Returnable Sample Tube Assembly (RSTA) Acquisition System: Pickup and Stowage System Developments in SFR Mission Context

DEFENCE AND SPACE

AIRBUS

Mission Context - MSR

- Mars Sample Return (MSR) is a collaboration between the NASA and ESA, with the objective to return samples from the surface of Mars for scientific study on Earth.

- Currently the Perseverance rover is on Mars collecting regolith samples and leaving some on the surface of Mars for retrieval.

- In the 2018 MSR architecture, the retrieval mission consisted of a lander carrying the Sample Fetch Rover (SFR) and the Mars Ascent Vehicle (MAV). SFR would fetch up to 30 Returnable Sample Tube Assemblies (RSTAs) from the depot and deliver them to the MAV.

- However in 2022, the retrieval part of the campaign underwent major revision, leading to the removal of SFR and termination of its development.

- Despite the SFR mission cancellation ESA elected to continue development of the key SFR fetching breadboard with the aim of demonstrating an end to end autonomous traverse and fetch capability in field trials conducted in a suitable Mars analogue environment, such as a quarry. This is the Integrated Breadboard 3 (IBB3) campaign.

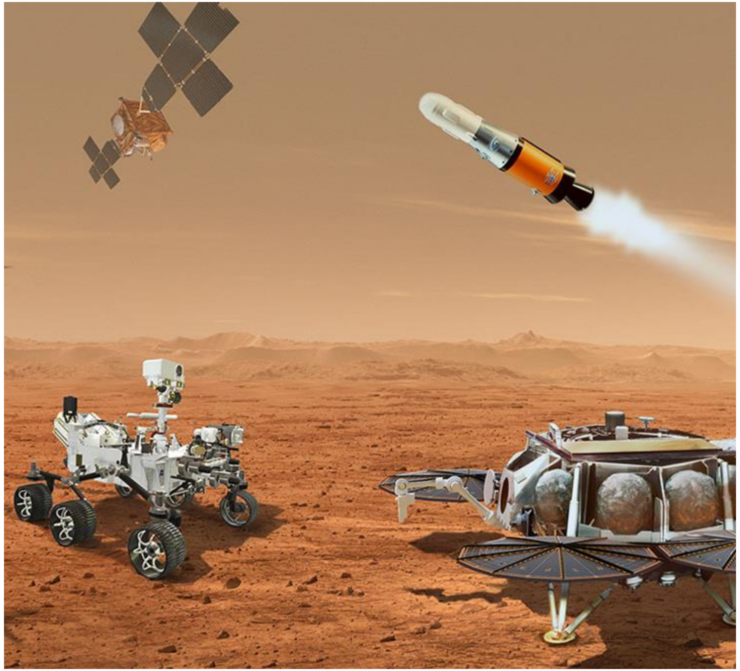


Image from https://mars.nasa.gov/msr/#Returns-Samples

Mission Context - IBB3

- IBB3 is the follow-up breadboarding campaign to SFR

- The goal of which is to develop the SFR breadboard to a degree where it can demonstrate fully autonomous fetches of RSTAs in Martian analogue environment.

- Also included use cases to demonstrate human in the loop operation and autonomous recovery from some failure cases

