INTERNATIONAL HELLENIC UNIVERSITY

Design of a modular robotic system

Dimitrios Moudiotis

UNIVERSITY CENTER OF INTERNATIONAL PROGRAMMES OF STUDIES
SCHOOL OF SCIENCE AND TECHNOLOGY

A thesis submitted for the degree of
Master of Science (MSc) in Strategic Product Design

Student Name: Dimitrios Moudiotis

SID: 1106200009
Supervisor: Prof. Dimitrios Tzetzis

I hereby declare that the work submitted is mine and that where I have made use of another's work, I have attributed the source(s) according to the Regulations set in the Student's Handbook.

November 2022
Thessaloniki - Greece

1. Abstract

This dissertation was written as part of my MSc in Strategic Product Design at the International Hellenic University. The purpose of this thesis is to design a modular robotic system, which can be used in different use contexts and applications. The robot is designed with a modular structure and parts, so that it can handle different tasks in various environments provided the right equipment. The designed robot could potentially be used in areas such as health care, tourism, security, and public spaces surveillance. The result work is a deliverable containing the conceptual modular design and a set of one potential /alternative blueprints that correspond to a different use context.

The thesis focuses on the design principles for the mechanical and electrical components of each module by using an iterative design process, in order to achieve the final design that corresponds to the initial specifications. To achieve this goal, an investigation of the existing products and concepts, and also research on how existing concepts from other disciplines can be applied to robotics systems design, and analysis of the electronics (sensors, motors, batteries) and other parts of low-cost robotic system is made. The final concept is a low cost, easy and to manufacture and maintain, adaptive modular robot using as much eco-friendly material as possible.

Keywords: robot, modular, robotic, system, 3D print

Dimitrios Moudiotis
7/11/2022

2. Contents

3. Table of Figures

4. Preface

Let us firstly start, by defining the term “robot”. According to Wikipedia (wikipedia, September 2022)., *the term comes from a Slavic root, robot, with meanings associated with labor. A robot is a machine, especially one programmable by a computer, capable of carrying out a complex series of actions automatically*. The guidance of a robot could be internal or external, depending on its type. Robots maybe designed to have human form, but most robots are specific task machines, designed with emphasis on functionality and not on their aesthetics.

Britannica encyclopedia (Britannica, 2019), would give the definition of a robot as *any automatically operated machine that replaces human effort, though it may not resemble human beings in appearance or perform functions in a humanlike manner*. Therefore, the engineering discipline dealing with the design, construction, and operation of robots is called robotics engineering (SHARON, 2013).

Figure 1: One of first image in google search for the word “robot” (SHARON, 2013)

The word “robot” was first used in Greek mythology, referring to a giant machine guarding the island of Crete. As technology progressed, more practical applications appeared, such as automated machines and remote-control mechanisms. (Mayor, 2022).

Figure 2: Talos, the killer robot from ancient Greek Mythology (Mayor, 2022)

Industrial robots, medical operating robots and other forms of autonomous machines have been developed. The first stationary industrial robot was the programmable Unimate, an electronically controlled hydraulic heavy-lifting arm that could repeat arbitrary sequences of motions. It was invented in 1954 by the American engineer George Devol and was developed by Unimation Inc., a company founded in 1956 by American engineer Joseph Engelberger. In the 1960s and 1970s, researchers at the Massachusetts Institute of Technology (MIT) and Stanford University developed advanced computer-controlled electric arms guided by sensors.

5. Types of robots

As stated above, the term robot could be kind of general. And this is particularly true, given the wide variety of robot types that exist in the present. Robotpark (RobotPark Academy, 2022) website has done a marvelous job to try to mention the basic types of robots. To begin with, the classic type of robots is what is called a Stationary robot.

Stationary Robots: Stationary robots are those that don't move. They're not actually stationary. It's just the base of the robot that doesn't move. Stationary robots are not limited by weight or power. A possibility to modify the modular robot to stationary will be considered.

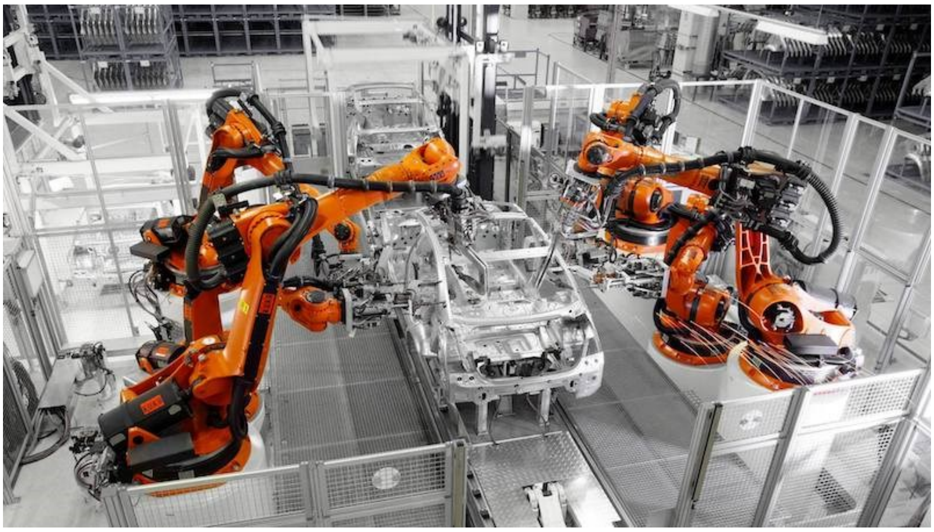


Figure 3: Stationary robot in automotive factory (control.com 2022.)

Wheeled Robots**:** Robots that roll are robots that move by pushing along with their wheels. Their movement is generally easier to control, and their costs are low. They are one of the most commonly seen robots because they can easily be constructed from cheap materials like metal and plastic. The types of wheels will be further discussed in the next chapters.

Figure 4: Wheeled robot (SOFFAR, Wheeled robots types, uses, advantages and disadvantages, 2019)

Legged Robots**:** Legged robots are mobile robots, similar to wheeled robots, but their locomotion methods are more sophisticated and complicated than their wheeled counterparts. As their name suggests, these robots use their legs as the primary method of locomotion. They can perform much better on uneven terrain than wheeled robots because of this advantage. Furthermore, legged robots need a high level of complexity in terms of production cost and complexity due to their larger size and weight compared to wheeled robots, thus legged robots will not be considered for this application.

Figure 5: Four legged robot (CLEAR-Lab , 2019)

Swimming Robots – Robot Fish: Swimming robots are robots which move underwater. This could be fish-like robot or submarine type, depending on the application and their purpose, they differ in size and cost. While interesting to have a version of a modular robot that could operate on land and underwater, this could risk being very complex for our current application, and it will not be considered.

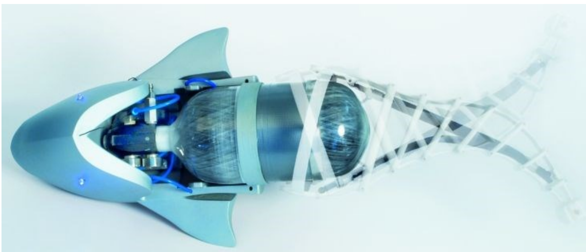


Figure 6: Swimming robot (robot.cfp.co, 2022)

***Flying Robots*: **Flying robots are robots that use wings, propellers, or balloons to fly through the air. They can be either plane-like or bird/insect-inspired. Examples include airplane robots, bird/insect inspired wing flapping robots, propeller based multicopper and balloon robots and of course drones. While a late tendency, we will not consider a drone for our current application. On the other hand, a good idea would be to enable cooperation of the designed modular robots and third party drones.

Figure 7: DJI Mini 2 Drone

***Swarm Robots*: **Swarm robots are small, self-contained robotic systems that consist of multiple small robots. These robots do not create a single united robot but operate as their modules operate cooperatively. Although similar to modular robotic systems, elements of swarm robots have much less functionality and herd configurations do not create new robots. The modular robot will be designed in such a way that will enable the cooperation of more than one robot.

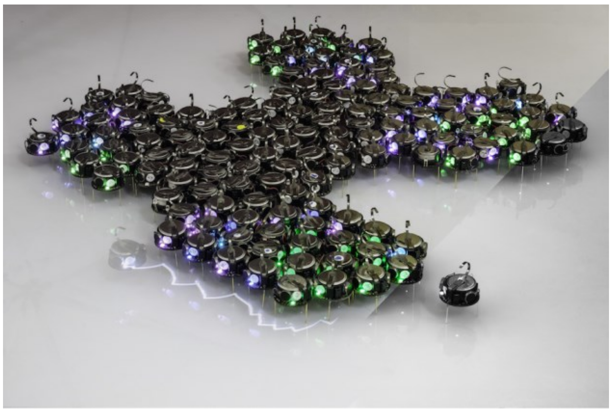


Figure 8: Swarm robot example (robohub.org 2018)

***Micro Robots*: **By definition, micro robots are robots that have dimensions on micrometer scale and can operate on micrometer resolution. Therefore, both very big stationary robots that manipulate their environment on a micrometer scale and small robots that are actually measured by micrometers can be called micro motors. A micro-robot is out of the scope of the current design.

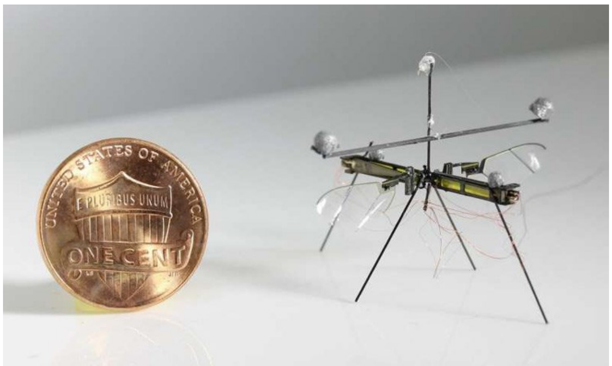


Figure 9: Micro robot example (circuitdigest.com 2021)

Soft Elastic Robots**:** We say that soft robots like the octobot are the latest in a long line of bio-inspired robots. Most of these robots borrow either their structural or functional qualities from squids or inchworms. The soft-bodied cephalopod inspired many roboticists to build squishy bots: octopus' arms, limbs with suckers, and inflatable pneumatic arms are just a few possibilities. While extremely efficient in some cases, the design and implementation of a soft elastic robot risks to be difficult and thus will not be considered for the current thesis.

Figure 10: Soft elastic robot (Jablonski, 2011)

Modular Robot: Last but not least, the modular robot. Now that we have defined the other types of a robot, let's try to define the term "modular robot". Basically, a modular robot could be a combination of all the above types. A modular robot could be defined as a robotic system with interchangeable parts that will create a multifunctional automatic machine or as we call it, a multifunctional robot.

Figure 11: Modular robot design example (Uraga, 2017)

Robotpark (RobotPark Academy, 2022) *website would argue that modular robots are usually composed of multiple building blocks of a relatively small repertoire, with uniform docking interfaces that allow transfer of mechanical forces and moments, electrical power, and communication throughout the robot*.

Modular robotic systems are made up of multiple robots that are smaller and more functional than robotic herds. A single module of a modular robotic system can have self-mobility, which means it can move around on its own. Modular robots offer many advantages over other types of robots. The central idea is that a core set of modules can be combined and recombined to form a customized robot, which enables greater flexibility in the workplace. Modular robots also allow for better serviceability of the robots because if one should fail, it simply needs to be replaced. Moreover, modularity sometimes helps the rapid design of near-final systems because this tight design loop between the designer and user generally creates a streamlined product.

Modular robots, which can be switched from one task to another without having to be entirely rebuilt, are being used more frequently in situations where weight is a major concern. One example of this is space exploration—where the weight of the robot must be kept to a minimum—and another example is disaster relief, where modular robots can be used to help clean up hazardous environments after earthquakes or other natural disasters.

6. Market Benchmarking

A good start for every new product development can always be to research what is already implemented and developed in a research or industrial scale. This does not have as purpose to copy or steal the brilliant ideas of other people, but to inspire us in order to adopt the good ideas and even develop new, more innovative, better solutions to these problems. Let us see bellow some designs, products, and open-source parts.

