ROVER DATA ACQUISITION IN BARDENAS REALES

Levin Gerdes[1,2,*], Raúl Castilla Arquillo[1], Tim Wiese[2], Laura Bielenberg[2,3], Martin Azkarate[2], Hugo Leblond[2,4], Felix Wilting[2,5], and Carlos Pérez del Pulgar[1]

[1] *Space Robotics Lab, Department of Systems Engineering and Automation, University of Málaga, Spain.*
gerdes@uma.es, raulcastar@uma.es, carlosperez@uma.es
[2] *Planetary Robotics Lab, Automation and Robotics Section, European Space Agency, The Netherlands.*
tim.wiese@ext.esa.int, martin.azkarate@esa.int
[3] *Mars Exploration Group, Human and Robotic Exploration Directorate, European Space Agency, The Netherlands.*
laura.bielenberg@gmx.de
[4] *Télécom Nancy, France. hugo.leblond@telecomnancy.eu*
[5] *Delft University of Technology, The Netherlands. f.d.wilting@student.tudelft.nl*
[*] *Corresponding and presenting author: Levin Gerdes, gerdes@uma.es*

ABSTRACT

The generation of datasets on relevant planetary exploration scenarios is key to demonstrating the performance of novel methods for perception and localization. Available datasets usually include information from cameras, Lidars, and inertial sensors. The Planetary Robotics Laboratory (PRL) of ESA's Automation and Robotics Section and the Space Robotics Lab (SRL) of the University of Málaga went beyond, recording rover sensor data, including thermal information, as well as wheel force/torque measurements. This dataset acquisition was carried out in Bardenas Reales in Northern Spain in July 2023. This paper provides an overview of the involved systems, the test area, encountered obstacles, and lessons learned.

Figure 1: MaRTA in the field. In this image, MaRTA is heading down one of the steeper slopes. We captured such terrain features in multiple traversal directions.

1. INTRODUCTION

Autonomous planetary exploration requires advancing the current state of the art for Guidance, Navigation, and Control (GNC) components. This would support future missions, increasing their scientific return as it has been demonstrated with the NASA Perseverance rover [11]. However, improvements on the GNC subsystem require validation of their performance on Earth, increasing their Technology Readiness Level (TRL) prior to being qualified for space and placed onboard rovers to be sent to other planets. For this purpose, datasets from analog planetary exploration scenarios are needed. They can be used to validate novel components related to navigation, i.e. perception and localization. In this sense, several datasets have been recently published. As examples, the Katwijk dataset, generated by the PRL [5], was collected at the Katwijk beach (Netherlands), where artificial obstacles were placed, and the Heavy Duty Planetary Rover (HDPR) was equipped with different cameras, a LiDAR, and inertial sensors. Similar datasets were taken in more representative scenarios later on. Some areas from Morocco were identified in 2018 to retrieve some datasets for planetary exploration [7, 9], using a similar set of sensors. These datasets have been widely used to demonstrate novel navigation methods [2, 6, 8]. However, the use of thermal information [4, 10], as well as traction and vibration [3] have been proposed in the literature to increase the rover awareness, and therefore improve its navigation capability on remote planets.

Based on these statements, the main objective of this field test activity was the acquisition of a planetary dataset that contains data from a sensor combination we have not yet seen in other datasets. The collected data features, among others, traditional stereo camera images, thermal images, Force-Torque (F/T) sensor readings, and ground truth data for the rover pose and for the traversed reference terrain. This could for example enable the development of new terrain segmentation and classification approaches. The data can also be used like other planetary datasets, which primarily offer stereo images and rover pose as well as a detailed Digital Elevation Model (DEM) of the traversed terrain. Hence, it lends itself to the development of localization algorithms for unstructured terrains such as planetary surfaces. In addition to the main objective of acquiring this novel planetary dataset, a secondary objective was to prepare and test our recently acquired field test equipment.

The paper follows a chronological approach. Section 2 outlines the field test plan and the reasons behind our decisions. This includes a brief overview of our systems, infrastructure, a presentation of the test area, boundary conditions, and known unknowns. Notes on the test execution can be found in section 3, with preliminary results in section 4, lessons learned in section 5, and a final conclusion in section 6.

