

Development and control of an omnidirectional robot for competition purposes

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Master degree in Industrial Engineering

2022-2023

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Thesis report

Master degree in Industrial Engineering

Escola Superior de Tecnologia e Gestão de Bragança - ESTiG.

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Dedication

I dedicate this modest work to :

My family, my father Naceur BAIDI who always did his best to give us everything we needed and made sure we had the best education.

My mother Latifa MATHLOUTHI my source of life, love and affection.

My brothers Ahmed BAIDI and Maher BAIDI who helped and supported me in this new experience.

To all my friends, may this be a token of my deep affection and unwavering love. May God bless them with long life.

Kais BAIDI

Resumo

Esta dissertação mergulha no mundo da robótica, com uma abordagem estruturada que se desenrola ao longo de vários capítulos. O primeiro capítulo estabelece o cenário, proporcionando uma visão geral. O segundo capítulo lança uma base sólida ao introduzir conceitos de robótica, várias categorias de robôs e suas características distintivas. Sublinha o impacto da robótica na educação e na investigação, enfatizando a sua conexão integral com as disciplinas de ciência, tecnologia, engenharia e matemática (STEM). Além disso, destaca a importância do RobotAtFactory (RAF) e apresenta a equipa da IPB. O terceiro capítulo é dedicado à seleção de componentes do robô. Isso envolve a análise minuciosa dos atuadores, sensores, unidades de controlo e fornecimento de energia do robô. Simultaneamente, a atenção volta-se para a modelagem 3D e o design do robô, assegurando a conformidade com as especificações da competição RAF. No quarto capítulo, exploramos a integração dos elementos e conceitos discutidos anteriormente. Salienta o papel crítico de ferramentas de software como o SolidWorks e o Simtwo na fase de design. Além disso, aprofunda os sistemas de controlo de baixo nível, com foco na gestão em tempo real dos sistemas de controlo e técnicas de controlo da velocidade dos motores.

Por fim, o capítulo de conclusão fornece um resumo abrangente de todo o projeto. Esta dissertação oferece uma perspetiva holística da nossa jornada no domínio da robótica, culminando na nossa preparação para a competição RAF. Com um olhar voltado para futuras competições, as nossas experiências e descobertas estão posicionadas para ser valiosas contribuições para a evolução contínua deste campo dinâmico.

Palavras-chave: Educação em engenharia, Indústria 4.0, Competição de robótica.

Abstract

This dissertation delves into the realm of robotics, with a structured approach spanning several chapters. The introductory chapter sets the stage, offering a general overview. The second chapter lays a solid foundation by introducing robotics concepts, various robot categories, and their defining characteristics. It underscores the impact of robotics on education and research, emphasizing its integral connection with science, technology, engineering, and mathematics Science, Technology, Engineering and Math (STEM) disciplines. Furthermore, it underscores the significance of RobotAtFactory (RAF) and introduces the Instituto Politécnico de Bragança (IPB) team. The third chapter is dedicated to the selection of robot components. This involves examination of the robot's actuators, sensors, control units, and power supply. Simultaneously, attention is directed toward 3D modeling and robot design, ensuring compliance with RAF competition specifications. In the fourth chapter explores the integration of previously discussed elements and concepts. It underscores the critical role of software tools like SolidWorks and Simtwo in the design phase. In addition, it delves into low-level control systems, focusing on real-time management of control systems and motor speed control techniques.

Lastly, the concluding chapter provides a comprehensive summary of the entire project. This dissertation offers a holistic perspective on our journey through the robotics domain, culminating in our readiness for the RAF competition. With an eye on future competitions, our experiences and findings are poised to be valuable contributors to the ongoing evolution of this dynamic field.

Keywords: Engineering Education, Industry 4.0, Robotics competition.

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Acronyms

ADC Analog Digital Converter. 33

AGV Automated Guided Vehicle. xi, xiii, xiv, 3, 10, 13–15

AMR Autonomous Mobile Robots. xi, 10

AV Autonomous Vehicle. 13

CAD Computer-Aided Design. 38

CPR Count Per Revolution. 27

EEPROM Electrically-Erasable Programmable Read-Only Memory. 33

HMI Human Machine Interface. 30

I/O Input/Output. 31

I2C Inter-Integrated Circuit. 33

I4.0 Industry 4.0. 13, 15

IFR International Federation of Robotics. 4

IMU Inertial Measurement Unit. 27

IPB Instituto Politécnico de Bragança. ix, 18, 20, 62, 65

LCD Liquid Crystal Display. 30

LED Light-Emitting Diode. 27

LiDAR Light Detection and Ranging. 28

LiPo Lithium Polymer. xiii, 37

NASA National aeronautics and space administration. 11

NC Normally Closed. 26

NO Normally Open. 26

PWM Pulse Width Modulation. 24

RAF RobotAtFactory. ix, xiv, 1–3, 15–20, 46, 50, 62, 65

SPI Serial Peripheral Interface. 33

SRAM Static Random Access Memory. 33

STEM Science, Technology, Engineering and Math. ix, xiv, 3, 8–10, 19

TTL Transistor-Transistor Logic. 24

USART Universal Synchronous Asynchronous Receiver Transmitter. 33

XML Extensible Markup Language. xv, 50, 51

Chapter 1

General Introduction

In today's world, the integration of mobile robots is growing rapidly in a variety of fields, covering tasks ranging from domestic cleaning to the discovery of new planets [1]–[3]. Robotics is currently an innovative technology used to carry out a variety of tasks in the industrial sector, particularly as part of Industry 4.0, transforming the way factories operate on a global scale.

Industry 4.0 devices must capture, interpret and operate on the data collected from their environment, taking into account efficiency and continuous optimization [4].

The RAF competition plays an essential role in education through its multidisciplinary approach offered to students from different technological fields. In addition, the competition can be used to solve problems similar to those encountered in a real industrial environment, pushing back the boundaries of what is currently possible in robotics and stimulating research and development in the field. The key to success in the RAF competition lies in designing a system that maximises quality and reliability through advanced technology and careful planning. Therefore, this research presents the development of a mecanum wheeled platform for the RAF [5] [6].

In this thesis, we board a journey through the world of robotics, encompassing various key aspects and complex details. Our exploration begins in the first chapter, where we dive into the fundamental principles and concepts of robotics. In this context, we study the classification of robots according to their types and applications, highlighting the

profound impact of robotics on education and research, particularly in the STEM field.

In the second chapter, we focus on the critical task of sizing and selecting robot components, with an emphasis on ensuring optimal functionality. We detail the component identification process, based on the competition specifications and the team's previous experience, ultimately opting for an omnidirectional mobile robot structure to improve the efficiency of tasks accomplishment in the competition.

The third chapter continues our journey with a multi-faceted assessment of the robot's performance. We begin our exploration with motion simulations using Simtwo software, giving us valuable insights into the robot's behavior. We then dive into the low-level control systems that operate the robot, taking a close look at the controllers, motor speed control and microcontroller functionalities. The chapter concludes with a review of the challenges encountered during robot assembly and commissioning, highlighting potential improvements in the robot's performance.

Together, these chapters establish a comprehensive framework for understanding the importance of robotics in education, research and innovation, while exploring the challenges of designing and optimizing robots for real-world challenges.

This competition helps to open up promising prospects for the future of industrial robotics by highlighting the importance of robot mobility, flexibility and efficiency, thus opening up new applications and automation possibilities in various industrial applications.

In conclusion, our exploration of the dynamic world of robotics reveals its ever-increasing role in today's various fields, from domestic tasks to interplanetary exploration. With Industry 4.0 driving transformative changes in global manufacturing, robots' ability to capture, interpret and optimize data is becoming paramount. The RAF competition is emerging as a vital educational and problem-solving platform, fostering innovation and pushing the boundaries of robotics ever forward.

Chapter 2

Related work

2.1 Introduction

In this first chapter, we begin with a presentation of the fundamental principles and concepts of robotics. Next, we will look at the classification of robots according to their types and fields of application. After that, we will look at the influence of the field of robotics on education and research, highlighting the contributions of educational and research robots, as well as their significance in the context of STEM.

This chapter takes a closer look at autonomous mobile robots and AGV, exploring their functionalities and the technologies used in these devices. Finally, we conclude with a presentation of the RAF 4.0 competition where we will explain its main objectives, the specifications of the competition field, and the requirements for robot participation.

All this will establish a formal framework for understanding the importance of robotic competitions in innovation and solving real-life challenges, while facilitating the integration of students into this vast field.

2.2 Generalities about robotics

Over the past decade, robotics has transformed many aspects of modern life. This evolution has been driven by the need to increase efficiency and productivity in industry, by

improvements in sensor technology and computing power, and by the desire to improve people’s safety and quality of life. As a result, robotics research has led to the creation of an enormous variety of robots, from industrial manipulators and mobile models to humanoids and drones.

Today, we can find many different types of robot on the market, all with different functions and capabilities to suit our needs.

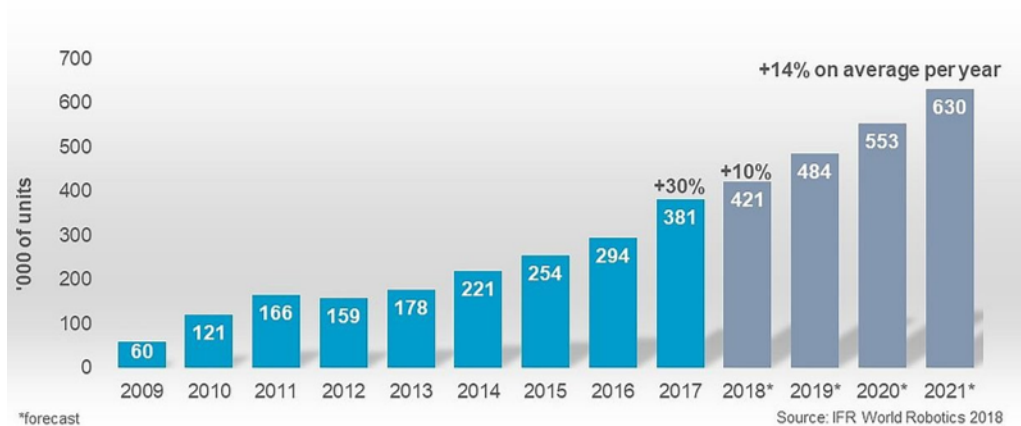


Figure 2.1: Estimated annual worldwide supply of industrial robots (2009-2017) [7]

Figure 2.1 is a study done by the International Federation of Robotics (IFR) [7] that shows the demand for industrial robots from 2009 to 2017 and the estimated demand from 2018 to 2021. As you can see, the need of robots is growing, not only for the industry, but for all sectors. Robots can be classified into several categories based on their design, function and application. To better understand the context, in the next section, we will explain the different types of robotic structures with their characteristics as well as their fields of application.

2.3 Classification of robotics and their applications

Based on their design, function, and intended use, robots may be divided into a number of different sorts. The following are some of the most popular categories of robots:

- Industrial robot : This type is used in industrial environments, such as factories and warehouses.They are used to preform repetitive tasks of assembling, welding, and packing.
- Mobile Robots: Designed to move and explore their surroundings. Many uses for them exist, including logistics and transportation, exploration, and monitoring.
- Humanoid robots: Both in form and behavior, these robots are created to resemble humans. They are often employed in entertainment, teaching, research, and development.
- Medical Robots: These robots are employed in healthcare facilities to carry out a range of duties, including surgery, patient monitoring, and rehabilitation.
- Service Robots: Designed to carry out jobs that are traditionally done by people, such as cleaning, cooking, and customer service.
- Educational robots: Students of all ages may learn programming and engineering principles with these robots.
- Military Robots: These robots are made to be used in warfare, bomb disposal, and other military operations.

Each type of robot has a different design as well as distinct features and each has a wide variety of possible uses. As artificial intelligence develops, we can expect to see even more types of robots being created in the coming years.

2.4 Roles of Robots in Education and Research

2.4.1 Education robots

Robots of this kind, known as educational robots, are used to teach students of all ages about programming and engineering principles. They are frequently used in classrooms

and after-school programs to expose them to robotics and make it more easier for them. There are several categories of educational robots, such as programmable robots, modular robots and remote-controlled robots, etc.



Figure 2.2: Robotic kite developed by the company MakeBlock[8]

Figure 2.2 present a variety of robotic structure proposed by the company Makeblock[8], these robots are distributed in the form of developmenet kit based on Arduino microcontroller, they are dedicated to help students to program the different Input/Output and control the robot.

Educational robots are a useful tool for teaching students about engineering and robotics principles while improving their ability for problem-solving, critical thinking, and collaborative abilities, also they make learning enjoyable and interesting.

2.4.2 Research robot

Usually, these robots are quite specialized and created to meet the demands of a particular research subject. Research robots are employed in a variety of disciplines, including environmental science, engineering, medicine, and computer science. Also they are used to collect data to try new technology, and discover new areas [3].

Field of use of research robot :

- Environmental : They are used to gather information in unsafe distant places, such the deep sea or space. They might be constructed to endure extremely high or low pressures, temperatures, or radiation levels [9], [10].
- Humanoid Robots: Those mecatronics system are designed to research how people and robots interact and to develop creative uses for robotics in industries like healthcare and education [11].
- Autonomous Robots: Designed to function independently and make decisions in response to their environment. They are frequently employed in industries. Example, like agriculture, where they are useful for monitoring and planning about watering, fertilizing, and harvesting.
- Assistants: These machines are made to help researchers with activities including data gathering, analysis, and experimentation.
- Experimental: In a controlled setting, That type of robots are used to try out new methodologies and technologies. They might be created to replicate the actions of people or animals in order to research how they move and behave.

Research robots are essential to the creation of new technologies since they are frequently used to test and improve robotics-related innovations.

Before implementing new technologies in practical applications, researchers may test and optimize them in controlled conditions. As a result, new technologies may be developed more quickly and effectively since researchers can spot possible concerns early on and take appropriate action to resolve them.

Expertise in areas like robotics, computer science, and engineering are essential for the creation of research robots. Researchers from many fields frequently work together to obtain this knowledge, and collaborations with businesses and governmental agencies are also commonly formed. It can also continue to push the limits of robotics and create new

technologies that might revolutionize how we live and work by utilizing the capability of research robots.

2.4.3 Robotics based in Science, Technology, Engineering and Math (STEM)

Robotics is a field that is often associated with STEM, as it combines its elements to design, build, and program robots. STEM is indeed a fundamental element of robotics, as it requires a thorough understanding of physics, electronics, mechanics, computer programming, and mathematics to create and control intelligent, autonomous devices. Figure 2.3 represents the main pillars of STEM and how they are linked to the robotics domain.

