PSSOH 2023, DOI: https://zenodo.org/doi/10.5281/zenodo.8403828

FROM THE FIRST ARDUINO TO A SPACE EXPLORATION ROVER AND A FUNCTIONAL DRONE

EXPERIENCES FROM A STUDENT'S PERSPECTIVE

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ABSTRACT

Arduino has a profound and transformative impact on the field of electronics. Since its inception in the early 2000s, Arduino open-source ethos and user-friendly approach have democratized electronics development. Moreover, Arduino has empowered individuals, from novices to seasoned engineers, to prototype rapidly and implement a wide array of electronic projects. Arduino standardized hardware and software interfaces, exemplified by the iconic Arduino Uno board, have simplified the complexities of microcontroller programming, making it accessible to a broader audience. This accessibility has fostered innovation across diverse domains, including robotics, home automation, wearable technology, and scientific research. Moreover, an extensive ecosystem of shields, sensors, and libraries has accelerated project development, enabling inventors to focus on creative problem-solving rather than "*reinventing the wheel*". Arduino has become an educational staple in academia, enhancing Science, Technology, Engineering, and Mathematics (STEM) learning and encouraging a new generation of electronics enthusiasts. The goal of this paper is to demonstrate the power and versatility of Arduino and the concept of open-source hardware through the Author's personal experience and projects as a student of electrical engineering.

Keywords: open hardware, open-source, Arduino, open educational resources, robotics, drone.

1 Introduction

The overarching objective behind Arduino was to engineer a device characterized by simplicity, seamless connectivity to diverse peripherals (e.g., relays, motors, sensors), ease of programmability, and cost-effectiveness, catering to the resource constraints often encountered by students and artists. To realize this vision, they used Atmel AVR family of 8-bit microcontroller unit (MCU) devices, designed a circuit board with easy-to-use connections, wrote the MCU bootloader firmware, and packaged it into an integrated development environment (IDE). The culmination of these engineering endeavors materialized into what we now know as Arduino.

The most recognizable and famous board that was made is the Arduino Uno with Atmel ATMEGA328p MCU [1]. Back in 2021, Arduino reported on selling 10 million Uno boards [2], but the actual number is much higher since it does not account for all of the copies that are on the market. Uno is not the only board they are selling. Their portfolio includes a wide range of different boards, each tailored to a specific purpose. Taking a look at their MKR family [3], there are now Arduino boards that support various communication technologies out of the box like Wi-Fi, GSM (Global System for Mobile Communication), LoRa (Long Range), and others. Most recently, Arduino Pro has been launched, which is aimed towards industrial use and includes new, more powerful boards, a new IDE, and Arduino Cloud Support [4].

The Author's first contact with Arduino was through an Arduino Starter Kit which sparked an interest in robotics and electrical engineering which ultimately led to studying electrical engineering at the University of Belgrade as well as dozens of various projects that had an Arduino as a core element. This paper will present a couple of representative projects that use Arduino and show the use of different, specialized Arduino boards.

2 Power of the Arduino

Selection of Arduino development boards is continuously growing, adding development boards with new features year after year, making Arduino more popular. These development boards are developed to be easy to start using, boards are shipped with a bootloader and they are selectable through the Arduino IDE, and were developed to keep the core functions the same between different boards, meaning that most codes can easily be transferred from one board to another. These two factors paired with the sheer number of people using them, as well as the free software and open-source hardware nature of Arduino products mean that there is an abundance of resources for any Arduino board or project, whether it is software-related or hardware-related.

Tackling a board-specific problem which can include something from the errata sheet can be a rather difficult and tedious process, but due to the number of people actively working with the boards and sharing their designs, insights, and troubleshooting online with other people, there is a good chance that someone has already found a solution for that problem. The issues faced in the context of Arduino are not confined solely to the hardware or software intricacies of the Arduino board itself. They often extend to encompass broader challenges encountered in the projects employing Arduino as a fundamental building block. These challenges are further compounded by the ever-growing online community of Arduino enthusiasts who avidly share their projects, solutions, and insights. This collective knowledge repository has facilitated a culture of collaborative problem-solving and innovation.