2. FIELD TEST PLAN

2.1. Robotic system and sensors

The Martian Rover Testbed for Autonomy (MaRTA) [1] is the latest six-wheeled rover testbed at the PRL and features an Xsens Inertial Measurement Unit (IMU), a Realsense D435i RGB-D stereo camera, a Bumblebee XB3 stereo camera, an Optris 640pi thermal camera, a KVH DSP-1760 Fiber Optic Gyro (FOG), six F/T sensors (one at each rover wheel leg), and a Global Navigation Satellite System (GNSS) positioning system (integrated in the Xsens module) with Real Time Kinematic (RTK) corrections input enabled. Figure 1 shows MaRTA in the test area. Additionally, a DJI Mavic 2 pro Unmanned Aerial Vehicle (UAV) recorded aerial images of the test area based on which we computed a detailed map (point-cloud, DEM, and Ortho-Rectified Image (ORI)) using the commercial Pix4D software.

The SRL ran additional measurements which may be included in a future dataset. First, a weather station at the base control station recorded temperature, humidity, and radiation throughout each testing day. The weather station consists of a Vantage Pro2 solar pyranometer to measure solar irradiance, and a BME280 sensor to measure ambient temperature, humidity, and pressure. Secondly, the mineralogy of select rock samples along the rover's path was measured using a Laser Induced Breakdown Spectroscopy (LIBS) instrument.

2.2. Base control station and network

We used our field test van CRAFTER (Carrier for Relocating Advanced Field Test Equipment and Rovers) as our base control station as well as for the transport of all test equipment and two to three team members.

CRAFTER, which can be seen in Figure 2a, is a transport van that has been outfitted to serve as a mobile mission control center, providing workplaces with desks and screens, tools for repairs, networking capabilities, and power. It allowed us to control the rover while being sheltered from sun and wind, as well as provide access to the Internet and charge our equipment.

Internet access was provided by an LTE router, which was mainly needed for RTK corrections, to access code hosted on the ESA GitLab, as well as for general research.

To connect to the rover over long ranges and with adequate speeds, a dedicated setup with Ubiquiti Bullet AC $2.4\,\mathrm{GHz}$ WiFi radios was used. Since we expected there to be no direct line of sight to the rover at all times, which could lead to significant drops in transfer speeds or even loss of signal, an extender (see Figure 2b) made up of two additional Bullets (one receiver, one transmitter) was placed at strategic locations (see Section 3.1).

(a) CRAFTER in operation during the field test, with Bullet access point and solar panel deployed.

(b) WiFi extender.

Figure 2: Field test van and network equipment.

Power in the van is supplied by a $200\,\mathrm{A/h}$ lithium-ion battery in combination with a solar panel. This allowed us to work off the grid for a full working day, without the need for noisy and less eco-friendly generators.

Overall, CRAFTER has proved invaluable to our test campaign and is a big improvement over a rental van with a tent setup, both in terms of working efficiency and comfort for the field test participants. Please refer to our poster on CRAFTER for more details on this specialized outfitting.

2.3. Field test area

The field test was performed in Bardenas Reales, a semi-deserted natural landscape located in Navarra, the north of Spain. Its landscape presents plateaus and canyons shaped by water and wind erosion. The traverse took place inside a canyon area with coordinates 42°04'12.6"N, 1°30'07.8"W. During July, global sun irradiance can get up to $1000\,\mathrm{W/m^2}$, average daily temperatures range between $20\,^{\circ}\mathrm{C}$ and $35\,^{\circ}\mathrm{C}$ and the wind can show a strength of up to $95\,\mathrm{km/h}$.

Our team profited from the fact that field test campaigns from other industrial entities were conducted in parallel at the same location in the Bardenas. The teams of another two ESA activities named Absolute Localisation for Planetary Rovers (ALPER) and Robust and (semi) Autonomous Platform for Increased Distances (RAPID) were co-located. This fact allowed us to create some synergies in the logistics and programmatic of the campaign. The permits to conduct the tests in the area were managed by RAPID (led by GMV Spain), including contacting and planning with the local authorities. In addition, RAPID also procured an air-cooled container where to work protected from the environmental conditions and a portable toilet for everybody's use. The initial scouting of the area was done one year in advance by the ALPER team, al-

Figure 3: Terrain types in the test area include loose soil, rock outcrops, gravel, sand, compacted soil, and dried river beds at different slopes.

lowing us to identify beforehand the location where the field trials could take place. A couple of months before the test campaign, the RAPID team did a second scouting, this time acquiring a map of the terrain with a drone (for which a dedicated drone piloting license is nowadays necessary in Spain), allowing us to define more precisely the areas or paths the different rovers would use and agree on those with the local authorities.