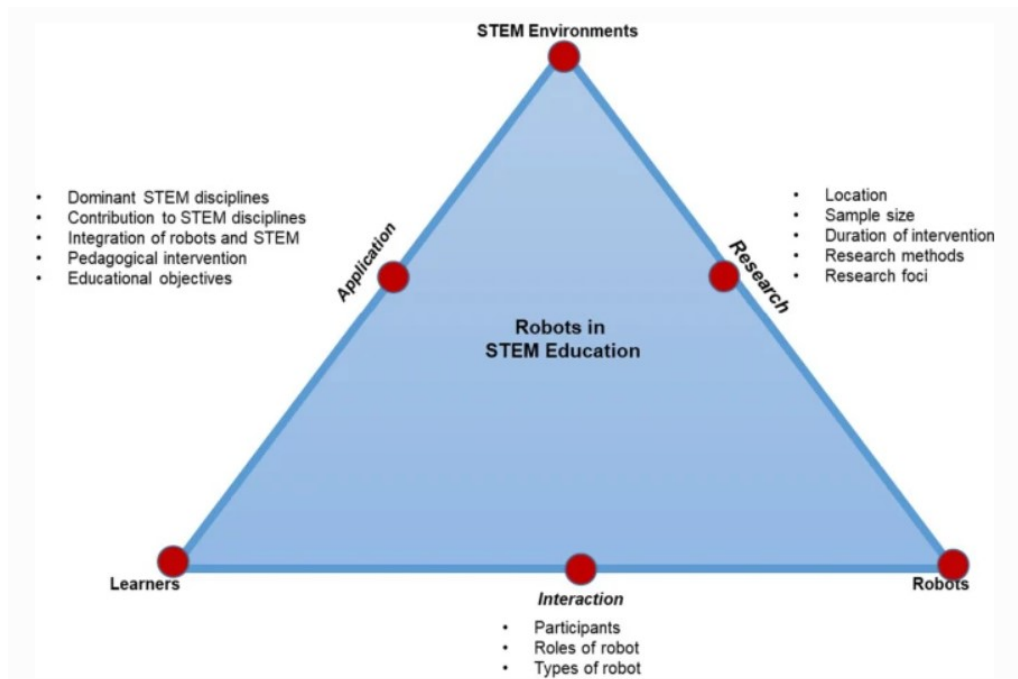


Figure 2.3: Model of STEM education theme framework[12].

Robotics in STEM education

Robotics in STEM education has been encouraged as part of an innovative and systematic approach to learning. Similarly, recent research has found that using robots in education has an effect on students' curiosity, arts and crafts activities, and reasoning[13]. When robots and educational robotics are viewed as essential components of STEM education, they provide a chance to promote STEM disciplines such as engineering principles or even collaborative practices.

Learner interest may motivate the development of a wide range of skills, including computational thinking, creativity, problem solving, and other thinking abilities.

Robotics in STEM industrial

As in the education sector robotics plays a essential role in the fields of STEM industrial applications. This integration of robotic technology has revolutionized industries and brought forth transformative advancements across various sectors. In the next, we will explore the significance of robotics in STEM industrial applications.

- **Automation and efficiency** : In industries, automation is synonymous with efficiency. Robots have the capacity to perform repetitive, intensive tasks with high precision and consistency. This is particularly valuable in manufacturing, where automation simplifies production processes, reduces errors and improves overall productivity[14].
- **Security and risk minimization** : Robots help reduce risk associated with hazardous work environments. Industries dealing with chemicals, extreme temperatures, or radioactive materials rely on robots to perform tasks that are unsafe for humans[15]. This not only safeguards the well-being of workers but also minimizes the potential for accidents and environmental damage.
- **Quality control and inspection** : Maintaining product quality is crucial in production industry. Robotics systems equipped with advanced sensors and cameras

can inspect and assess product quality with unparalleled accuracy[16]. From detecting defects in manufactured parts to ensuring conformity with strict industry standards, robotic inspection systems are indispensable tools for maintaining high-quality output.

The future of STEM industries is intrinsically linked to the continued evolution of robotics technology. As robots become more intelligent, adaptable, and capable of working alongside humans, the potential applications in STEM industries will only expand[15].

In conclusion, the integration of robotics into STEM industrial applications is not simply a technological advance, but a major factor in progress. It enhances efficiency, safety, and quality. As STEM industries continue to grow, robotics will remain a cornerstone of innovation, advancing the frontiers of science, technology, engineering and mathematics.

2.5 AMR's and AGV's

AMR's and AGV's are becoming more important than ever. These autonomous, multifunctional systems have revolutionized logistics, manufacturing and a variety of other industries. In this section, we look at AMR's and AGV's, exploring their applications and capabilities.

2.5.1 Autonomous mobile robots

AMR's are very practical these days. They come in a wide range of sizes and shapes, each created for a particular mission or situation, which is why there are a variety of mobile robot types :

- Robots with differential-drive architecture, which feature two separately controlled wheels or tracks that enable the robot to turn and move in any direction. Differential drive robots are widely used in research and teaching because they are easy to operate and economic.

- **Robots with Omnidirectional Drives:** These robots are equipped with omnidirectional drive systems, which allow them to move in any direction without the need to turn. They typically feature three or more independently rotating wheels or multi-wheels that can move independently in any direction. This sophisticated mobility system makes them ideal for a wide range of industrial and commercial applications that needs a high precision movement, such as factories and warehouses.
- **Robots with tracks:** These robots can navigate obstacles and tough terrain because to their tank-like treads. Military, search-and-rescue, and exploration applications frequently employ this kinde of robots.
- **Legged Robots:** These robots can navigate rough terrain and obstacles because they have legs rather than wheels or tracks.

One example of a mobile research robot is National aeronautics and space administration (NASA)'s Mars Curiosity rover [17], Figure 2.4, which currently explores the surface of Mars. The rover is equipped with a variety of scientific instruments that allow it to collect data on the geology, atmosphere and environmental conditions of Mars. It is also capable of drilling rocks and analyzing samples, providing valuable information about the planet's history and potential habitability.



Figure 2.4: Curiosity rover (Robot developed by NASA, used on Mars for scientific research)[17].

Due to their independence and capacity to make decisions depending on their environment, autonomous robots are increasingly being employed in different sectors like research and industry. These machines are made to function independently and without human assistance, which makes them perfect for usage in dangerous, challenging-to-access, or constantly monitored areas[18]. The capacity of autonomous robots to gather and analyse massive volumes of data in real-time is one of their key advantages.



Figure 2.5: Robot with machine vision that can identify important visual attributes of citrus groves linked to pests, diseases and physiological events[19].

The extracts of figure 2.5 are the results of a robot designed for the agricultural domain, its task is to perform counting, disease detection and growth monitoring of the agriculture product based on machine vision systems[20]. Other tasks can be performed such as weeding, planting, etc.

The capacity of autonomous robots to perform constantly without the need for breaks or rest periods is another benefit. This makes it possible to collect data over an extended period of time, which may be particularly helpful for observing phenomenon changes on a long period of time.

2.5.2 AGV's

AGV's are autonomous mobile robots that have revolutionized material handling and logistics in various industries. In the next, we will focus on research published by Dr.Ahmed in 2021[21] that illustrates the integration of Autonomous Vehicle (AV) in the Industry 4.0 (I4.0).

This research defined the concept of AGV's and the different levels of autonomy, going from level 0 (no automation) to level 5 (full automation), Figure 2.6.

Autonomy levels of the AGV:

- **Level 1 - Remotely operated robots:** These are robots that are entirely controlled by a remote human operator, who uses interfaces such as joysticks or screens to control the robot's movements.
- **Level 2 - Semi-autonomous robots:** These robots can do certain tasks autonomously, but they still require human supervision. They may be equipped with sensors to detect their surroundings and avoid impediments, but a human operator must always be there to make critical decisions.
- **Level 3 - Autonomous robots:** These robots can operate autonomously in well-defined environments without the need for continual human interaction. They are capable of making decisions based on data collected by their sensors, but may require human assistance in the event of an unforeseen situation.
- **Level 4 - Fully autonomous robots:** These robots can operate autonomously in a variety of environments without the need for human interaction. They are capable of making complicated decisions by utilizing sophisticated data-processing algorithms and can adapt to unexpected conditions.
- **Level 5 - Self-adapting robots:** These are robots that can learn from and adapt to their surroundings over time. They can improve their performance by drawing on previous experiences and employing automatic learning algorithms. These robots may be thought of as advanced artificial intelligence systems.

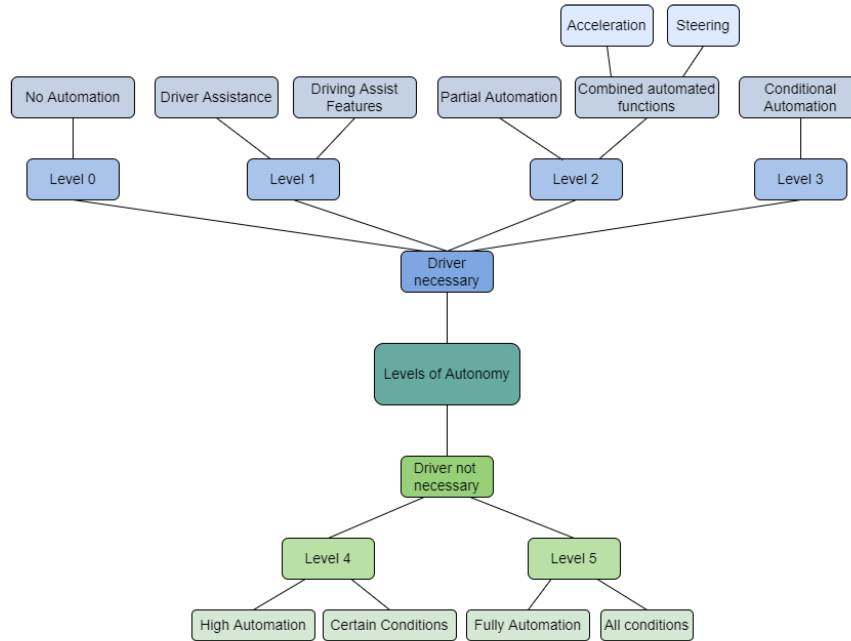


Figure 2.6: Autonomy levels of AVs[22].

Sensors used in AGV:

AGV employ a variety of sensors to detect and interpret their surroundings. The table below represent some of the sensors that are often used: Autonomous vehicles often

Type	Description
LiDAR	Light Detection and Ranging, sensors can build a 2D or 3D representation of the environment around the vehicle using laser beams. LiDAR sensors can detect objects at significant distances and provide a precise representation.
Camera	Cameras record visual information about the area and can be utilized to detect objects, detect tracks, and recognize traffic signs. Several cameras are frequently employed to offer a 360-degree picture of the vehicle's exterior.
Radar	Radar sensors detect the distance, speed, and direction of objects around the vehicle by using radio waves. They are especially useful in poor weather or low-light environments, where other sensors may be inefficient.

Table 2.1: Most common sensors in AGV's.

employ a variety of these sensors to detect and comprehend their environment. Onboard computers evaluate the data from these sensors and make decisions about how to move the car safely and effectively, Those different technologies are generally placed in AGV's, figure 2.7:

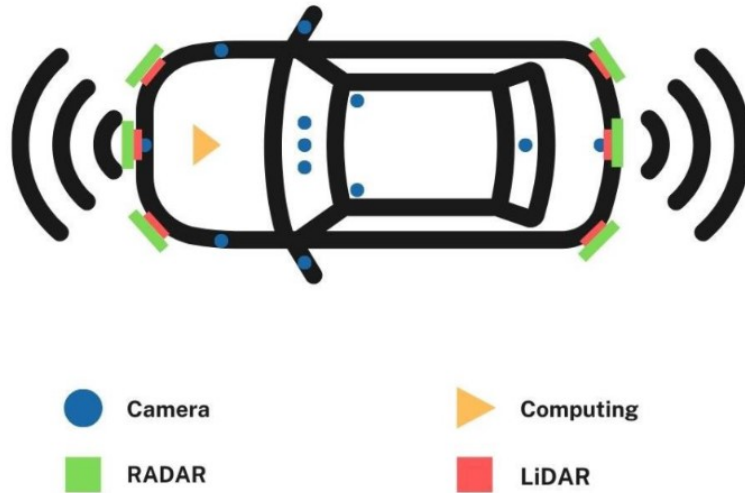


Figure 2.7: Placement of the different types of sensors in AGV's[22].

2.6 RobotAtFactory 4.0 competition

2.6.1 Introduction

The RAF competition plays a vital role in education due to the multidisciplinary approach it provides to students from different technological areas[6]. Additionally, this competition can be used to solve problems similar to those presented in a real industrial environment, pushing the boundaries of what is currently possible in robotics and driving research and development in the field.

The competition emulates a stage in the I4.0 automated production chain, specifically the logistics stage, where autonomous robots are able to transport materials from the supply warehouse to the machines, wait for the materials to be processed, and then return them to the final product warehouse. Robots must therefore be able to collect, transport and position materials accurately, locate themselves and navigate in the designated environment without collisions.

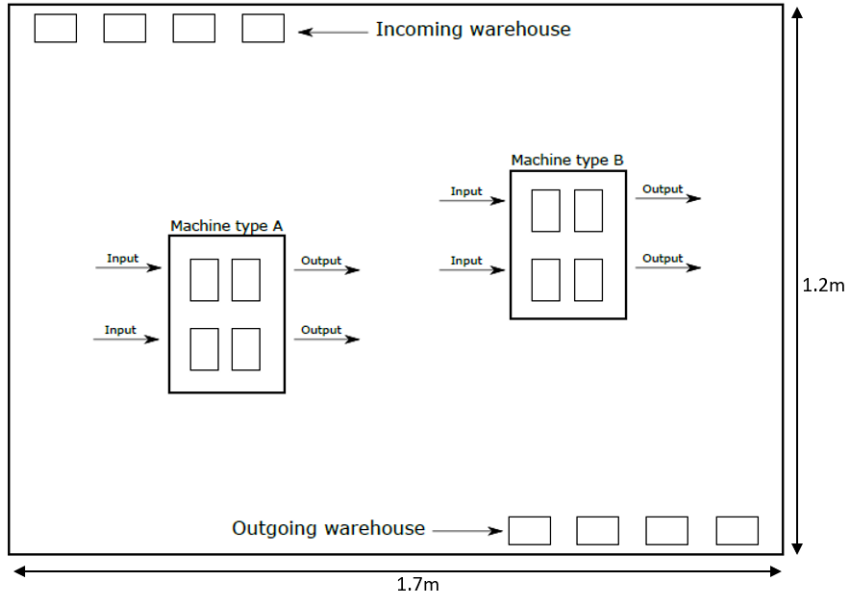


Figure 2.8: Competition area of RAF [23].

2.6.2 Competition area specifications

The competition area is designed to be similar to a factory, with warehouses and machinery. The maximum dimensions of this area are 1.7 and 1.2 m. Four machines and two warehouses are available. The incoming warehouse is the source of the materials, while the outgoing warehouse is their final destination, Figure 2.8.

In Raf@Factory Lite competition, the robot can identify the path to its task using a black line drawn on a white background, figure 2.10, so it can use dedicated sensors to follow the line to perform its tasks. However, in RAF, ArUco labels are printed on a white background, figure 2.11. They can be used to locate robots, and other labels are also available, printed on warehouses, to identify the category of equipment.

2.6.3 Part specifications

The robots will move items with standard dimensions of 90x60x65 mm of length, width, and height, respectively. A metal plate measuring 20 x 80 mm is mounted on the box's front wall 2.9.

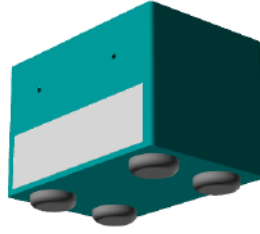


Figure 2.9: 3D virtual photo of the competition parts of the RAF competition[23].

In RAF competition, participants engage in a series of three distinct rounds, ideally conducted on consecutive days. Prior to the commencement of these rounds, each participating team is granted a dedicated 10-minute period for preliminary field tests, ensuring the optimal functionality of their robotic systems.

