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ARDITO, a modular technology demonstrator for robotic planetary surface exploration and operational support: an overview

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***Abstract*—This paper presents ARDITO, a modular technology demonstrator designed for robotic planetary surface exploration and operational support. Developed by the DIANA student team at Politecnico di Torino, ARDITO aims to serve as a versatile platform for research and educational applications. The rover's design emphasizes modularity, allowing for the asynchronous development of components, subsystems, and payloads. ARDITO's architecture is inspired by real space mission requirements, ensuring that students gain hands-on experience with space-compatible methodologies and technologies. The rover features a rocker-bogie locomotion system, a distributed electronic architecture, and a variety of payload configurations tailored for different mission scenarios. This paper details the system design, development process, and the educational impact of the ARDITO project. While ARDITO has achieved its initial goals, further advancements in materials, redundancy, and reliability are required to make it a viable candidate for actual space missions. The project's emphasis on modularity will be instrumental in overcoming these challenges and advancing the capabilities of robotic planetary exploration.**

***Index Terms*—Space Rover, Space Robotics, Student Team.**

I. INTRODUCTION

Since humanity began exploring beyond Earth, robots and autonomous systems have played a pivotal role. The first proper rover, Lunokhod 1, landed on the moon in 1970, establishing the field of Planetary Robotics systems. A crucial milestone was NASA's Sojourner [1], which reached Mars in 1997. It became the first rover on another planet and served as a testbed for technologies used in later missions. The Mars Exploration Rovers, Spirit and Opportunity [2], landed on Mars in 2004 to search for past water evidence. Their discoveries provided evidence of ancient hydrothermal environments and prepared the way for NASA's Curiosity rover [3], which continues exploring Mars today. These platforms remain essential for space exploration. Perseverance [4], the most advanced rover to date, landed on the Jezero Crater [5] in 2021. Its cutting-edge instruments search for ancient life signs, collect return samples, and prepare for future human exploration. In a recent breakthrough, India's Chandrayaan-3 mission successfully landed its Pragyan rover on the lunar South Pole in August 2023. For upcoming years, space exploration will see significant advances. Simulation technology is developing rapidly to test and refine robotic systems before deployment [6]. Additionally, the European Space Agency's Rosalind Franklin rover [7] will launch in 2028 for a Mars mission.

The future of space exploration demands a paradigm shift towards modular and cooperative rover systems, as standalone, monolithic, single-purpose rovers become less equipped to handle the expanding range of mission requirements. These adaptable platforms could operate across diverse mission scenarios as components of an integrated system-of-systems architecture, utilizing swarm coordination to achieve robust, scalable, and highly adaptable operations. This paradigm distributes both production and development costs while reducing operational risks associated with single-platform failures.

This collective work aims to present a possible solution for a medium-sized, highly modular rover, developed within the Politecnico di Torino framework, that serves as a development platform for research and educational applications.

II. BACKGROUND AND DRIVERS

This work is carried out by DIANA, a University Student Team from Politecnico di Torino. The Team was born in 2008 under the guidance of Professor Emeritus Giancarlo Genta, with the ambitious goal of sending a rover to the moon as part of the Google Lunar X-prize challenge. After the project's closure, the team decided to preserve its expertise by participating in student competitions such as the European Rover Challenge.

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Throughout its sixteen-year history, DIANA has focused on developing technological demonstrators of space robotic systems, striving to adhere to rigorous space development rules and methodologies. To achieve this, DIANA has adopted a highly structured organization that allows for both vertical development, based on each member's area of study, and horizontal integration, ensuring seamless collaboration across all rover subsystems. The rover development process is guided by a multi-V model, complemented by the utilization of various software tools for requirement identification and work package management.

The ARDITO project, launched in 2019, was built upon the team's experience prototyping three rovers, the latter two featuring rocker-bogie suspensions and six degrees of freedom arms. ARDITO emphasizes modularity, enabling asynchronous development of components, subsystems, and payloads. This approach allowed the team to develop and continuously refine the rover over four years.

Within the constraints of a university team and a limited budget, DIANA maintains a focus on a "space-like" approach, adopting space-compatible methodologies and architectures. While ARDITO is just a rover technology demonstrator, it is developed and designed with an emphasis on avoiding materials that are not suitable for space applications, such as 3D printed plastics, and prioritizing design choices that align with future space missions.

In this context, a series of research works have been developed, ranging from the design and testing of AMALIA Rover wheels [8] [9] to a design methodology for additive manufacturing components [10], and even the application of reinforcement learning for navigation algorithms [11].

Beyond these technical aspects, DIANA is also committed to an educational purpose. Team students engage in a space project while at university, applying classroom-learned skills and acquiring new ones, while developing, sometimes from scratch, novel technologies. They gain hands-on experience with every aspect and phase of a development life cycle, from engineering and management to design and procurement. Furthermore, participating in a student competition like the European Rover Challenge provides a pace to the project and an industry-like environment, allowing members to gain experience in a semi-protected setting.

III. SYSTEM DESIGN

A. System Requirements

Guided by the drivers that influenced the system's early design, a requirement and functional analysis was conducted to ensure consistency with the European Rover Challenge's goals. For this analysis, processes for Requirement Engineering and Mission Analysis derived from ECSS-E-ST-10C and ECSS-E-ST-10-06C have been followed, and the Valispace software has been used [12] [13].