With this information and locally acquired data, our team was able to define the specific paths in which to run our dataset collection. The path contained a variety of terrain types that can be seen in Figure 3. The selected path was running along a canyon riverbed which can be seen in Figure 5, where three different zones have been identified.

2.4. Boundary conditions

The area of interest stretches ca. $900\,\mathrm{m}$ long and features different terrain types not only along the direct path but also in the close vicinity. Part of the traverse was planned to take place inside a canyon which meant obstructed lines of sight to the WiFi access point at the base control station at some point during every traverse. Parking the van and setting up of the base control station was also limited to certain locations along the test area. Figure 4 depicts the average daily irradiances and temperatures. This is relevant information for the use of the thermal camera, which may exploit thermal inertia to differentiate between different terrain types, and underlying composition. As can be seen in Figure 4, we had better record our data within the windows of 8 to 11 AM and 3 to 6 PM, times at which the thermal inertia properties of the different terrain types could show most different signatures in our thermal camera. Due to MaRTA's driving speed of 3 to $5\,\mathrm{cm/s}$, we estimated a traverse of ca. $300\,\mathrm{m}$ would take half a day.

2.5. Timeline and schedule

The constraints laid out above led us to split the test area into the aforementioned three zones of $300\,\mathrm{m}$, $372\,\mathrm{m}$, and $210\,\mathrm{m}$ length respectively. On a given day, the plan was to traverse one zone in the morning and record additional terrain patches around the same path in the afternoon. With all these considerations, this yielded the following plan:

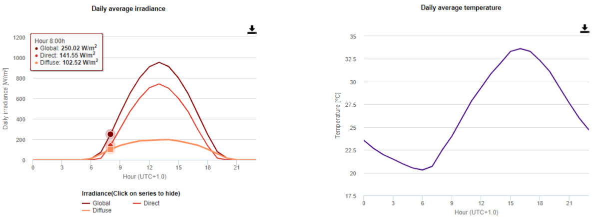

Figure 4: Average daily irradiance and temperature.

Figure 5: The traversed area is highlighted in this satellite overview. Red circles indicate the two base control station positions and blue stars are the locations of the WiFi extenders at different times during the field trip. The underlying image is taken from Google Maps.

- Day 0: Area scouting, functional rover system checkout, and new drone map recording.
- Day 1: Recording of zone 1 as defined in Figure 5
- Day 2: Recording of zone 2 as defined in Figure 5
- Day 3: Recording of zone 3 as defined in Figure 5
- Day 4: Contingency day

Therefore, we originally had planned to record a certain zone for three hours in the morning, then break for the midday when the sun irradiance was highest, and continue with the recording of different terrain patches at the same zone in the afternoon for another three hours. However, we ended up maximizing the amount of data collected and started recording as soon as we were ready for it and only broke briefly at lunchtime to continue with the recording again as soon as possible.

3. FIELD TEST EXECUTION

3.1. Scouting

The first day in the field primarily served to survey the test area. Critical points to figure out were: which areas and paths are still of interest, i.e. some parts for example displayed more vegetation than anticipated and were discarded, which of those are traversable, which are the most important, i.e. the most varied or unique, and which can be served with our given infrastructure setup. Especially the latter point was too uncertain to plan ahead of time because of the topography. The paths were planned to take place inside a (small) canyon with multiple bends and steep escarpments of varying altitudes.