A significant aspect lies in individuals' ability to readily combine and adapt existing free software and open-source hardware Arduino project components, like assembling a puzzle. This capability accelerates project development, encourages innovative applications, and enhances Arduino adaptability and accessibility in the field of electronics and embedded systems.

2.1 Simple as pushing a button

The Arduino IDE is a great tool that lets the user compile and send the code to the board with a single mouse click. A small button is the simplest form of hardware user interface that can be connected to an Arduino, and to read the pin value Arduino provides the command *digitalRead()*. While reading a simple button input on an Arduino is not impressive in itself, this low-level use of Arduino can still produce excellent scientific results. One example of that can be measuring a person's reaction time which is used in psychology, another example would be the apparatus designed to prove the Fast Chain Problem hypothesis for the International Young Physics Tournament (IYPT) 2017 [5][6].

The fast chain problem describes the phenomenon where a chain of wooden planks where the planks are inclined alternating to which side (Figure 1). Compared to free fall, the chain that falls on a horizontal surface falls faster.

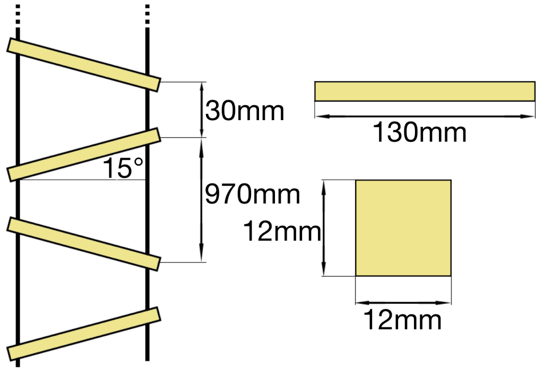

Figure 1 - The Fast Chain Problem - The Chain consisted of identical wooden planks connected by thin rope at both ends where the planks were angled at 15 degrees. Photo credit: Miloš Rašić.

Engineering an apparatus that can prove this phenomenon uses the same Arduino basics as those shown for reading a button press with an addition of tracking internal time on the Arduino using the *micros()* function. To prove this phenomenon, the experimental setup was constructed [7], it included a mechanism for dropping two identical chains that were shown in Figure 1 as well as a pair of laser gates that are connected to the Arduino, the setup can be seen in Figure 2. A laser gate consists of a light-emitting diode (LED) and a phototransistor that functions as a button depending on the amount of light hitting it.

Figure 2 - Experimental Setup - The setup consisted of the quick release mechanism at the top, horizontal reference lines in the background, 120 frames per s (FPS) capable camera, and two sets of laser gates connected to an Arduino. Photo credit: Miloš Rašić.

With the described experimental setup, a code was developed to treat the phototransistors as buttons so it can measure the time in μs between phototransistors being triggered. The difference in times measured with the Arduino represented the time it took for a single wooden plank to go between the two phototransistors that were mounted at a known distance. Calculating that time for each plank provides a comprehensive picture of the speed of the chain changing as it goes further down. One of the recorded results is shown in Figure 3 where a clear difference can be seen between the speeds of the two chains and how that difference increases as the chain is going further down. Analyzing those results, a conclusion has been made that the chain that was not free-falling started accelerating faster than gravity once it hit the table, thus, proving the hypothesis of the experiment.

