ExoMy: An Open Source 3-D Printed Rover for Education

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ExoMy: An Open Source 3D Printed Rover for Education

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I. Introduction

Students profit greatly from working with rovers during their studies. JPL created an advanced open source rover for educational projects [1]. The cost of 2100 € and tools required, make it a project for advanced hobbyists and engineers. 3D printing enabled a more cost effective version at around 420 € [2]. The project uses aluminium profiles with printed parts to simplify the manufacturing.

This paper presents the design of ExoMy, a fully 3D printed rover, that features advanced locomotion capabilities, a web interface to steer the rover and a camera for teleoperation. All source files and a comprehensive set of instructions were published on the project website [3]

II. Mechanical Design

The mechanical design of the 2.5 kg rover draws inspiration from the ExoMars rover Rosalind Franklin, as shown in Fig. 1. The design replicates its most characteristic features, such as the triple-bogie system [4], the shape of the solar panels, the wheels and the drill.

The locomotion system consists of the triple-bogie system and six dual motorized (steer and drive) wheels, with a diameter of 90 mm. The chassis houses the electronics and the battery. The head is mounted to the chassis via a mast and further houses the camera.

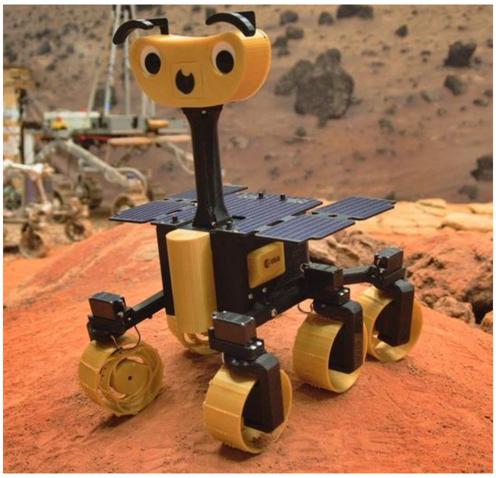

Figure 1. The design of ExoMy is inspired by the ExoMars rover Rosalind Franklin and features a triple bogie system with six steerable wheels.

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The head features an exchangeable hat and mouth to rapidly change the appearance of the robot. The drill mock-up and port cover can be removed, which allows for toolless change of battery and access to all ports of the on board computer. The cables are routed internally and all parts are designed such that they can be printed with a minimum of support material.

III. Electrical Design

A Raspberry Pi 4 functions as the on board computer and provides a variety of interfaces for the customizability of the system. The twelve motors are controlled using PWM, which is provided by a Raspberry Pi addon board, connected via I2C. A Raspberry Pi camera module v2.1 connected via the dedicated camera socket, opens the possibility for image processing applications.

The electronics are powered with a 3S lithium polymer battery and two adjustable DC/DC converters to convert the battery voltage of 11.1 V to a 5 V bus for the Raspberry Pi and a 6 V bus for the motors. All components are widely used in the hobby robotics community and therefore low cost, easily accessible and well documented.

IV. Software Design

The software was developed in the robotic framework ROS [5], which allows for high modularity and the use of open source code.

Raspberry Pi OS is installed natively on the Raspberry Pi, because of its ease-of-use and high reliability. ROS is run in a Ubuntu Docker container. The pre-packaged ROS binaries for Ubuntu simplify the installation and using Docker leads to easy and repeatable installations, independent of the Raspberry Pi version used.

The rover can be controlled using a gamepad or a custom web GUI. The web interface can be accessed by a wide range of devices (laptop, tablet, smartphone) via a Wi-Fi hotspot, that is hosted by the Raspberry Pi. The user can drive and switch between the locomotion modes: ackermann, spot turn and crabbing and sees a livestream of the on board camera.

V. Results

Multiple tests were carried out in the mars yard of the Planetary Robotics Laboratory, to show that ExoMy can traverse rocks up to the size of its wheels, loose soil and stone slabs. An endurance test, with the robot driving in a predefined trajectory showed that the rover can be operated for over 3 h on single battery charge.

The full design and source code of ExoMy is open source, allowing for easy customization and expansion of the platform. An extensive documentation describes the assembly and programming process, enabling anyone with a 3D printer to build ExoMy.

VI. Conclusion

We present a fully 3D printed rover with six steerable wheels, capable of traversing rough terrain. The robot can be operated using a web GUI, as well as a gamepad. A built-in camera allows for remote teleoperation and could provide computer vision capabilities.

The rover performed reliably during two ESTEC open-day events and the VSV Symposium at TU Delft. It was controlled by more than 50 people and generated interest and public awareness for space robotics. Furthermore, various people have begun and successfully completed the build of ExoMy, based on the online instructions. The open source nature of the project gives anyone with a 3D printer access to an advanced rover platform at the very low cost of 360 €.

References

[1] Jet Propulsion Labratory et al., (2020). *Open Source Rover.* Retrieved from https://opensourcerover.jpl.nasa.gov

[2] Roger Cheng, (2018). *Sawppy Rover.* Retrieved from https://hackaday.io/project/158208-sawppy-the-rover

[3] Planetary Robotics Laboratory ESA, (2020). *ExoMy Rover Project Website*. Retrieved from https://esa-prl.github.io/ExoMy/

[4] Patel L. et al. (2010) *Journal of Terramechanics, 47,* 227-242.