The Robotics Institute Carnegie Mellon University

The Biorobotics group has designed a modular robot. Modular robots allow for customization. They also are easier to service because if a part goes down, it can simply be replaced rather than repaired. (Choset, 2022).

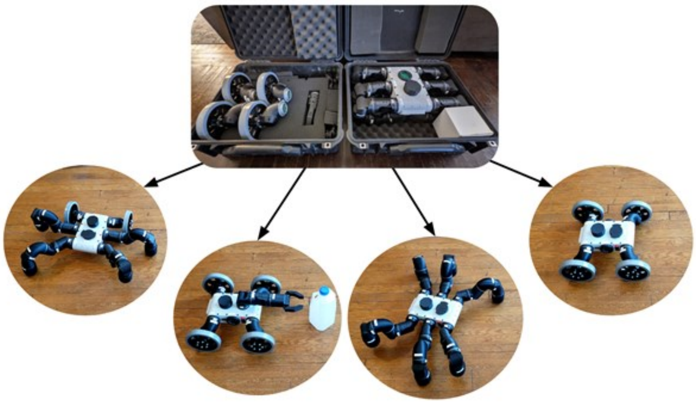


Figure 12: Modular robot design (Choset, 2022).

What we can see in the image above, is that a common platform can be connected to different types of moving mechanisms, such as “spider legs”, wheels or combination of both, and different parts can be mounted on it, such as a robotic clump.

ChainFORM

ChainFORM, is concept from the MIT Media Lab. Modules are servo motors surrounded with PCB for brain, sensing, and actuation. (Ken, 2016)

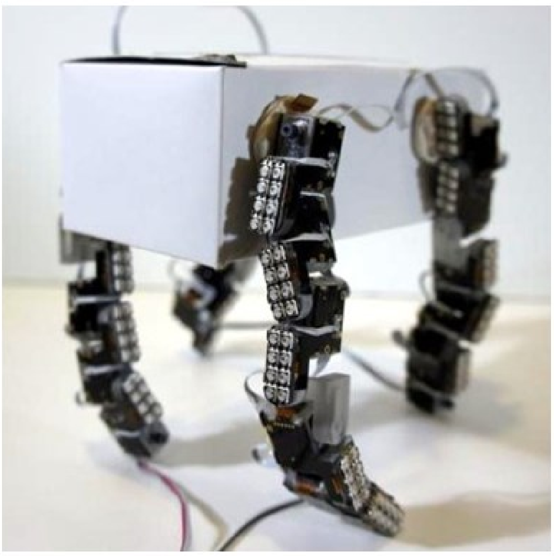


Figure 13: ChainFORM robot with parts tasked as legs (ACKERMAN, 2016)

ChainFORM is a linear, modular actuated hardware system that allows users to construct and customize a wide range of interactive applications. Each module includes a servo motor wrapped with flexible circuit board with an embedded microcontroller. (ACKERMAN, 2016).

Robot articulé TC200

The TC200 mobile base offers autonomous navigation features, electromagnetic brakes and encoders. Equipped with 4 individually motorized wheels and a 120 kg payload, it can carry numerous items of equipment to develop interaction and perform all kinds of missions in an industrial environment. It will make designing new robotics and industrial applications easier. This ROS mobile base is intended for teachers training the engineers of tomorrow and researchers and designers seeking industrial solutions (generationrobots, 2022).

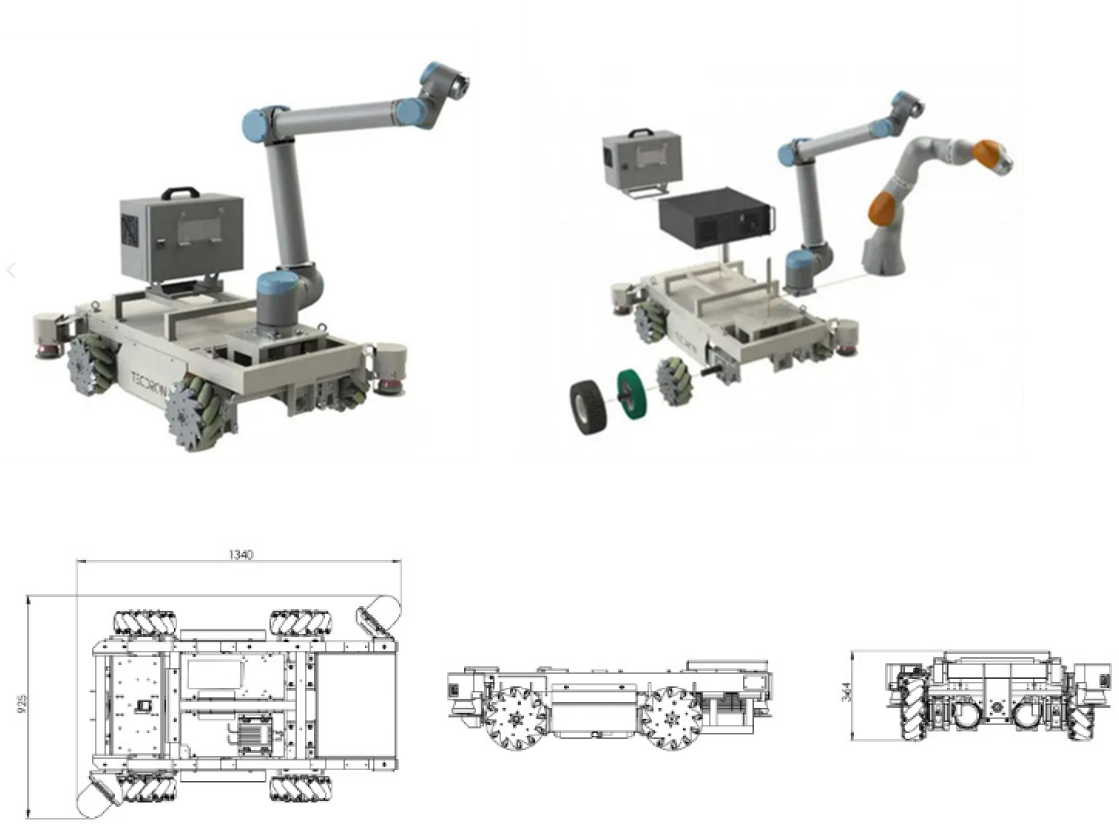


Figure 14: Modular robot TC200 (generationrobots, 2022)

Adeept RaspTank Pro Robot Car Kit

RaspTank Pro is a perfect STEAM toy and the coolest robotic kit for adults and seniors to learn in play. The toy can be used to build your own robot and explore endless learning activities, improving innovative minds, hands-on ability, scientific thinking, computational thinking, logical thinking, problem-solving ability, and other. (Adeept, 2022)

Figure 15: Adeept modular robot (Adeept, 2022)

HUENIT - AI camera and modular robot arm

HUENIT has AI vision, a 3D printer, and a laser engraver. It also has an AI camera module that can do face recognition and image classification as well as object detection. Its high power laser(2500mW) with automatic cooling system can cut and engrave various materials This robot arm rotates 180 degrees thanks to a built-in servo motor. HUENIT supports WiFi and Bluetooth, so you can easily connect it to your mobile devices. (Huenit, 2022).

Figure 16: HEUNIT modular robot (Huenit, 2022)

RoboMaster S1

The RoboMaster S1 is a game-changing educational robot built to unlock the potential in every learner. Inspiration for the S1 was drawn from DJI's annual RoboMaster robotics competition. By using a powerful CPU, the Intelligent Controller can support features like low-latency high-definition image transmission, AI computing, and programming development. It also coordinates transmission seamlessly to execute command signals. For added safety, the blaster uses non-toxic gel bead projectiles and also offers limitations on launching rate and angle. (dji, 2022)

Figure 17: RoboMaster S1 (dji, 2022)

The philosophy behind RoboMaster S1 is "learn by doing—discover and have fun." The S1 bridges the digital world and the real world together, which allows users to learn math, physics, and AI technology through practical operations. The S1 supports Scratch and Python programming languages, so you can take your coding abilities to the next level. Powerful programming blocks allow you to explore a series of new features with your robot. For example, new Scratch blocks for line following allow your robot to make turns at intersections or T-junctions on a road. . (dji, 2022)

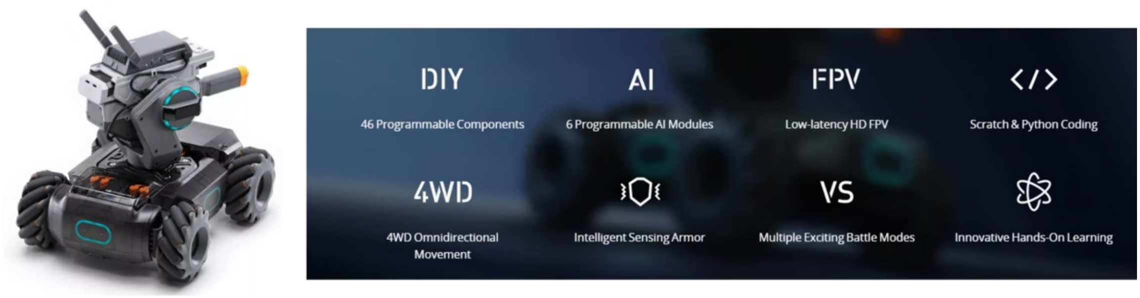


Figure 18: Robomaster S1 (dji, 2022)

7. Design Methodology

To begin with, in this chapter we shall see the design methodology that it will be followed for the design of the modular robot. As stated above, the robot will be designed with a modular structure and parts, so that it can handle different tasks in various environments, provided the right equipment. The designed robot could potentially be used in areas such as health care, tourism, security, and public spaces surveillance. The result work is a deliverable containing the conceptual modular design and a set of one potential /alternative blueprints that correspond to a different use context. The process that we will follow is to start with the outputs of the benchmarking of the existing products, followed by initial specifications of the design, and a benchmarking of electronics, parts, motors, batteries, grippers, robotic arms, and other parts used in robots. After that, we will proceed to screening these ideas and finding what we shall keep for our design.

Initial Specifications of the design

Few would argue that the most important part of designing a new product is the part that the initial specifications are set. The product design specification (PDS) is the essential definition of what the product is required to provide. Writing a strong PDS increases your chances of producing an effective product. (Geddes, 2022).

Product design specification is the document that gives clear information about the product. The document provides brief information on how the product will be designed, manufactured and delivered. It also contains information about the target market, budget and time frame.The document gives all details about the product like its performance, target audience and financial and time restrictions. The main purpose of this document is to ensure that there is a clear understanding of what needs to be done and how it should be done before designing a product. (Geddes, 2022).

In complex times, we can design virtually anything, but we cannot have a product that does everything. The initial specification will set the advantages and the disadvantages of what it is designed for, based on the purpose and the tasks that the modular robot will undertake.

We are designing a modular robotic system that can be used by multiple users, in different contexts and applications. The robot will be made of interchangeable parts so that it can be customized for each user's specific needs. It could potentially be used in areas such as health care, tourism, security, and public spaces surveillance.

The first essential thing we will try to do, is to set some initial specification for desired outcome and use these specifications as a guide for the future design. This is of paramount importance since it will help us narrow down the possible designs and ideas. The sooner these specifications are fixed, the better changes there are to arrive to a final design that corresponds to the initial goal. The basic specification, that the design should be modular, is already set.

Let’s proceed to discuss some more specifications, that could be useful for the scope of this thesis, since it could be extremely complex to try and tackle all the desired aspects of the design at once.

- ✓ Weight should be maximum 20kg, so the robot can be portable.
- ✓ Maximum external dimensions to be around 1000mm x 500mm x 500mm.
- ✓ The robot should be able to move autonomously but also get fixed to the ground.
- ✓ Should be dustproof and waterproof.
- ✓ Should have at least 2h of autonomy.
- ✓ Should be able to move in multiple terrains.
- ✓ Design should be minimal and versatile.
- ✓ Easy to maintain and repair.
- ✓ Longlisting and robust.
- ✓ Simple to manufacture.

- ✓ Use eco-friendly materials and manufacture processes.
- ✓ Ideally, be able to combine more than one modular unit to a single unit.
- ✓ Have at least 5 different modular functions.
- ✓ Unit should cost no more than 500€ to manufacture.
- ✓ The design should be user-friendly and understandable to the average user.
- ✓ Aesthetic design, without compromising functionality or cost.