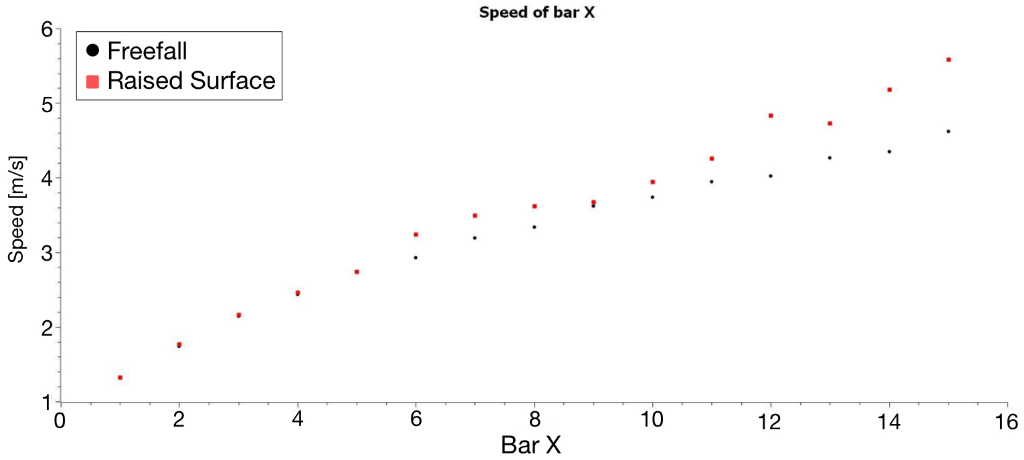

Figure 3 - Experimental Results - The results prove the hypothesis of the given problem and the first 5 planks prove that the setup is working since the planks had not started hitting the surface yet at that point, so the speeds on both chains should match. Photo credit: Miloš Rašić.

3 Advanced uses of an Arduino

While the majority of use cases for an Arduino are of an educational and experimental nature, that does not mean that an Arduino can not be used in more advanced projects or even in commercial products. This section will give an overview of three advanced Arduino student projects, an open-source Arduino-based drone and two mobile robotics projects, one completely Arduino-based, and the second one using an Arduino as a hardware controller.

3.1 Arduino-based drone

The drone was developed for the Attack of the Drones Competition [8], and it was based around MultiWii [9], which is an open-source flight controller (FC) that can run on any Arduino. MultiWii also includes a graphical user interface (GUI) for configuring different kinds of copters as can be seen in Figure 4.

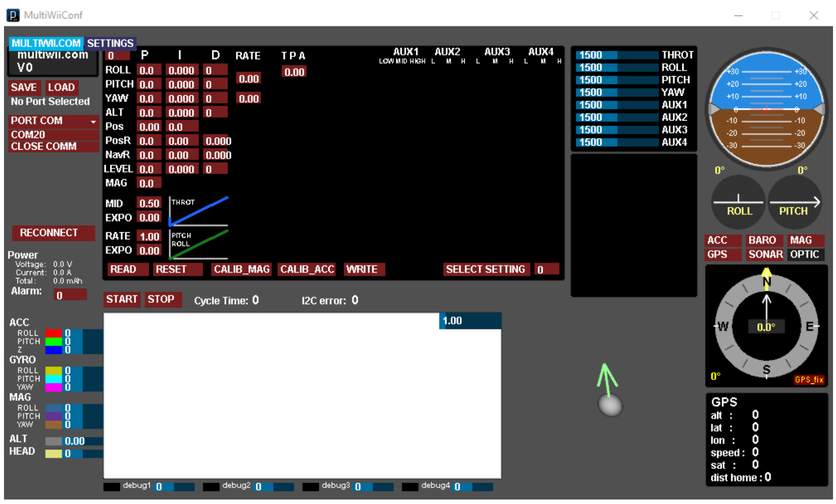

Figure 4 - Multiwii GUI - Screenshot of the interface for configuring an Arduino-based drone with MultiWii firmware. Photo credit: Miloš Rašić.

Pairing an Arduino that has configured MultiWii with motors and motor controllers encapsulated all of the electronics needed for a functioning drone besides the communication with the pilot. Another great thing about the Arduino ecosystem is that because of its popularity, a lot of third-party companies are developing modules for Arduino in the form of sensors, actuators, shields, or even custom Arduino boards. Using off-the-shelf third-party wireless communication modules with two additional Arduino Nanos, all of the electronics for the drone are covered [10] as can be seen in Figures 5 and 6.