The first step was deriving a formalised set of requirements from the competition rules. This preliminary specification encompassed all necessary provisions including safety, operational and performance requirements. In addition, this specification has also been harmonized with a series of requirements and assumptions derived from the above-mentioned project drivers. A summary of the most significant design and functional requirements is reported below.

- The ARDITO System's design and development processes shall align with the practices, standards, and technologies employed in actual space exploration missions, in order to allow students to gain relevant hands-on experience in various engineering disciplines.
- The ARDITO System shall be based on a modular platform capable of hosting different devices and payloads, in different configurations, in order to accommodate various mission needs.
- The ARDITO System's design shall allow for easy accessibility and replacement of its devices and payloads for maintenance purposes or to quickly accommodate changes in the mission scenario.
- The ARDITO Rover shall be able to navigate, with various degrees of autonomy, in an unknown environment, featured with various challenging terrain types, including flat surfaces, slopes, and obstacles.
- The ARDITO Rover shall be able to manipulate objects and interact with human-operable and human-rated equipment, in order to fulfill maintenance operations on dedicated panels, with various degrees of autonomy.
- The ARDITO System shall be able to interact with and analyse the surrounding environment by collecting and storing soil samples and probes, and perform scientific analyses of both the environment and the collected samples.
- The Operators shall be able to control and monitor in real-time the mission execution and systems status from a remote location, without having direct line-of-sight of the ARDITO System.

B. System breakdown and configurations

After the first preliminary specification was defined, the proper functional analysis was performed. In particular, all required functions have been extracted and grouped to create a function tree. Then, by means of a table, each function was linked to its parent requirements (to provide backward traceability), as well as to relevant operational and performance requirements. The last step saw the allocation of each function to one or more of ARDITO subsystems. At this point, following the grouping used for the function tree and the function-subsystems allocations, the ARDITO Product Tree was defined (its latest version is here reported in fig 1) and a detailed System Technical Specification was drafted.

To accommodate both the evolving technological landscape and the dynamic nature of the European Rover Challenge, the process has been refined annually. Notably, in response to the increasing number of payloads, diverse mission scenarios, and enhanced team management requirements, ARDITO Rover systems have been reorganized into two distinct sections: the *Platform*, encompassing the core subsystems essential for nearly every scenario, and the *Payloads*, comprising all interchangeable equipment. This organization underscores ARDITO's modularity requirements, aimed at enabling seamless integration of payloads.

