THE ARCHES MOUNT ETNA DATASET (AMEDS): A PLANETARY ROVER DATA COLLECTION IN A LUNAR ANALOGUE ENVIRONMENT

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ABSTRACT

This paper describes a dataset collected on the slopes of Mount Etna during the 2022 Autonomous Robotic Networks to Help Modern Societies (ARCHES) test campaign organised by the German Aerospace Center (DLR). The European Space Agency's (ESA) Human Robot Interaction (HRI) lab's rover "Interact" was used to perform a series of nine traverses and two rock picking experiments. The data from the onboard sensors was recorded during these experiments and it was converted into a convenient, timestamped, format in order to produce a multidisciplinary robotic dataset from a lunar analogue environment. In order to create this dataset, Interact was remotely operated for more than two km and recorded data for longer than an hour and a half. During the dataset acquisition, Interact's onboard sensor suite included two vision cameras, a scanning light-detection-and-ranging sensor (LiDAR), wheel odometry and a Real-time Kinematic (RTK) enabled inertial navigation system (INS).

Key words: dataset; planetary robotics; lunar analogue; ESA; mount etna.

1. INTRODUCTION

This paper aims to introduce a new dataset that was acquired during a test campaign performed on the slopes of Mount Etna in the summer of 2022 by ESA's HRI lab. The test campaign was organised by the DLR as part of the ARCHES project in collaboration with the European Space Operations Centre (ESOC) [4]. The robotic platform used to acquire the data, Interact, is a rover that was designed for experimenting realistic teleoperation scenarios by utilising the advantages of scalable autonomy. For this purpose, Interact was controlled by Luca Parmitano in 2019 during his stay onboard the ISS with the intent of demonstrating robot control with short time delay. During this experiment, named Analog-1, Luca used the HRI's haptic controller and joystick onboard the ISS to manoeuvre Interact within a simulated lunar environment and perform a series of rock picking experiments on Earth [5]. These experiments reflected typical tasks that an astronaut onboard the Gateway might be required to perform in the near future. During Analog-1, the operator's environment, referred to as the space segment, was very realistic. While the rover's environment, referred to as the ground segment, was highly simulated as it took place inside a plane hangar. To remedy this lack of realism, Interact was brought to Mount Etna for the ARCHES campaign in 2022, where it was controlled by Thomas Reiter during two lunar exploration experiments [1]. In the ARCHES scenarios, Thomas investigated the analogue lunar surface using the same controllers as Luca and a newly designed operator User Interface (UI). With the help from geologists at ESOC, he identified scientifically interesting rocks to pick-up and store for later analysis. Mount Etna served as a great analogue for the Moon. Due to its peculiar rock formations, loose sandy terrain, and barren grey surface devoid of any Earth like nature, the ground segment for the ARCHES experiments was very representative of a lunar environment. Therefore, following the original test campaign, the HRI decided to use Interact to record data from all of its onboard sensors in order to provide the scientific community with a multidisciplinary robotic dataset from a lunar analogue environment. Interact was well suited to collect this dataset due to its numerous onboard sensors and actuators. Additionally, the robotic platform's sturdiness, its capability to be operated from multiple input sources (gamepad, joystick, haptic controller), and its 4-wheel drive makes it a ideal system for data collection in all sorts of challenging and rugged environments such as the slopes of Mount Etna.

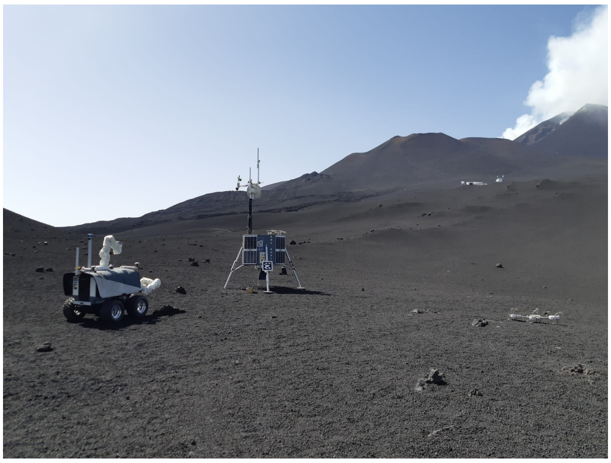

Figure 1. Interact, while teleoperated by Thomas Reiter, approaches the ARCHES lander on the slopes of Mount Etna during the 2023 ARCHES test campaign.