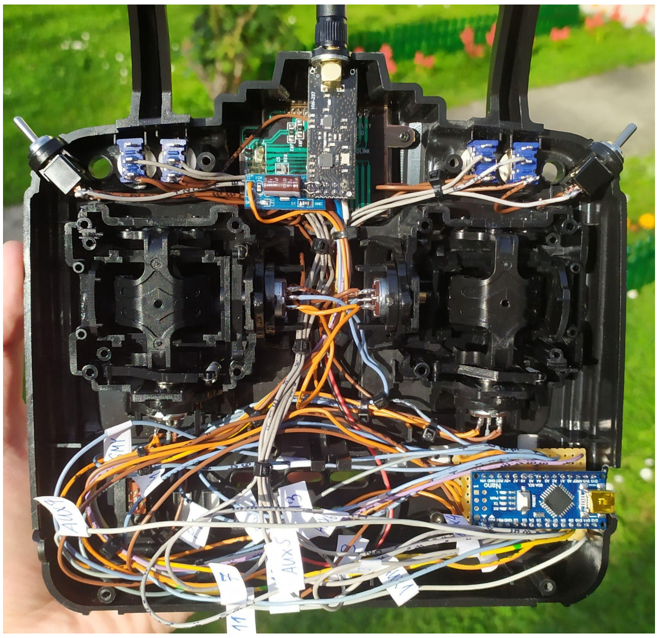

Figure 5 - Radio Control (RC) Transmitter - An off-the-shelf RC transmitter modified with additional inputs with an added wireless communication module and an Arduino Nano. Photo credit: Miloš Rašić.

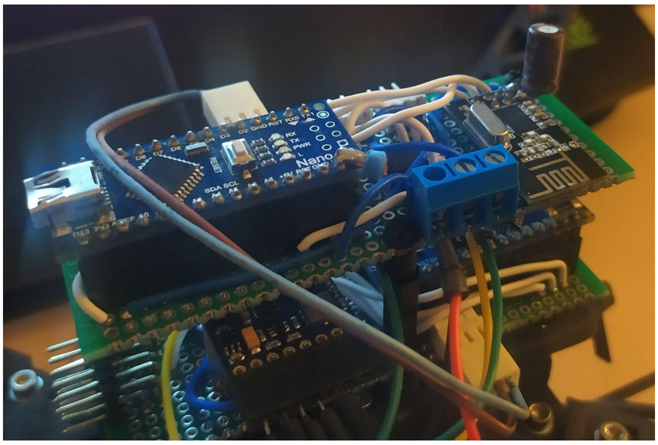

Figure 6 - Arduino FC and RC Receiver - Two Arduino Nanos are used for the whole drone's electronic setup, one is used as the FC and the other one as the RC receiver. Photo credit: Miloš Rašić.

Electronics setup shown in Figures 5 and 6 provides the bare minimum needed for operating a drone manually with the system only performing calculations to keep the drone level or at a set angle depending on the input from the drone pilot. However, with this open-source setup, adding additional sensors, actuators, or single board computers (SBC) like a Raspberry Pi [11] is not an issue, the use case dictates the additions to the drone. A completed drone with an added Raspberry Pi 4 can be seen in Figure 7.

Figure 7 - Completed Drone - The drone houses all of the electronics shown in Figure 6, the frame of the drone is constructed out of polyvinyl chloride (PVC) pipes, and out of polylactic acid (PLA) three-dimensional (3D) printed plastic. Photo credit: Miloš Rašić.

3.2 Arduino mobile robotics platform - Rover

For simpler robotics projects an Arduino is powerful enough to be the main processor of the whole robot, this means it needs to handle the communication with the user, put the user commands through control algorithms to produce output, perform low-level control of hardware, control all of the actuators, and reading all of the sensors. An Arduino-based mobile robotics platform that was developed for the Just Encase Design Challenge [12][13] can be seen in Figure 8.