The above specifications are set after the initial discussions with the respective professor that supervises this thesis, the external advisors of the thesis, but also are based on the authors personal interest on modular robot design. The above specifications are not tight rules to be followed, but rather guiding points, as we said previously, toward the final design. A good final design will incorporate these specifications and ideally will solve all of the user's specified problems.

Ideas Screening

Idea screening refers to the process of evaluating new-product ideas to spot good ones and eliminate poor ones as soon as possible. Product development costs increase greatly as the later stages are reached, so the company wants to go ahead only with those product ideas that will turn into profitable products.

There are a many reasons firms use idea screening in product development:

- Identify the most promising ideas: When you come up with product ideas, it's important to recognize which ones will be useful for customers, and which ones are best left on the drawing board.
- Focus efforts and investments: Rather than pursuing several directions at once, use idea screening to focus your efforts on the ideas with the greatest promise.
- Validate ideas with niche audiences: You can test your idea with a small group of people known to share a common interest or occupation. This will help you determine whether your target market finds your product useful and worthy of spending money on.

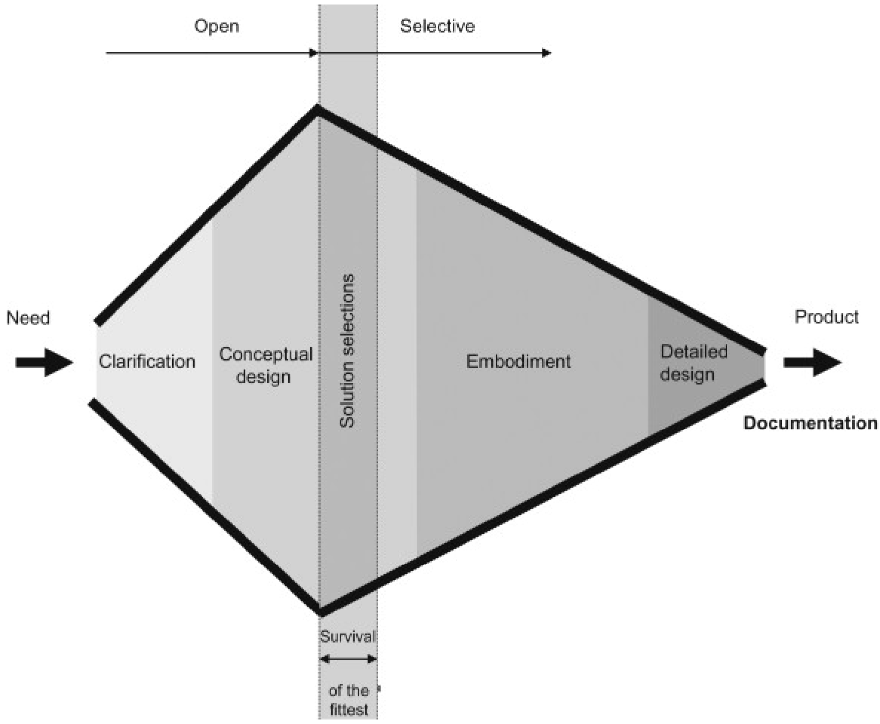


Figure 19: Ideas screening of products (Kent, 2016)

Let's list the different ideas we have seen in the benchmarking phase.

Movement parrts

- ***Spider legs***: Many designs are used in robotics because they have advantages over other types of designs. This also applies to the design of a robot's propulsion system. The shape of the wheel is modified for use in various fields, such as movement on various terrains. The movement system of the robot is adapted to that of a spider's legs. This idea was suggested because there are places where wheels cannot be used. Advantages of this drive system include (mechspdcm, 2021):

  - ✓ Can work with lower sound.
  - ✓ Stronger to work in bad terrain.
  - ✓ Can move more freely on irregular surfaces.
  - ✓ Not easy to mine because the distance from the body to the surface can be adjusted
  - ✓ More efficient movement mechanism.

Figure 20: Spider legs robot (mechspdcm, 2021)

Robots with eight legs are often slower than those with fewer appendages. This is because the number of legs affects the center of gravity. The development of robotic technology raises concerns about the number of legs on such robots. For example, there are robots with 4 to 8 feet. On the contrary, the spider legers require higher and more complex levels of controls, are less reliable and also, require more energy and moving parts, thus, spider legs will not be considered for this application.

- ***Wheels***: Wheeled robots are a type of mobile robot that moves on the ground by using its motorized wheels to propel itself, which is simpler than other types of legged designs. Design, production, and programming processes for moving on flat terrain are easier, which is why wheeled robots are most popular among the consumer market.

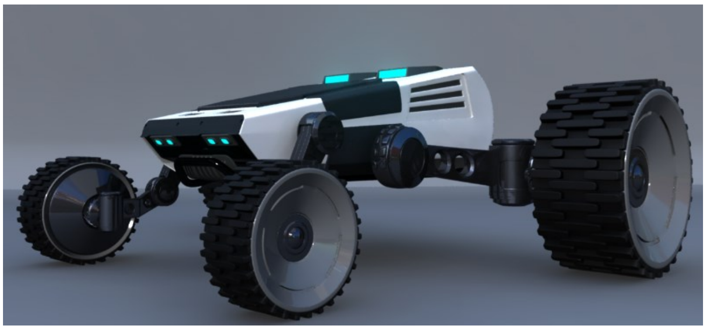


Figure 21: 4X4 Wheel Robot Drone Model

- **Omni Wheels robots:** Omni wheels are another option for wheeled robots, Omni-wheeled robots can move at any angle in any direction, without rotating first. Some Omni wheel robots use a triangular platform, with the three wheels spaced at 60-degree angles. The benefits of using 3 wheels and not 4 are that they are cheaper, 3 points can be used on the same plane, and only one wheel will be rotating in the direction of travel. The drawbacks of using Omni wheels are that they have poor efficiency due to not all the wheels rotating in the direction of movement , which also causes loss from friction , and they are more computationally complex because of the angle calculations for movement. Since omni wheels offer a wide range of advantages in the right environments, a solution with omniwheels will be considered for this application.

o

Figure 22: Omniwheels example (Wikipedia, 2022)

- o **4 wheel drive robots:** A 4-wheeled robot comes with two pairs of powered wheels. Each pair can turn in the same direction. If the pairs do not run at the same speed, the robot will slow and will not be able to drive straight. A good design incorporates some form of car-like steering. A solution will be considered for our desin, in order for the user to be able to apply two wheels drive and for wheels drive, depending on the application.

- o **Disadvantages of wheeled robots:** Wheeled robots may have difficulty navigating over obstacles, especially rocky terrain, sharp declines, or areas with low friction. Certainly, there are some situations where the wheels are not the best choice. The robot may need to pass small or large obstacles, or travel over terrain that is not flat and has a low friction coefficient. A rule of thumb to apply, is that for a wheel to get over a vertical obstacle, it has to be at least twice as tall as the vertical obstacle.

- ***<u>Tracked movement</u>*:**

Tracked vehicles are used when wheels won't work, such as on uneven terrain or when a high-traction system is needed. Tracked vehicles can move over slippery surfaces like snow or wet concrete. They have high performance and optimized traction systems, which lead to power efficiency. Robots that move on rubber tracks have a lower ground impact. This is one of the reasons that robots with rubber tracks can support a heavy load.

Disadvantages of track movement robots are that, they are less maneuverable than robots on wheels and require more power when turning (Wheels vs Continuous Tracks: Advantages and Disadvantages, 2013).

Figure 23: Tracked military robot (Talon Military Robot, 2020)

Since tracked robots can clearly over some advantages, a solution with tracked wheels will be considered.

Robotic arms:

There are several types of robotic arms. Let's try to have a better understanding of that. (BERNIER, 2022). Types of robotic arms include:

- Articulated arm
- Six-axis
- Collaborative robot
- SCARA
- Cartesian
- Cylindrical
- Spherical/Polar
- Parallel/Delta
- Anthropomorphic

Let's see some more details for each one in the following paragraphs and discuss their usage, advantages, and disadvantages.

Articulated arms are general-purpose robotic arms with 5 or more joints or degrees of freedom. An umbrella term for many other types of industrial robots, articulated arms include six-axis and collaborative robots. (BERNIER, Articulated Robots: A Guide to the Most Familiar Industrial Robot, 2021). Articulated robots could be used for:

- Material Handling: Articulated robots are great for material handling applications.
- Welding: Welding is one of the first applications for industrial robots
- Assembly: Articulated robots are ideal for assembly applications because they can move in ways other robots can't.

Figure 24: Articulated arm robot (**Indiamart 2022)**

- ***<u>Collaborative robots</u>*** have certain safety features that make them ideal for use in hybrid work environments. The robot is designed to work near humans, which means it can also be used in a wide range of applications.

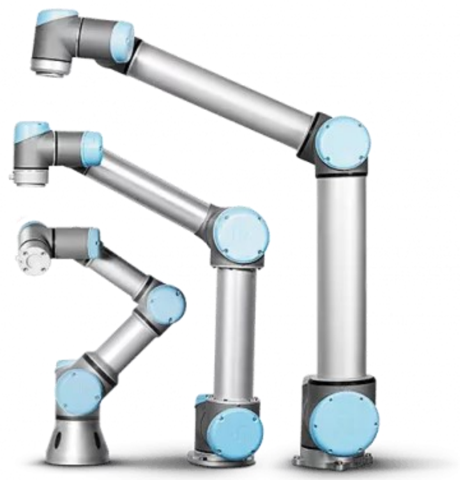


Figure 25: Collaborative robotic arm (Quantum Robotics, 2022)

- ***<u>SCARA robots</u>*** *are selective compliant robot arms*. This means they have the same flexibility afforded to articulated arms, but this makes them steadier and more precise than most articulated arm types.

Figure 26: SCARA Robotic Arm example (DOBOT M1, 2022)

- ***Cartesian robots*** use three linear actuators to move around in a 3D coordinate plane. They are typically constructed of three linear actuators: one that moves left and right in the x-axis, an additional actuator attached to the x-axis member and moving up and down in the y-axis plane, and a final actuator attached to the y-axis member and moving back and forth in the z-axis plane. Cartesian robots are positioned for small applications.

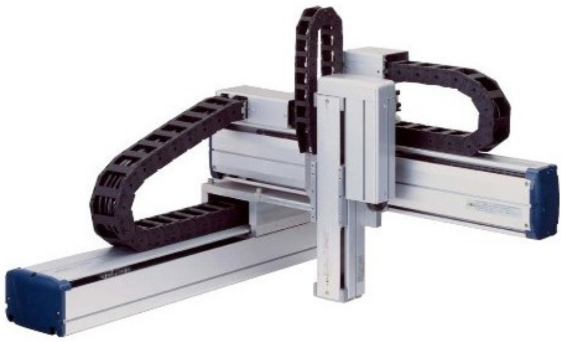


Figure 27: Cartesian robotic arm example (Industrial Robots, 2020)

- ***Cylindrical robots*** are designed with a single arm that moves up and down a vertical member. The vertical member rotates the arm horizontally, allowing it to extend and retract. These robots are very compact and are deployed for small and simple tasks.

Figure 28: Cylindrical robotic arm (Articulated Robotic Arm, 2020)

- ***Spherical (polar) robots*:** The first modern industrial robot was a **spherical (polar)** robot. This robot type has a simple design that isn't as common today as it once was. Spherical robots are similar to cylindrical robots except they swap the vertical linear axis with an additional rotary axis. This axis allows it to rotate vertically, but at slower rates than most other robot designs.

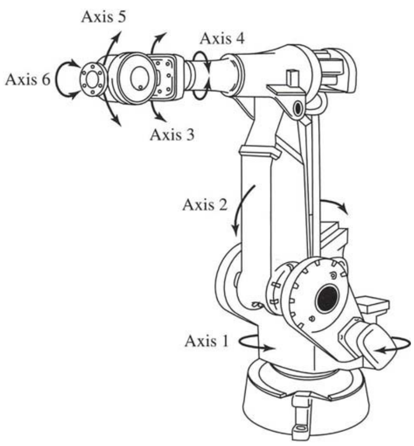


Figure 29: Spherical robotic arm example

(Jointed Spherical (Articulated Arm) Robots, 2008)

- ***Parallel/Delta robots*** are high-speed options for robotic automation. A Parallel/Delta robot's unique design allows it to reach incredible rates of speed because it has a very low moment of inertia. The delta robot is a great choice for high-speed lightweight tasks.