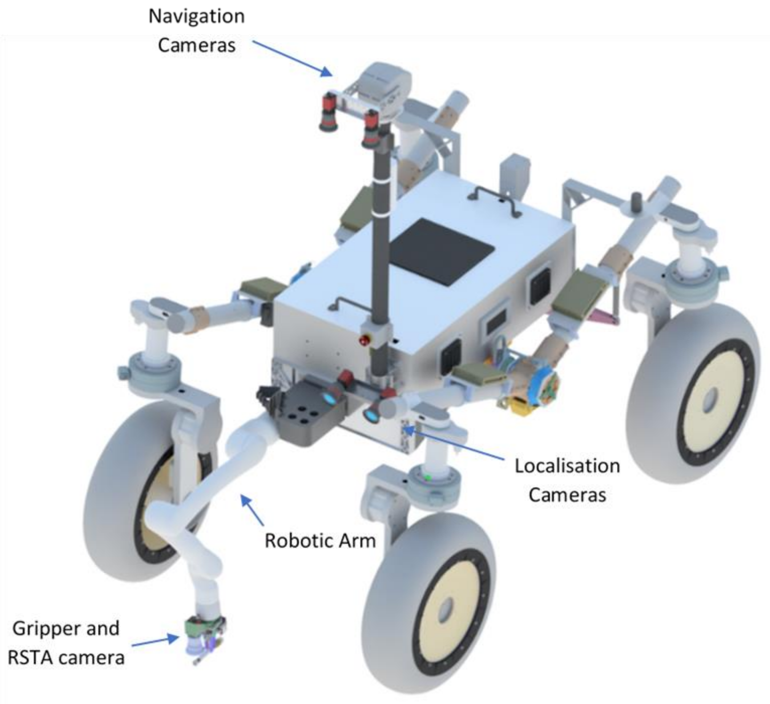
- Field Trials conducted over 2 weeks in September 2023

- The breadboard rover itself is called the Field Trial Rover System (FTRS), and the main components are the:
    - Mobility System - handles the planning, localisation and execution of the rover motion
    - RSTA Acquisition System - handles the detection and pickup of the RSTA on the surface

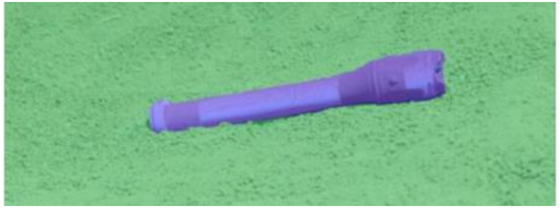
RSTA Acquisition System

- Purpose of the RAS is to detect and pickup the RSTA from the ground

- Consists of:
  - Robotic arm and gripper system
  - Vision based detection system
  - Planning, control and state machine software

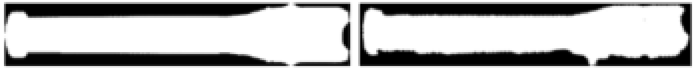


Step 1: RSTA Identification



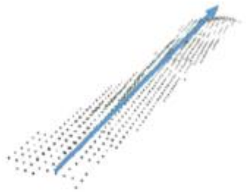
- Step 1 is a function of the vision based detection system

- A stereo image is captured by the Navigation cameras at the top of the mast (1.73m above the ground)



- Uses the images to identify the location of the RSTA within the defined pickup area, and to provide a 5DOF estimation of the pose of the RSTA

- Segmentation is performed to split the image into RSTA and terrain



- Principal Component Analysis identifies the longitudinal axis and centroid of the RSTA

- The head direction is estimated by comparing the segmented RSTA with a binary template of the RSTA.

- With the position in the image plane and the head direction determined, the 5DOF pose is estimated by mapping to the point cloud