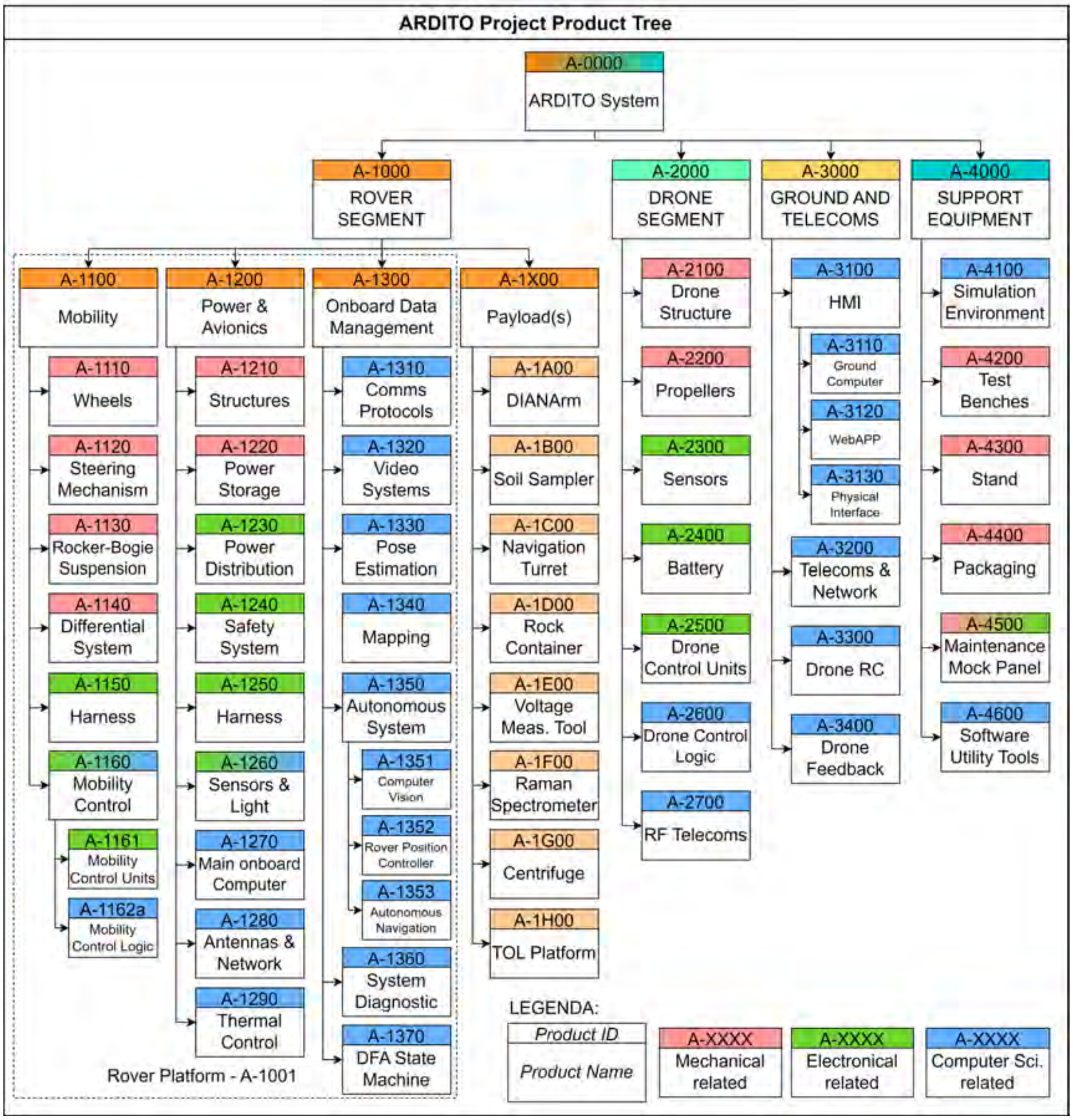

Fig. 1. *ARDITO project product tree.*

At the current moment, the ARDITO System foresees three different configurations. Each one of them was designed for a specific mission scenario, based on the rover competitions tasks:

- Navigation: this configuration is meant for mission scenarios that require traverse and mapping of unknown environments. For this reason, the Rover is equipped with only a *Navigation Turret* which allows for a better positioning of the depth and tracking cameras. This lightweight configuration results to be optimized for extended missions and more challenging terrain, relying on reduced power consumptions and increased stability.
- Maintenance: the maintenance configuration is equipped with the Robotic Arm and is specifically meant to fulfil maintenance operations on electrical panels and other infrastructure. In particular, the arm End-Effector in this configuration is equipped with fingertips for handling tools and objects, and ad-hoc tools can be integrated to perform specific tasks like socket voltage measurement.
- Science: the heaviest of the three configurations, this includes many payloads, like the Robotic Arm for collecting soils samples or probes, the Soils Sampler to extract below surface samples while preserving terrain stratigraphy, and the Science Payload to store and analyse collected rocks or surface samples.

In addition, depending on the mission needs, the Rover can also be paired with a Drone companion, in order to enhance the System exploration and analysis capabilities. The three different configurations are displayed in figure 2. Table I explains in detail some technical data of the three different configurations.

IV. ARDITO ROVER

A. Platform

The platform's electronic architecture embodies a distributed design [14], with the *Main On-Board Computer*

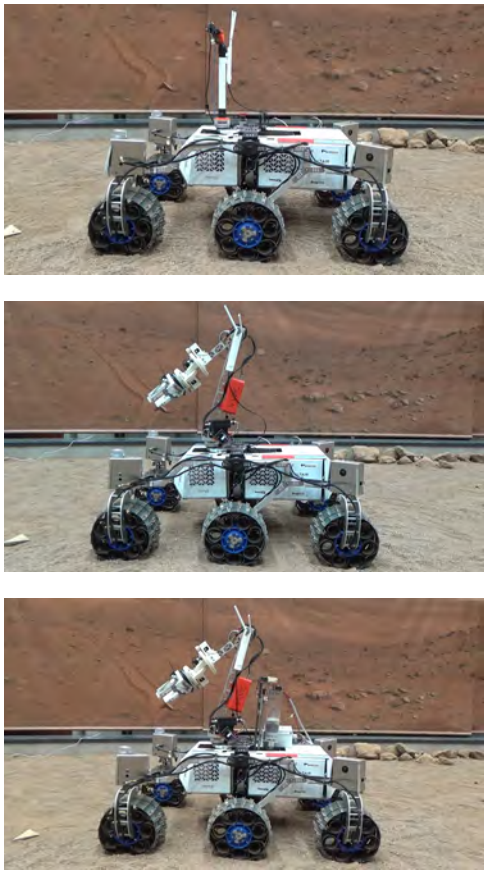

Fig. 2. *ARDITO Configurations, from top to bottom: Navigation, Maintenance, Science. (These photos were taken at the ALTEC Mars Terrain Simulator - MTS Facility - which was developed for ESA ExoMars program under Thales Alenia Space Italy contract).*

(MOBC) serving as the rover's central processing unit. On it, the DIANA Software runs its microservices, engaging in a continuous exchange of information with the ground station. Utilizing the CAN Bus protocol, they relay commands to the Control Units (CUs) distributed in the system, simultaneously receiving feedback about their execution.

Two CUs, communicating with *MOBC* and with the lower level controllers, are installed on the platform: the *Propulsion and Steering Control Unit (PSCU)* and the *Power Control Unit (PCU)*. The PSCU assumes responsibility for managing the locomotion system, while the PCU meticulously monitors the battery pack and system power consumption, ensuring optimal energy utilization and performance.