Figure 30: Parallel robotic arm example (Topstar 4-Axis Parallel-Mechanism Robot Arm)

Because anthropomorphic robots are a rare sight in industrial settings, they are often deployed in collaborative environments where they are working in near proximity to human operators.

We have now seen all the usual types of robotics arms. For the scope of this Thesis, we will consider 2 interchangeable solutions, an articulated arm, and a SCARA type arm. More interchangeable parts can be part of a future research on this topic.

Robotic Grippers:

After choosing the robotic arm, the end of the arm is also another part that plays an important role. Different endings can be used for different tasks, especially in a modular robot. The ending of the robotic arm is usually called a gripper (Grippers For Robots, 2022). There are several types of grippers:

- vacuum
- pneumatic
- hydraulic
- servo-electric

A robot's gripper is its physical interface with the work piece. A good choice of gripper can improve overall efficiency and reduce part damage. We will see them in their simplest form bellow.

Vacuum arm gripper

Vacuum grippers, also known as suction cup grippers, are a simple yet highly effective gripping solution for a wide range of applications. With the right type of gripper in the right integration, vacuum grippers provide safe, powerful gripping capabilities in collaborative robot applications. Using the difference between atmospheric pressure and vacuum pressure, vacuum grippers lift, hold, and move objects.

The vacuum is created by a miniature electromechanical pump or compressed air-driven pump. To ensure a robot can safely hold an object, the vacuum flow must not be interrupted. Vacuum grippers come with added advantages such as the ability to handle a variety of item types and at lower cost than other types of grippers. However these benefits are offset by additional electricity costs to power compressed air or vacuum pumps. Additionally, vacuum grippers are sensitive to dusty conditions. (pfa-inc, 2022)

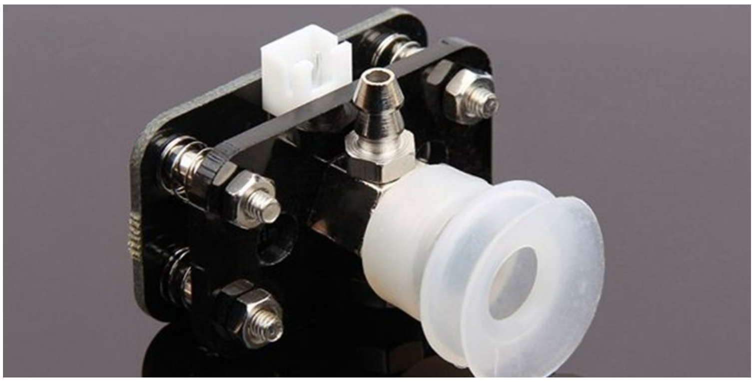


Figure 31: Vacuum gripper example (pfa-inc, 2022)

Vacuum grippers work best in applications when the vacuum flow is uninterrupted. They are ideal for parts that are large enough and flat enough to create enough difference in pressure between the vacuum and atmospheric pressure. Vacuum grippers are an effective gripping solution for applications in which the material being handled has large, flat sides. However, if a part is too heavy or bulky to fit into the opening of a vacuum cup then it won't be able to effectively use this form of gripping. Since their application is relatively and their functionality can be of great effectiveness, a solution with vacuum gripper will be consider for our application.

Pneumatic Grippers

Pneumatic grippers are pick-and-place devices that use compressed air to operate gripper jaws, also called fingers. The fingers, which resemble human fingers, help in grasping, holding, and releasing the work pieces. Pneumatic grippers are commonly used in automated manufacturing processes to grip a work piece (Tameson, 2022). The compressed air supply system powers the gripping fingers, which open and close in parallel or angular ways. The Pick-and-Place mechanism can be used to place or change an object's orientation.

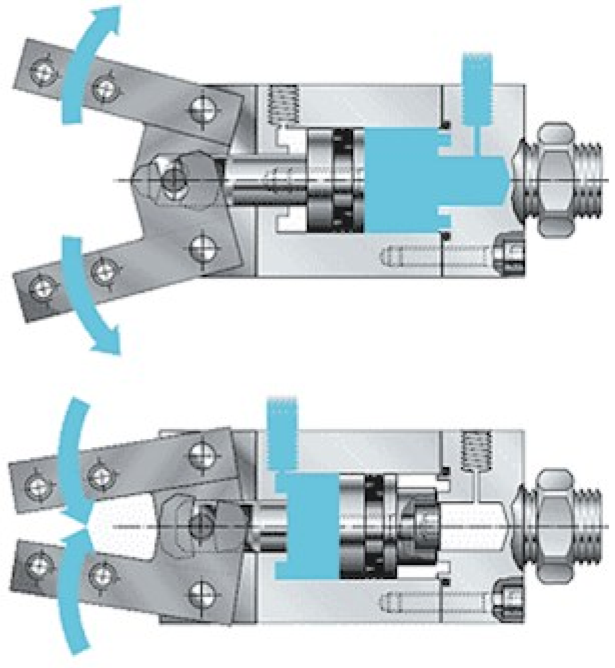


Figure 32: Example of pneumatic gripper (Tameson, 2022)

The pneumatic gripper is popular because of its compact size and light weight. The fact that it can easily be incorporated into tight spaces makes manufacturing easier. They may have two, three or four jaws depending on the type and shape of part that they will be interacting with.

Figure 33: Different examples of pneumatic grippers (www.destaco.com, 2022)

Grippers can be used in many applications, here is a sampling (HENEY, 2016):

- Oversize loads
- Heavy loads
- Part ejection
- Part seating
- Part handling
- Clamping and fixturing
- Pick and place
- Material transfer

• Camming and indexing

Pneumatic grippers and electric grippers each have their own advantages and disadvantages. Pneumatic grippers have higher gripping forces than electric grippers, and they are also lighter, smaller in size, and less expensive. The accuracy of a pneumatic gripper can be adjusted with an analog pressure valve, but it cannot be controlled precisely. On the other hand, one advantage of an electric gripper is that it can be controlled precisely. The speed of both types of grippers can be adjusted by using flow control valves and adjusting operating pressure. (MIKE GUELKER, 2012). For the above reasons, and of course the necessity of the air compression gear and the complexity coming with it, we will not consider pneumatic grippers for our application.

Hydraulic Grippers

Hydraulic grippers use hydraulic pressure to create a hold on whatever you are gripping. Hydraulic grippers are the best choice for applications that involve significant amounts of force. Hydraulic fluids usually power hydraulic grippers, and they generate their strength from pumps that can provide a high of 2000psi. Their advantage is their excellent gripping power makes them ideal for heavy-duty applications. (Davis, 2021). Similar but even worse than the pneumatic, the require significant amount of power and special hydraulic equipment to operate, thus they will not be considered for our application.

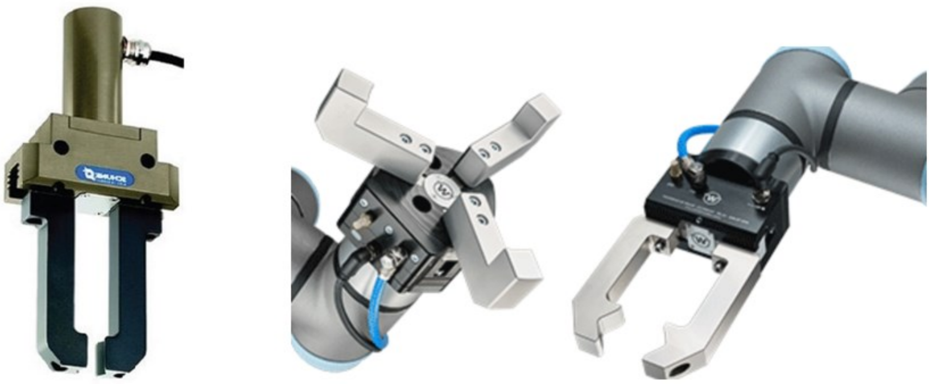


Figure 34: Hydraulic grippers examples (Qviro, 2022)

Servo-Electric Grippers

In an electric gripper, or servo-gripper, electric motors control the movement of the jaws using electric input from the robot controller. These end-of-arm tools are electrically driven and are used in industrial applications (Bouchard, 2011). Grippers are manipulated by robots through a control unit. This unit is usually pre-programmed by an operator via a teach pendant. Grippers accept commands in the form of position, speed, or grip force. The gripper control module receives commands from the robot controller that are sent to the gripper to drive the motor(s). This can be done by embedding the gripper control module in the gripper or by placing it in a separate box.

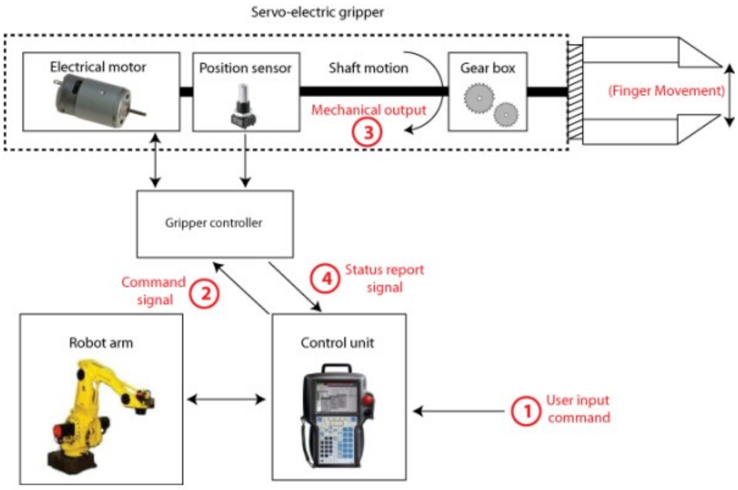


Figure 35: Servo-electric gripper operational process (Bouchard, 2011)

Figure 36: Example of servo grippers (NIRYO NED ROBOT, 2022)

Electric grippers use microprocessors to control the force and speed of gripping. They also include force sensors that let the gripper determine the appropriate grip strength necessary for each task. Electric grippers also have several other advantages over conventional systems: no compressor is needed, improving efficiency while decreasing noise and expense. While servo-electric grippers cannot have the same amount of grip force as pneumatic and hydraulic grippers, due to their simplicity and their compact size, they make a very good choice for some low cost, easy to manufacture and maintain applications, and thus they will be considered for this work.

Magnetic grippers

Magnetic grippers are commonly forgotten, but we will see some of their characteristics. Electromagnetic grippers are generally powered by direct current and used for handling material. Electromagnets can be turned off by shutting down the current, which can help remove the magnetism of handled parts. It's another type of handling parts other than mechanical and vacuum grippers. (HVR MAG, 2021).

Figure 37: Example of magnetic gripper (Bernier, 2014)

There are several advantages to using electromagnetic grippers over other types of grippers: no moving parts, uncomplicated energy supply, flexibility in holding complex parts and reduced number of set-ups. The size of the permanent magnet is directly related to the required gripping force. (HVR MAG, 2021).

Figure 38: Magnetic gripper examples (Robot Enthusiast, 2022)

Due to its simplicity and effectiveness, the magnetic gripper makes an excellent candidate for our modular robot, and it will be considered as a part suitable for out modular robot system. An immediate disadvantage, for non-stationary robots, is the power consumption from the electromagnet that can shorten the power cycle of a moving robot. Since magnetic grippers are relatively simple and can be very useful in specific situations, a solution with a magnetic gripper will be considered.

Interaction with the Robot

To control the robot, a certain amount of code needs to be uploaded in the control unit. Then, the control can be don autonomously, or directly through another device. The most typical example, especially for stationary robots, is a cable connection to central computer, where a user will use script commands to directly control the robot/machine. These commands could be written in various programming languages and there are many open-source platforms that will support such communication, provided the right parts.