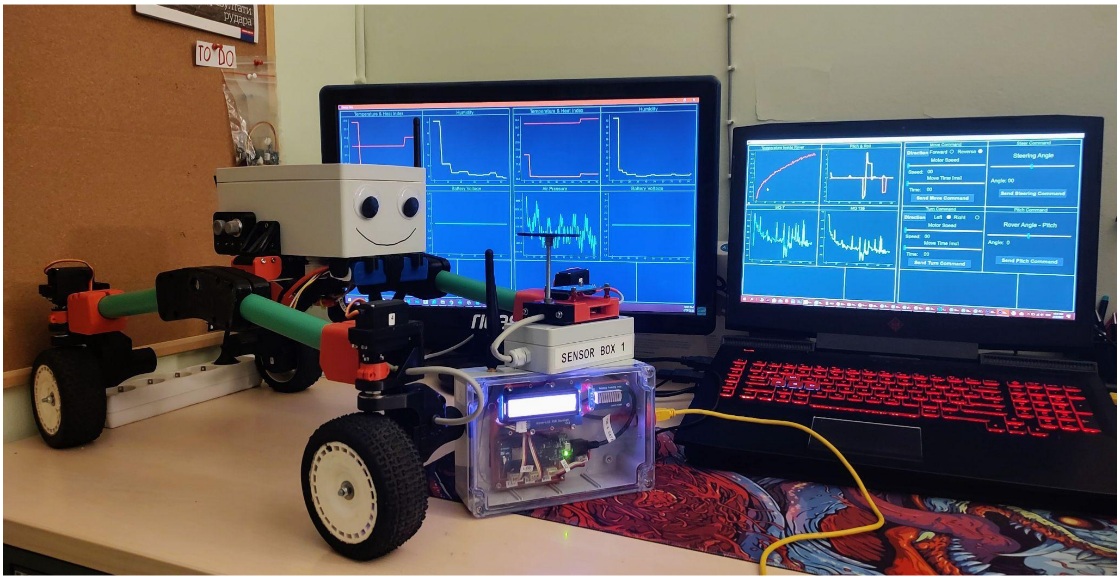

Figure 8 - Orbweaver Rover V1 (OR V1) - Completely Arduino-based rover with LoRa communication presented with the GUI as well as the communication link and sensor node box. Photo credit: Miloš Rašić.

The rover in Figure 8 is completely Arduino-based, it uses an Arduino Mega2560 [14] for controlling all of the motors and an Arduino MKR WAN 1300 [15] for communicating with the personal computer (PC) over LoRa, electronics inside the rover can be seen in Figure 9.