The intention of this dataset, which will be presented in detail in this paper, is to offer the scientific community new data specifically targeted to the emerging field of lunar Space robotics. It is indeed the latest robotic dataset to have been collected on Mount Etna, providing new images and telemetry from the moonlike environment. More specifically, as the dataset contains raw sensor data and processed data from a large fleet of sensors, as well as ground truth models from a surveying drone, it is particularly suitable for testing algorithms for localisation, visual and laser odometry, object detection, slope detection and 3D mapping. It can also be of interest in the field of human-robot teleoperation, for example in order to research user comfort when facing live lunar telemetry and video feed during space exploration operations.

2. ROVER PLATFORM AND ONBOARD SENSOR DESCRIPTION

Interact's rover platform is a robust 4-wheel steer and drive GRP-4400 from Ambot with encoder readings for both the steer and drive motors. For global localisation and orientation, Interact is fitted with a inertial navigation system (GNSS/INS & AHRS) Spatial Dual from Advanced Navigation, combining the power of a RTK compatible GNSS receiver, an Inertial Measurement Unit (IMU) and a pressure sensor for high precision pose measuring. For higher heading precision and better signal reception, two GNSS antennas G5ANT-53A4T1 from Antcom are placed at both extremities of the rover. A Velodyne VLP-32C LiDAR is mounted on top of Interact in order to cover a large circular field-of-view around the rover. Centred on Interact's back is a LWR IV+ 7 degree-of-freedom (DOF) robotic arm from Kuka, which is equipped with a Prosilica GT 1290 high performance machine vision camera mounted with a Ricoh FL-CC0418DX-VG 2/3" lens that is referred to as Main Camera or simply *MainCam*. Finally, a second LWR IV+ arm is mounted in front of Interact, and it is equipped with a Realsense D435i depth camera from Intel that is referred to as Auxiliary Camera or simply *AuxCam*. The full list of Interact's onboard sensors and actuators can be seen in Figure 2, while a detailed description of the main characteristics of each sensor is detailed in Table 1.

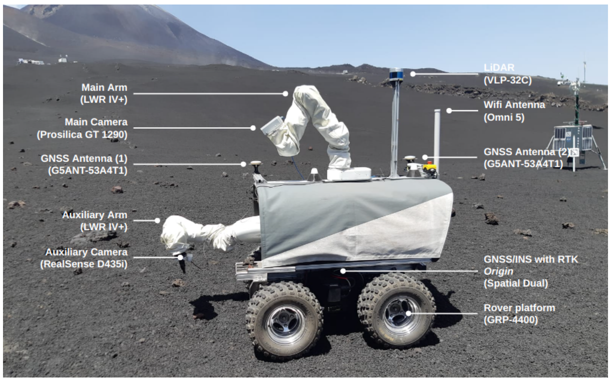

Figure 2. Overview of Interact's rover platform, sensors and actuators.

All the onboard sensors have predefined coordinate frames, which can be used to transform data to a global coordinate system, or compare points-of-interest between sensors. The Spatial Dual's origin and coordinate frame is defined as being the origin of Interact, and is referred to hereafter as *Origin*. The *Lidar*'s coordinate system is fixed, while those of the cameras and the wheels depend on the robotic arm joint angles and the platform encoders respectively. While the *MainArm* can act as a pan-and-tilt unit for the *MainCam*, it was kept in a stationary position during the dataset acquisition. The *AuxArm* on the other hand has a gripper mounted at its end-effector for rock sampling, and is only stationary during the traverses (c.f. traverse 0 through 8), but not during the rock picking experiments (c.f. rock picking 0 and 1). The technical drawings in Figure 3 provide a detailed view of all the reference frames of the different sensors onboard Interact and where they are located with respect to the Origin. Additionally, Figure 4 shows a simplified view of all the different coordinate frames referred to in this dataset, as well as how they are linked together.