The fundamental objective of this competition lies in the precise placement of parts within specified locations, with varying degrees of value assigned to different part types. Blue parts carry a single-point value, green parts are deemed twice as valuable, and red parts are the most valuable, carrying a three-point weight.

The ultimate victor in this competition is determined by the cumulative count of correctly placed parts achieved across the span of these three rounds. In the event of tied scores, the resolution hinges on the total count of parts correctly placed within the outgoing warehouse, followed by the consideration of the shortest completion time based on each team's optimal performance throughout the competition[24].

2.6.4 Robot specifications

Each robot must fit into a cube with dimensions of 30x30x30 mm of length, width, and height, respectively. The robot must be completely autonomous and cannot establish any kind of communication with an external system that is not explicitly provided by the organization.

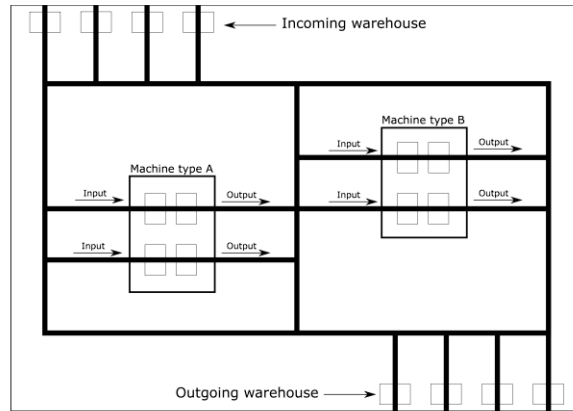


Figure 2.10: 3D virtual photo of the competition area of the Robot@Factory Lite[24].

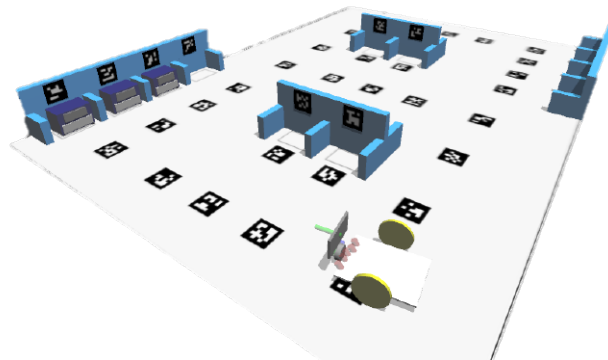


Figure 2.11: 3D virtual photo of the competition area of the RAF competition[23].

2.6.5 IPB Team

This is not the first time that IPB has participated in RAF competition. This makes the project more challenging for several reasons. Through the experience of the team members and our supervisors, we have to develop an optimal and reliable strategy to increase our chances in the competition. Therefore, the management and planning phase of the project is essential to ensure that the project is carried out in the best possible conditions.

This year we have opted for a new robot structure so each part of the project must be built from the beginning, which means that a large amount of components and tools

must be purchased or manufactured, the same goes for the robot software, so all the parts have to be coordinated with each other to ensure the proper construction of the robot.

The project is planned as a group effort in order to split the workload. Basically, it was divided into four areas of responsibility. It is critically important to ensure that all parts of the project are completed properly as all areas are complementary. The distribution of tasks is elaborated in the table 2.2.

Member	Task
José Lima	Supervisor and coordinator.
João Braun	Co-supervisor / Coordinator and captain, developer of the robot's system, localization, low-level and high-level control, firmware, tester
Kais Baidi	3D design and realization of the structure; Electronics and actuation firmware; Testing and commissioning
Abder-rahim Arezki	Path planning developer.
Alexandre Oliveira	Path planning developer.
Luciano Bonzatto	System development and tester

Table 2.2: Team members and their responsibilities.

2.7 Conclusion

In this introductory chapter, we have explored the state of the art of robotics, looking at different facets of this constantly evolving field.

We began with a general introduction, highlighting the growing importance of robots in our daily lives. We then looked at the general concepts of robotics, looking at the different categories of robots and their impact in various sectors. We also explored the role of robots in education and research, highlighting their importance in stimulating, learning and innovation. Next, we explored the link between robotics and STEM, we observed that robotics and STEM disciplines are mutually linked.

To conclude, we highlighted the RAF competition, pointing out its essential role in

education and research and also we introduced our team, the IPB team, which will be taking part in this year competition.

This chapter laid the foundations for our research by providing a comprehensive background on robotics, its influence in education and research, and the crucial importance of the RAF competition.

Chapter 3

Design and implementation

3.1 Introduction

In this chapter of the report, we focus on the sizing and selection of robot components, which are essential to ensure the robot's proper operation. The first step is to identify the components we need, such as actuators, end-effectors, sensors, and other elements. Through the competition specification as well as the experience of the team members during the previous years of this competition, we have agreed to go for an omnidirectional mobile robot structure. With this type of structure, the robot will have more fluidity in movement while managing the materials between the warehouses and the machines, and this will help us save a lot of time.

Once we have defined the components we are going to use, we begin the 3D modeling of the robot. In this section, we describe in detail the structure and mechanisms of the different parts of our robot. This 3D modeling is performed in strict accordance with the requirements detailed in the competition specifications. We will also discuss the realization of the structure, explaining the manufacturing process used and the difficulties we faced during the robot assembly.

We conclude this chapter with a kinematic study of the robot's structure. This analysis will enable us to obtain the control equations needed to start up and control the robot.

3.2 Component choice

The creation of multidirectional robots is a task that depends on many factors, among them the careful selection of components. In this competition, where precision, mobility and stability are crucial, every component from motors to sensors to structural materials plays an essential role in determining the robot's performance and final results.

3.2.1 Actuators and drivers

Motors and wheels

The first step is to select the motors and wheels that will be used according to the requirements also the movements and tasks that will be performed. So the robot must navigate the competition area while manipulating cubic items with a dimension (90 x 60 x 65mm) having a negligible weight. The competition area is 1.7m long and 1.2m wide, with four machines and two warehouses. And, according to the specifications, the robot should respect these following dimensions (300 x 300 x 300mm).

Therefore, in order to have an optimal performance, we have been opting for a compact robot with a reduced weight and a fast speed, always ensuring the precision of the movement. Referring to the available products on the market we have chosen to use the motor **Pololu 37D**, figure3.2 and **mecanum wheels with 60mm** of diameter, figure3.1



Figure 3.1: Mecanum wheels 60mm[25]

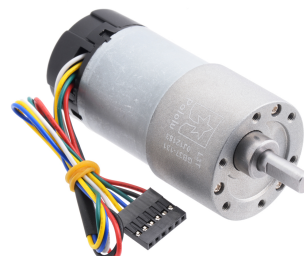


Figure 3.2: Motor Pololu D37[26]

In order to have the possibility to make all the combination possible of movements with these types of wheels we have to feed each wheel with movement separately. These motors

have a nominal power of 12W and running at a speed of 330RPM at 12V. Therefore, each wheel can move at a linear speed of 1 m/s, according to equation 3.1 .

$$V = rw \iff V = r \frac{2\pi N}{60} = 30 \frac{2\pi 330}{60} = 1036,2mm/s \quad (3.1)$$

Motor driver

To make the robot move, we need to provide voltage to our four motors. A microcontroller or microprocessor is not able to provide the power needed to run a DC motor, but it can control a transistor, so we usually use electronic circuits called H-bridges based on transistors to perform this task, the name comes from the arrangement of transistors inside these circuits, Figure 3.3.

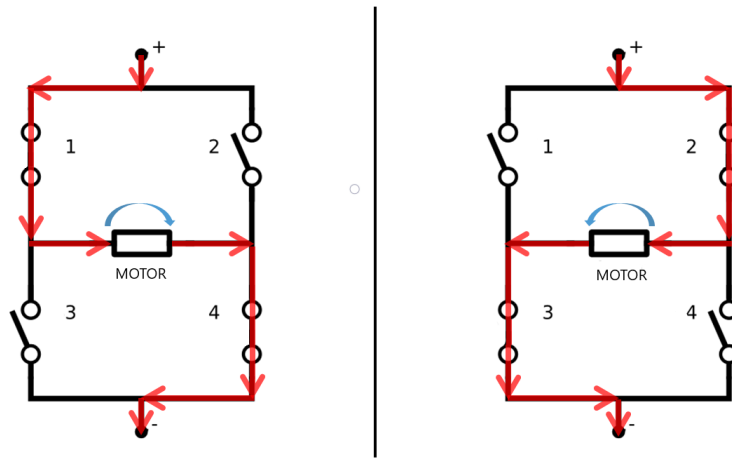


Figure 3.3: H-bridge operating diagram[27].

An H-bridge is an assembly of four transistors, which allow the motor to be connected to the power supply in various ways:

- Forward: By closing switches 1 and 4, the current passes through the motor in one direction.
- Reverse: By closing switches 2 and 3, the current is now connected in the other direction.

With this principle it is possible to move in all directions with the robot but with a constant speed. First of all we have to know that the speed of a motor is directly related to its supply voltage. That's why we use Pulse Width Modulation (PWM) technique. This technique consists of sending pulsed electrical signals to a DC motor. The duration of each pulse determines the amount of power sent to the motor, If the pulse duration is longer, it means that more power is sent, which makes the motor run faster and vice versa if the pulse duration is shorter.

We evaluated several electronic circuits available on the market, in particular those equipped with H-bridges, in order to achieve precise speed control of the DC motor. After careful consideration, we opted for the IBT-2 driver. This decision was primarily based on practical considerations, including cost-effectiveness and the IBT-2 driver's unique ability to handle up to 32 amps of current. This high current handling capacity is particularly advantageous for our case, which prevent the bridge from overheating or malfunctioning. This choice is in line with our objective of ensuring robust, reliable motor control, and makes the IBT-2 driver an optimal selection,figure 3.4.

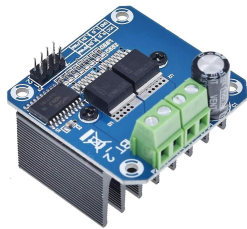


Figure 3.4: IBT-2 driver motor[28].

The IBT-2 module is a H-bridge motor control device. It is designed to control the speed and direction of one DC motor. The module is capable of delivering a maximum current of 32A with a supply voltage range which varies from 6V to 27V DC. It is also equipped with an emergency braking function that allows to the motors to be quickly braked when power is lost or a control error is detected. It can be controlled via a PWM or Transistor-Transistor Logic (TTL) signal interface.

Electo-Magnet

The items to be moved by the robot are equipped with a metal sheet in the front with a dimension (20 x 80mm). Since the weight of the boxes is negligible, we can move these objects simply by attaching them to the robot with an electro-magnet. The electro-magnet we will use made by Grove company[29] it is easy to set up because of its compact shape and also it's powered with 5V, so we can control it directly from the microcontroller without the need for any conditional component, figure 3.5.



Figure 3.5: Grove Electro-magnet[29].

3.2.2 Sensors

In robotics, sensors have an essential role as a subset of transducers. They are ideal for converting various physical attributes such as temperature, pressure, light, humidity or proximity into valuable electrical signals. By exploiting these sensors, robots acquire the ability to gather vital information about their environment, allowing them to analyze this data and make decisions based on a predefined program.

In the case of our robot, which has to navigate autonomously and perform tasks in the competition area, the selection of appropriate sensors is crucial. To guarantee the precision of its movements and interactions, we have chosen to use a combination of interoceptive and exteroceptive sensors. These sensors will not only enable our robot to understand its internal state, such as temperature, orientation and energy levels (interoceptive sensors), but also to gather essential data on its external environment, such as mapping and obstacle detection (exteroceptive sensors). This integration provides a solid foundation for our autonomous navigation.

Limit switch

During the competition, the score of each robot will only be counted when the materials are correctly placed in the machines or in the warehouses. We have already chosen the actuator that will attach the box to the robot, but first the robot needs to receive the information that it is already in a position that allows it to attach the box. To do this, we will use a contact limit switch, figure3.6.

A limit switch is a mechanical device that requires physical contact between an object and the switch actuator to change the state of the contact (open/closed). When the object makes contact with the switch, it eventually moves the trigger to the limit where the contacts change state.



Figure 3.6: Industrial limit switch with roller lever[30].

In a Normally Closed (NC) circuit, this mechanical action opens the electrical contacts and in a Normally Open (NO) circuit, it closes them. The connections switch the flow of current in an electrical circuit on or off, which is how the conversion of the physical contact into an electrical signal is done.

Odometry

Odometry is a technique used to estimate the position of a moving robot. It involves tracking the robot's movements over time using sensors like encoders, gyros, and accelerometers. These sensors help measure changes in the robot's position. It's important

to note that encoders, which count wheel rotations, can accumulate errors over time. In a general sense, all these sensors are part of 'dead reckoning' a term that covers the use of sensors like Inertial Measurement Unit (IMU) to continuously estimate a robot's position and account for errors that may accumulate over time.

Basically, two main operating principle help us to understand the functionality of the encoders:

Operating principle of encoders:

- Incremental encoders: These encoders produce pulses as they rotate in one direction or the other. They can be simple or quadratic, with two channels phased at 90 degrees to each other to determine the direction of rotation. The number of pulses per revolution depends on the encoder's resolution.
- Absolute encoders: As their name suggests, absolute encoders provide information on the exact position of an axis. They generate a unique digital code for each position[31].

Technology used :

- Optical rotary encoders: These encoders use a Light-Emitting Diode (LED) and an optical sensor to measure axis rotation. Optical rotary encoders can be absolute or incremental.
- Magnetic rotary encoders: These encoders use a permanent magnet and a magnetic sensor to measure the axis rotation. Like optical rotary encoders, magnetic rotary encoders can also be classified as absolute or incremental[31].

Our robot is equipped with four magnetic encoders, one for each wheel. Each encoder is composed of two hall effect sensors used to detect the rotation of a magnetic disk on the back shaft of the motor.

The quadrature encoder offers 8 Count Per Revolution (CPR) of the motor shaft. However, these are quadrature encoders, which means that we have two quadrature channels

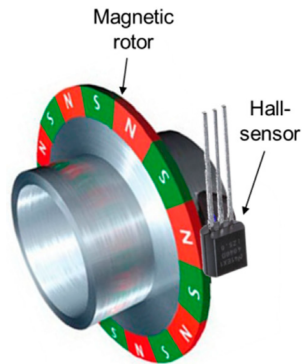


Figure 3.7: Operating principle of a magnetic encoder with a magnetic rotor and hall sensor[31].

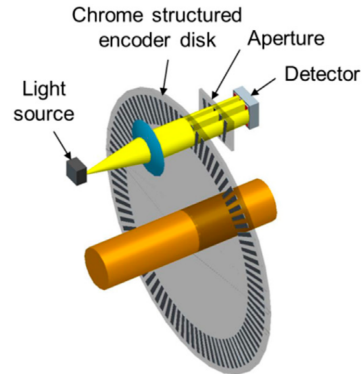


Figure 3.8: Operating principle of an optical encoder with a light source, encoder disc, aperture, and detector[31].

(90 degrees out of phase). Therefore, if we recognize all possible states in two quadrature channels, we have 4 possible states (00, 01, 10, 11), which means we have 4x resolution. To determine the encoder resolution on the output shaft, we have to multiply by the transmission ratio (1/120). The final output resolution is then equal to 3840 states/rev. By combining the mecanum wheel with a diameter of 60 mm and the encoder resolution of 3840 states/rev, it is possible to control the wheel with a minimum step angle of 0.09375 degrees, equivalent to 0.05 mm.