The easiest method we found was to pull up the annotated map of the intended test area, walk along the intended

paths and pay attention to the ground features w.r.t. interest and traversability while keeping track of which possible parking areas we could reach and which vantage points would give our antenna & repeater setup the most suitable range.
Once we had passed through the entire test area, we drove the van to the most promising base control station locations to test for LTE coverage and confirm that RTK corrections were received, both from our antenna as well as from a local provider in the nearby town of Tudela.
The results of these scouting activities can be seen in Figure 5:

- half of zone 1 was not usable,
- some fields north of the riverbed were uncultivated and could be used,
- we only needed two base control station locations and four repeater locations to cover the whole area

The fact that we only needed two base control station locations was a welcome discovery as this would save the most time and facilitate daily planning.

3.2. Functional checkout

The next item for the first day was a checkout of MaRTA: We made sure MaRTA did not get damaged during transport, in particular, we verified that driving and all sensors worked as expected and ran our calibration procedures for the different platform sensors.

3.3. Drone flights

The drone was up in the air only when the wind allowed. This was needed to map the relatively large area from different angles at low altitudes, in order to achieve the resulting high resolution.

3.4. Challenges and obstacles

During the field test execution, we have faced technical, environmental, and organizational issues as well as combinations thereof.

PTU decalibration It was a known issue that the Pan-and-Tilt Unit (PTU) might decalibrate at times. For this reason, we procured a new PTU with higher gear ratios. Limited manpower in the lab and different prioritization have led to not fully integrating the new PTU in time for the field trials. The PTU decalibrated far more rapidly and frequently than feared. Luckily though, the only affected sensor is the Bumblebee stereo camera, as all other sensors are mounted to the chassis.

Rear bogie decalibration While running MaRTA in the field, we noticed that the sensor readout of the rear bogie position was not reliable. It decalibrated significantly between individual test runs, showing a highly inclined bogie position when in reality it was almost flat. A first analysis of the problem pointed towards an encoder issue, which we were unable to resolve in the field. As a workaround, we introduced a calibration procedure at the beginning and end of test runs, by moving the rear bogie into both end-stop positions and thus recording the extreme sensor values. Under the assumption that the encoder readings decalibrate slowly and nearly linearly, this allows us to correct the bogie position while post-processing the dataset.

Power autonomy Two weeks before heading out to the field campaign, we noticed that the van's solar power unit did not deliver any power. We organized a portable solar panel, which could replace the van's solar panel to increase our base control station's autonomy. This was also strongly needed since we could not charge the van battery overnight at the hotel because there was no power outlet at the parking lot. The relatively short drive to and from the test area (ca. $20\,\mathrm{min}$ one way) only charged the battery by around $20\,\mathrm{pp}$. Thus, we were depleting the battery over the course of the field test, and even though we could charge it by idling the van in the field, this is both noisy and wasteful, and the solar panel helped us reduce that to a minimum.

Strong winds Drone mapping can be greatly affected by strong winds as the drone battery may discharge faster due to compensation of perturbations or even lose control. During scouting, we lost connection to the drone while mapping due to winds and had to search for it after its emergency landing.
Strong winds are also a logistical and comfort challenge, as well as a hazard for the equipment (dust ingress, items falling over or blowing away). Our CRAFTER provided shelter in these conditions, but care needs to be taken to avoid e.g. doors slamming shut and damaging cables.

Overheating rover motors From our experience with other rovers in strong, direct sun, we expected the heat to be a problem for our rover. Hence, we brought reflective material, made sure that the fans worked, and reprinted any 3D printed parts in heat-resistant Polyethylene Terephthalate Glycol-modified (PET-G) material. The main problem we encountered did not concern the On Board Computer (OBC) or similar inside the chassis though. Instead, we noticed that the wheel drive motors would shut off if we drove them relatively fast for too long. This further limited the speed at which we would record the data.

4. PRELIMINARY RESULTS

Throughout the field campaign, we have collected a total of $433.7\,\mathrm{GB}$ of rosbag logs. A first breakdown of the collected data can be seen in Table 1.
The data is already being used for an internal R&D activity of the PRL but requires more post-processing and clean-up.

5. LESSONS LEARNED

This section presents the main lessons we learned on this field trip, some directly related to the issues above. Some

Data	Entries (approx.)
Thermal images	36,900
Depth images	36,900
Realsense color images	36,900
Navcam images	61,600
F/T measurements	15,830,600
GNSS position	108,400
IMU (accel., ang. rate, orientation)	1,355,500
FOG (angle, ang. rate)	2,711,000
Transformation tree	474,600

Table 1: Overview over the collected data, amounting to a total of 433.7 GB in mcap rosbags. The transformation tree is ROS's representation of transformations between rover components.

points were learned during earlier tests but they should not be omitted here.