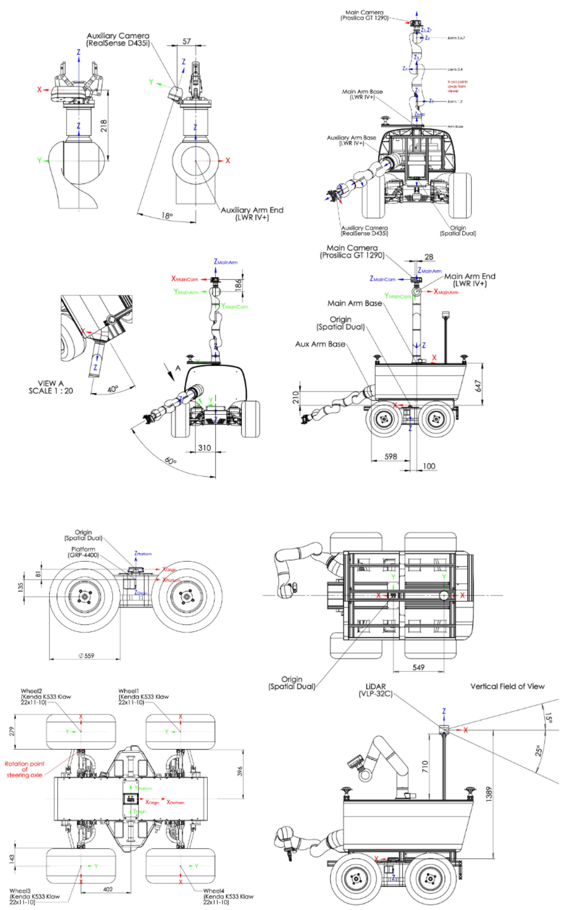

Figure 3. Interact technical drawings with the position of all onboard sensors and actuators with their respective coordinate frames.

Table 2 summarises the fixed relative pose transformations between Interact's onboard devices. For the readers convenience, all translation values (x_A^B, y_A^B, z_A^B) are given in millimetres, while all rotation values (ψ_x, θ_y, ϕ_z) are given in degrees. The rotation values correspond to the three Euler angles given in XYZ extrinsic convention, also known as Tait-Bryan angles (i.e. first rotation about z, then y and then x with respect to the fixed original coordinate system). No calibration was performed before the dataset acquisition, therefore these values are derived

Table 1. Nomenclature of Interact's platform, sensors and actuators, with their principal properties.

Device (Manufacturer)	Name	Type	Notable Specifications
GRP-4400 (Ambot)	*Platform*	Rover platform	• 4 wheel steer and drive (independent) • 250 kg payload capacity • 20 cm clearance • Steer and drive encoders
LWR IV+ (Kuka)	*AuxArm / MainArm*	7-DOF robotic arm	• $\pm$ 0.15 mm pose repeatability • 820 mm maximum reach • 14 kg payload capacity
Prosilica GT 1290 with Ricoh FL-CC0418 DX-VG 2/3" lens (Allied Vision)	*MainCam*	Camera (color)	• 15 fps • 1920 x 1080 (HD) resolution • Auto exposure and gain • 96.4° x 54.2° FOV (H x v)
Spatial Dual (Advanced Navigation)	*Gnss*	GNSS/INS & AHRS (RTK)	• 8 mm horizontal position accuracy • 15 mm vertical position accuracy • 7 mm/s velocity accuracy • 0.03° roll and pitch accuracy • 0.06° yaw accuracy
Realsense D435i (Intel)	*AuxCam*	Depth Camera (color)	• 30 fps • 1280 x 720 resolution • 69° x 42° FOV (H x v)
VLP-32C (Velodyne)	*Lidar*	LiDAR (scanning)	• 32 laser channels • 200 m range • 3 cm range accuracy • 360° x 40° FOV (H x v) • 300 rpm • Capture mode: strongest

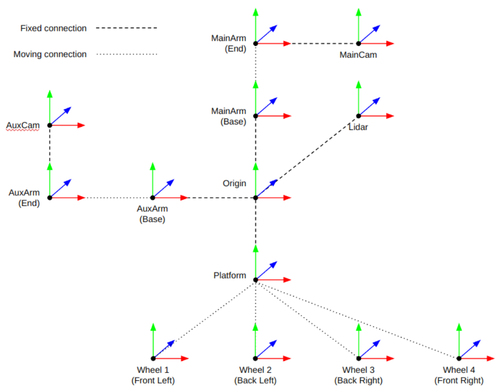

Figure 4. Overview of Interact's sensor and actuator coordinate frames referred to in the AMEDS.

from the CAD model of the robot, and they are subject to slight offsets due to mounting inaccuracies. These offsets can be as severe as 5 mm in positioning accuracy, and 2° in orientation accuracy. Vibrations, caused by the platform when it drives over uneven terrain, can also considerably affect the position of all the sensors. This is notably the case for the *Lidar* as it is perched at the top of a mast. The vibrations can therefore induce additional offsets that cannot be accounted for.