However, odometry can generate errors, especially due to sensor deviation, wheel friction or ground irregularities. Therefore, it is important to combine odometry with other location techniques, such as GPS or computer vision, to improve the accuracy of the estimated position.

LiDAR

Light Detection and Ranging (LiDAR) is a sensor that uses laser beams to measure the distance between objects and the sensor. More precisely, it emits a laser beam and measures the time it takes for the light to reflect and return to the sensor, thus calculating the distance between the sensor and the object. These types of sensors are used in a variety of applications, such as mapping, tracking, pattern recognition and navigation of autonomous vehicles. They are often used in conjunction with other sensors such as

cameras to obtain complete information about the environment.

For our application case we will use the YDLIDAR X4, figure3.9. This reference is equipped with a motor that rotates continuously to allow us to make measurements in all horizontal directions (360 degrees) in two dimensions, which means that it can measure the distance of all objects located around the robot in a horizontal plane.



Figure 3.9: Radar YDLIDAR X4[32].

The principles characteristic of the YDLIDAR X4 :

- Remote sensing frequency: 5000 pulses per second.
- Rotation frequency of the motor varies from 6 to 12 Hz.
- Detection distance ranging from 0.12 to 10m.

3.2.3 Image processing

The combination of the two previous technologies allows our robot to navigate in the competition area with a good accuracy and precision[33]. According to the specifications of the competition, ArUco tags are printed on the map, each one of these tags indicates a precise location, also there are other tags printed on the walls. These marks are reserved to identify the different types of boxes. For this reason we will use the Raspberry Pi V2 camera, figure3.10. Which will allow us to detect, analyze and recognize these labels in order to identify the boxes and move them to their correct location.



Figure 3.10: Raspberry Pi V2 camera[34].

3.2.4 Human Machine Interface

The Human Machine Interface (HMI) allows the user to communicate with the robots in an intuitive and efficient way. The HMI can take different forms, going from physical interfaces, such as buttons, joysticks and touch screens, to vocal or gestural interfaces, which allow users to communicate with the robots without having to use physical devices. In this version we have implemented a 5 inch LCD touch screen, figure 3.11. This one will be connected to the control unit to allow us to perform the following tasks:

User interface : The main function of a screen is to display values, such as robot status, operating instructions, task results, etc. So with this device we can interact with the robot by touching the screen to enter commands or select predefined options.

Programming and configuration : This screen can be used to program and configure the robot, displaying the configuration options and allowing us to modify the robot parameters.

Monitoring and diagnosis: Aanother task is to monitor robot performance in real time by displaying robot status and other metadata.

Remote control: Finally, we can control the robot remotely, displaying the live video of the robot and controlling it's movements using touch commands.

The Waveshare 5" touchscreen is an Liquid Crystal Display (LCD) display with a resistive touch panel designed to be used with microprocessors such as the Raspberry Pi. It offers 800x480 resolution and supports a variety of operating systems including Raspbian, Ubuntu and Windows[35].



Figure 3.11: Waveshare 5 inches LCD touch screen[35].

3.2.5 Command unit

A command unit is a critical component in robotics that controls the robot's operation. It is an electronic system that processes input from the robot's sensors, makes decisions based on predefined programs and algorithms, and sends instructions to actuators to perform the necessary movements. Depending on the complexity and functions of the robot, it may take the form of an embedded computer, a microcontroller, or a specialized processor.

Inputs and Outputs of the robot

In this part of the project we are interested in locating and identifying the different inputs and outputs of our robot. This step is essential for us to be able to properly define the control unit that we will use.

The Input/Output (I/O) of the various robot peripherals are listed as follows:

- Motor Pololu (x4): This component has two encoder pins, Encoder A and Encoder B, both serving as output channels for encoder data.
- Driver IBT 2 (x4): This driver features several input and output pins, including RPWM and LPWM for forward and reverse PWM level, R-EN and L-EN for drive enable inputs, and R-IS and L-IS for forward and reverse drive current alarms.
- Limit Switch (x1): The limit switch has one output pin, OUT NC, which is a normally closed contact.

- Electro Magnet (x1): This component has an input pin, EN, used to enable or disable the electromagnet.
- Raspicam V2 camera (x1): The camera module has several output pins, 4 output pins for MIPI data and 2 pins for the MIPI clock. In addition, it includes an output pin for the LED indicator and SCL, SDA pins for I2C communication.
- Ydlidar X4 (x1): This component includes input pins for motor enable control (M-EN), ranging enable control (DEV-EN), and motor speed control (M-SCTP). It also features communication pins Tx and Rx for USART communication.
- Waveshare 5" Touch Screen (x1): This screen has an HDMI port for digital audio/video interfacing.

Microcontroller and Microprosesor

Microprocessors and microcontrollers are widely used in robotics to control robot motion, perception and communication. Microcontrollers are often used for simpler, stand-alone applications, while microprocessors are used for more complex tasks requiring high processing power. Microcontrollers are used to control the movements of robots, such as controlling the speed and position of motors, this is done through the data provided by the sensors or by communicating with other devices. Microprocessors are commonly used for more complex tasks such as perception, planning and communication. For example, they can be used to process sensor data, like images or audio signals, also we can use them to communicate with external systems. Figure 3.12, shows the connection between the control boards and the different components of the robot:

Arduino Mega :

Arduino Mega is a microcontroller that has 54 digital I/O pins, 15 of which can be used as PWM outputs and 16 analog inputs. The board is equipped with a 16 MHz crystal oscillator.

The Mega model is based on a ATmega2560 microcontroller which is the heart of the system, it is an 8-bit microcontroller manufactured by Atmel. It has 256 KB of

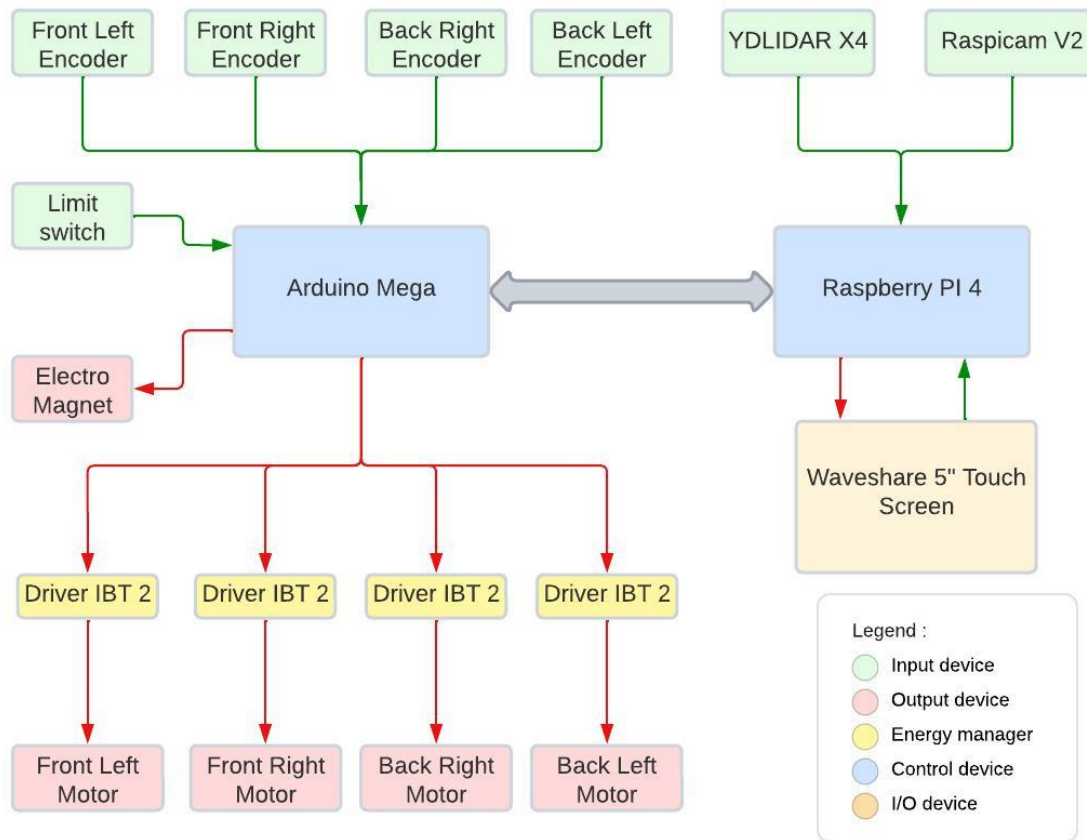


Figure 3.12: Input/Output diagram of the robot hardware.

Flash memory for program storage, 8 KB of Static Random Access Memory (SRAM) for running data and 4 KB of Electrically-Erasable Programmable Read-Only Memory (EEPROM) for storing non-volatile data. Figure 3.13, presents the internal architecture of the microcontroller ATmega2560.

The ATmega2560 chip has I/O ports for connection to external devices, 6 timers, an Analog Digital Converter (ADC), as well as communication interfaces such as Universal Synchronous Asynchronous Receiver Transmitter (USART), Serial Peripheral Interface (SPI) and Inter-Integrated Circuit (I2C) for communication with other devices.

After checking the inputs and outputs of the robot, this development board is ideal to perform the following tasks:

Read and process the data coming from the 4 encoders and the limit switch sensor.

Control the motors and the electro-magnet.

Ensures the communication with the microprocessor, transmit the data from the sensors and receive the task to be performed.

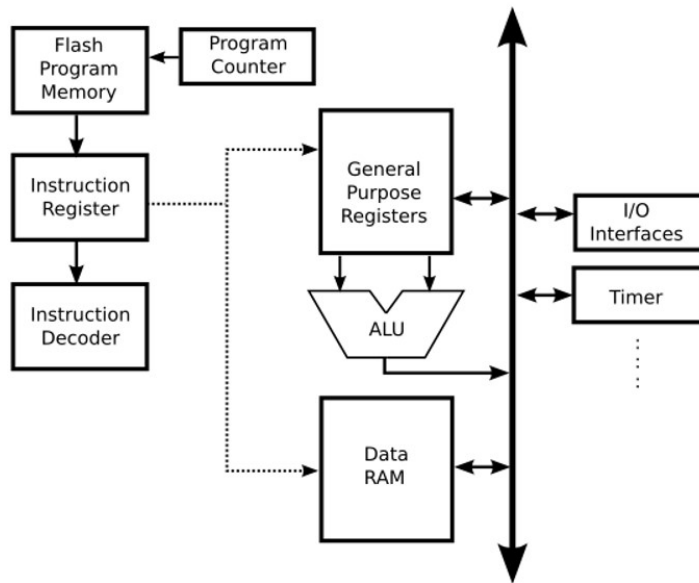


Figure 3.13: Architecture of a microcontroller[36].

Raspberry PI 4 :

The Raspberry Pi 4 is a microprocessor equipped with 1.5GHz quad-core ARM Cortex-A72 processor, offering great processing power with RAM memory ranging from 2GB to 8GB. The board has numerous I/O ports, including:

2 USB 2.0 ports.

2 USB 3.0 ports.

2 micro-HDMI ports for connection to external displays.

1 Ethernet port.

1 Camera Pi port.

1 micro-SD port.

1 micro-SD port for storing the operating system and user data.

40 GPIO pins for connecting to external electronic devices.

It also integrates wireless communication functions such as WiFi and Bluetooth.

Considering the huge quantity of data to be processed in a very short time, the use of a microprocessor is essential to guarantee the performance of the robot.

This board will be responsible for the following tasks:

- Reading the YDLIDAR X4 and camera feedback.
- Receive through a serial communication the data from the Arduino Mega.
- Process all this information referring to the navigation algorithm and path planning.
- Read the user's commands and write the requested information on the LCD touch screen.

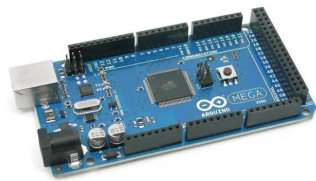


Figure 3.14: Arduino Mega development board[37].



Figure 3.15: Raspberry Pi4 development board[38].

3.2.6 Power supply

The power supply is one of the key elements to ensure the proper functioning of all the devices.

Batteries are often used as a power source for mobile robots because they offer a mobile and easily rechargeable power source. However, batteries have an output voltage that can vary depending on the charge level, which can affect the performance of various robot components.

This is where the step-down voltage comes in, by reducing the input voltage of the battery to a stable and constant output voltage, the step-down voltage ensures that

all robot components receive the proper voltage and current for their proper operation, regardless of the variations in the input voltage or the applied load. This optimizes the use of electrical energy from the battery and ensures that the robot operates correctly under the different conditions.

After referring to the datasheet of the robot components, two voltage levels should be provided :

- 5V for supplying the control units, sensors, camera and the LCD touch screen.
- 12V for the motors, for that we don't need an additional electrical component to supply this voltage since we can use the motor driver to regulate and supply the appropriate tension, by modulating the source voltage in order to control the current power supplied to the motors.

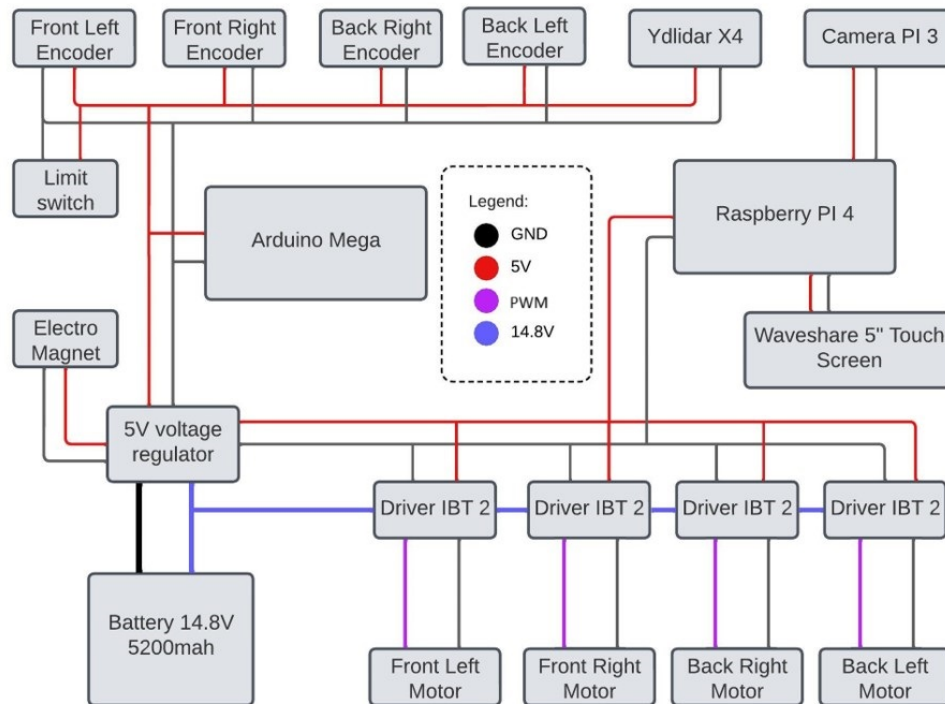


Figure 3.16: Diagram of energy distribution between the robot devices.

Battery :



Figure 3.17: Battery Li-Po Sigma 45C 5200 mAh 4S[39].