1) Mobility: ARDITO's mobility system is based on a rocker-bogie locomotion mechanism, equipped with six independent driving wheels, made of spring steel, four of which are capable of steering. Over the years, the design of the wheels improved the adaptability to harsh terrain and load peak absorption that could induce undesired high stress on ARDITO's mechanical structure. After more than two years of usage, the fatigue cycle has led the previous version of elastic wheels to plastic deformation. The latter and more encroaching problem has been mitigated, in the new solution, adding a mechanical end stop. Wheels' behaviour and maximum imposed displacement has been computed by software, through FEM models. Therefore, the results were compared with the test's outcomes to validate the design of the wheels. [15] The locomotion system is composed of two halves, made of 6061 aluminium alloy squared profiles joined together by aluminium plates and blind rivets sized and verified thanks to FEM models. The differential system, based on a gearbox, connects the two sides of the mobility system. On the top of the structure, coupled with the upper gear, is placed an encoder to obtain real-time information on the rocker-bogie relative position [16].

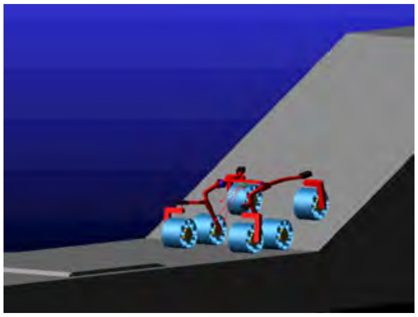

Fig. 4. *ARDITO Mobility System ADAMS model.*

The rover's locomotion system demonstrates robust performance, easily overcoming obstacles up to 500 mm and climbing 30-degree ramps. The system's foundational geometry was established through meticulous optimization using *Hexagon MSC ADAMS* software during the preliminary development phase. However, the current version was rebuilt following structural failures in earlier iterations.

To understand and expand the system's operational limits, an extensive analytical study was conducted. This study utilized state-of-the-art finite element analysis (FEA) in *Hexagon MSC Apex* to assess structural behaviour under a wide range of scenarios, including rest, acceleration, reversing, and steering on both flat and inclined terrain.

Importantly, cost-effectiveness was a key consideration throughout the design process. The locomotion system's performance has been preliminarily validated through testing at the *ALTEC S.p.A.* Mars Terrain Simulator Facility, utilizing the Tilting Platform to simulate various terrain conditions.

The *Propulsion and Steering Control Unit* (*PSCU*) plays a crucial role in managing this system. Its primary functions

TABLE I
Technical Specifications.

Configuration	Length [mm]	Height [mm]	Width [mm]	Weight [kg]	Max. Obstable height [mm]	Max. Slope [°]	Max.Speed [m/s]	Autonomy
Navigation	1538	1402	1207	71.3	500	30	1	3h10min
Maintenance	1538	1458	1207	80.3	500	30	1	2h26min
Science	1538	1458	1207	95.6	490	30	1	3h10min