The values in Table 2 are meant to be interpreted as the transformation that needs to be applied to transform a point x^A from the coordinate frame A to x^B in the coordinate frame B. In other words, they correspond to the translation and rotation of the coordinate frame B relative to the coordinate frame A. These values can directly be used to create a homogeneous transformation matrix to convert between frames as follows:

$$T_{B\leftarrow A} = \begin{pmatrix} R_{B\leftarrow A} & t_A^B \\ 0 & 1 \end{pmatrix} \tag{1}$$

$$\begin{aligned} T_{B\leftarrow A} &= \text{Transformation from A to B reference frame} \\ R_{B\leftarrow A} &= \text{Rotation from A to B reference frame} \\ t_A^B &= \text{Translation from A to B reference frame} \end{aligned}$$

Where t_A^B is defined as:

$$t_A^B = \begin{pmatrix} x_A^B \\ y_A^B \\ z_A^B \end{pmatrix} \tag{2}$$

$$\begin{aligned} x_A^B &= \text{x coordinate of A origin in B reference frame} \\ y_A^B &= \text{y coordinate of A origin in B reference frame} \\ z_A^B &= \text{z coordinate of A origin in B reference frame} \end{aligned}$$

Table 2. Relative homogeneous transformation parameters of all Interact sensors and actuators.

From frame A	To frame B	x_A^B	y_A^B	z_A^B	ψ_x	θ_y	ϕ_z
Lidar	*Origin*	-549	0	-1389	180	0	180
MainArm (base)	*Origin*	-100	0	-647	0	180	0
MainArm (end)	*MainArm* (base)	Depends on MainArm joint angles					
MainCam	*MainArm* (end)	28	0	186	0	-90	90
AuxArm (base)	*Origin*	598	310	-210	-60	50	180
AuxArm (end)	*AuxArm* (base)	Depends on AuxArm joint angles					
AuxCam	*AuxArm* (end)	-57	0	218	0	18	90
Platform	*Origin*	0	0	81	180	0	0
Wheel 1-4	*Platform*	Depends on steer and drive motor positions					

And where $R_{B\leftarrow A}$ is defined as:

$$R_{B\leftarrow A} = R_x(\psi)R_y(\theta)R_z(\phi) \tag{3}$$

$$R_x(\psi) = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\psi & -\sin\psi \\ 0 & \sin\psi & \cos\psi \end{pmatrix}$$

$$R_y(\theta) = \begin{pmatrix} \cos\theta & 0 & \sin\theta \\ 0 & 1 & 0 \\ -\sin\theta & 0 & \cos\theta \end{pmatrix}$$

$$R_z(\phi) = \begin{pmatrix} \cos\phi & -\sin\phi & 0 \\ \sin\phi & \cos\phi & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

3. CAMERA AND ROBOTIC ARM RELATIVE POSE COMPUTATION

The pose of the cameras with respect to a common coordinate system (extrinsics), as well as the camera intrinsic parameters, are required in order to use the images captured for this dataset as a source of odometry, for vision-based mapping, for object detection, or for depth estimation (provided that there is overlap between both cameras).

3.1. Robotic arm extrinsics

It is possible to compute the camera poses relative to Interact's origin because they are mounted at the end of robotic arms, with joint encoders, which therefore act as pan-and-tilt units. The robotic arms' End-effectors' coordinate frames relative to their Base's coordinate frames are dependent on the arm's joint angles and link lengths. The link lengths are provided by Kuka and the joint angles are provided by integrated sensors. Therefore using the Denavit-Hartenberg modified DH parameters it is possible to determine the homogeneous transformation matrix between the arm's End-effector and the Base. Table 3 summarises the LWR IV+ modified DH parameters (α, d, θ, r), where α is the angle about the common normal, d is the offset (along previous z) to the common normal and r is the length of the common normal. The angle θ about the previous z of each joint is given by the arm's joint angle sensors.

Table 3. LWR IV+ modified DH parameters.