- Scout the test area. We did this a couple of months before our trip to get an understanding of which areas are most feasible and promising. During the test week, we planned in another day for both scouting and checkout.
- Use as few 3D printed parts as possible. But if you do, make sure it withstands the heat (we reprinted everything in PET-G instead of Polylactic Acid (PLA) before the campaign) and bring multiple spares of every printed part. If possible, even bring a printer along.
- Take pictures with GNSS information and time stamps of everything remotely related to the tests, base control station, or test area because your logs might be incomplete or you may want to understand what happened and what conditions you found during a run or just before a failure.
- Try all equipment beforehand, even if it is only a backup that you will never need. Because you will need it. And it might not work. Case in point: we brought soldering equipment along for the off chance that we might need it. In the end, one of the repeater Power over Ethernet (PoE) cables broke and needed resoldering. Only at this point did we find out that the soldering iron did not work with floating grounds, so we could not use it with our van's power supply[1].
- Extend the autonomy of your base control station as much as you can. As an outcome of the test campaign, we will outfit the CRAFTER with more solar panels and upgrade the LTE router to an industrial model with a roof antenna to improve cell reception.
- Prepare for heat, dust, and strong wind. We thought we had this covered in terms of the rover, the attire, and base control station. As can be seen in Figure 6, plenty of dust still entered the rover chassis. Next time we will bring heavier antenna tripods or attach weights to the tripod feet. The 3D-printed tripod mount for the WiFi extender was destroyed after the first crash. Also, be aware that the wind can throw car doors shut suddenly and with force. Avoid routing cables through them and use dedicated openings instead.

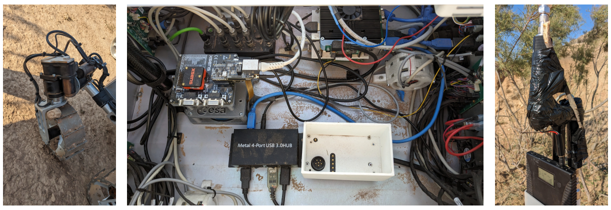

Figure 6: Some of the hazards encountered during the field test. A rock stuck between the wheel grousers and the steering assembly, dust inside the rover (the rover's panels were always closed except when changing batteries), and a broken WiFi extender bracket due to wind, fixed temporarily with a stick.

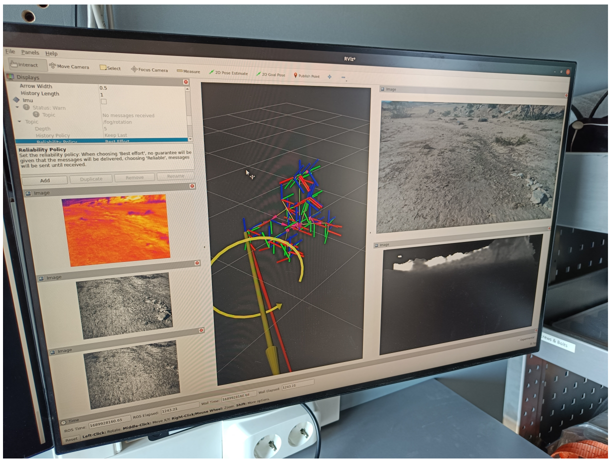

Figure 7: Checking sensor data and transformations from within the base control station.

- Write data sanity check scripts before the dataset collection to make sure everything is working properly and to be able to monitor each bag after collection easily. This was a goal we had to descope. Instead, we checked everything by inspecting different topics by hand before the recordings, sporadically while driving the rover, and after the recording (see Figure 7).
- We took note of georeferences (for the drone map) with an RTK-enabled handheld GNSS receiver and took pictures of the landmarks. For next time we highly recommend using chalk (or patterns) to mark the georeferenced measurements before taking the drone images instead. This can render the process of georeferencing the map much easier, by hand and even automated by the software.
- Most importantly: Be sure to know which elements of the trip have the highest priority. We descoped

---

[1] see Acknowledgments

some goals beforehand, but we continued to do so during the trip instead of losing too much time for nice-to-haves.