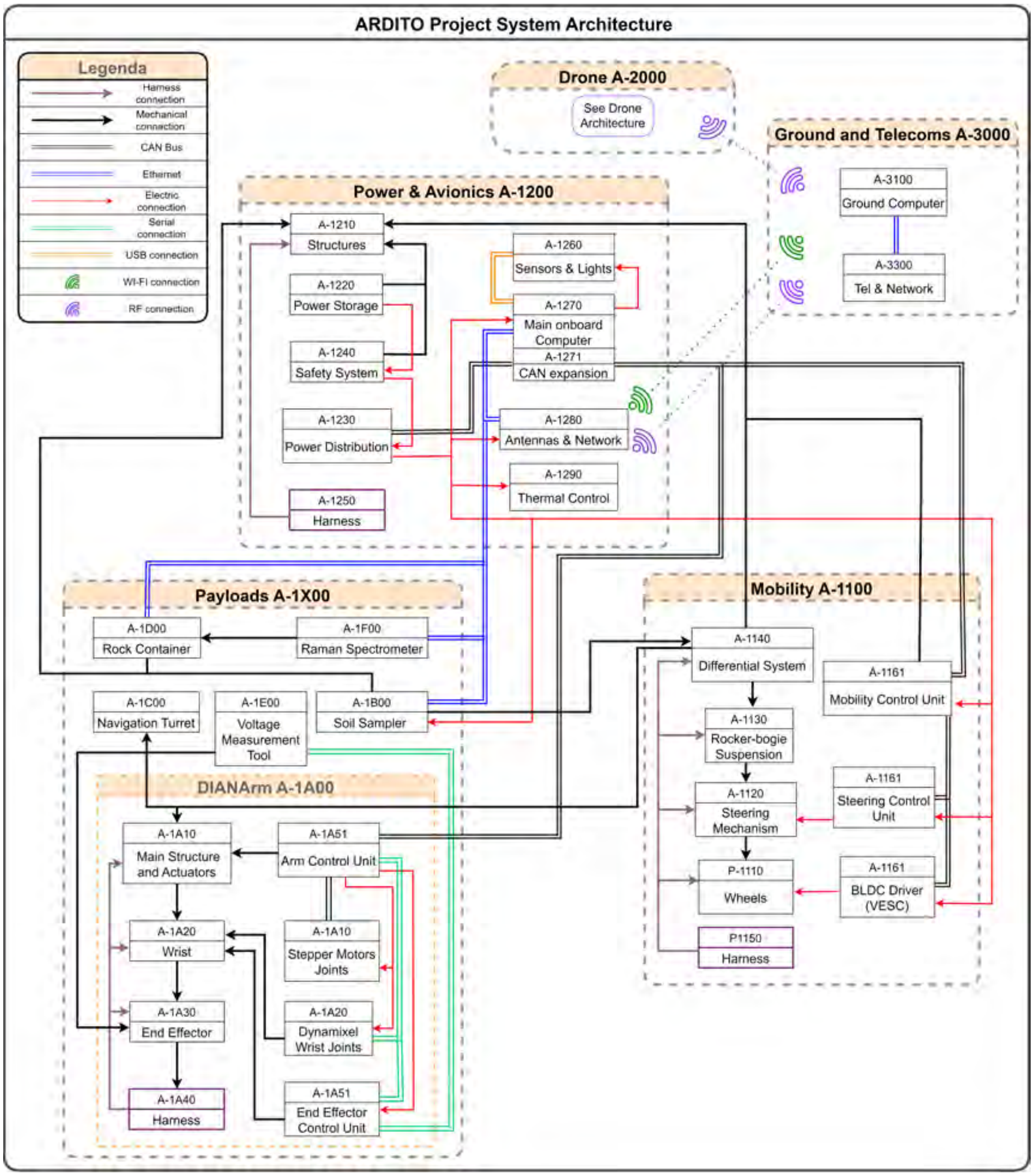

Fig. 3. *ARDITO system architecture.*

include transmitting movement parameters to the *VESC* [17] boards and retrieving system status data, as well as transmitting the angle of steering to the *SCUs* (Figure 6). The communication with these boards happens through CANBus [18], following the ISO 11898-2 standard.

The *PSCU*'s firmware oversees the entire mobility system. It's based on the *RTEMS* [19] real-time operating system, able to handle safety-critical and time-critical tasks efficiently. Using the Cheddar Framework [20] a scheduling feasibility analysis has been performed to check in advance the proper function of the firmware.

Each steering joint employs a high-torque NEMA17 stepper motor capable of generating 0.4 Nm. The motor is equipped with an encoder that provides precise feedback on the current steering angle. A gearbox amplifies the torque to a maximum of 13 Nm at the output, enabling controlled steering manoeu-

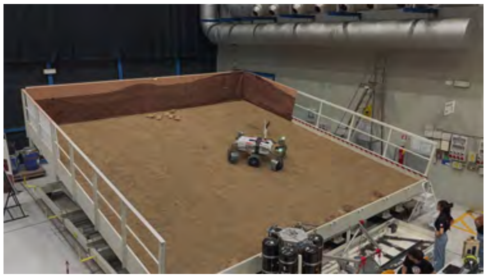

Fig. 5. *ARDITO on the Tilting Platform (These photos were taken at the ALTEC Mars Terrain Simulator - MTS Facility - which was developed for ESA ExoMars program under Thales Alenia Space Italy contract)*

vres even in harsh terrains.

A dedicated control board, the *Steering Control Unit* (*SCU*) manages each joint. The *SCU* implements a simple closed-loop position control strategy. It receives the desired angular position from the *PSCU* and precisely adjusts the stepper motor to achieve that position. The *SCU* also continously samples and transmits joint position to the higher logic.

Additionally, *SCUs* are in charge of controlling status RGB LEDs positioned on top of the steering boxes. These LEDs act as a visual communication channel, conveying information about the rover's operational status through a pre-defined colour code. This allows for quick and intuitive understanding of the rover's state, including different operational phases and potential error conditions.

The locomotion system utilizes two dedicated CAN buses managed by the *PSCU*. One bus is used for the communication with the six *VESCs* that control the wheel motors, while the second bus handles communication with the four *SCUs*. This dual-bus architecture efficiently avoids potential bus saturation caused by the high volume of data exchanged during operation. It ensures reliable and timely communication throughout the entire mobility system.

The controlling strategy of the locomotion subsystem is to define layers, with different levels of control and increasing autonomy. The first level of control aims to enable movement, instant by instant, via an operator. Only the Velocity Controller, developed using a model-based approach in Simulink, is involved at this level. It resides in the *PSCU*, receives the desired velocity and steering angle of the rover and translates them into commands to be sent to each wheel, following the Ackermann model applied to six-wheel rocker-bogie geometry. To optimise certain operations, such as manoeuvring in tight spaces as a crater, a special mode of operation of the speed controller has been developed: the spinning mode. During the spinning mode, the steering wheels are positioned to allow the rotation of the rover around an imaginary axis passing through the centre of the locomotion system. Increasing the autonomy level, it's possible to assign a target position in a Cartesian plane, that the rover will attempt to reach. The Mobility Position Controller is executed on the *MOBC* and is part of the DIANA Software that will be described later.

Fig. 6. Custom-made modular joint Control Unit

2) Power & Avionics: At the heart of the rover lies a modular power and avionics system designed for ease of use. This system prioritizes independent maintenance, testing, and inspection of each module. Constructed from lightweight yet robust aluminium sheets (Al 5754 H111), the modules can support the weight of internal electronics while withstanding vibrations caused by rover movement. Linear guides fixed to the differential system through plates ensure secure mechanical connections between modules.

A key element in achieving modularity is the Junction Box. This interface box, composed of modular industrial connectors mounted on a sturdy aluminium frame, acts as a central hub for electrical connections (both power and logic) between modules. It also seamlessly connects to the locomotion system via circular connectors. Different module versions, all utilizing the same mechanical and electrical interfaces, offer interchangeable functionality based on payload and operating conditions.