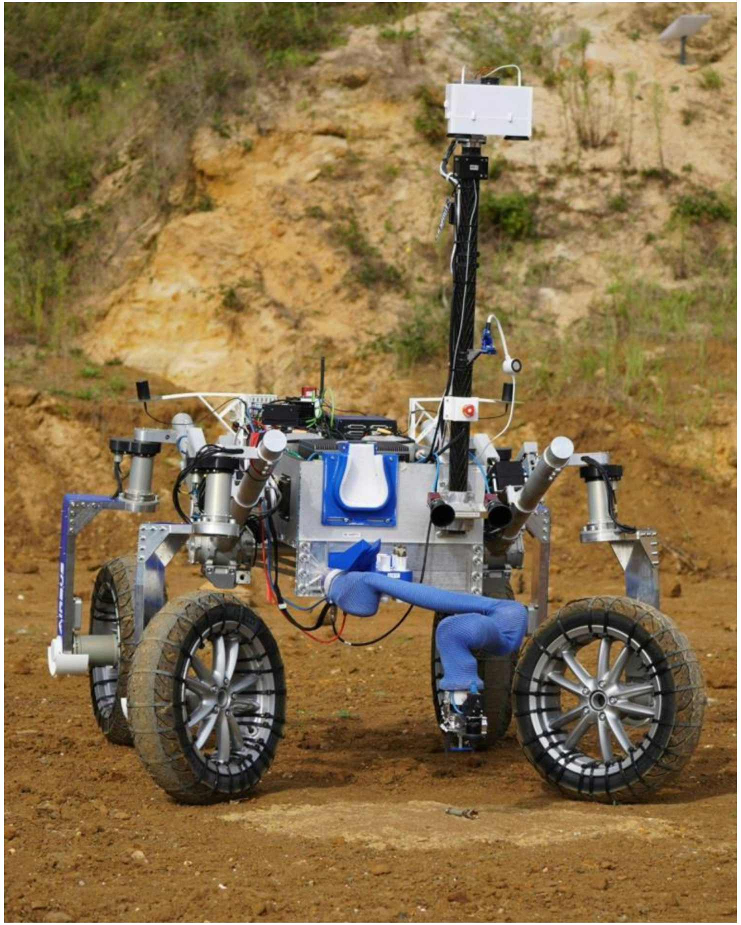
Step 2: Arm Deployment

- If the RSTA has been identified and is determined to be within reach, the arm is deployed to an intermediate idle pose

- The robotic arm being used is a Kinova Gen3 6Dof variant
  - The selection of this manipulator was made primarily due to the mass constraints of the platform. Many industrial arms long listed were far too heavy for the platform and would have impacted its drivability

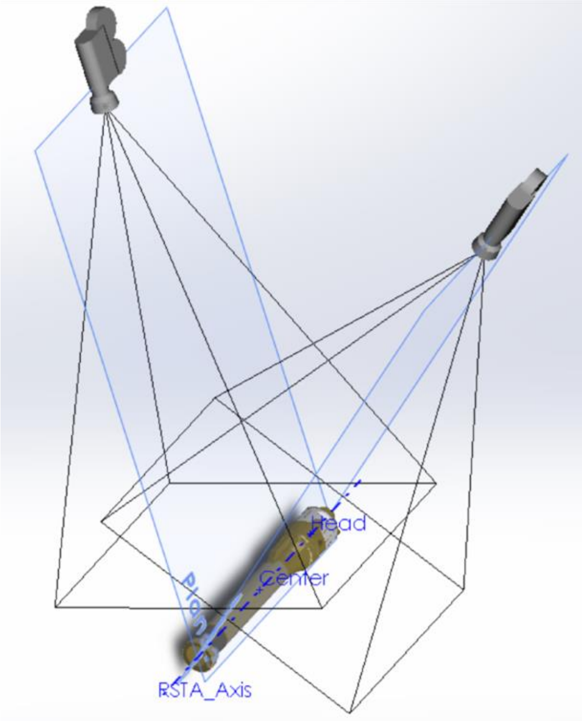
- The control for the robotic arm is based around ROS2
  - Import in knowledge of the arm kinematics through its URDF to be used by MoveIt
  - Add colliders for the rover chassis and ground plane to allow for collision avoidance
  - Force and torque estimated from the joint current via the Kinova and used to perform emergency stops if necessary

- Cable management achieved through a sleeve which is attached at the wrist via a slip ring to allow the sleeve to rotate whilst maintaining a strain relief of the harness