6. CONCLUSION

The paper gives an insight into the planning and encountered obstacles as well as the final execution of the dataset collection.

The main contributions are lessons learned, an overview of the testing area, the introduction of our field testing equipment, and a preliminary introduction to the collected data products.

The lessons learned can serve the robotics community to help them avoid learning these lessons from their own experience. Most lessons are not unique to dataset collection campaigns, but more generally to robotic field tests overall.

Future work includes exporting, cleaning, and documenting the dataset so that it can be used by more researchers without the ROS 2 framework and version we used to record it.

ACKNOWLEDGMENTS

Thanks to Ares Papantoniou for fixing our repeater cables in the hotel when our soldering station did not work in the van and to Nico Ustarroz for 3D printing a broken part for us that kept our infrastructure up and running smoothly.

REFERENCES

[1] M. Azkarate, L. Gerdes, T. Wiese, M. Zwick, M. Pagnamenta, J. Hidalgo-Carrió, P. Poulakis, and C. J. Pérez-del Pulgar. Design, Testing, and Evolution of Mars Rover Testbeds: European Space Agency Planetary Exploration. IEEE Robotics & Automation Magazine, 29(3):10–23, Sep. 2022. ISSN 1558-223X. doi: 10.1109/MRA.2021.3134875.

[2] M. S. Bahraini, A. Zenati, and N. Aouf. Autonomous cooperative visual navigation for planetary exploration robots. In 2021 IEEE International Conference on Robotics and Automation (ICRA), pages 9653–9658. IEEE, 2021.

[3] C. A. Brooks and K. Iagnemma. Vibration-based terrain classification for planetary exploration rovers. IEEE Transactions on Robotics, 21(6): 1185–1191, 2005.

[4] R. Castilla-Arquillo, A. Mandow, C. J. Pérez-del Pulgar, C. Álvarez-Llamas, J. M. Vadillo, and J. Laserna. Thermal vision for soil assessment in a multipurpose environmental chamber under martian conditions towards robot navigation. arXiv preprint arXiv:2304.13525, 2023.

[5] R. A. Hewitt, E. Boukas, M. Azkarate, M. Pagnamenta, J. A. Marshall, A. Gasteratos, and G. Visentin. The katwijk beach planetary rover dataset. The International Journal of Robotics Research, 37(1):3–12, 2018.

[6] B. Kuang, C. Gu, Z. A. Rana, Y. Zhao, S. Sun, and S. G. Nnabuife. Semantic terrain segmentation in the navigation vision of planetary rovers—a systematic literature review. Sensors, 22(21):8393, 2022.

[7] S. Lacroix, A. De Maio, Q. Labourey, E. P. Mendes, P. Narvor, V. Bissonette, C. Bazerque, F. Souvannavong, R. Viards, and M. Azkarate. The erfoud dataset: a comprehensive multi-camera and lidar data collection for planetary exploration. In 15th Symposium on Advanced Space Technologies in Robotics and Automation, 2020.

[8] H. Liu, M. Yao, X. Xiao, and H. Cui. A hybrid attention semantic segmentation network for unstructured terrain on mars. Acta Astronautica, 204:492–499, 2023.

[9] L. Meyer, M. Smíšek, A. Fontan Villacampa, L. Oliva Maza, D. Medina, M. J. Schuster, F. Steidle, M. Vayugundla, M. G. Müller, B. Rebele, et al. The madmax data set for visual-inertial rover navigation on mars. Journal of Field Robotics, 38(6): 833–853, 2021.

[10] V. Polizzi, R. Hewitt, J. Hidalgo-Carrió, J. Delaune, and D. Scaramuzza. Data-efficient collaborative decentralized thermal-inertial odometry. IEEE Robotics and Automation Letters, 7(4):10681–10688, 2022.

[11] V. Verma, M. W. Maimone, D. M. Gaines, R. Francis, T. A. Estlin, S. R. Kuhn, G. R. Rabideau, S. A. Chien, M. M. McHenry, E. J. Graser, et al. Autonomous robotics is driving perseverance rover's progress on mars. Science Robotics, 8(80): eadi3099, 2023.