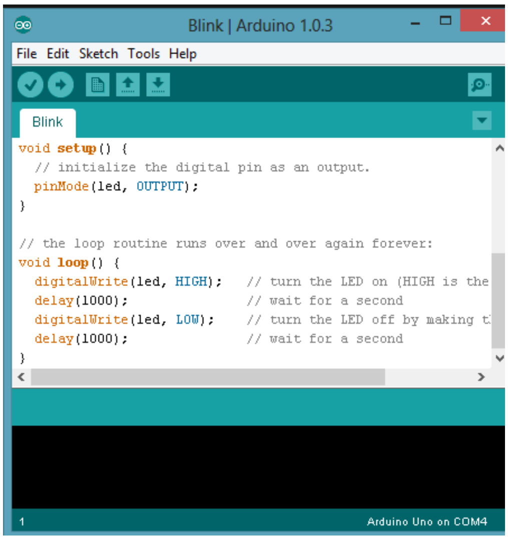


Figure 39: Arduino GUI controlling the blink of a led button

A more useful approach, more tailored to robots, could be the use of an application with friendly user interface, that can pass the script commands the central control unit of the robot. The connections could be direct with cables, or it can be wireless, via connection through radio signals, Bluetooth, or Wi-Fi. Again, there are available applications that are open source, that can be used for such controls, desktop, or even mobile apps. Of course, usually these apps are tailored to basic moving functions, but it could be a good stat for people that are not familiar with coding for robotics controls.

Figure 40: Igus robot control software (Robot Control Software: program and control robots, 2022).

Another way to facilitate daily interaction with the robot is to provide some visual interaction with the robot. This could be achieved by means of a screen, maybe also tactile on the robot, that would accept input from the user. Other means are voice control and gesture control via optical gesture recognitions.

Figure 41: Example of touch screen communication with robot (Ayari, 2017).

Using a ***tactile screen***, voice control or image processing can be very demanding in terms of computational power and energy consumptions. This can be a very limiting factor for non-stationary robots that do not have unlimited space and power supply. Hopefully, today with fast wireless connection, it is possible to use a conventional low computing power processor to receive all the necessary data from sensor and cameras and the processing can be done remotely on another computer with greater computational force. Then, the results return to the robot, as action on the actuator or as output message for the user. This is a very promising idea that we will try to exploit in this current application.

Electronics:

What it really plays an important role for a robot design is the sensors and other electronics that incorporates. While the detail electronics are out of the scope of this thesis, we shall have a look at the different types of electronics and sensors that are commonly used and decide if we are going to incorporate them in anu of the modules. A basic criterion for their choice would be, their effectiveness, practicality, cost, and functionality. To begin with, the categories that the electronics of robots are divided are the following:

1. Power systems
2. Sensors
3. Actuators
4. Microcontrollers and processors
5. Useful software

Batteries:

We have already seen about the actuators and the software tools, now we shall see some details about the rest of the categories in the list, begin with the **power systems**.

The power system is in other words, the battery pack of the robot. It is not hard to conclude that the larger the battery, the more energy is stored, and the greater the robot's autonomy can be. It is generally appreciated to have large autonomy, although most of the times the battery size is a trade of space and weight. Since in this thesis scope, we have excluded flying operations, and autonomy desired is more than two hours, we will try to maximize the size of the battery. We could choose from different categories, the most suitable candidate for or application being lead-acid batteries (K, 2020):

Lead-Acid/SLA Batteries:

SLA batteries remain the cheapest option for high-capacity power. They are the same batteries used in automobiles. They need little maintenance for several years and can undergo thousands of charge and discharge cycles until the discharge is no more than 30% of their capacity. In addition, these batteries output tons of current and are easy to charge. They are widely available in low-cost, but they're heavy and cumbersome for mobile robots and not preferred for hobby models. On the other hand, it is an ideal candidate for our model, since they can be found easily in the market and have the largest possible capacity compared to the other types (K, 2020).

Figure 42: Lead-Acid/SLA Batteries example

Sensors:

There are numerous sensors to choose from, and we will identify a few of the most popular and explain why they are used in certain situations and not others. Let's see the most important of them (Types of Robot Sensors, 2022 and Top 10 sensors which can be integrated into Arduino, 2018):

Light sensor:

Light sensors are used to detect light and create a voltage difference. Two common types of light sensors are photoresistors and photovoltaic cells. Photoresistors are resistors whose resistance varies with the intensity of the light, more light leads to less resistance, and less light leads to more resistance

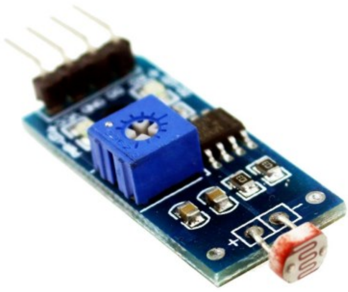


Figure 43: LM393 Photosensitive Light-Dependent Control Sensor LDR Module

Sound Sensor:

Sound sensors can be implemented in a variety of ways. For example, as the name suggests, this sensor (generally a microphone) detects sound and returns a voltage proportional to the sound level. A simple robot can be designed to navigate based on the sound it receives. Imagine a robot which turns right for one clap and turns left for two claps. Complex robots can use the same microphone for speech and voice recognition.

Figure 44: xcluma Sound Sensor Module Sound Detection Module UNO

Temperature Sensor:

Imagine if a robot had to work in the desert and transmit ambient temperature. One simple solution would be to use a temperature sensor. Tiny temperature sensors provide voltage difference for a change in temperature.

Figure 45: Digital Temperature Sensor DS18B20

Proximity Sensor

Proximity sensors are a type of sensor that detects the presence of nearby objects without physical contact. Proximity sensors come in many varieties, but only a few are generally used in robots.

Figure 46: HC-SR04 Ultrasonic Module Distance Measuring Sensor

Distance Sensor

If you want to determine the distance between two points, several types of sensors can be used. The most common is an ultrasonic sensor, which sends a pulse of high-frequency sound waves and measures how long it takes for the echo to return. Infrared sensors also measure distance by sending out a beam of light and measuring how long it takes for the light to bounce back.

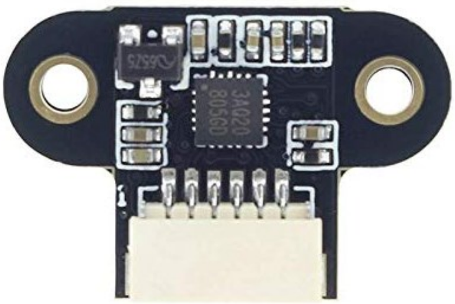


Figure 47: TOF10120 distance sensor with range of 2m

Pressure Sensor:

Pressure sensors are used to measure pressure. Tactile pressure sensors measure touch, force, and pressure.

Figure 48: Barometric pressure sensor BMP180 GY68

Navigations / Positioning Sensors

The positioning sensors used in robots range from low-cost to high-cost. The Global Positioning System (GPS) is the most commonly used positioning sensor, but it can be affected by weather conditions and blocked by buildings. An inertial measurement unit (IMU) is a low-cost module that can be combined with a GPS module to provide both location information and navigation for robots.

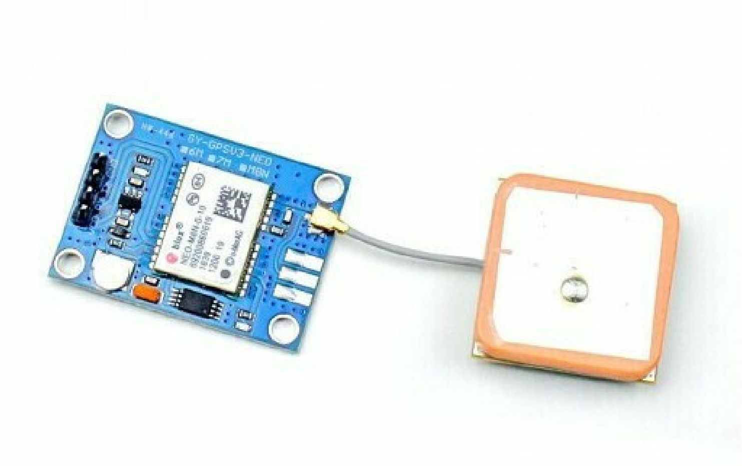


Figure 49: Ublox GYGPSV1 NEO-8M GPS Module for Arduino

Accelerations/ Gyroscope Sensor

An accelerometer measures changes in acceleration, tilt, and vibration. An accelerometer can measure static forces as well as dynamic ones. Static forces are the frictional force between any two objects. For example, Earth's gravitational force is a static force that pulls an object toward it. Measuring this gravitational force can tell you how much your robot is tilting.

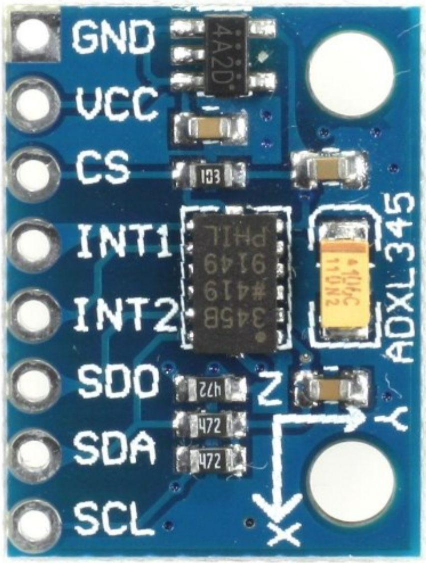


Figure 50: ADXL345 Module accelerometer

Gas Sensor

This gas sensor is based on a change in resistance of the sensing material when the gas comes into contact with it. A simple voltage divider network can be used to detect concentrations. The MQ2 gas sensor uses roughly 800mW and works on 5V DC. It has a detection range of 200 to 10000ppm for LPG (liquefied petroleum gas), smoke, alcohol, propane, hydrogen, methane, and carbon monoxide.

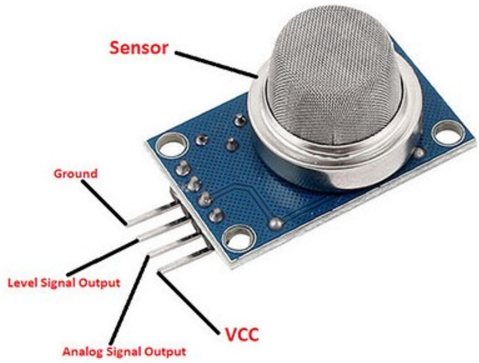


Figure 51: MQ2 is a gas sensor

Fire and flame sensor

Flame detectors are a type of detector that reacts to the advent of a fire or flame. The response of the flame detector can be affected by its configuration. In industrial boilers, these sensors are employed to verify whether or not the boiler is operating properly. They usually achieve this by employing one of two detection technologies, ionization detectors, and photoelectric detection.

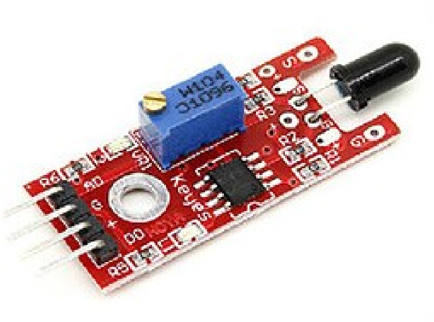


Figure 52: KY-026 Flame Sensor Module IR Sensor Detector

Humidity Sensor:

Humidity sensors are electrical devices that detect and report the moisture and air temperature of the environment in which they are used, such as air, soil, or tight spaces. Humidity measurements reveal the amount of water vapor present in the atmosphere and provide relative humidity information. Many applications, such as HVAC (Heating Ventilation Air Conditioning) and comfort optimization applications in Smart Buildings and Facilities Management, use relative humidity.

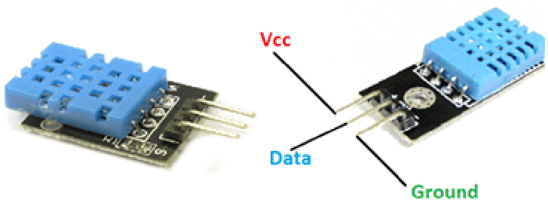


Figure 53: DHT11 Module ηθμιδιτυ σενσορ

PIR Sensor (Pyroelectric (“Passive”) InfraRed Sensors)

PIR motion sensors detect movement and are most commonly used to determine whether a human has entered or exited their range of detection. They are compact and inexpensive, as well as low-power, easy to use and reliable. As a result, they are common in household and commercial appliances.