LiPo batteries are very popular in robotics due to their low weight, high energy efficiency and ability to deliver high voltages at high rates of current. This makes them particularly suitable for mobile applications, such as our cases, where weight and autonomy are crucial factors. We have chosen to use the battery, figure 3.17. Here are some of its main characteristics:

Table 3.1: Main characteristics of the LiPo battery[39]

Characteristics	Capacity	Voltage	Weight	Dimensions
Value	5200 mAh	14,8V (4S)	450g	139 x 45 x 35 mm

Voltage regulator :



Figure 3.18: LM2596 Adjustable DC-DC Voltage Regulator with Display[40].

The LM2596 is a step-down voltage regulator. It is often used in robotics to regulate the supply voltage of various electrical components such as sensors, microcontrollers, communication modules, etc. Here are some of its main features:

This model is equipped with a digital display that allows monitoring the input and output voltages of the regulator in real time, which is useful for supervising the charge level of the battery.

Table 3.2: Main characteristics of LM2596 Adjustable DC-DC Voltage Regulator[41]

Characteristics	Input voltage	Output voltage	Conversion efficiency
Value	4.5 V to 40 V	1.25 V to 35 V	Up to 92%

3.3 Robotic design

This section will focus on the modeling of our robot. To do this, we will perform a systemic study including the robotic part, which will enable us to identify the control equations that will be implemented in the control units to manage the robot’s movements. But first, we will present the 3D model of the robot and explain its main mechanisms.

3.3.1 Design software

The mechanical design of the robot is developed according to the different points discussed in the previous chapters. We begin with a brief review of the technical requirements is made. Then, the design of the robot is described as well as its different parts and mechanisms and we will look about the manufacturing processes that we will use for the realization.

We used SolidWorks software to design and model the robot, it is a Computer-Aided Design (CAD) software that allows engineers and designers to create 3D models of parts and assemblies. It also allows to simulate the behavior of parts and assemblies in real conditions, which can help to identify potential problems before manufacturing.

3.3.2 Technical requirements

The robot designed in this project is used in the context of a robotic competition that simulates a real situation in industry. It can eventually be used to develop and test complex algorithms of movement and path planning that can be implemented in industrial robots.

The design phase is critical, as it is essential to take into consideration the realization aspects and the procedures that will be used to minimize as much as possible the

mechanical anomalies that could occur. This approach will facilitate the control of the robot's movement once it is built.

According to the specifications, the dimensions of the robot should not exceed 30x30x30cm. However, we decided to aim for dimensions of 25cm in length and width, which will offer us more fluidity in the movements, especially during the phase of moving of the items from one place to another.

Regarding the weight, the selected motors have an important performance, so we will try to maintain a medium weight while keeping the mass center in the middle of the robot. This will help the mecanum wheels to have equal friction with the ground, as they have less contact surface than the traditional wheels.

3.3.3 3D design of the structure

The dimensions of the robot are [262, 250, 196]mm respectively in length, width and height and it is made of three parts, the front structure, the rear structure, and the upper platform, figure 3.19.

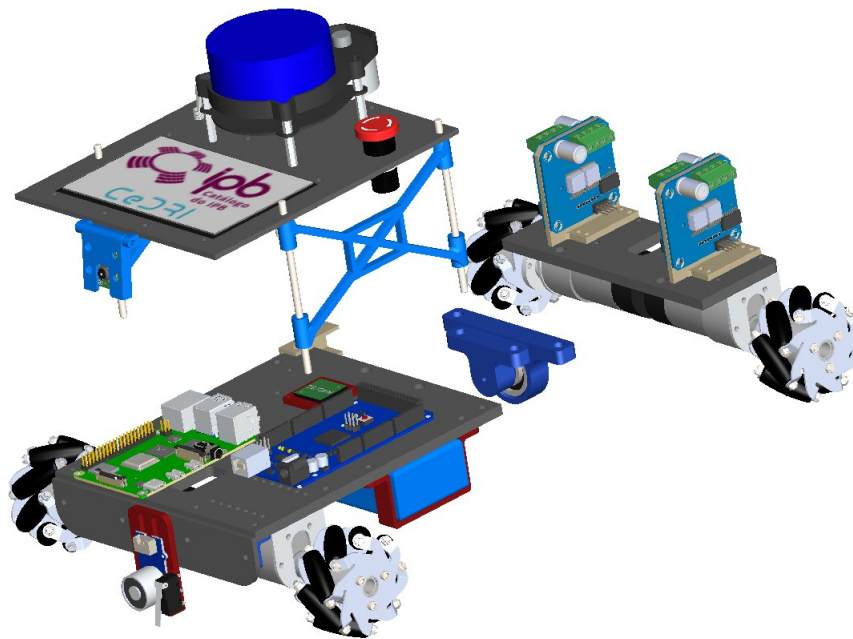


Figure 3.19: Exploded view of the main sub-assemblies of the robot.

Front structure

The front structure is the main part, as this is where all the other structures will be attached. It contains two motors with their supports and wheels, the control units (Arduino Mega and Raspberry Pi 4B) as well as the system for moving the boxes, which is placed at the front of the structure, figures 3.22 and 3.21.

Because of its heavy weight the battery is also linked to the bottom of this structure in the middle of the robot, which allows an equal distribution of the weight on the robot.

The base of this structure also includes the mounting brackets for the other parts of the robot. The dimensions of this sub-assembly are [203, 250, 76] mm in length, width and height respectively, and its weight is estimated at 4kg.

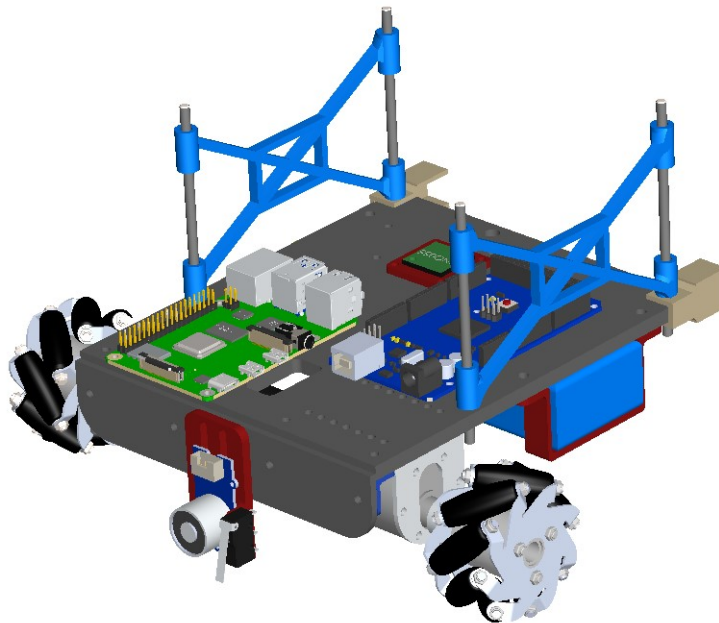


Figure 3.20: Exploded view of the front structure of the robot.

The system responsible for picking up and moving the boxes is located in the front of the robot. This system consists of an electromagnet and a limit sensor. When the sensor changes state, it indicates that the robot has made contact with the box. This information allows the robot to activate the electromagnet to catch the box. Two mechanical forms have been designed to manually adjust the heights of the limit sensor and

the electromagnet, figures 3.22 and 3.21. This adjustment helps us find the ideal position for these two components to perform their tasks in the most precise way.

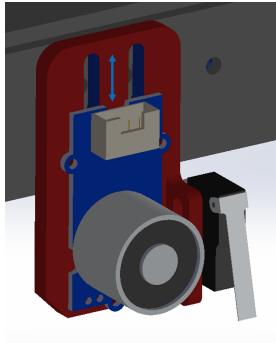


Figure 3.21: Height adjustment system of the Electro-magnet.

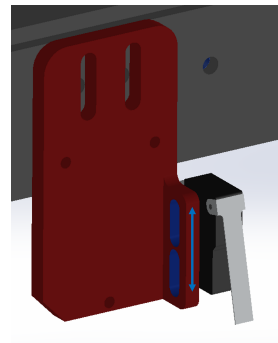


Figure 3.22: Height adjustment system of the limit switch sensor.

Rear structure

This part is the smallest substructure, figure 3.23, it contains two motors with their support and their wheel, two plastic supports in which we will fix the four motor drivers IBT-2 and a system that will connect it to the front part of the robot.

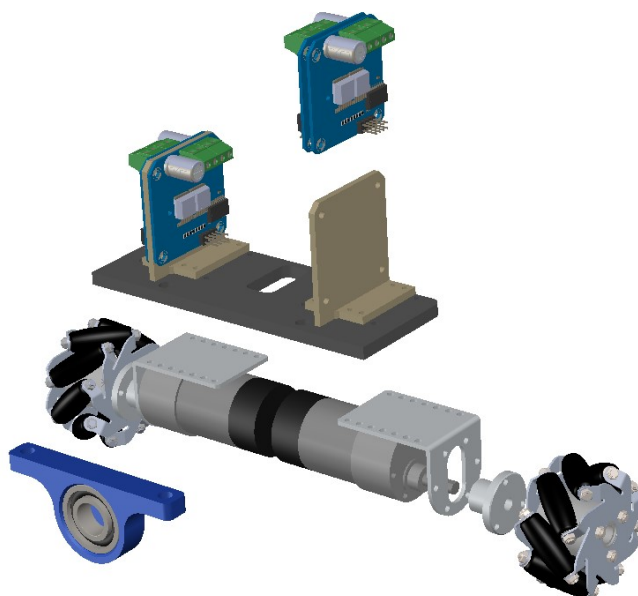


Figure 3.23: Exploded view of the rear structure of the robot.

All these components will be mounted on a rectangular plastic base of 6mm thickness. The volume of this sub-assembly is [56, 250, 114]mm respectively in length, width and height and its weight is estimated at 1.5Kg.

A four-wheeled mecanum architecture uses special wheels that have rollers that are oriented at an angle of 45 degrees relative to the direction of the wheels rotation. This allows the structure to move in all directions, including laterally and diagonally, but in terms of contact between the robot and the ground, the mecanum wheels have less grip than traditional wheels because the rollers with the orientation offset are in less contact with the surface.

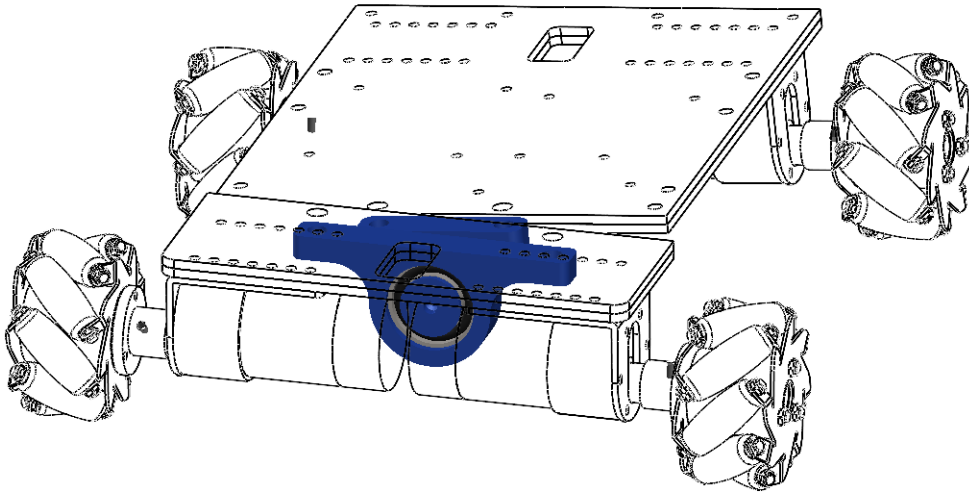


Figure 3.24: Draft illustrating the connection between the front and rear parts of the robot.

This can make the structure less efficient. That's why the connection between the two structures (front and rear) is established with a mechanism that provides a degree of freedom along the robot's X axis, figure 3.24.

This movement in rotation between the robot's front and back wheels ensures that each wheel keeps contact with the ground. This is a primordial function to ensure a fluid and precise movement, figure 3.25.

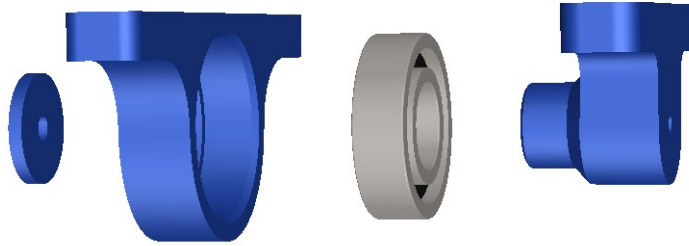


Figure 3.25: Exploded view of the joint between the front and the rear part of the robot.

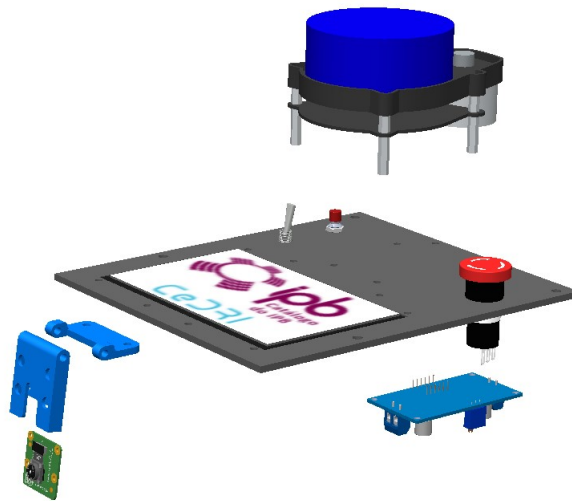


Figure 3.26: Exploded view of the upper platform of the robot.

Upper platform

This part will contain the elements that allow the robot to communicate with the external environment. It includes :

- The laser scanner placed in the center of the robot.
- The camera at the front with an adjustable support, which will allow us to set the ideal position of the camera according to the captured image.
- An LCD touch screen to establish a human-machine interface.
- An emergency stop button, two digital inputs (push-button and switch) and the voltage regulator module.

Result

In this subsection, we have presented in detail the design of the robot using the software SolidWorks, describing each sub-assembly of the robot. The manufacturing process adopted for this project is 3D printing, which makes this approach valuable in the prototyping phase.

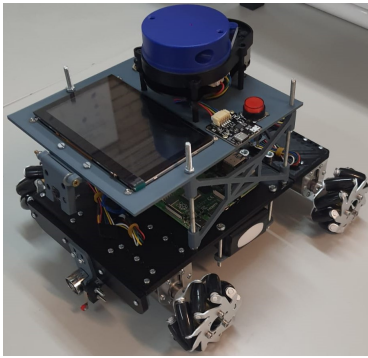


Figure 3.27: Reel picture of the robot.

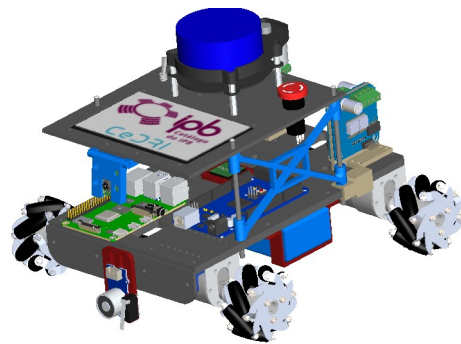


Figure 3.28: Virtual view of the robot.

3.4 Kinematic modelling

Omni-directional wheel allow to a vehicle to move in all directions, sideways as well as forward and backward, with a fixed axis of rotation. The principe is to add small wheels on the edges with a 45 degree rotation axis and a free rotation. This additional degree of freedom allows the wheel to roll without slipping in all directions without having to turn the axis of rotation as for a conventional wheel [42], [43].