Link #	α [°]	d [m]	r [m]
1	0	0	0.31
2	90	0	0
3	-90	0	0.4
4	-90	0	0
5	90	0	0.39
6	90	0	0
7	-90	0	0

3.2. Camera intrinsics

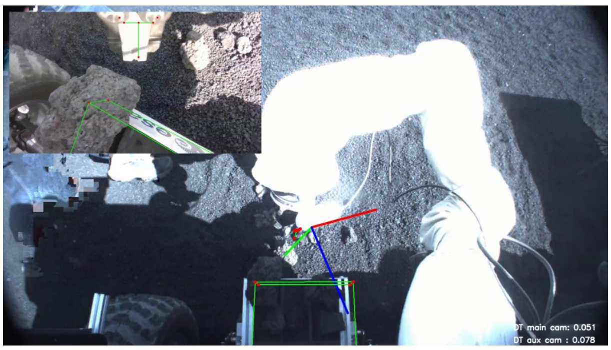

Figure 5. MainCam and AuxCam images with rock container, gripper and AuxCam coordinate frame projections. The DT values indicate the timestamp offsets with respect to the arm joint angles in seconds.

The *MainCam* and the *AuxCam* intrinsic parameters were precisely computed after the dataset acquisition using the open-cv methodology available open-source in both python and c++ [3]. The results of these calibrations are summarised in Table 4. The parameters were computed multiple times and the calibrations with the lowest root-mean-square error were kept. The quality of both the intrinsic and extrinsic calibration have been visually evaluated by projecting known parts of Interact (e.g. rock container, gripper and *AuxCam* coordinate frame) onto the *MainCam* and *AuxCam* images from the two rock-picking experiments (see Figure 5). Thanks to this simple analysis, it is noticeable that cm level offsets are present in the projections at roughly 1 m and 50 cm distance from the camera in the *MainCam* and *AuxCam* images respectively. These offsets are likely due to a summation of errors in the camera extrinsics, camera intrinsics, rover construction, arm joint angles and the position of the camera origin.

Table 4. Camera intrinsic and distortion parameters.

Parameters	*AuxCam*	*MainCam*
Intrinsic parameters		
f_x	908.087	885.015
f_y	910.723	887.440
c_x	656.119	955.893
c_y	356.394	533.638
Distortion parameters		
k_1	0.1431	-0.2418
k_2	-0.4744	0.0974
p_1	0.00068	0.00048
p_2	0.00123	0.00019
k_3	0.4215	-0.0226

4. WHEEL RELATIVE POSE COMPUTATION

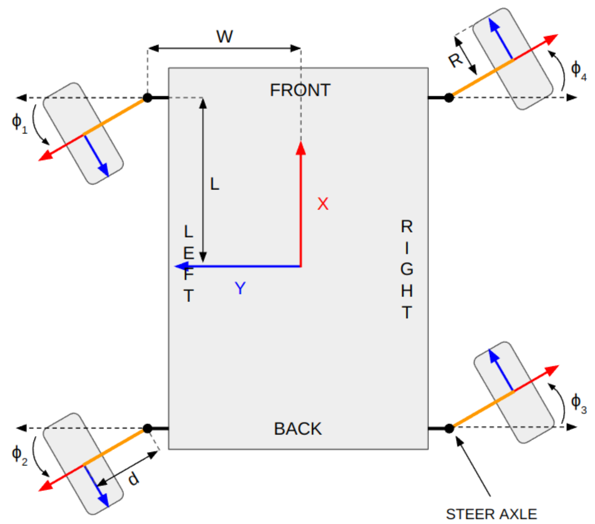

Figure 6. Interact's rover platform wheel steering and drive angle convention.

The pose of the *Platform*'s wheels depend on the fixed dimensional parameters and on three variable parameters: the drive angle ψ, the steering angle ϕ and the suspension height h. The drive angle and the steering angle can be deduced from the *Platform*'s motor encoders, but the suspension height is not measured and can therefore not be taken into account. The dimensional parameters, intrinsic to each wheel, are dependent on the *Platform*'s half length L=402 mm, half width W=396 mm, wheel height at rest H=135mm and steer axle, or swivel, length d=143 mm (see Figure 3). The drive angle in degrees can easily be computed as follows:

$$\psi = 360 \cdot \Delta E_\psi / k_\psi \quad (4)$$

ΔE_ψ : Drive motor tick encoder offset [ticks]

k_ψ : Tick to revolution ratio [ticks/rev]

In Equation 4, the tick offset can be measured via the drive motor encoders and the tick to revolution ratio of the drive motor is 30000 ticks/rev. The drive motor encoder values increase when the rover is moving forward and decrease when it is moving backwards. The steering angles are computed based on the convention depicted in Figure 6. This convention implies that the rover steering angles are all positive when the rover is performing a "Left Crab Turn". All the possible *Platform* manoeuvres are shown in Figure 7. During the AMEDS data gathering only "Left Turns" and "Right Turns" were commanded. However, in some occasions, due to loose terrain below the rover producing considerable slip, the actual manoeuvres performed by the rover are sometimes comparable to "Crab Turns" or "Spot Turns".