Power and logic connections are carefully routed to minimize electromagnetic interference. Separate power lines are used for actuators and logic circuits, while shielded cables ensure protection for logic signals. Additionally, sensitive components like the *MOBC* and *PSCU* are isolated for further safeguarding.

The logic module houses the Main On-Board Computer (MOBC), the core computational element responsible for high-level control algorithms. Additionally, it integrates essential control boards for locomotion, including the *PSCU* and *VESCs*.

To supply energy to these boards, a DC-DC converter is used. This converter transforms the raw power from the battery into stable, regulated voltages required by the various electronic boards. This ensures consistent power delivery and protects sensitive electronics from voltage fluctuations. Furthermore, an Ethernet switch facilitates a high-bandwidth, reliable communication network between the MOBC and the PSCUs. The rover's primary mobile power source consists of Lithium-ion battery packs housed inside the forward-mounted Power Module. The selection between battery packs of different capacity is made based on mission requirements. The high-capacity main battery utilizes 21700 Lithium-ion cells in a 6 series, 7 parallel (6s7p) configuration, delivering a nominal voltage of 24V and a maximum capacity of 777Wh. This configuration provides sufficient energy for extended operation or demanding tasks.

For scenarios requiring lower operational range, two secondary 6s1p Lithium Polymer batteries are available. Each of these batteries offers a capacity of 355Wh.

During indoor testing phases, a separate laboratory power supply unit can be employed. This unit provides a stable 24V DC voltage with a maximum current output of 50A. The power supply can be utilized for testing the entire rover system or for isolated testing of individual subsystems.

3) On-Board Data Handling & GNC: A detailed description of the entire software architecture, or *DIANA Software*, would go beyond the scope of this paper. It is provided here just a brief overview.

DIANA Software is a modular, scalable, and extensible software suite developed by DIANA to control and monitor ARDITO, or possibly any similar rover. It runs on top of a Linux operating system (Ubuntu 22.04). It is based on a