The robot's kinematics is divided into forward and inverse kinematics. The forward kinematics model allows the computation of the structure speeds relative to the robot's frame based on the angular speed of each wheel. The inverse kinematics model refers to computing the wheels angular speeds from the structure speeds. Figure 3.29 shows the robot's kinematic architecture.

To calculate the kinematics models based on Figure 3.29 is important to define the forward parameters:

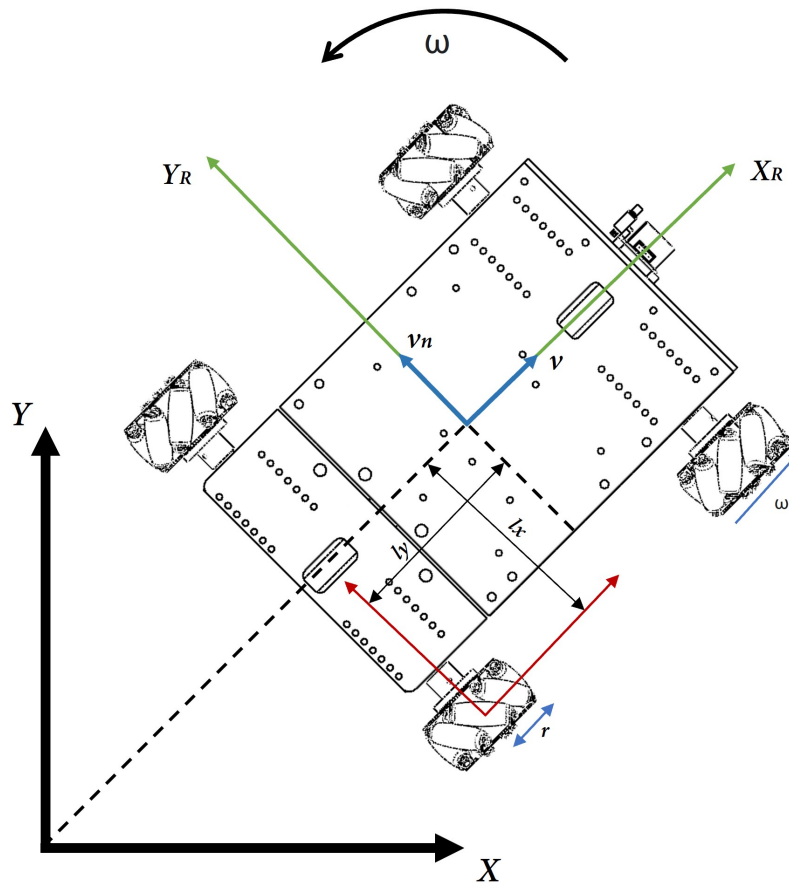


Figure 3.29: Robot's kinematic architecture. Adapted from [43].

- X_R, Y_R : Cartesian coordinate system associated to the robot's frame;
- l_x : The distance between the midpoint of a wheel and the X_R axis;
- l_y : The distance between the midpoint of a wheel and the Y_R axis;
- v, v_n : Robot's linear speeds [m/s];
- ω : Robot's angular speed [rad/s];
- ω_i : Wheels' angular speeds [rad/s];
- r : Radius of the wheel [m];

The forward kinematics model can be expressed by the following equations, where X_R and Y_R represent the cartesian coordinate system associated with the robot's frame, l_x and l_y indicate the distances between the midpoint of a wheel and the X_R and Y_R axes, respectively, v and v_n are the robot's linear speeds, ω is the robot's angular speed, and ω_i represents the wheels' angular speeds[43]:

$$\begin{bmatrix} v \\ v_n \\ \omega \end{bmatrix} = \frac{r}{4} \begin{bmatrix} 1 & 1 & 1 & 1 \\ -1 & 1 & 1 & -1 \\ -\frac{1}{l_x+l_y} & \frac{1}{l_x+l_y} & -\frac{1}{l_x+l_y} & \frac{1}{l_x+l_y} \end{bmatrix} \begin{bmatrix} \omega_1 \\ \omega_2 \\ \omega_3 \\ \omega_4 \end{bmatrix} \quad (3.2)$$

The inverse kinematics model can be expressed by the following equations, where the wheels' angular speeds ω_1 , ω_2 , ω_3 , and ω_4 are computed based on the desired structure speeds v , v_n , and ω [43]:

$$\begin{bmatrix} \omega_1 \\ \omega_2 \\ \omega_3 \\ \omega_4 \end{bmatrix} = \frac{1}{r} \begin{bmatrix} 1 & -1 & -(l_x + l_y) \\ 1 & 1 & (l_x + l_y) \\ 1 & 1 & -(l_x + l_y) \\ 1 & -1 & (l_x + l_y) \end{bmatrix} \begin{bmatrix} v \\ v_n \\ \omega \end{bmatrix} \quad (3.3)$$

These kinematics models allow the robot to accurately control its movement and ensure precise maneuverability within the RAF competition arena.

3.5 Conclusion

This chapter has been dedicated to the process of selecting and configuring the components integrated into the robot, a crucial stage in our work. We examined in detail the various categories of actuators and effectors, as well as the sensors used. In addition, we carried out a detailed analysis of the robot's control units and power supply, taking into account aspects such as batteries and energy distributors.

Once the selection phase was complete, the second part of this chapter focused on the

3D modeling and design of the robot. We highlighted the robot's various substructures and the connections between them, taking care to respect the requirements defined in the specifications.

In the final part, we worked on the robot's kinematic model, a key element for the next chapter, which will focus on the robot's control.

Chapter 4

Results and discussion

4.1 Introduction

The following chapter is structured into three parts, each of them makes a significant contribution to the complete evaluation of the robot.

In our initial exploration, we dive into the field of movement simulation using Simtwo software. This initial phase is of considerable importance, as it gives us an insight into the robot's behavior.

We then proceed to study the low-level control systems that form the basis of our robot's operation. This comprehensive exploration includes an examination of various elements, including the controllers used to manage the robot's position and orientation, as well as the speed control of its four motors. In addition, we provide a detailed review of the tasks performed by the microcontroller and the data exchanges that took place with the robot's various peripherals, clarifying the distinct functions performed during each operational cycle.

In the final section, we focus on the assembly and commissioning of the robot, while acknowledging the challenges that faced us during this process. Furthermore, we take a close look at potential future upgrades to improve the robot's performance.

4.2 Simulation

4.2.1 SimTwo Software

SimTwo is a software used for robotics simulation. It offers a complete set of tools for creating virtual environments, simulating robot behavior and evaluating algorithms. Users can model realistic environments according to their application cases as well as simulate physical interactions and customize robot models, sensors and actuators.

Generally SimTwo integrates with robotics environments and handles various control algorithms and programming languages. It accelerates the development cycle, reduces costs and allows researchers to design efficient autonomous systems.

The RAF competition environment, figure 4.1, has already been modeled on SimTwo software and it is available online[23]. This makes our task much simpler, as we only need to model our robot and simulate all these object in the same environment.

4.2.2 Implementation and configuration of the robot model

In order to run a simulation, it is necessary to prepare the infrastructure, which means defining the physical model of the robot and the competition environment. In the SimTwo software, we can accomplish this by using the "XML Scene edit" interface.

SimTwo uses XML files to describe the simulation environment, including the layout of fixed objects as well as robots and their properties. These XML scene files provide a structured representation of the simulation scenario.

To make changes to an XML scene, it is usually necessary to open the XML file using a text editor or a dedicated editor. Among the modifications that can be made are adding or removing objects in the scene, adjusting their position, size or orientation, changing the properties of robots or sensors, setting the initial state of objects, etc. It is even possible to import 3D files in ".stl; .obj; .3ds" format to visualize the real models during the simulation.

Once the desired changes are made in the scene XML file, we can save the changes

and restart or reload the SimTwo simulator to apply the modified scene. The simulator will then interpret the updated XML file and recreate the scene according to the modified specifications.



Figure 4.1: Simtwo software interface showing the competition environment and robot definition using the XML editor.

4.2.3 Simulation

To be able to compare the behavior of the virtual model with the real one, we need to define the robot’s kinematic control equations in the SimTwo software. Using these equations, we can adjust the motor parameters to control the robot’s motion, which can be done in the "Code Editor" section of the software.

The simulation of the model has been elaborated with the help of my supervisor Professor Braun, a simple trajectory has been defined composed by a linear movement and a rotation, this trajectory has been used to validate the controllers (real and simulated environments). Figure 4.2 shows the position and orientation of the real and simulated robot, respectively.

Although the result of the real scenario has more noise (due to the real ground truth acquisition system) [6], [33], the trajectory is similar with acceptable errors, validating the proposed real and simulated architecture.

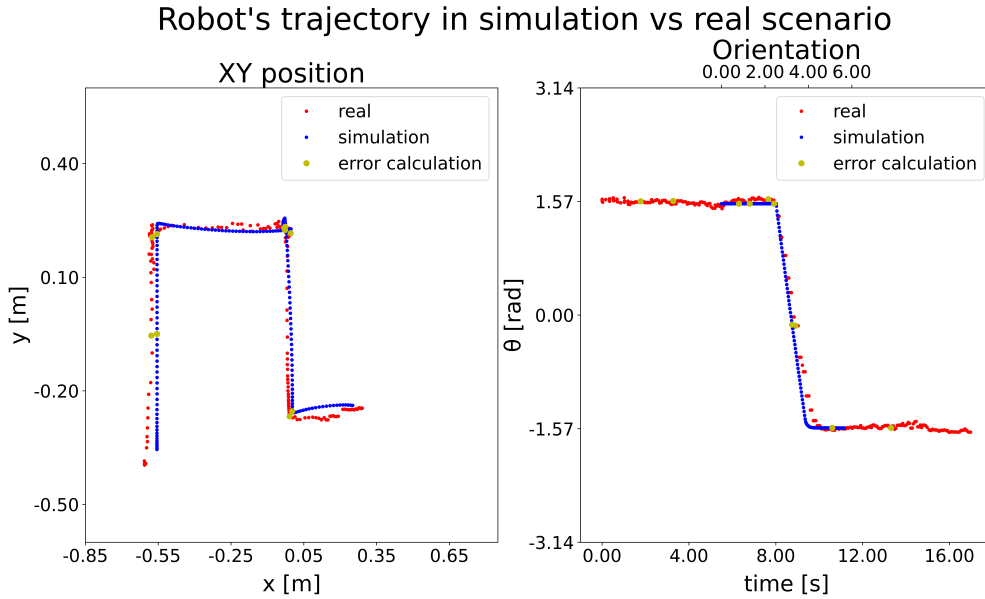


Figure 4.2: Trajectory performed in the simulation and in the real scenario[33].

In the simulated scenario, the robot moved faster than in the real scenario, so the time axis in the orientation graph in figure 4.2 was moved for better visualization. The axis of the real scenario appears at the bottom of the image and the axis of the simulated landscape appears at the top. Due to the difference in velocity between the scenarios, it was impossible to calculate the mean absolute error and the mean square error. Furthermore, the calculation of variance was not necessary, since the methodology has already been validated in the paper[33]. Therefore, the absolute error was calculated at specific points along the trajectory that are highlighted in yellow in figure 4.2. The error values are shown in the table 4.1.

Table 4.1: Absolute pose error between both trajectories in specific points[33].

Points	x [mm]	y [mm]	θ [rad]
First	23.45	4.16	0.03
Second	20.25	8.17	0.04
Third	0.84	8.64	0.06
Fourth	26.85	13.52	0.02
Fifth	10.53	13.26	0.00

4.3 Low level control

The robot is equipped with two control units, each one has its own role. The Arduino Mega microcontroller, controls the motors and manages the input and output devices, while the Raspberry Pi 4 B microprocessor, processes all the data captured by the camera, the YDLIDAR X4 and the information received from the microcontroller. In this section, we focus on microcontroller tasks and the programming cycle required, as well as on how informations are communicated to the microprocessor.

4.3.1 I/O Declaration and wiring

Before we start discussing the control program, it's essential to configure the microcontroller's inputs and outputs according to the robot's peripherals. In the following, we will describe and discuss the configuration of each robot peripheral.

Motors with encoders :

Front Left motor (F_L_Motor)

Wire color	Name	Connection
Red	-	M+
Black	-	M-
Green	-	GND
Blue	-	5V
Yellow	F_L_ENC_A	Arduino (18)
White	F_L_ENC_B	Arduino (17)

Front Right motor (F_R_Motor)

Wire color	Name	Connection
Red	-	M+
Black	-	M-
Green	-	GND
Blue	-	5V
Yellow	F_R_ENC_A	Arduino (19)
White	F_R_ENC_B	Arduino (16)

Back Left motor (B_L_Motor)

Wire color	Name	Connection
Red	-	M+
Black	-	M-
Green	-	GND
Blue	-	5V
Yellow	B_L_ENC_A	Arduino (20)
White	B_L_ENC_B	Arduino (15)

Back Right motor (B_R_Motor)

Wire color	Name	Connection
Red	-	M+
Black	-	M-
Green	-	GND
Blue	-	5V
Yellow	B_R_ENC_A	Arduino (21)
White	B_R_ENC_B	Arduino (14)

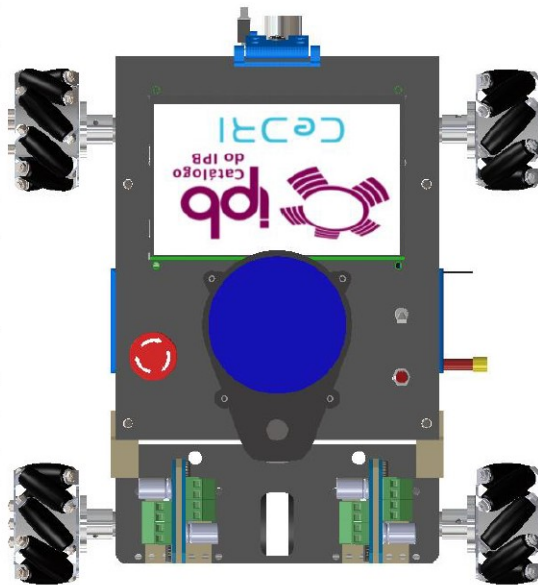


Figure 4.3: I/O declaration and wiring of the 4 encoder motors.

The motors used are DC type, which means they require two terminals to control the speed and the direction of rotation. In addition, each motor is equipped with an encoder with two channels, A and B.

Encoders generate high-frequency signals that need to be processed quickly. To enable the microcontroller to receive immediate notification when an interrupt signal is triggered by the encoder, we must use interrupts. This guarantees real-time responsiveness and allows us to determine the current position of the robot. The following figure shows the pin declarations for the 4 motors:

IBT2 modules :

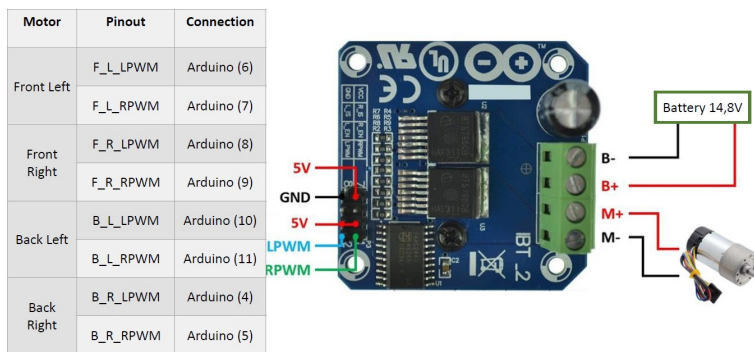


Figure 4.4: I/O declaration and wiring of the 4 IBT2 modules[28].