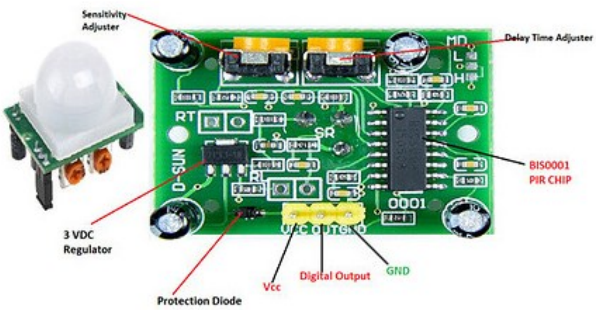


Figure 54: PIR Sensor HC-SR 501

Camera:

The camera is one of the most important electronics parts of a robotic project. Depending on the application, it can be infrared, thermal, high definition or low cost. For example there are low-cost Arduino cameras that can transfer image and video. A computer could even do an image analysis, even with a trained AI model, and then instruct back the robot to perform an action. A 360 degrees vision is essential for the project, thus, maybe two four cameras module could be used., to have a clear vision for ground and sky.

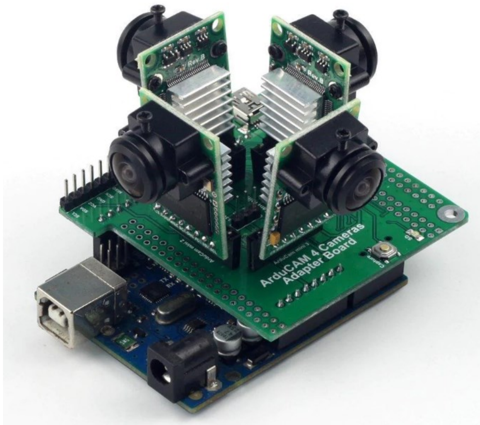


Figure 55: Arduino multicamera adapter B0074

Another solution could be a panoramic camera, mainly better for surveillance.

Figure 56: 360° VR Panorama Dual lens Camera Module with Micron MI0130 sensor

Wifi/Bluetooth connection:

Wireless communication and data transfer for the robot could be achieved with using WIFI and Bluetooth modules. Relatively low cost can use this well establish technology, not only to connect and interact with the robot, but also, transfer data, connect and interact with other robots and behave like a robot swarm.

Figure 57: Serial Wifi Module Arduino ESP8266

LTE Module:

Using an LTE module, we can connect the robotic system to the word virtually anywhere there is a good mobile phone signal reception. With a relatively lowcost LT module, 4g (and even 5g) connection could be achieved, allowing for real time data transfer to the robotic system.

Figure 58: DFRobot SIM7600CE-T 4G(LTE) Shield for Arduino

Motors:

There are 3 types of suitable electric motors that we could use for the different parts of a robotic system. Each one has its own advantages and disadvantages. Shortly, the 3 dominant types of motors are, simple dc motors, servo-motors, and Stepper motors. Let's see some details about below.

Simple dc motors:

A DC motor is an electrically powered mechanical device that converts electrical energy into mechanical energy. DC motors are smaller in size than other types of motors. They operate on direct current (DC), which allows them to be used in devices such as electronics. (Mundrathi, 2021)

Figure 59: Typical DC simple motor

Due to the presence of brushes, commutators, and slip rings, DC motors tend to wear out faster than AC motors. Since sparking occurs at the commutator, DC motors cannot operate in explosive or hazardous environments (Mundrathi, 2021). Taking the above in mind, having as main advantage the higher achievable speed but the difficulty in controlling accurately, DC motors are great for rotating wheels and moving the robotic system when speed is prioritized over accuracy (e.g. in agricultural applications).

Figure 60: DC motors with coupled gearbox for higher torque (KINMORE PRODUCTS, 2022)

Servo motors:

A servo motor is a rotary or linear actuator that allows for precise control of angular or linear position, velocity, and acceleration. It consists of a suitable motor coupled to a sensor for position feedback. We can get a very high torque servo motor in a small and light weight packages due to these features; they are used in many applications like toy cars, RC helicopters and planes, robotics machines etc. (What is Servo Motor – Advantages, Disadvantages Applications, 2020).

Servo motors have some disadvantage too. They have a higher cost than standard motors; they are not suitable for applications that need to prevent vibration; and when stopped, the motor's rotor continues to move back and forth one pulse.

Figure 61: Typical Servo-Motor (What is Servo Motor – Advantages, Disadvantages Applications, 2020)

Stepper motors:

The stepper motor is simple to construct and works in any situation. This provides flexibility, holding torque without the need for the motor to be powered, safety, reliability, and low accuracy. Excellent response to starting and stopping. Different kinds of rotational speeds can be realized as the speed is proportional to frequency of the input pulses. Thus, it is an excellent choice for controlling wheels, but only when controlled moment is preferred over speed.

Figure 62: Typical stepper motor200 Steps/Rev, 42×48mm, 4V, 1.2 A/Phase 0.35kg. Cost around 20 €

Controllers:

A control unit is what we call, the brain of the robot. It is the unit that will control the electronics, the motors, take signal from sensors and communicate with "outer word". There are many types of controllers, with the most popular of open-source controllers being Arduino and Raspberry Pi. Since Raspberry Pi is mostly for software applications, we will consider for this project and Arduino controller. The Arduino is a perfect choice, since it is open source, light, low cost, and there is a very wide-open library and open-source code to help build a prototype project. Let's see the main Arduino boards and their purpose.

The ***Arduino*** is a microcontroller platform that makes it easy to interface with different devices and capable of doing almost every assigned task. Since the Arduino is a hardware and software-based platform, programming the microcontrollers has also been made easy using the Arduino IDE. We have given five Arduino boards below (Javaid, 2022):

- Arduino Uno for basic level projects
- Arduino Nano for breadboard projects
- Arduino Mega 2560 Rev3 for advanced level projects
- Arduino due for big and complex projects
- Arduino MKRZero for audio and sound projects

The most promising candidate is Arduino Mega 2560 Rev3, or simply Arduino Mega. The Arduino mega is an advanced board suitable for complex projects that require a large number of input/output pins. The Arduino Mega has more memory, higher RAM and a faster microcontroller than the Arduino Uno and Nano. It also has more digital and analog pin available. Finally, more than one microcontroller could be combined to make more sophisticated controls and projects.

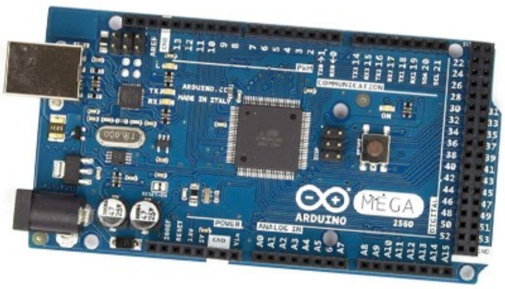


Figure 63: Arduino Mega

Suspension:

Last parameter to be considered, the suspension. For roughed terrain, it is a good, and sometimes necessary practice to integrate a suspension system to the robot. This will help stabilize movement, and even make the life of the system longer. A design module with suspension will be considered.

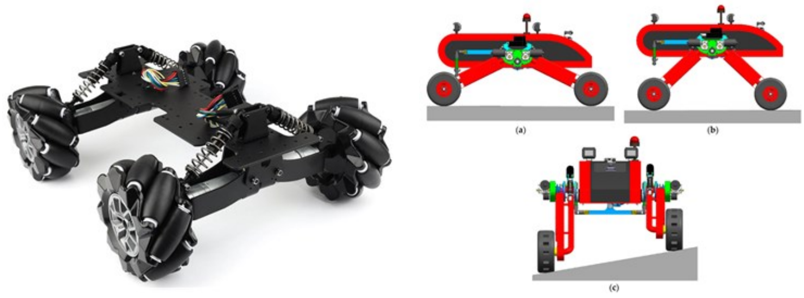


Figure 64: Suspension in robotic systems examples

Materials and Methodologies:

Since we are interested in creating a non-expensive model but on the other hand, environmentally friendly product, we have some limitation over the methodologies and the materials to be selected. Moreover, one of the parameters that dictates the construction methodologies is the number of parts that will be fabricated. In our case, since we want to design a product that could be potentially built as a prototype, we will favor methodologies that can offer highly customized design with lowest cost possible. The latest trends in manufacturing, that could provide such advantages is 3D printing and lazer cutting.

3D printed parts and materials:

3D printed parts can provide a wide range of possibilities, including a very rapid creation of precise parts. Relatively inexpensive, the right design can make a strong and robust. PLA and PLA+, are 2 materials that are easy to print, resistant and also, biodegradable, making them a more environmentally friendly choice than plastic.

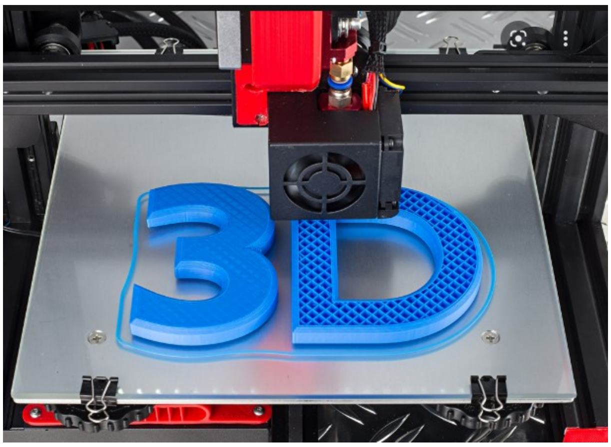


Figure 65: Conventional home 3D printer (2020: The Year Ahead In 3D (Printing), 2019)

Metal sheet laser cutting parts and materials:

Laser cutting, or laser beam machining, is a process of cutting parts from a material using a laser beam. It is used for cutting metal and nonmetal materials of different thicknesses. The beam, which is guided and formed by mirrors, heat up the material so it melts or vaporizes. As the laser power is concentrated in one point that's often less than half a millimeter, if more heat is introduced into this area than can dissipate through heat conduction, the laser beam will penetrate the material entirely the cutting process has begun. (Laser cutting as a contact-free slitting process, 2022).

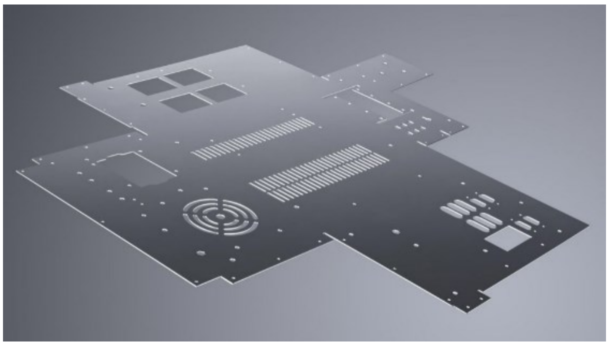


Figure 66: Laser cutted metal sheet (Laser cutting as a contact-free slitting process, 2022).

The laser is an ideal cutting tool for all kinds of materials. It can cut steel, aluminum, stainless steel, and non-ferrous metal sheets, as well as non-metal materials such as plastics, glass, wood, or ceramics. The laser can cut sheet thicknesses ranging from 0.5 mm to over 30 mm. (Laser cutting as a contact-free slitting process, 2022).

Thanks to its flexibility, this cutting procedure is often used for small lot sizes, large variant ranges and in prototype construction. Ultrashort pulse lasers vaporize materials so quickly that heat influence cannot be detected, thereby creating high-quality cutting edges without ejection of melted material. (Laser cutting as a contact-free slitting process, 2022).

Metal sheet parts are parts that are created using lasers to cut sheets of metal and usually, fold them in shape with a break press. The process can be applied to numerous materials and sheet foils, making it highly adaptive. Though aluminum is possible to be laser cutted, it tends to bend from heat coming from the laser, and also it is difficult to form with the break press since it will probably break apart due to its mechanical properties. Steel on the other hand, it is cheaper, can be welded, has great mechanical properties, making it a perfect candidate for such applications. Finally, as all metals can be recycled, it's a more environmentally friendly choice than plastic. (Laser cutting as a contact-free slitting process, 2022).