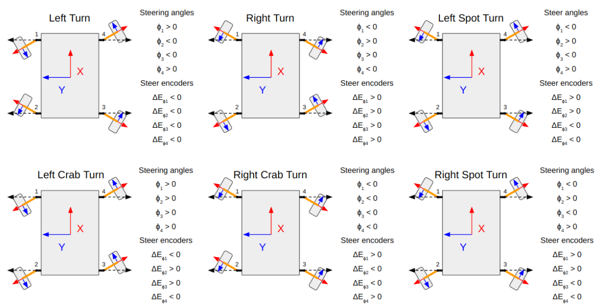

Figure 7. Steering angles and steer motor encoder values for various rover manoeuvres.

Due to the *Platform*'s transmission design, the suspension height influences the steering angle. Since the height cannot be measured, the suspension needs to be considered fixed at its rest position, which in turn can produce inaccuracies in the steering angle estimation. However, the following equation, deduced empirically by the HRI lab via a CAD analysis, estimates relatively accurately the steering angle in degrees:

$$\phi = \phi_0 + (p \cdot \Delta E_\phi / k_\phi - (r_0 + 60.67))/1.125 \quad (5)$$

ΔE_ϕ : Steer motor tick encoder offset [ticks]

k_ϕ : Tick to linear displacement ratio [ticks/mm]

r_0 : Rack position at rest [mm]

ϕ_0 : Steering angle position at rest [°]

p : Steer encoder polarity $\in \{-1, 1\}$

In Equation 5, the tick offset can be measured via the steer motor encoder, the tick to linear displacement ratio of the steer motor (linear actuator) is 806.3 ticks/mm, the rack position at rest is 40.58 mm, and the steering angle position at rest is 90°. For both front wheels (wheel 1 and 4), a positive encoder value corresponds to a negative steering angle. Therefore a multiplication factor, or polarity, equal to -1 (i.e. p = -1) needs to be introduced for the front wheels in order to respect the convention stated above. Once the drive angles and steering angles are known, it is easy to use a little trigonometry to determine the position of each wheel with respect to the *Platform*'s coordinate system as follows:

$$
\begin{aligned}
x_1 &= L - \sin(\phi_1)d & x_2 &= -L - \sin(\phi_1)d \\
y_1 &= W + \cos(\phi_1)d & y_2 &= W + \cos(\phi_1)d \\
z_1 &= -H & z_2 &= -H
\end{aligned}
$$

$$
\begin{aligned}
x_3 &= -L + \sin(\phi_1)d & x_4 &= L + \sin(\phi_1)d \\
y_3 &= -W - \cos(\phi_1)d & y_4 &= -W - \cos(\phi_1)d \\
z_3 &= -H & z_4 &= -H
\end{aligned}
$$

Finally, the orientation of each wheel can be determined using the sequential rotations (α, β, γ) in zxz intrinsic Euler convention (i.e. first rotation about z, then x and then y with respect to the rotating coordinate system) as defined in Table 5.

