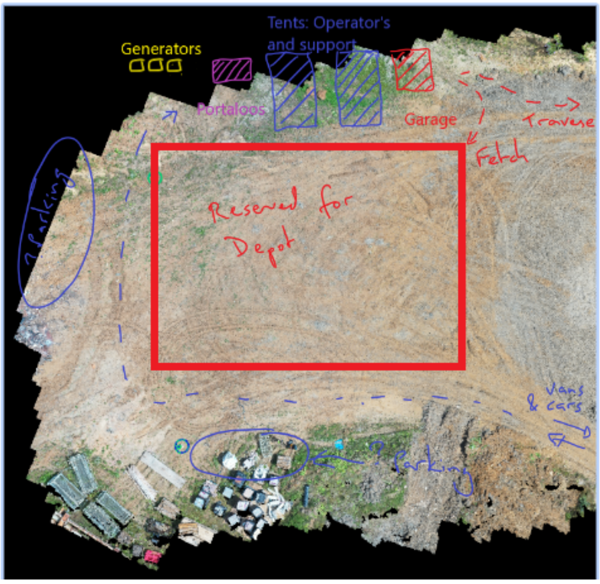

Figure 8. Campsite layout sketch

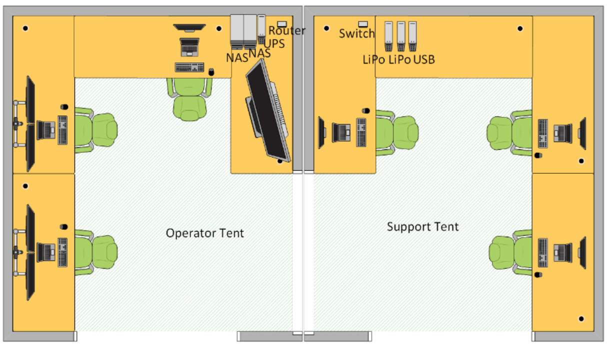

Figure 9. Proposed tent setup for operations and support in the frame of IBB3 field trials

Fig. 8 shows the initial plan for the quarry setup. The idea was to have two tents: one containing the operations equipment that would be used for running the UC's, and another, the support tent, which would serve as a place for members to conduct work while supporting the operators. During the field testing, it was decided to put tents further apart with a gazebo in between them, to enable more open space. The arrangement of the material inside each of the tents was planned beforehand as shown in Fig. 9. Further small changes were made from the plan, like placing the generators near the storage container so that they could be moved quicker in the event of rain. Fig. 10 shows the actual layout of the site used during the field trials.

Operations preparation and telemetry monitoring was achieved using the 3DROCS software running on the ground control laptop. 3DROCS communicates with the rover 3DROV software via activeMQ for collecting telemetry and sending start, stop, pause and abort commands to control the execution of the activity plan.

Figure 10. Actual campsite during IBB3 field trials - aerial view

The Local Control Centre (LCC) had a wireless access point meshed with the rover platform's wireless access point and any ancillary access points required. Connection can be achieved either by joining the WiFi network or by joining the wired network at any access point. The internet access point can be either achieved with a 5G hub or with a starlink roaming dishA high performance Network Attached Storage (NAS) equipped with SSDs in RAID5 configuration was used to centralise the recording of all test data. In addition, this NAS was powered by an Uninterruptible Power Supply (UPS) to eliminate any risk of data loss or corruption in case of power shortage. Fig. 11 shows a diagram with the equipment used in the field to support test activities.

A First Person View (FPV) camera with a long range HF emitter was installed on the rover with a fixed orientation giving a good view of the Kinova robotic arm. On the LCC side the FPV live video feed is displayed on a screen so that operators can monitor RAS operations and quickly intervene in case of malfunction. The LCC had 2 live power petrol power generators plus a third one as backup, and they needed refuelling every day.

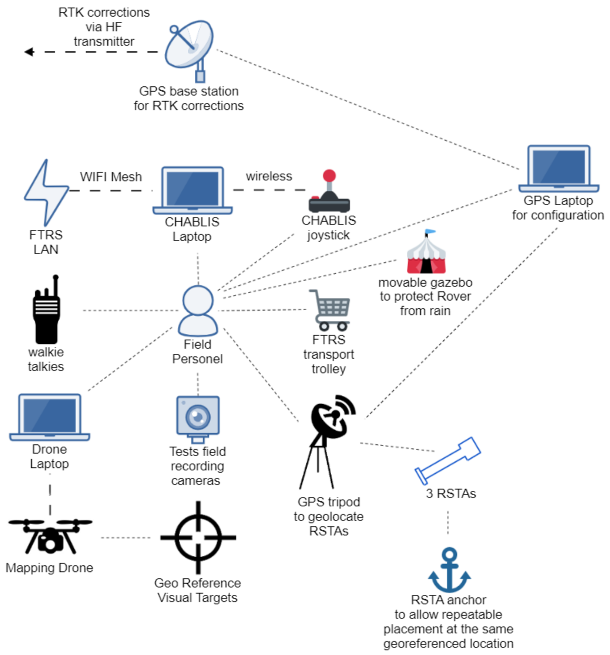

Figure 11. Overview of the campsite field equipment

Using a joystick it is possible to manually drive the rover to quickly reposition it in the field, drive it back to the LCC for storage overnight or drive it in/out of a van if a transport trolley is not used. A drone is used for aerial mapping of the test field. The data produced is then post-processed to create the reference map used on-board the rover for AGL and to create the reference map for visualisation in the ground control software 3DROCS. The drone used is a DJI Mavic 2 Pro and the software used for survey mapping is DroneDeploy.