Figure 67: Metallic Laser cutted part (Laser cutting as a contact-free slitting process, 2022).

Wooden laser cutted parts:

Another possible material choice that has great potential and it could be used to our design, is laser cutting of wooden sheets. With modern lasers, even 20mm thick wooden plates can be cutted with amazing accuracy. Moreover, wood is a cheap, biological material, making it an awesome example of environmentally friendly materials choice for some parts. A great idea could be to design a SCARA Arm with wooden parts or create wooden cases for robots that used in internal spaces.

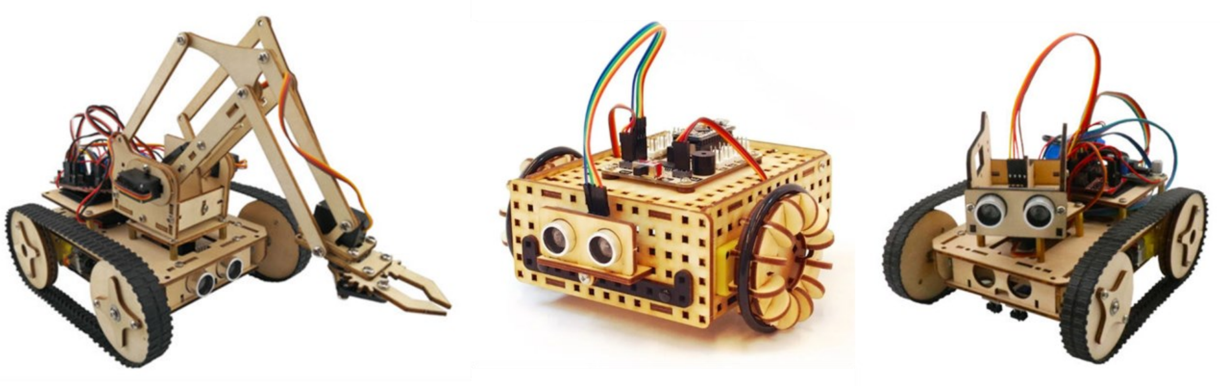


Figure 68: Robot having wooden parts (Rover Robot - Arduino and Lasercut Plywood, 2020)

Finally, another advantage of all the above methodologies is that in case of a part failure, another part can be fabricated on demand withing some hours. This is especially useful for high-value parts and when time is of the essence. The biggest advantage of additive manufacturing is that it allows for the creation of geometries that would have been impossible with traditional manufacturing. This can be extremely useful, especially in industries where the product must meet very strict specifications.

8. Concept Designs

We have discussed some of the robots' functionalities and characteristics, we have seen products and concepts that already exist in the market, and we have discussed their advantages and disadvantages. We are now ready to start making the design blue prints. But before we proceed to this phase, it is a good idea to list all the characteristics, concepts, and ideas that our design is aspiring to incorporate. We aspire to design a modular robotic system that it will incorporate all the following.

Specifications:

- Moving robot but with possibility to become stationary
- Wheeled Robot
    - 2 – 4 – 6 wheels solution
    - Omni wheels
    - Tracked wheels
- Possibility for Swarm Robot
- Incorporate a robotic arm:
    - Articulated arm
    - SCARA Arm
- Incorporate different grippers:
    - Vacuum gripper
    - Electromechanical Gripper, with different clump solutions
    - Magnetic Gripper
- Incorporate 3d printing, metal sheet/laser, wooden parts in construction process
- Use Lead Acid Batteries
- Incorporate Sensors and Controllers
    - Light
    - Temperature
    - Sound
    - Camera
    - Wi-Fi
    - Bluetooth
    - Arduino mega
    - color sensor
    - humidity
    - fire
    - proximity sensor
    - Distance sensor
    - Pressure sensor
    - Accelerometer
    - LTE Communication

  - Gas sensor
  - PIR sensor
- Suspension
- Touch screen
- Charging point

In the following pages, we shall see the final designs and concepts. Some details will be provided, explaining the ideas behind the designs, and more details will be presented in the Appendix.

A central idea of our design would be to use at the highest possible degree, autonomous blogs that can be combined and work together to create a robot based on the customer needs. This way, we aspire to have a design, that will have an autonomous block used as central base, autonomous arms, electronics blocks, batteries, wheels, and motor blocks, and finally, autonomous different clumps and screens. In this stage, it is not the compact design that should be prioritize, but the ability to assembly, maintain and adjust the modular robot. We will start with the most central part, the base.

Since we aspire to have a robust, tough single base and assembly all the other parts on it, we will stick to the idea of creating a light strong base using the laser cut and bending process. High load capacity is one of the required goals, and it should be taken in mind in the design and the material choice. The idea is to predict all the openings for the parts to be assembled, but also the right shape in order to achieve high strength and resistance of the structure without having excessive weight. The rectangular shapes, with clear angles and less curves, are easier and cheaper to manufacture in break presses thus, the design is limited from the manufacturing process. Let's analyze parts, and subassemblies used and see the final results of the different concepts in the end. Cables are not designed as this part is too complicated with less interest for the scope of the thesis. Also, all electronics are not accurately pictured but rather, their use is explanatory in the designs.

The parts shown below are the product of extensive design loops based on the required goals. Unfortunately, the design loop is to be detailed to be shown in this thesis, but we shall do our best to include all the important parameters.

Parts designed:

Monobase

A central, core, robust base, laser cutted and brake pressed is the base to hold all the parts of the robot. The base is made from 4mm thick carbon steel, and has fins welded on it to make it stiffer. Tab and slot technique is used to make the welding easier. With this technique, the welder makes no mistakes in dimensions, and also, we reduce the thermal shock of the part, resulting in less thermal stresses. It has a weight of a 5.6 kg. The openings for all the parts and botls/screws are cutted with great precision directly from the laser machine.

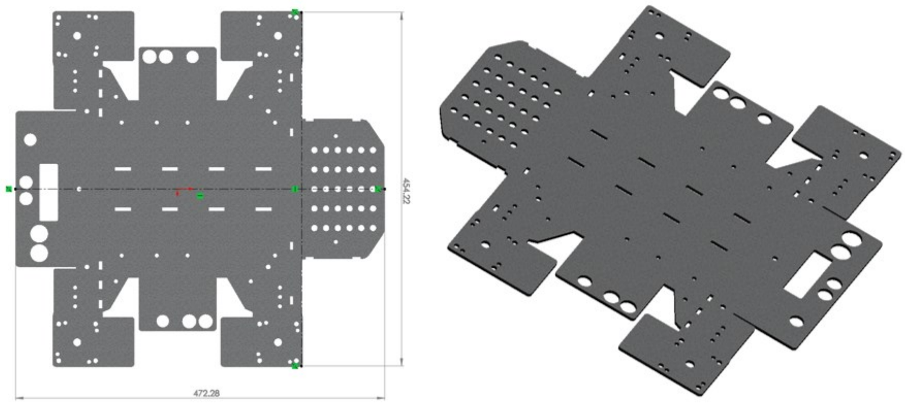


Figure 69: Monobase pattern, flatten to be cutted with laser before brake press.

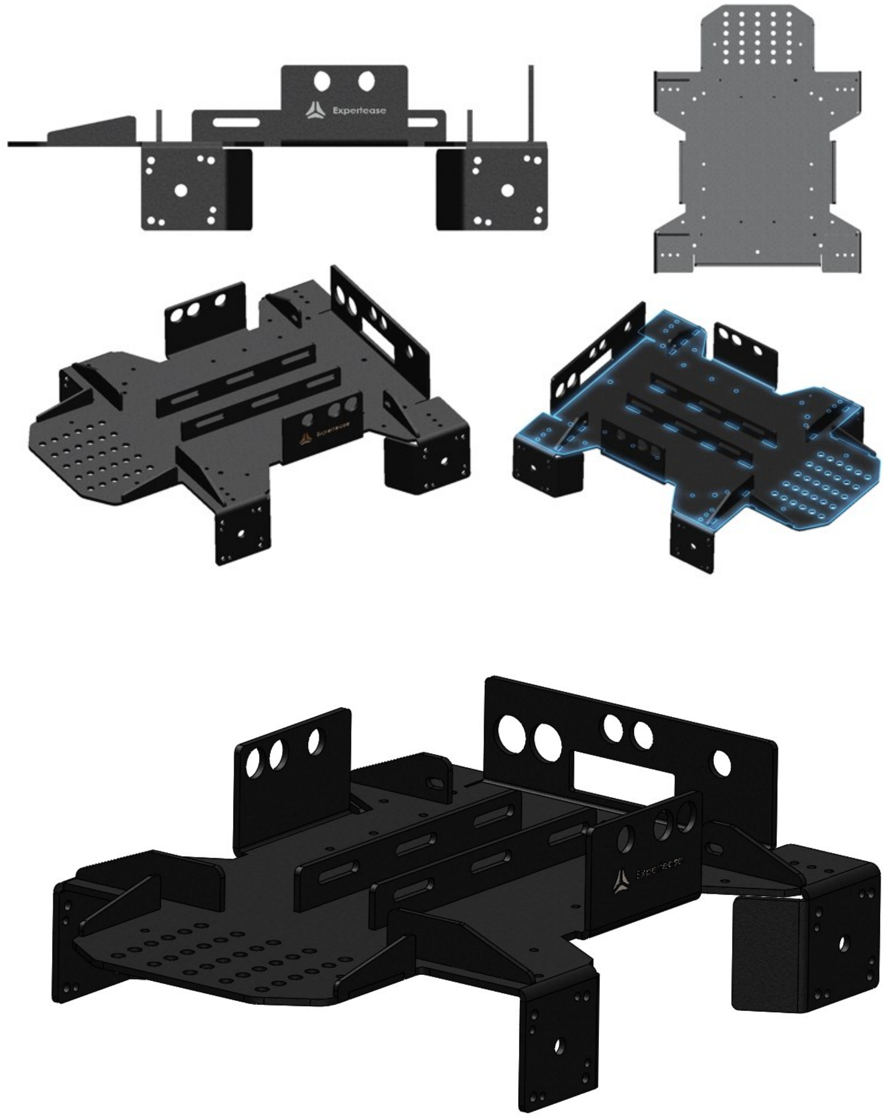


Figure 70: Monobase from steel, powder paint. Total weight of 5.6 kg. Nerves welded for structural strength.

Batteries and power supply:

Three lead acid batteries will be used to power the robot, each one of 12V and 1.3 Ah. This way, with the disadvantage of the weight, we shall have enough power for long time. The batteries will be held together with special parts designed to do so. A power supply unit will be necessary for charging and also for steady and correct power supply of the electronics.

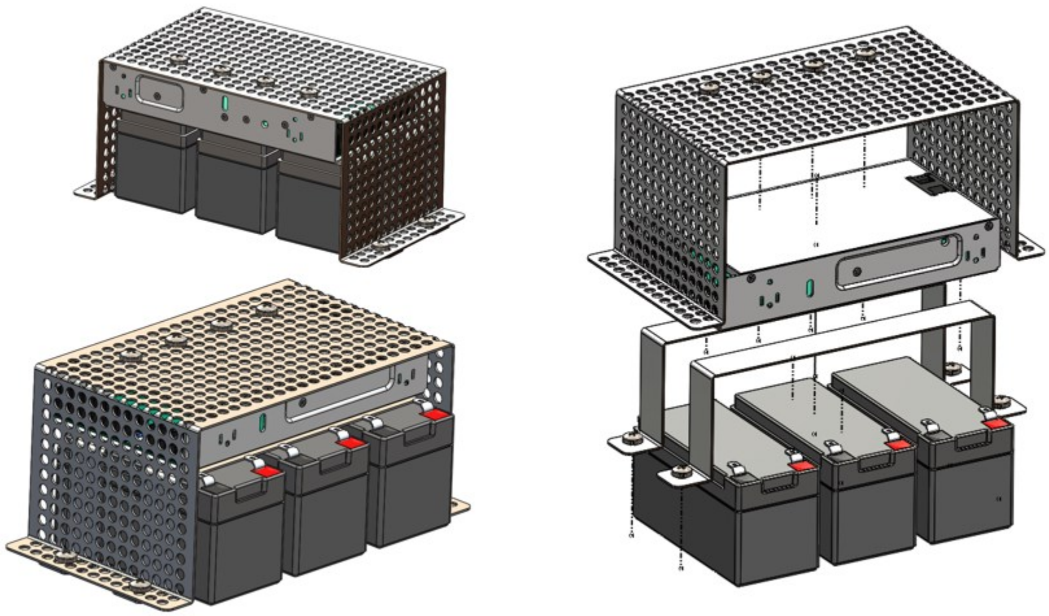


Figure 71: Batteries and power supply with holder and protective cup.