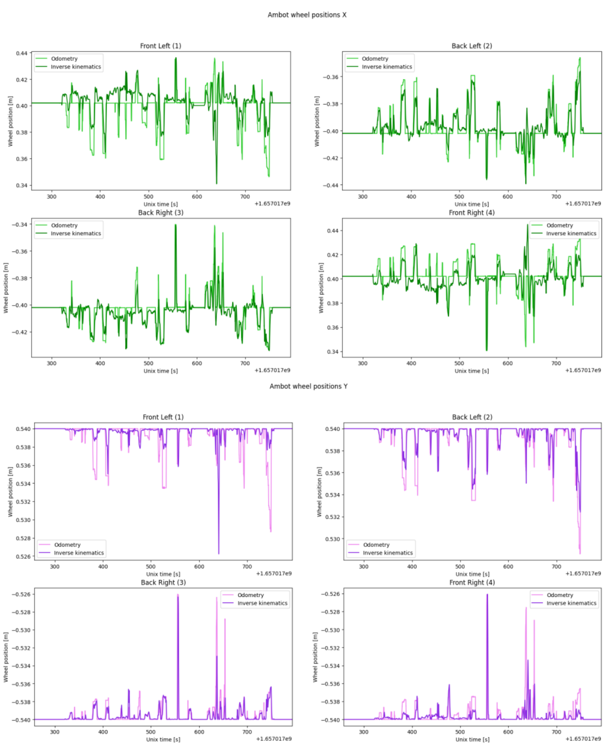

Figure 8. Comparison between the odometry approach and the inverse kinematics approach for Interact's wheel X and Y positions based on traverse 1 data.

The quality of this odometry based approach has been verified by comparison to an inverse velocity kinematics approach detailed in Alonzo Kelly (2014) [2], which

Table 5. Wheel orientation based on the steering and drive angles.

Wheel #	α [°]	β [°]	γ [°]
1	0	ψ_1	$\phi_1 + 90$
2	0	ψ_2	$\phi_2 + 90$
3	0	$-\psi_3$	$\phi_3 - 90$
4	0	$-\psi_4$	$\phi_4 - 90$

uses the *Platform*'s twist estimate as the velocity source. In this analysis, vertical body velocity is considered zero and the suspension height is considered fixed. The outcome of this analysis can visually be seen on an example from traverse 1 in Figure 8. An inverse kinematics approach can typically be useful to determine slippage, while odometry can be used in fusion algorithms to improve localisation.

5. DATA OVERVIEW

5.1. Traverses

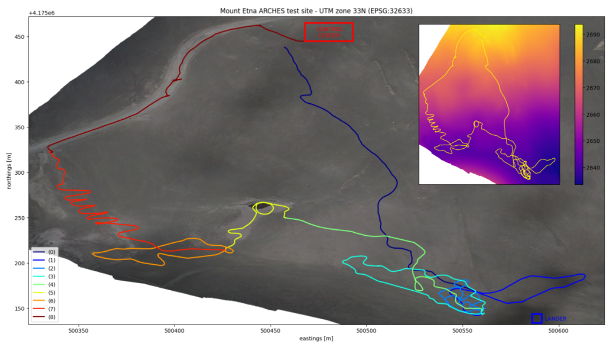

Figure 9. Overview of all AMEDS traverses within the ARCHES test site.

The traverses part of the dataset is comprised of nine short traverses, whose starting points and end points are connected, and thus can be combined to form a single large traverse. The first seven traverses are realistic when compared to a robot roving within a lunar environment. Whereas the last two traverses were captured when returning the rover to the control centre and do not hold as much realism with respect to lunar surroundings (i.e. cars and humans are visible) and rover behaviour (i.e. rover is driving backwards). Figure 9 is an aerial view of the traverses along with a heightmap of the traversed area and the locations of the lander and control centre. A summary of the main characteristics of each traverse is also displayed in Table 6.

5.2. Rock picking experiments

The rock picking dataset is comprised of two stationary rock picking experiments, during which the *AuxArm* and

Table 6. Main characteristics of the AMEDS traverses.

Traverse #	Length [m]	Max height difference [m]	Duration [mm:ss]	Mean velocity [m/s]	RTK coverage
0	329.8	46.6	25:02	0.22	No
1	195.6	4.7	08:55	0.36	No
2	202.8	1.7	08:46	0.41	Yes
3	239.1	4.8	14:44	0.30	Yes
4	210.9	9.6	07:26	0.50	Yes
5	134.1	6.5	09:31	0.37	Yes
6	191.7	2.1	09:39	0.39	No
7	304.2	22.2	08:26	0.67	No
8	246.6	22.4	06:40	0.81	No
Total	2054.8	–	99:09	–	–

it's gripper end-effector are used to pick-up a rock in view of the onboard cameras and store it in a small container in front of the rover. Both experiments take place in front of the control centre. The rock picking experiment 0 and 1 last 2 minutes 21 seconds and 1 minute 45 seconds respectively.