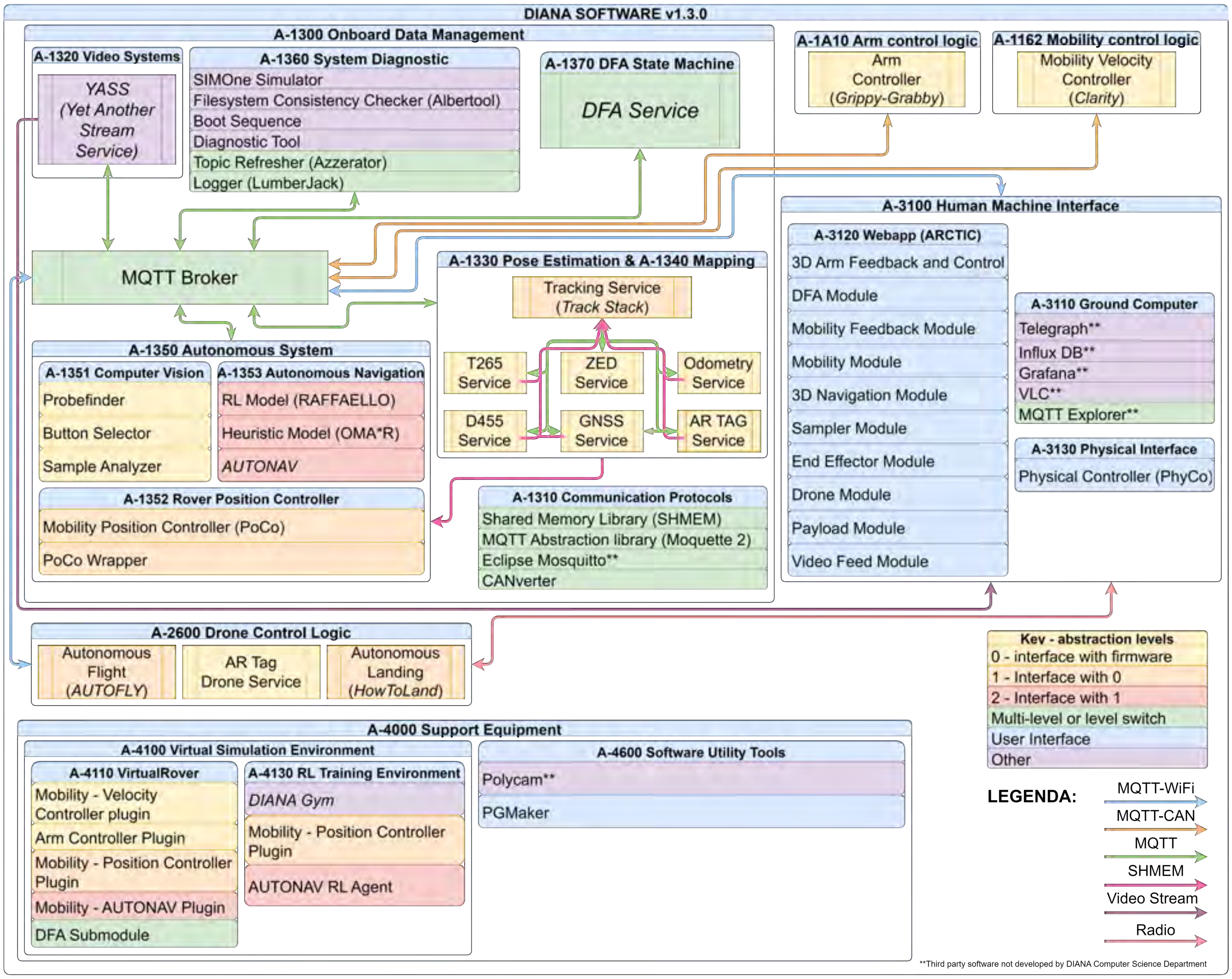

Fig. 7. *DIANA Software Architecture.*

microservices architecture: it features several custom system services and utility software tools, that communicate using custom-developed shared libraries as interfaces. It leverages mainly on the MQTT protocol to allow for information sharing between software entities as well as between the rover and the ground segment.

a) Communication Libraries: The Onboard Data Handling within ARDITO relies on two backbone libraries: *Moquette* for MQTT communication and *SHMEM*, an abstraction of the POSIX shared memory for fast, on-board only, inter-process communication. *Moquette*'s main purpose is to abstract the MQTT protocol to allow programmers to easily implement topic communication on multiple services. *SHMEM* has been developed to allow high-bandwidth inter-process communication on shared memory areas for different processes to share large amounts of data.

b) State Machine: A *Deterministic Finite Automata State Machine* (DFA) is responsible for redirecting incoming input to the desired services depending on the operating mode. For example, if the rover is in teleoperated mode, the DFA State Machine will prevent the AUTONAV service from controlling the rover. The State machine is implemented in the DFA-State-Machine service. This service also manages the transitions between the different states and modes of the rover.

c) Track Stack: The *Track Stack* is a collection of software services that form the core of ARDITO's autonomous navigation capabilities. The Track Stack is responsible for collecting and filtering pose data from a variety of software services reading and elaborating on data coming from multiple sensors, such as stereo cameras for visual odometry, positional encoders for wheels and steers-based odometry, GNSS, IMUs and AR tags recognition.
These sub-services are managed by a master service which is responsible for fault detection and recovery and to finally compute filtering and weighting operations to deliver the most accurate positional tracking data possible to other services.

d) Mobility Position Controller (PoCo): PoCo is a software service that controls the rover's mobility by receiving target coordinates and translating them to velocity and steering angle for the low-level controller. It generates a trajectory based on tracking data and applies real-time corrections. When the target point is reached, the software waits for another point to be reached. The controller is wrapped into a higher-level code in order to send messages from and to MQTT.

e) AUTONAV: AUTONAV is the uppermost software service in ARDITO's autonomous navigation stack. It receives the tracking data from MQTT and the point cloud data

Fig. 8. *ARCTIC AUTONAV module.*

from SHMEM to search for a safe path to a global goal. Once AUTONAV has computed a safe path, if one exists, it sends the path to the Position Controller (PoCo). The ideal path is continuously updated and refreshed at each time step (1 Hz). Should the rover at any moment deviate from the ideal trajectory, AUTONAV immediately recomputes a new trajectory to the given goal.

B. Payloads

1) DIANArm: DIANARM (Fig.9) is ARDITO's six degrees-of-freedom robotic arm that serves as a pivotal instrument for enabling ARDITO's interaction with its external surroundings. These interactions encompass a variety of tasks, including grasping and lifting objects, manipulating external tools, and depositing specimens into designated containers.

Fig. 9. *DIANArm tested in the MTS Facility.*

DIANARM consists of two main components, the *Structural Arm*, which houses the joints 1, 2 and 3; and the *Wrist*, which houses the joints 4, 5 and 6 and is attached to the end effector.

The Structural Arm is made out of aluminium Al6061 T6 square tubes, machined with a CNC milling machine to guarantee an optimal rigidity/weight ratio of the structure. It is reinforced by internal ribs, which are connected to the main structure with rivets. The 1st DOF is managed by a [30:1] reduced stepper NEMA17, which drives a slewing bearing with a further reduction of [3.5:1]. The 2nd DOF is driven by two reduced [47:1] steppers NEMA23, which drive two case-hardened steel (16NiCr4) helical gear wheels that allow for a further reduction of [3.25:1]. The 3rd DOF is driven by another reduced [47:1] stepper NEMA23, which drives a single 16NiCr4 helical gear wheel with a [3.25:1] reduction.

The Wrist features complex geometries and designs that have been produced by the utilization of additive manufacturing technologies. Two different materials are used to increase the precision of the wrist: ABS is used for the internal structural parts, and IGLIDUR I180 for the tooting of the gear wheels. Its joints are driven by three *Dynamixel MX-106* motors, reduced respectively to [5:1] for the 4th joint, [3:1] for the 5th joint and [4:1] for the 6th joint. The 4th and 6th joints achieve virtually continuous rotation thanks to *slip-rings*, electro-mechanical devices that enable uninterrupted power and signal transmission despite continuous wrist rotations.

The entire structure is modular thanks to a connection interface at the base of the arm that allows the interchanging of the arm with other payloads, depending on operational needs and mission profile, such as the Navigation Turret a payload designed to accommodate the cameras and primarily reduce weight during operations that not requires interaction with the environment.