Step 3: RSTA Pose Update

- Step 3 is another function of the vision based detection system
- A stereo image set is reconstructed by taking two mono images using the camera mounted at the end effector
  - Two images are taken at 22.5 degrees either side of the nadir at 30cm above the ground
- For each image the same segmentation and pose estimation process used for the RSTA identification is performed and the 2D pose in each of the images is derived
- As the position of the camera is known, from the arm forwards kinematics, it can be estimated in 5dof the pose of the RSTA with greater accuracy than with the navigation cameras



Step 4: RSTA Grasp

- With the RSTA position known with sufficient accuracy the arm is commanded to descend upon the RSTA with a linear motion to intercept the RSTA

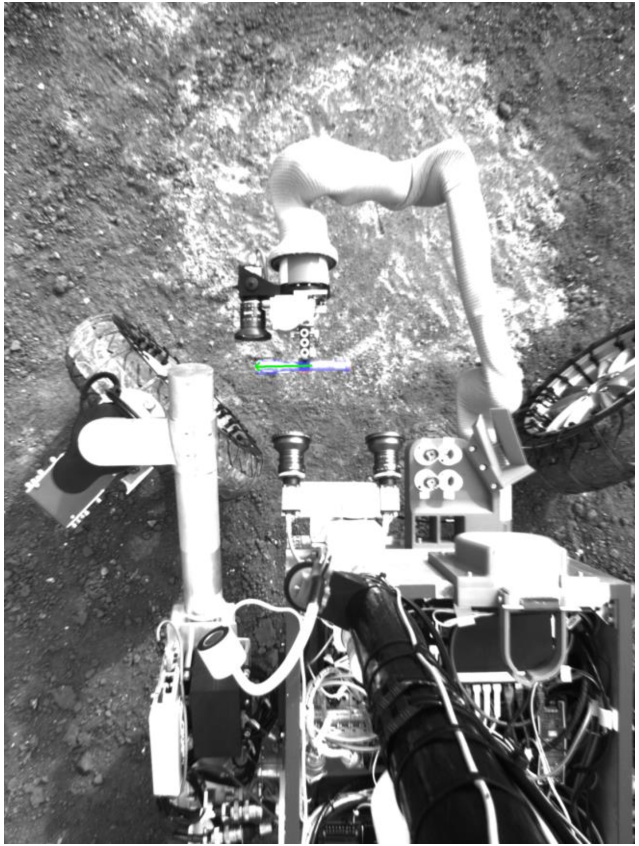
- The manipulator’s end effector accommodates a gripper-type end effector, whose jaws are designed to grasp the RSTA both transversally (body grip) and axially (head grip)

- Only one finger is motorized, while the motion of the other is achieved by a pair of gears connected to the motor. In this way, their motion is synchronized and symmetric, and only a single driving system is necessary

- Gripper contains a pressure switch which can detect the presence of the RSTA in side the grasping area. A detection with the switch or a high force torque reported by the arm will cause the arm to stop and close the gripper

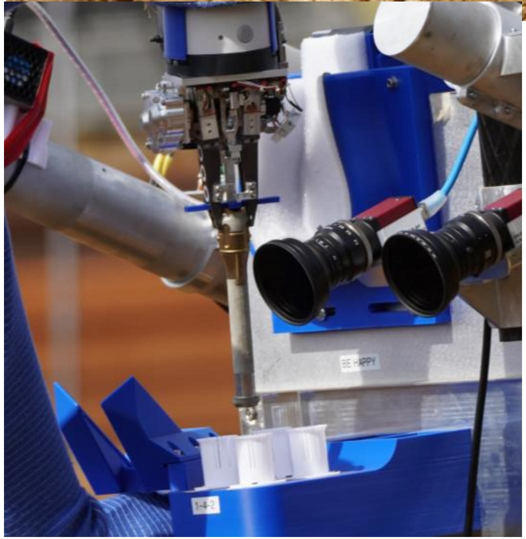
Step 5: RSTA Grasp Check

- Step 5 is the third and final function of the VBD system
- The RSTA, within the gripper, is placed in view of the Navcam stereo bench
- VBDS algorithm determines where in the image the RSTA is
- Vector of the gripper finger is determined using the fiducial markers along its length
- Point of intersection with this line and the RSTA main axis indicates the point at which the RSTA is grasped
- An offset from the center of the allowable grasping zone is provided