These modules are connected to the microcontroller through I/O's, figure 4.4. This configuration will allow the microcontroller to exchange information with each IBT2 module independently using I/O.

Table 4.2: IBT2 module pinout definition

Pinout	Function
RPWM	Forward level or PWM signal input, active HIGH.
LPWM	Inversion level or PWM signal input, active HIGH.
R-EN	Forward drive enable input, HIGH enable , LOW close.
L-EN	Reverse drive enable input, HIGH enable , LOW close.
R-IS	Forward drive—side current alarm output.
L-IS	Reverse drive—side current alarm output.
VCC	+5 V power input, connected to the 5V regulator power supply.
GND	Signal common ground terminal.

Box handling system :

This system consists of two elements: a limit switch and an electromagnet. A digital input will be connected to pin number 13, detecting the presence of the box via the limit sensor, and an electromagnet will attach or release the box depending on the state of the Arduino's digital output on pin number 12. The connection diagram is shown in the following figure.

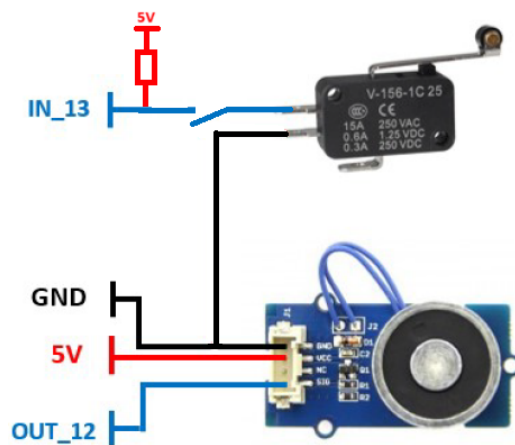


Figure 4.5: I/O declaration and wiring of the limit switches and electromagnet devices.

4.3.2 PID controller

PID controllers can be found in a wide range of applications, such as controlling the position and speed of a robotic structure, controlling and regulating temperature, pressure, flow rate of a fluid in a closed circuit, etc. The PID controller combines three main elements to adjust the control system, Proportional, Integral and Derivative, figure 4.6.

- The proportional term (P) is responsible for the instantaneous action of the controller as a function of the current error, that is, the difference between the setpoint and the measured value of the system. The output of the proportional controller is proportional to this error. A higher value of P will result in faster correction, but may also lead to oscillation or instability.

- The integral term (I) reacts to the accumulation of past errors over a period of time. It adjusts the controller output according to the integral of the error, thus reducing the constant error. It is useful for eliminating long-term error, but too high a value of It can lead to slow response and oscillation.
- The derivative term (D) takes into consideration the variation of the error over time. It reacts to the error slope, enabling the system trend to be predicted. The derivative term is useful for helping to improve transient response and reduce overshoot, but an excessive value of D can amplify noise or make the system unstable.

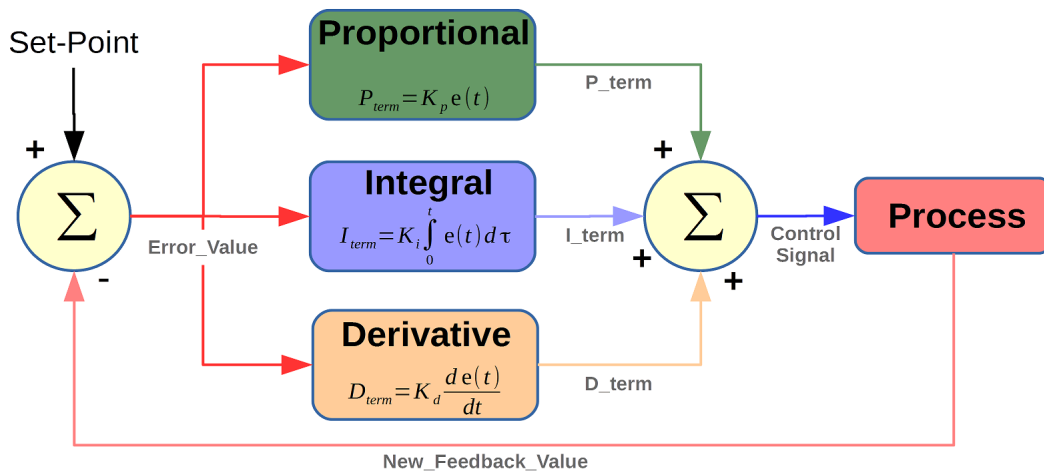


Figure 4.6: PID controller diagram block[44].

To be able to implement a PID controller in our robot in order to control its position and speed, we need to perform the following steps:

1. Measurement system: We need suitable sensors to measure the robot's position and speed. In our case, we will use the information provided by the 4 encoders integrated into the motors.
2. Set-point : We need to specify the position and speed we want the robot to reach at each microcontroller cycle.

3. Calculating the error: This step consists of comparing the measured values with the desired values in real time to determine the position and speed error. The error is the difference between the setpoint and the measured value.
4. PID term calculation: We apply the PID controller formulas to calculate the proportional, integral and derivative terms according to the error value.

In our case, we have chosen to use two P-type controllers with acceleration limitation, one for robot position and the other for its orientation. The advantage of this type of controller is that it's much simpler to implement, it responds quickly to errors and with the limited acceleration we will have less risk of instability.

5. Motor control: The final step is to use the output of the controller to adjust the speeds of the robot's motors. We used the kinematic model detailed in the previous section to transform the controller output into control signals for each motor. To do this, we implemented 4 PI-type controllers to control the speed of each motor independently of the others. This makes our controller less sensitive to variations, so we can achieve a smoother response.

These steps are integrated into a closed loop in the microcontroller, which updates and adjusts the controller output at each cycle according to the errors captured by the encoders. The controllers are implemented by my supervisor Prof. Braun.

Even with this type of control, errors still persist in the robot's position, and it was precisely the purpose of using YDLIDAR-X4, is to reduce position and orientation errors as much as possible.

4.3.3 Operating cycle

As explained in the previous sections, there are two different types of controller boards used to operate the robot. The first is responsible for managing the I/O and controlling the robot's movements, while the second is responsible for complex calculations such as

image processing, planning and generating the trajectory to be travelled by the robot, etc.

The two boards communicate via the UART protocol, this protocol is used to transfer data between electronic devices. It is based on asynchronous data transmission, with emitter and receiver both synchronized at the same baud rate.

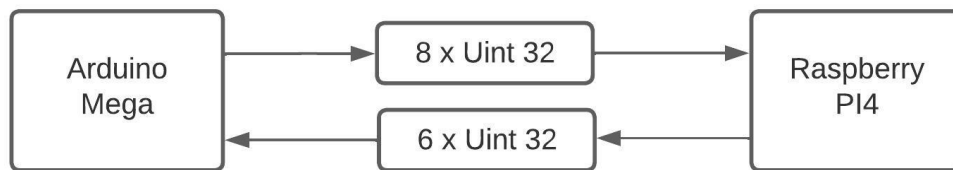


Figure 4.7: Diagram illustrating the data exchange between the Raspberry Pi4 and the Arduino Mega via UART.

During each cycle, the Arduino Mega sends four unsigned integer (Uint32) representing the speeds of the four wheels, one unsigned integer indicating the state of the limit switch, one unsigned integer that represent the current period and two unsigned integers, one indicating the timeout control (used for debugging purposes) and the other for acknowledgement. In addition, it receives (6 x Uint32) in total from the Raspberry Pi4 board. Four unsigned integer representing the speed setpoints for the motors, one unsigned integer indicate the state of the electromagnet (ON/OFF) and the last unsigned integer for acknowledgement, figure 4.7.

Diagram 4.8 present the tasks performed by the Arduino Mega microcontroller. The first step is to configure the I/Os and the UART communication interface also to initialize the variables. These operations are performed only once each time the microcontroller is restarted.

In the main loop, the Arduino Mega starts by checking the communication with the Raspberry Pi4. Once established, it reads the status of the inputs and the data transmitted via the UART. Next, it controls the speed of the four wheels based on the received

setpoints and the encoders responses (connected to the Arduino Mega via the input interrupt pins).

Depending on the commands received from the Raspberry Pi, it activates or deactivates the electromagnet. Finally, it updates the variables and sends them to the Raspberry Pi 4. This loop cycle runs at a constant frequency of 40 Hz.

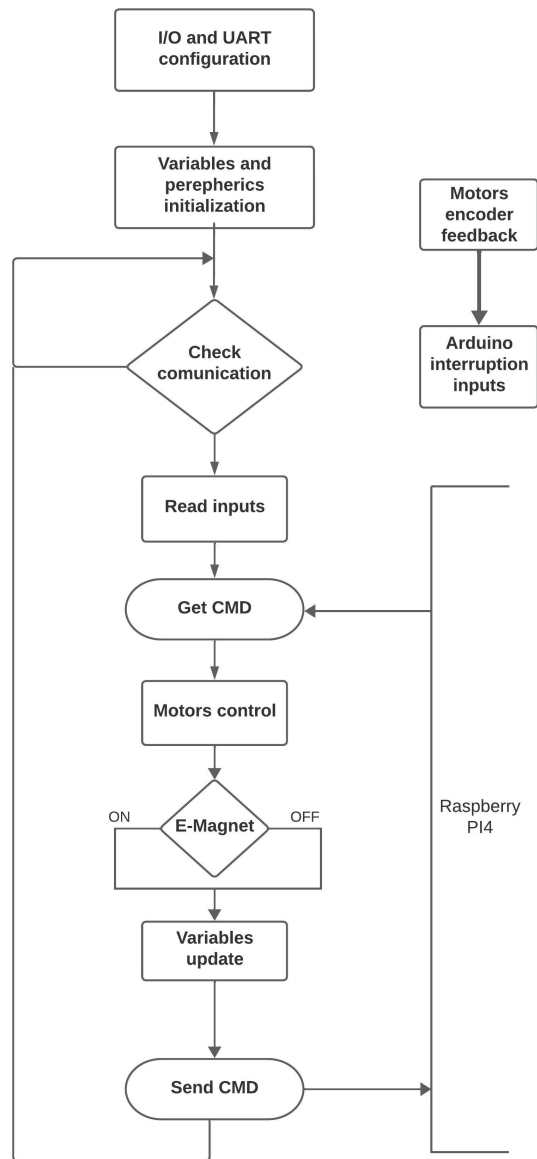


Figure 4.8: Diagram illustrating the program cycle on the Arduino Mega board.

4.4 Assembly and result

Robot assembly

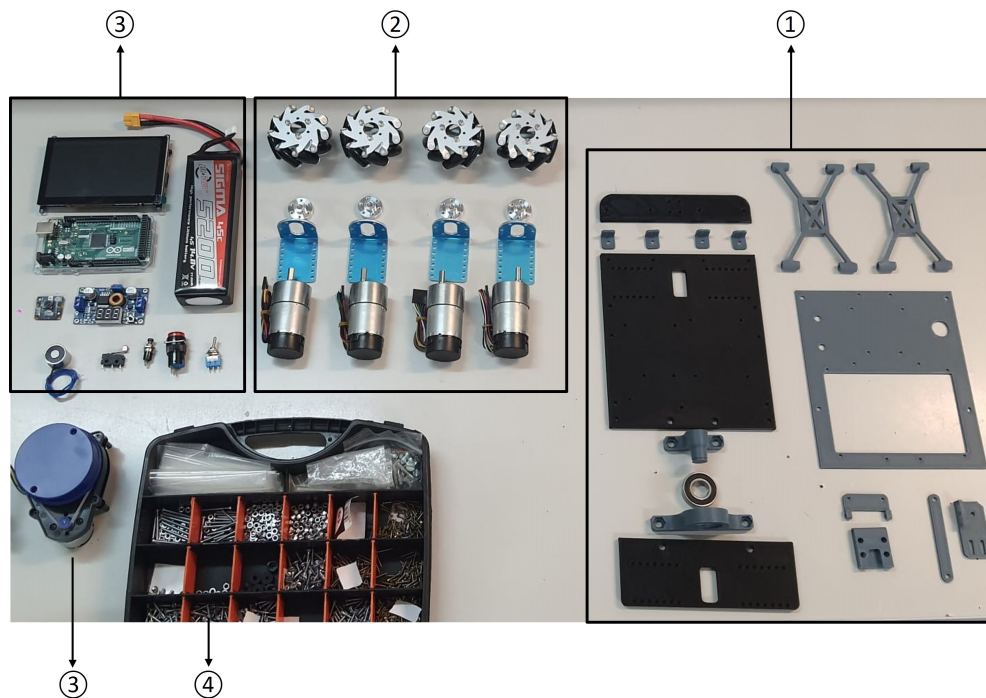


Figure 4.9: Picture of the robot components before assembly.

Table 4.3: Description of the robot component groups.

Group	Description
1	3D printed parts
2	3D Motors and wheels with mounting brackets
3	Electronic parts
4	Assembly items

All the brackets were manufactured using a 3D printer, which is a fast and efficient prototyping method that gave us great flexibility in the design of the parts. The thickness of each part was dimensioned according to the part's role in the robot, and reinforcement shapes were integrated into the 3D model to ensure a solid, robust structure. Bolts with diameters of 2, 3 and 4 mm were used to ensure a solid connection between the various parts.

The robot consists mainly of three sub-assemblies: the front structure, the rear structure and the upper structure. The connection between the front and rear structures was made using a mechanism containing a bearing. This configuration ensures that all wheels remain in contact with the ground (as explained in the third chapter). The connection between the upper part and the front part was made using 4mm-diameter screws and 3D-printed X-shaped brackets. These brackets are used to obtain the exact height required for the upper section.

To prevent the risk of short-circuiting or overheating of the electronic boards, plastic spacers were used when assembling the electrical components. These small parts play a crucial role in maintaining enough distance between the electronic boards and their supports, thus ensuring adequate ventilation.

For electrical wiring, industrial connection terminals were used. This components ensured that wiring was tidy and organized, while respecting the color-coding of wires for power, inputs and outputs. This makes any further interventions much easier.

The complete assembly of the robot was a delicate stage, as it concluded all the theoretical work already established. The 3D model developed on SolidWorks was a great help in ensuring the robot's successful assembly.

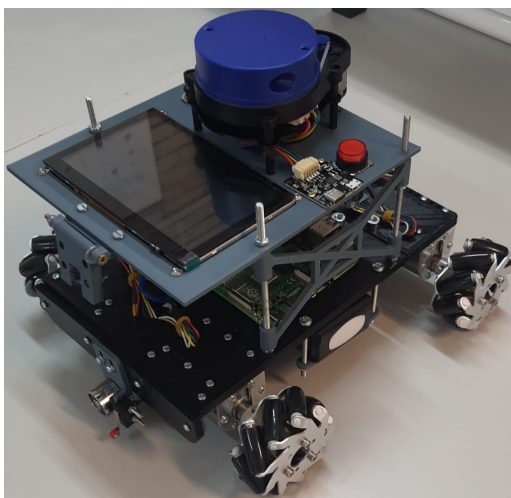


Figure 4.10: Picture of the robot assembled.