A set of geo-referenced visual targets were deployed in the field at specific GPS locations to help with map corrections during post processing. These targets, named Ground Control Points (GCPs), were used for accurate measurements and Ground Truth checks. Fig. 12 shows one of them.

A GPS receiver mounted on a tripod was used to geo locate the position of RSTAs and visual targets for mapping. The position of the RSTAs can then be added to the reference map of the depot.

Figure 12. Ground Control Point in use during field trials

4. FIELD TRIALS PREPARATIONS AND PLANNING

The responsibility of the team was divided into multiple roles, all of them presented on Fig. 13. Test managers were nominated on the day, and were the most senior person(s) on the test site. The person responsible for People Management was the first point of contact for all personal matters and team availability. The reporters were the ones logging results, the activities, pictures and videos of the tests. Test operators are responsible for running the tests, and making sure that the procedures are followed. Test observers are present near the rovers, responsible for changing batteries, and about the general rover safety, especially regarding unexpected rover behaviour and anomalies. Analysts and support engineers are responsible for checking the results, and supporting the wider team when necessary with test configuration and end of day wrap-ups.

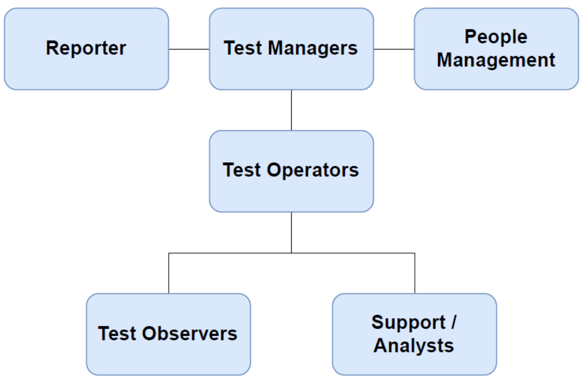

Figure 13. IBB3 responsibility chart

4.1. Activity

The nominal daily testing routine is planned to start with a general briefing where teams, responsibilities, and objectives are assigned for the day. This is followed by actual setup and testing, with an intermediate lunch around noon, and the day is closed with a debrief session. During the debrief every team reports on their testing success/failure, problems and miscellaneous items.

With multiple teams working in parallel, sometimes subteams within those teams working in parallel, walkie talkies were used to allow for easy communication across the site. This allowed for efficient support and kept the managers updated with all the activities occurring on the site. This was very useful for when the rover was being tested in the traverse area, shown in Fig. 14. A group, called observers, would watch the rover as it was performing its operations to make sure no harm would occur, while the operations team would be in the operations tent simulating a mission.

Figure 14. Overview of the test execution by test observers during field testing

4.2. Schedule

An initial plan was sketched up, assuming good weather conditions for the full length of the IBB3 field trial - 3 weeks. Contingent days were introduced into the planning and use case tests were assigned separate days to make sure that the IBB3 team had enough time to set up, run and archive results.

4.3. Weather

The weather can be very unpredictable during field trials, hence the team needs to specifically plan the dates of the trials such as to maximise the changes for favourable weather conditions. As the trials happened in the UK, the team was lucky enough that there was constant sunshine and no rain for the first two weeks of the trials. This excellent scenario has allowed us to utilise the environment with multiple robotic platforms.

Local weather was studied and understood in advance to plan the field trials, with counter measures in place to be flexible with its unpredictable nature. High winds caused damage to the support tent on the weekend between the first and second week, along with damage to the operations tent happening during the pacing up on the third week. The team had planned for this and added extra support to the tent beforehand, which made the damage light. Further, the storage container was selected to be robust enough not be affected by the wind, and served well in protecting valuable equipment

5. CONCLUSION AND OUTLOOK

The 2023 IBB3 Field Trials demonstrated both autonomous and human directed fetching of samples (Returnable Sample Tube Assembly or RSTAs) in real world conditions. Hence, this year the rover was equipped with a robotic arm subsystem that allowed it to detect, grasp and then stow on board these RSTAs using a gripper. The trials also provided a real world demonstration of the autonomous Sun Sensing Heading Estimation (SSHE) function. All those functionalities were integrated as one system that in end-to-end demonstrated full operation in the context of SFR mission respecting representative constraints.

6. ACKNOWLEDGEMENT

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