[5] Stanford Artificial Intelligence Laboratory et al., (2018). *Robotic Operating System*. Retrieved from https://www.ros.org

ExoMy

An Open Source 3D Printed Rover for Education

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Motivation

ExoMy is a 3D printed rover platform, designed to be built by robotic enthusiasts and for use in education. It can be used for demos during events, increase awareness of the Planetary Robotics Laboratory at ESA, create a diverse community passionate for planetary robotics and give hands on robotics experience to the future generation of scientists and engineers. The NASA JPL open source rover project [1] and its derivative project Sawppy [2] show that interest in such projects exists.

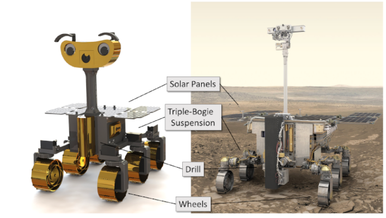

Figure 1. Functionality and design of ExoMy was inspired by the ExoMars rover of the European Space Agency.

While they serve as a great robotic platform, their cost of 420 - 2000 € and the need for metal work with special tools and skills, further increases the barrier of entry. The ExoMy project takes a different approach by using 3D printed structural parts, thus reducing the cost to 360 € as seen in Table 1.

It takes advantage of widely available off-the-shelf hardware and open source software. To allow anyone with a 3D printer to build ExoMy, a complete build and installation guide was developed and published online [3].

Mechanical Design

ExoMy uses major design features of ESA's Mars rover Rosalind Franklin, as shown in Figure 1, in order to promote this mission. One example is the passive triple-bogie suspension design [4]. Each of the six wheels is actuated by two Parallax servo motors, one for steering and one for driving. ExoMy measures 392 mm × 300 mm × 420 mm (length × width × height) and weighs 2.5 kg.

Figure 2. The interchangeable hat and mouth make ExoMy fun to customize.

The structural parts are printed using polylactic acid (PLA) filament as it is sufficiently strong and environmentally friendly. ExoMy's head can be easily customized, as both the mouth and the hat are easily exchangeable as seen in Figure 2. The battery and ports inside of the rover, shown in Figure 3, stay accessible due to removable covers.

The grousers of the wheels offer traction on loose soils. On smooth surfaces, wheel sleeves printed out of thermoplastic co-polyester (TCP) can be slid over the wheels to make driving smoother.

Electronics

The electronics subsystem, as shown in Figure 4 consists of components that are widely used in hobby projects and therefore are easily accessible, low cost and with good documentation. The design is centered around the Raspberry Pi as the on-board computer. It controls the 12 motors via a pulse-width modulation board, installed on top.

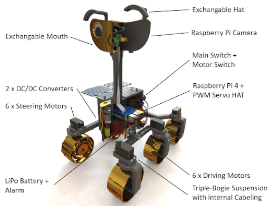

Figure 3. ExoMy uses off-the-shelf components, making it easily reproducible.

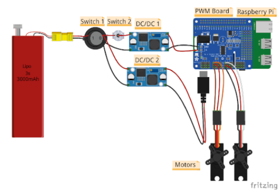

Figure 4. The setup is possible with beginners skill level in soldering.

A 3S lithium polymer battery feeds two DC/DC converters, that make 5V available for the Raspberry Pi and 6V for the motors. Power to the system is controlled with two switches.

Software Design

The functionality of ExoMy was implemented using Python and the Robotic Operating System (ROS). To reliably deploy the software stack, independently from the Raspberry Pi version used, ROS is run in an Ubuntu Docker container, on top of the native raspberry Pi OS, as shown in Figure 5.

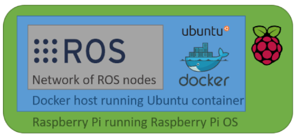

Figure 5. Running ROS in an Ubuntu docker container allows reliable installations.

Table 1. Low cost components make ExoMy accessible to a wide audience.

Component	Quantity	Supplier	Total Cost
Motors	12	RS	180 €
Microcomputer	1	Conrad	50 €
Camera	1	Conrad	20 €
PWM Board	1	Adafruit	15 €
Power Electronics	1	Conrad	25 €
Filament	1.5 kg	RS	50 €
Screws	143	RS	20 €
Total Cost			**360 €**

The separation of functionalities in multiple ROS nodes allows a seamless expansion and reusability of the software. The rover can be teleoperated using a gamepad, or a custom web GUI, featuring a live video stream. It allows changing between the locomotion modes of Ackermann, Spot-Turn and Crabbing. The web interface can be accessed by a wide range of devices, via a Wi-Fi hotspot hosted by the Raspberry Pi.

Results & Conclusion

Traversability tests in the Planetary Robotics Laboratory showed that ExoMy is able to overcome rocks roughly the size of its wheel, as shown in Figure 6, showcasing the abilities of the triple-bogie system.

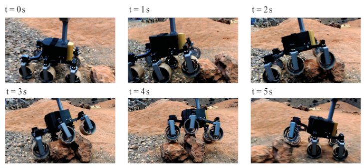

Figure 6. The triple-bogie suspension design helps ExoMy to overcome large obstacles in rough terrain.

Demonstrations at the ESTEC Open Day 2019 and the VSV Symposium of the Technical University of Delft showed the reliability of the software stack in Wi-Fi congested environments and a battery life of around 5 h.

The goal of ExoMy was to serve as an affordable and robust rover demonstration platform for enthusiasts and education. A one week course for university students starring ExoMy is currently in development, and multiple people have shared their ExoMy build progress on the community's chat server.

[1] JPL's Open Source Rover, Online: opensourcerover.jpl.nasa.gov, (accessed 10.2020)

[2] Sawppy the Rover, Online: hackaday.io/project/158208-sawppy-the-rover, (accessed 10.2020)

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