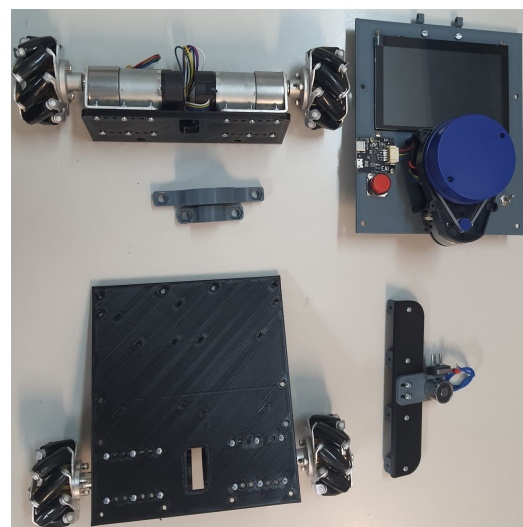


Figure 4.11: Picture of the three main sub-assemblies of the robot.

Result and upgrades

Last year, the IPB team took part in this competition by deploying a robot with a unicycle structure. This year, however, our participation at the RAF was distinguished by the use of a robotic structure equipped with mecanum wheels. This transition proved particularly beneficial, considering the variety of possible movements for the robot as well as its size, which significantly improved the fluidity of its movements in the field.

To improve the precision of the robot's movements, we considered incorporating two Aruco tags on the top of the robot, figure 4.12. This modification could be a significant step forward, as it would enable the robot's position to be accurately identified using a fixed camera installed at the competition site.

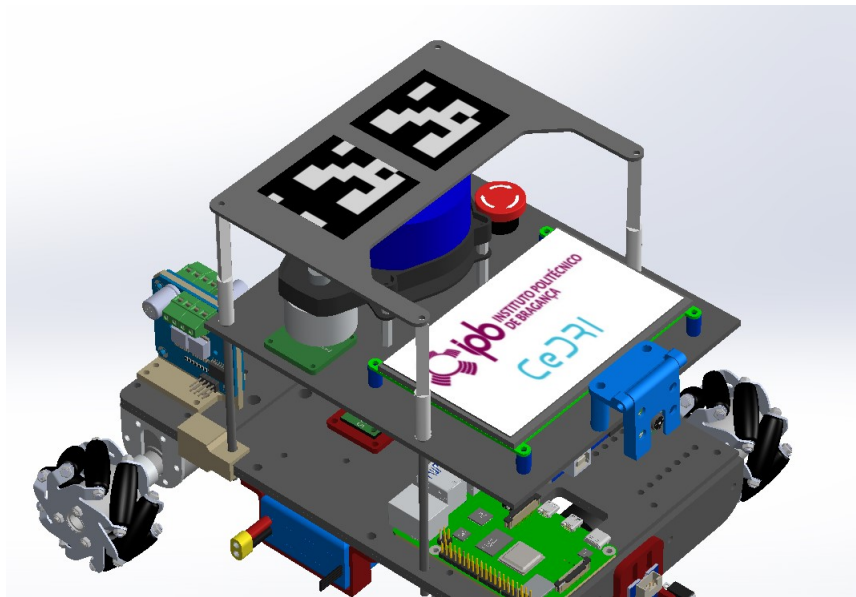


Figure 4.12: Virtual 3D model of the improvements to be made on the next version of the robot.

4.5 Conclusion

In conclusion, this chapter reflects a crucial stage in the development of our robot, integrating the elements and concepts discussed in the previous chapters.

We have highlighted the importance of software tools such as SolidWorks and Simtwo, which played a decisive role in the design phase. They enabled us to anticipate and predict the results we observed in the real robot, underlining the effectiveness of our approach.

Our exploration then turned to the low-level control systems, highlighting the real-time management of motor speed and the control techniques implemented, notably PID. This analysis laid the foundations for the precise, responsive operation of our robot.

Finally, we looked at the manufacturing and assembly stages, identifying the challenges we faced throughout this process and we concluded our discussion with potential improvements to optimize the robot's performance.

Chapter 5

Conclusion and future works

To conclude this comprehensive report, we have synthesized the ideas and achievements of each chapter to provide a coherent overview of our robotics journey and our preparations for the RAF competition.

The first chapter served as a general introduction to clarify the entire report. The second chapter played a crucial role in providing an overview of the evolution of the field of robotics, exploring fundamental concepts, categorizations and the profound impact of robotics in education and research. This exploration provided a solid foundation for the importance of the RAF competition. In addition, we presented the IPB team that will participate in the competition.

The third chapter was dedicated to the process of selecting and configuring the robot's components. We navigated the complexities of selecting actuators, effectors, sensors, control units and power supply considerations. Our focus on 3D modeling and design ensured that our robot's structure met the competition specifications, setting the stage for further exploration of robot control.

The fourth chapter presented the essential elements of our robot development, translating theoretical concepts into practical implementation. Software tools such as SolidWorks and Simtwo proved essential for the design and simulation of our robot, enabling us to effectively anticipate real-world results. We delved deeper into low-level control systems,

focusing on real-time motor speed management and control techniques such as PID. In addition, we reviewed the manufacturing and assembly challenges we faced, while discussing potential performance optimizations for future competitions.

As for my academic contributions, they encompass publications in indexed international conferences, covering topics in the field of robotics, as detailed in the annex.

To summarize, this comprehensive report highlights the depth of our robotics journey, from its foundations to the concrete challenges of competition. Our team is ready to demonstrate the fruits of our efforts, testifying not only to our commitment to the advancement of robotics, but also to our ongoing dedication to innovation, education and excellence. As the next competitions approach, our experiences and results are ready to contribute to the ongoing evolution of robotics, pushing the boundaries of what's possible in this dynamic field.

Annex: List of Publications

Published

E. Luiz, L., Pilarski, L., Baidi, K., Braun, J., Oliveira, A., Lima, J., & Costa, P. (2022, November). Robot at factory lite-a step-by-step educational approach to the robot assembly. In Iberian Robotics Conference (pp. 550-561). Cham: Springer International Publishing.

Accepted

João Braun, Kais Beide, Luciano Bonzatto, Guido Berger, Milena Pinto, Rebeca Kalbermatter, Luan Klein, Ana Pereira, Paulo Costa and José Lima. (April,2023). Design and Development of an Omnidirectional Mecanum Platform for the RobotAtFactory 4.0 Competition. In CALWAR 2023 Conference.

Bibliography

- [1] D. Leite, M. Vellasco, and K. Figueiredo, “Robotic device for mobility assistance to elderly people in urban environments,” in *2016 IEEE Latin American Conference on Computational Intelligence (LA-CCI)*, IEEE, 2016, pp. 1–6.
- [2] A. Garcia-Cerezo, A. Mandow, J. Martinez, *et al.*, “Development of alacrane: A mobile robotic assistance for exploration and rescue missions,” in *2007 IEEE International Workshop on Safety, Security and Rescue Robotics*, IEEE, 2007, pp. 1–6.
- [3] E. Garcia, M. A. Jimenez, P. G. De Santos, and M. Armada, “The evolution of robotics research,” *IEEE Robotics & Automation Magazine*, vol. 14, no. 1, pp. 90–103, 2007.
- [4] C. Martinez, “Industrie 4.0, l’homme et le robot,” 2018.
- [5] J. Braun, A. O. Júnior, G. S. Berger, J. Lima, A. I. Pereira, and P. Costa, “Robotat-factory 4.0: A ros framework for the simtwo simulator,” in *2022 IEEE International Conference on Autonomous Robot Systems and Competitions (ICARSC)*, IEEE, 2022, pp. 205–210.
- [6] J. Braun, L. A. Fernandes, T. Moya, *et al.*, “Robot@ factory lite: An educational approach for the competition with simulated and real environment,” in *Robot 2019: Fourth Iberian Robotics Conference: Advances in Robotics, Volume 1*, Springer, 2020, pp. 478–489.

- [7] A. Jurkat, R. Klump, and F. Schneider, "Tracking the rise of robots: The ifr database," *Jahrbücher für Nationalökonomie und Statistik*, vol. 242, no. 5-6, pp. 669–689, 2022.
- [8] Makeblock. "Makeblock official web site." Consulté 05/2023. (2023), [Online]. Available: <https://www.makeblock.com/>.
- [9] A. Navarro, C. Van Sice, C. Montgomery, K. La Joie, and M. Pryor, "Autonomous radiation survey with augmented reality for hazardous environments,"
- [10] F. Zhuang, C. Zupan, Z. Chao, and Z. Yanzheng, "A cable-tunnel inspecting robot for dangerous environment," *International Journal of Advanced Robotic Systems*, vol. 5, no. 3, p. 32, 2008.
- [11] M. Hirose and K. Ogawa, "Honda humanoid robots development," *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, vol. 365, no. 1850, pp. 11–19, 2007.
- [12] D. Darmawansah, G.-J. Hwang, M.-R. A. Chen, and J.-C. Liang, "Trends and research foci of robotics-based stem education: A systematic review from diverse angles based on the technology-based learning model," *International Journal of STEM Education*, vol. 10, no. 1, pp. 1–24, 2023.
- [13] E. B. Witherspoon, C. D. Schunn, R. M. Higashi, and E. C. Baehr, "Gender, interest, and prior experience shape opportunities to learn programming in robotics competitions," *International Journal of STEM Education*, vol. 3, pp. 1–12, 2016.
- [14] S. Jones and M. Brown, "Robotics and automation for enhanced efficiency in manufacturing," *Journal of STEM Engineering*, vol. 6, no. 4, pp. 87–102, 2019.
- [15] A. Gupta and R. Johnson, "Robotics in hazardous environments: Ensuring safety in stem industries," *Industrial Safety Review*, 2018.
- [16] X. Chen and Y. Wang, "Robotic inspection systems for quality control in stem industries," 2021.

- [17] R. Welch, D. Limonadi, and R. Manning, “Systems engineering the curiosity rover: A retrospective,” in *2013 8th international conference on system of systems engineering*, IEEE, 2013, pp. 70–75.
- [18] F. Fahimi, *Autonomous robots*. Springer, 2009.
- [19] A. Name, “How artificial intelligence can enhance the citrus industry,” *Citrus Industry*, May 2021. [Online]. Available: <https://citrusindustry.net/2021/05/10/how-artificial-intelligence-can-enhance-the-citrus-industry/>.
- [20] E. Mavridou, E. Vrochidou, G. A. Papakostas, T. Pachidis, and V. G. Kaburlasos, “Machine vision systems in precision agriculture for crop farming,” 2019.
- [21] H.-M. Huang, K. Pavsek, B. Novak, J. Albus, and E. Messin, “A framework for autonomy levels for unmanned systems (alfus),” *Proceedings of the AUVSI’s unmanned systems North America*, pp. 849–863, 2005.
- [22] D. Parekh, N. Poddar, A. Rajpurkar, *et al.*, “A review on autonomous vehicles: Progress, methods and challenges,” *Electronics*, vol. 11, no. 14, p. 2162, 2022.
- [23] P. Costa, J. Lima, and V. Pinto, *RobotAtFactory 4.0*, <https://github.com/P33a/RobotAtFactory>, 2023.
- [24] P. Costa and J. Lima, *RobotAtFactory Lite*, <https://github.com/P33a/RobotAtFactoryLite/>, 2022.
- [25] *Mecanum wheels 60mm*. [Online]. Available: <https://www.botnroll.com/pt/rodas/4335-roda-mecanum-60mm-esquerda-com-hub.html>.
- [26] *Motor pololu d37*. [Online]. Available: <https://www.pololu.com/category/51/pololu-metal-gearmotors>.
- [27] *H-bridge operating diagram*. [Online]. Available: <https://www.modularcircuits.com/blog/articles/h-bridge-secrets/h-bridges-the-basics/>.
- [28] *Ibt-2 driver motor*. [Online]. Available: <https://www.mpja.com/High-Current-H-Bridge-Motor-Driver-43A.html>.

- [29] *Grove electro-magnet*. [Online]. Available: <https://www.botnroll.com/pt/solenoides/976-grove-electromagnet.html>.
- [30] *Industrial limit switch with roller lever*. [Online]. Available: <https://diyables.io/products/limit-switch>.
- [31] J. Seybold, A. Bülau, K.-P. Fritz, *et al.*, “Miniaturized optical encoder with micro structured encoder disc,” *Applied Sciences*, vol. 9, no. 3, p. 452, 2019.
- [32] *Radar ydlidar x4*. [Online]. Available: <https://www.ydlidar.com/lidars.html>.
- [33] J. Braun, A. O. Júnior, G. Berger, *et al.*, “A robot localization proposal for the robotatfactory 4.0: A novel robotics competition within the industry 4.0 concept,” *Frontiers in Robotics and AI*, vol. 9, 2022, ISSN: 2296-9144. DOI: 10.3389/frobt.2022.1023590. [Online]. Available: <https://www.frontiersin.org/articles/10.3389/frobt.2022.1023590>.
- [34] *Camera raspberry v2*. [Online]. Available: <https://www.raspberrypi.com/products/camera-module-v2/>.
- [35] *Waveshare 5 inches lcd touch screen*. [Online]. Available: <https://www.waveshare.com/5inch-hdmi-lcd-h.htm>.
- [36] Atmel, “Atmel atmega640/v-1280/v-1281/v-2560/v-2561/v,” Atmel, Tech. Rep., 2014. [Online]. Available: https://ww1.microchip.com/downloads/en/devicedoc/atmel-2549-8-bit-avr-microcontroller-atmega640-1280-1281-2560-2561_datasheet.pdf.
- [37] Arduino, “Arduino® mega 2560 rev3 product reference manual,” Arduino, Tech. Rep., 2023. [Online]. Available: <https://docs.arduino.cc/resources/datasheets/A000067-datasheet.pdf>.
- [38] R. Pi, “Raspberry pi 4 model b datasheet,” Raspberry Pi (Trading) Ltd, Tech. Rep., 2019. [Online]. Available: <https://datasheets.raspberrypi.com/rpi4/raspberry-pi-4-datasheet.pdf>.

- [39] *Battery li-po sigma 45c 5200 mah 4s*. [Online]. Available: <https://rc4all.pt/produto/sigma-bateria-li-po-45c-5200-mah-4s1p-14-8v-xt-60/>.
- [40] *Lm2596 adjustable dc-dc voltage regulator with display*. [Online]. Available: <https://www.botnroll.com/en/step-down/3398-lm2596-step-down-adjustable-4-40vdc-to-1-3-37vdc-2a-10w-with-display.html>.
- [41] T. instruments, “Lm2596 adjustable dc-dc voltage regulator with display,” Texas instruments, Tech. Rep., 2023. [Online]. Available: https://www.ti.com/lit/ds/symlink/lm2596.pdf?ts=1696526024704&ref_url=https%253A%252F%252Fwww.google.com%252F.
- [42] E. Maulana, M. A. Muslim, and V. Hendrayawan, “Inverse kinematic implementation of four-wheels mecanum drive mobile robot using stepper motors,” in *2015 international seminar on intelligent technology and its applications (ISITIA)*, IEEE, 2015, pp. 51–56.
- [43] H. Taheri, B. Qiao, and N. Ghaeminezhad, “Kinematic model of a four mecanum wheeled mobile robot,” *International journal of computer applications*, vol. 113, no. 3, pp. 6–9, 2015.
- [44] J. E. Ruiz Sarrío, K. V. Mani, B. Morris, and F. Topputo, “Flexible electrical power system for interplanetary and lunar cubesats,” Ph.D. dissertation, Jul. 2018.