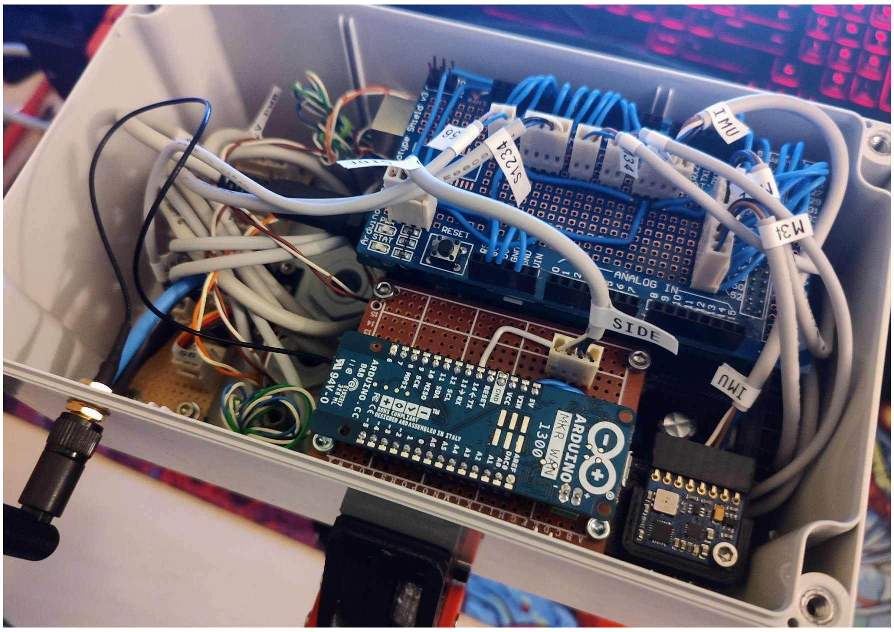

Figure 9 - Electronics inside the rover - Electronics inside include the two Arduino boards used for controlling and communication, an inertial measurement unit (IMU), motor controllers as well as additional power electronics. Photo credit: Miloš Rašić.

A special feature of this rover is the sensor node boxes which house another Arduino MKR WAN 1300 with various environmental sensors (Figure 10). The rover's mission was to drop sensor node boxes in a net to monitor environmental data in a greater area.

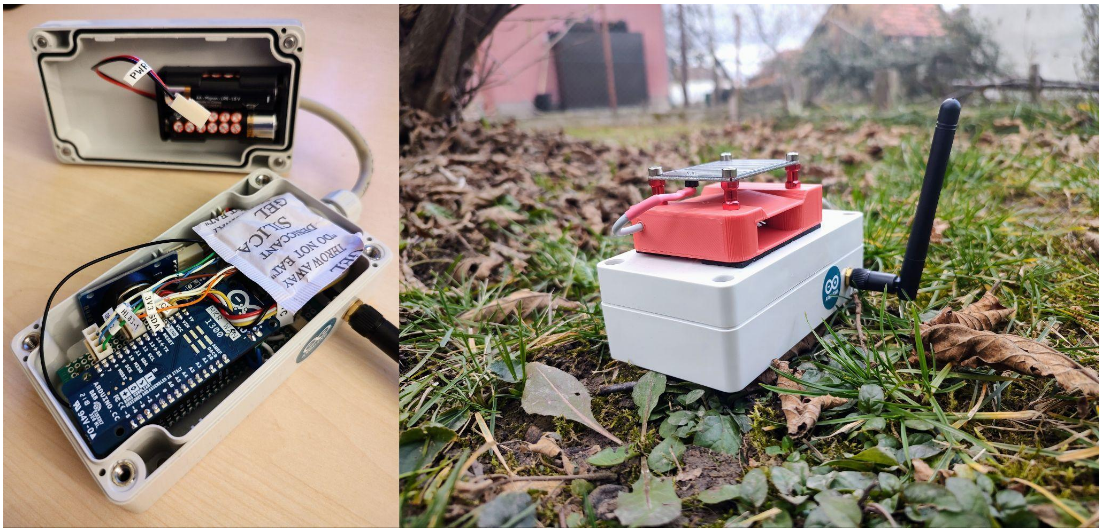

Figure 10 - Sensor Box - Sensor boxes are made to be completely weatherproof as well as waterproof, besides the Arduino they house sensors for measuring air pressure, temperature, humidity, and whether it is raining or not. Photo credit: Miloš Rašić.

For more advanced robotics projects, an MCU might not be optimal to be used for everything like shown on the rover above, in those cases, an SBC is used for running all of the algorithms and the operating system for the robot, while MCUs are used for real-time hardware control and smaller algorithms. An example of such a robotics project that was developed for Bachelor thesis [16] is presented in Figure 11 [17][18].