The platform's electronic architecture seamlessly extends to the robotic arm, employing hardware similar to that of the PSCU, now designated as the *Arm Control Unit* (*ACU*). The ACU forms a direct interface with the *Joint Control Units* (*JCUs*), strategically positioned at each of the three joints: base, shoulder, and elbow. These boards not only control motor drivers but also read encoder data from the rotation axes, enabling a closed-loop control system. This approach guarantees precise joint positioning and movement control, allowing the arm to execute intricate tasks with unwavering accuracy.

The *ACU* also manage the wrist, interfacing with the Dynamixels to command their movements. Additionally, it has a communication channel with the electronic board responsible for controlling the end effector.

From a firmware standpoint, the *ACU* employ *FreeRTOS* for real-time operations. Each task within the *ACU* is assigned to manage a distinct subsystem, ensuring that the arm's movements are orchestrated with precision and efficiency. Two dedicated tasks handle the CAN Bus communication, one for receiving and one for transmitting messages to the *JCUs*, ensuring seamless data exchange. The *ACU* also dedicates a task to controlling the wrist and another to managing the end effector, ensuring that the arm's movements are synchronized and coordinated.

The end effector is equipped with several sensors to provide the operator with real-time feedback, enabling precise and safe operation of the DIANArm. Two pressure sensors embedded in the fingertips inform the operator of the force being exerted, while a time-of-flight (TOF) sensor measures the distance between the end effector and any object in its path. Additionally, a connector allows for the attachment of various payloads, further expanding DIANArm's versatility in diverse operational scenarios.

2) Soil Sampler System: ARDITO's soil sampling system employs a novel telescoping design based on two linear guides. This configuration ensures a compact form factor when the system is not deployed, maximizing space utilization on the rover. The mechanical core of the system is realized through a percussive mechanism based on a lead mallet acting on two concentric tubes, the outer one is equipped with a sharp tip to facilitate soil penetration while the inner one, realized from a transparent plastic material, can be extracted after soil acquisition. This allows for visual inspection and analysis of the collected soil stratigraphy, providing valuable insights into subsurface layering.

The system's control board receives commands from the MOBC to which it also communicates status feedback. Through power drivers, it controls the movement of two sets of motors, used to lower the structure down to the soil surface and bring it back up so that the rover's navigation can be resumed. Through a TOF sensor, it is possible to get information on the depth reached during the sampling phase. With this information, it is possible to decide to either proceed with operations or abort them, as in the case of excessively tough ground.

C. Aerial Companion

ARDITO also features an aerial companion – a drone designed to expand its vision capabilities. This UAV is being developed to autonomously fly to and precisely hover over specific target locations, where it can capture images and video. Equipped with an array of sensors and two onboard computers, the drone is designed for multiple levels of autonomy. However, this recent addition to the ARDITO project is still under active development.

V. GROUND & TELECOMMUNICATIONS

A. ARCTIC

The main interface to control the rover operations and to monitor its activities is *ARCTIC* (Advanced Rover Command and Terrain Interaction Control). It is a graphical application which runs locally on the ground segment main computer, but it can easily be ported and used on different devices (pc, tablets, smartphones) for those situations which do not allow for a complete set-up of the ground segment.ARCTIC communicates with the rover's MQTT broker via websocket-MQTT encapsulation. It is designed to host graphical modules which enable the user to interact with each of the rover's subsystems through a modern and user-friendly UI.

B. Telecommunication architecture

Radio link at 2,4GHz exploiting IEEE 802.11b/g/n [21] protocol allows rover control and monitoring from the control station. The communication is accomplished with two access point, one on the rover and one on the ground segment. Working in range extender mode, they allow a robust communication link up to 100Mbps and 100m far. Being the main, communication channel data, both commands and telemetry are exchanged through this link. The system is improved with two custom-made bi-quad [22] omnidirectional antennae exploiting up to 4dBi of directivity, increasing the link budget margin. Thanks to the Radio link, a tunnel between the rover's internal network and the ground segment network is created, allowing operators simultaneous access to different subsystems.

VI. CONCLUSIONS

The ARDITO project has successfully demonstrated the potential of a modular technology demonstrator for robotic planetary surface exploration and operational support in multiple real-world scenarios [23]. The rover has proven to be a versatile platform for research and educational applications, providing valuable hands-on experience for students.

To transition ARDITO to a space-grade system, several improvements are necessary. The use of space-compatible materials is essential to withstand the harsh conditions of space. Additionally, enhancing redundancy and reliability at both hardware and software levels is crucial. Implementing redundant systems and rigorous testing will ensure continuous operation and robustness.

The modularity of the ARDITO rover is a key strength, allowing for easy integration and replacement of components and subsystems. This approach facilitates continuous improvement and adaptation to new mission requirements, enhancing the rover's versatility for various space exploration missions.

In conclusion, while ARDITO has achieved its initial goals as a technology demonstrator, further advancements in materials, redundancy, and reliability are required for actual space missions. The project's emphasis on modularity will be instrumental in overcoming these challenges and advancing the capabilities of robotic planetary exploration.

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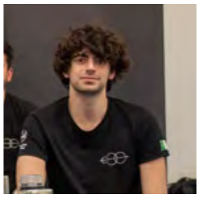

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