The data for both types of experiments is in the same format and it is comprised of both raw sensor data (straight from the sensor, unaltered by mathematical calculations) and processed data (based on raw data but transformed either onboard in near real-time or during post-processing with python scripts). All the data is timestamped by the RTI Connext DDS middleware, which is based on the onboard computers' clocks. All computers running on Interact were time synced with a common Network Time Protocol (NTP) server. In Table 7 is a list of the data provided in this dataset as well as some insightful information concerning the format and the content of the files, as well as the acquisition frequency. The North-East-Down (NED) coordinate system origin of the "world", in which Interact is globally localised, is located at 37.72351° (latitude), 15.00668° (longitude) and 2639.838 m (altitude) in WGS84 standard. This location corresponds to the position of the ARCHES campaign lander and is located at the bottom of the test site (see Figure 9).

Depending on the source of positional, angular, velocity and acceleration measurements the coordinate system convention can vary between body frame, NED (North-East-Down) and NWU (North-West-Up). When not explicitly mentioned, the measurements are given in body frame. All the data files from one experiment are bundled together into a single folder and compressed into a zip format. The data from each traverse and rock picking experiments can be found online: `https://robotics.estec.esa.int/datasets/arches-mount-etna-dataset/`.

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Table 7. AMEDS data content and formatting. All csv files contain the unix timestamp in their first column.

Device	Raw data	Processed data
Aux/Main Arm	Aux/MainArmJointAngles.csv - 1 Hz • Joint 1-7 angles [rad]	
Aux/Main Cam	AuxCam_*unixseconds*.jpg - 30 Hz • 1280×720 pixel color image (unrectified) MainCam_*unixseconds*.jpg - 30 Hz • 1920×1080 pixel color image (unrectified) Aux/MainCamVideoFeed.mp4 - 30 fps • Reconstructed color video feed (unrectified)	Aux/MainCamPoseEstimate.csv - 1 Hz • (x, y, z) position [m] • (roll-x, pitch-y, yaw-z) attitude [rad] MainAuxCamProjected_*unixseconds*.jpg – 15 Hz • MainCam and AuxCam images with rock container, gripper and AuxCam coordinate frame projections
Gnss	GnssBodyAcceleration.csv – 100 Hz • (x, y, z) acceleration [m/s^2] GnssBodyAngularVelocity.csv – 100 Hz • (x, y, z) angular velocity [rad/s] GnssBodyVelocity.csv – 100 Hz • (x, y, z) velocity [m/s] • (x, y, z) std velocity [m/s] GnssImu.csv – 100 Hz • (x, y, z) accelerometer [m/s^2] • (x, y, z) gyroscope [°/s] • (x, y, z) magnetometer [G] • Imu temperature [°C] • Outside pressure [Pa] • Outside temperature [°C] GnssNedVelocity.csv – 100 Hz • (x, y, z) NED velocity [m/s] • (x, y, z) std NED velocity [m/s] GnssPose.csv – 100 Hz • Device timestamp [unix seconds] • (lat, lon, alt) geodetic position [rad, rad, m] • (x, y, z) NED position [m] • (x, y, z) std NED position [m] • (roll-x, pitch-y, yaw-z) NED attitude [rad] • (roll-x, pitch-y, yaw-z) std NED attitude [rad] • gnss fix type [0-7]	
Lidar	LidarPointcloud_*unixseconds*.pcd – 5 Hz • Reconstructed pointcloud from one full revolution with point intensities indicating surface reflectance (0-255)	
Platform	PlatformMotorEncoders.csv – 50 Hz • Drive motor 1-4 velocity [m/s] • Drive motor 1-4 cmd velocity [m/s] • Drive motor 1-4 position [ticks] • Steer motor 1-4 position [ticks] Platform2DVelocity.csv – 50 Hz • (x, y) velocity [m/s] • (z) angular velocity [rad/s] • (x, y) std velocity [m/s] • (z) std angular velocity [rad/s]	Platform2DPoseEstimate.csv – 100 Hz • (x, y) NWU position [m] • (yaw-z) NWU attitude [rad] • (x, y) std NWU position [m] • (yaw-z) std NWU attitude [rad] Platform2DTwistEstimate.csv – 100 Hz • (x, y) velocity [m/s] • (z) angular velocity [rad/s] • (x, y) std velocity [m/s] • (z) std angular velocity [rad/s] PlatformWheelPoseEstimate.csv – 100 Hz • Wheel 1-4 (x, y, z) position [m] • Wheel 1-4 (roll-x, pitch-y, yaw-z) attitude [rad] • Wheel 1-4 drive angle [rad] • Wheel 1-4 steering angle [rad]