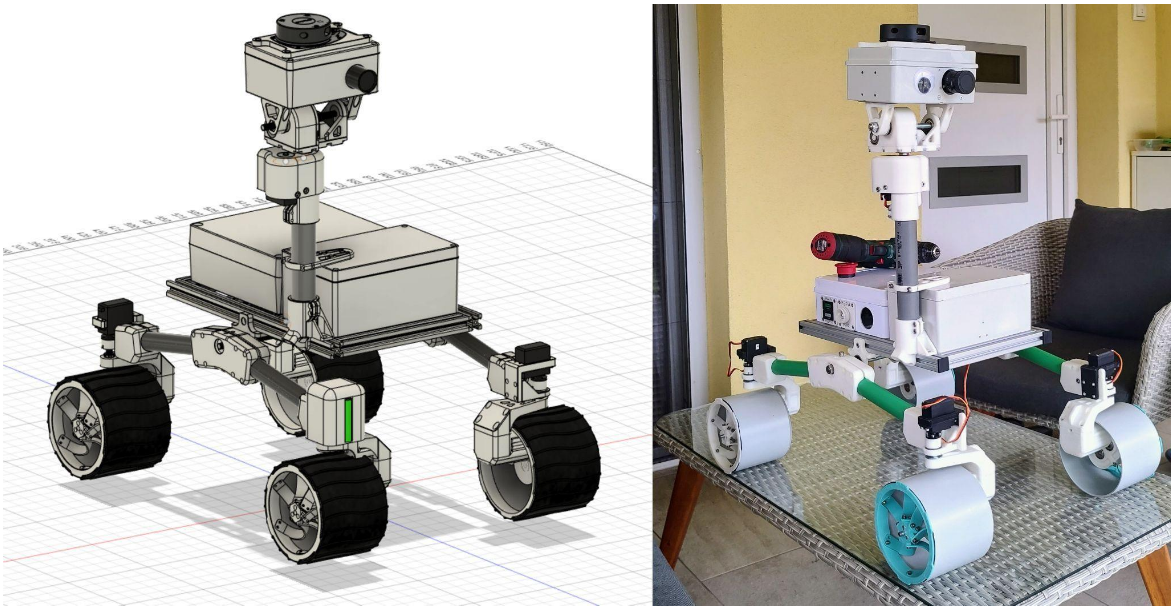

Figure 11 - Orbweaver Rover V2 (OR V2) - A more advanced and bigger version compared to the V1. It is not completely Arduino-based, it uses a Raspberry Pi 4 running robot operating system (ROS) On the left is the CAD model of the OR V2 designed in Autodesk Fusion 360 [19], and on the right is the actual OR V2 made according to the CAD model. Photo credit: Miloš Rašić.

The OR V2 rover uses the same materials as OR V1 with the addition of an aluminum frame, it also has a more powerful drive system, custom-engineered active differential suspension, and a head with two degrees of freedom.

4 Conclusion

In conclusion, Arduino has undeniably played a pivotal role in revolutionizing the field of electronics since its inception in the early 2000s. Its open-source philosophy, user-friendly design, and standardized hardware and software interfaces have democratized electronics development, empowering a wide spectrum of individuals, from beginners to seasoned engineers, to engage in rapid prototyping and diverse electronic projects.

Furthermore, Arduino has established itself as an indispensable educational tool, enhancing Science, Technology, Engineering, and Mathematics (STEM) learning and fostering a new generation of electronics enthusiasts. Its global community and collaborative spirit have nurtured a culture of shared knowledge and collective problem-solving, propelling Arduino influence to greater heights. In this paper, this is illustrated by the presentation of the Author’s projects from a student perspective with the beginnings as a hobbyist that resulted in the construction of an award-winning drone and a rover designed and built for a Bachelor thesis at the University of Belgrade – School of Electrical Engineering and showcased on Arduino Youtube channel.

Acknowledgment

I would like to thank Assoc. Prof. Nadica Miljković, PhD, for her initiative and support for this paper, as well as Assoc. Prof. Kosta Jovanović, PhD for the mentorship for the Bachelor thesis (OR V2). I am also grateful to Arduino for the opportunity to be an official community speaker for Arduino Day 2023 as well as my colleagues who helped me along the way with this paper, especially Pavle Radojković.

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