Step 6: Regrip

- During the grasp, the body grip by the gripper to handle the RSTA
- During the insertion into the stowage assembly, the RSTA must be grasped by the head
- To perform this regripping from body to head, a bracket is used to place the RSTA into a known position, for it to be extracted again from the desired grip configuration
- The RSTA Regip Bracket (RRB) is designed to be passive, using gravity to settle the RSTA into a good position to be grasped by the head
- The grasp offset calculated by the previous step is used to determine where the RSTA needs to be dropped into the bracket



Step 7: Stowage

- With the RSTA now grasped by the head in a deterministic position, the RSTA can be stowed into the RSTA Storage Assembly (RSA)

- Insertion is performed by commanding the arm to follow a series of predetermined motions as the RSTA is now in a deterministic position

- The full sequence is broken down in smaller chunks as the motions of the arm is through a highly constrained area, close to the rover chassis

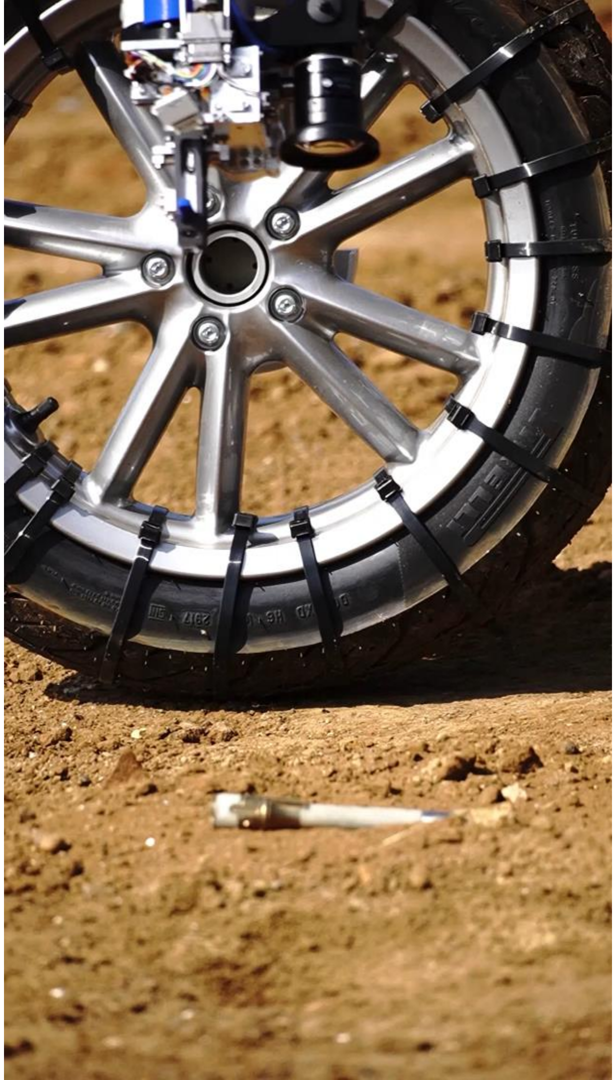
- Storage slots designed to be slightly compliant at the top, guiding the RSTA inside and allowing a small margin of error

Pickup Sequence

- RSTA Identification
- Deployment
- Move arm to each RDC capture location
- Calculate RSTA location

Pickup Sequence

- RSTA grasping
- Lifting and tightening of the gripper



Pickup Sequence

- Moving to grasp check
- Perform grasp check

Pickup Sequence

- Drop into regrip bracket

Pickup Sequence

- Extraction
- Insertion into RSA slot
- Stowage of the arm

Acknowledgements

- ESA – Customer
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