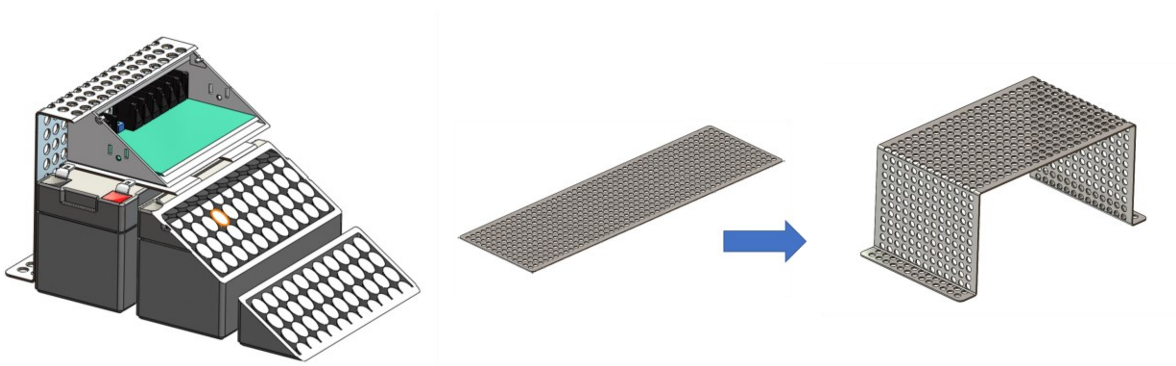


Figure 72: Battery protective cover with openings for weight reduce and part fix.

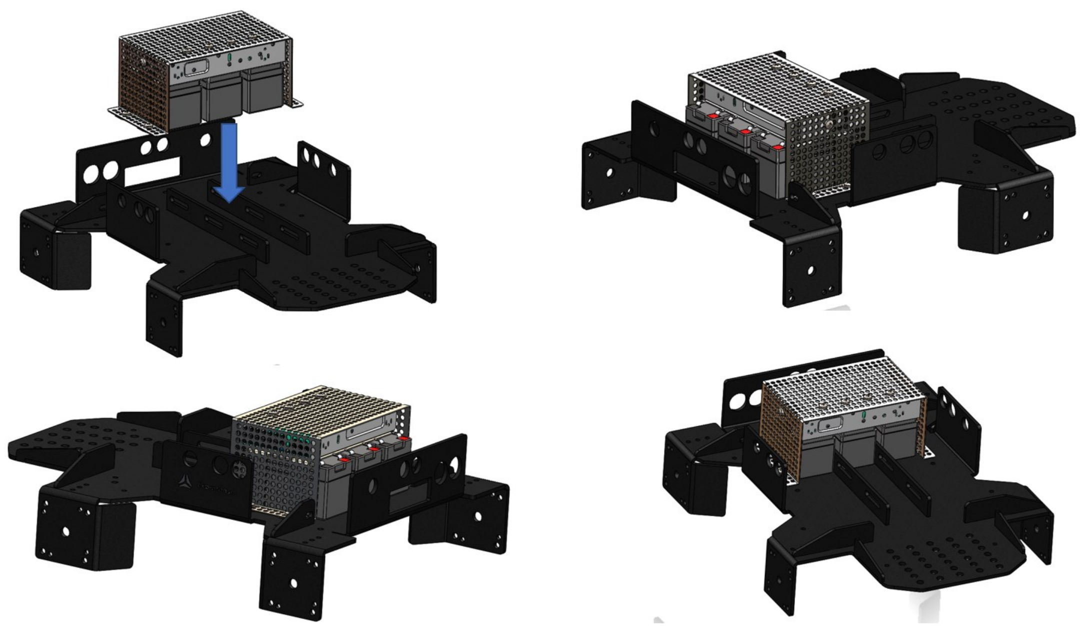


Figure 73: Battery placed and secured on the monobase.

__Wheels and stationary bases:__

Three types of wheels designed, normal wheels, tracked wheels and meconium wheels. Wheels will be directly mounted on stepper motors, and the stepper motors will be directly mounted on the base. Finally, stepper motor drive shields and protective plastic covers will be added on them. Stepper motors chosen are the Nema 23 PHB57M56 430, the details can be found in the specs.

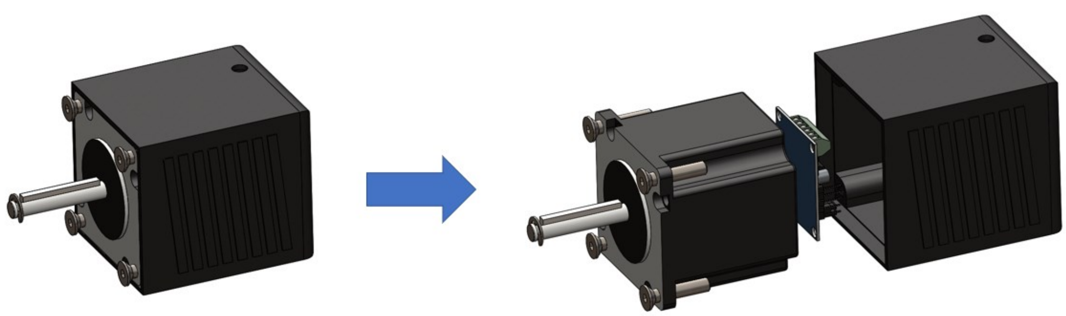


Figure 74: Stepper motor in the 3D printed protective cover, with integrated shield drive.

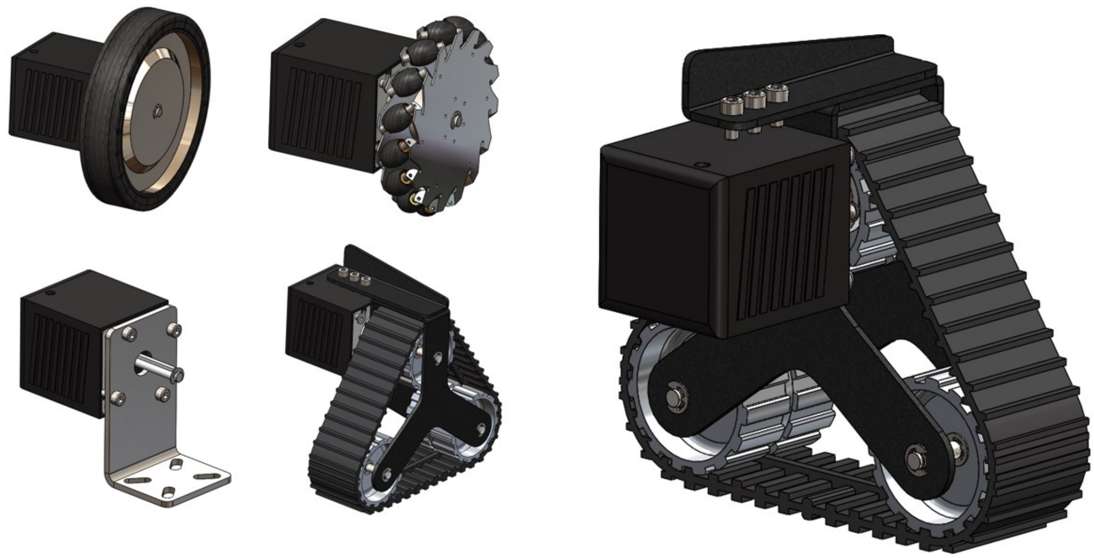


Figure 75: Normal wheel, mecanum wheel, stationary base and tracked wheel mounted on the stepper motor.

Figure 76: Tracked wheels.

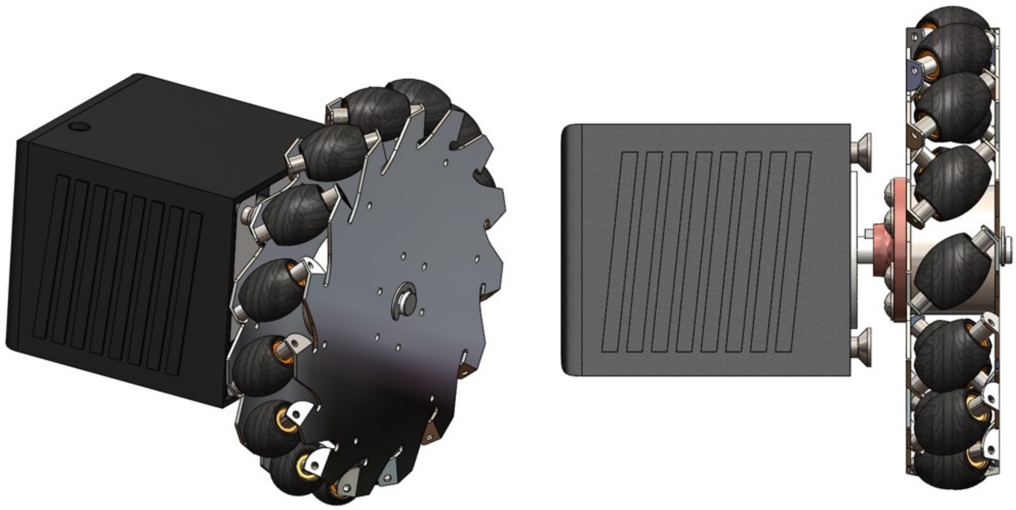


Figure 77: Mecanum Omni wheels design.

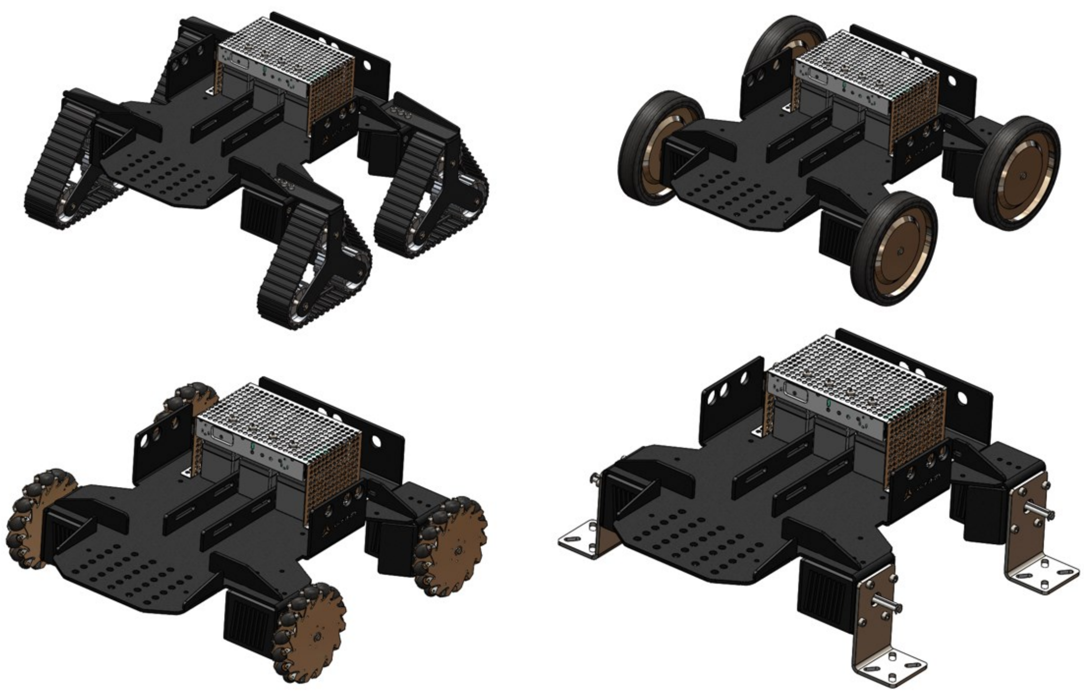


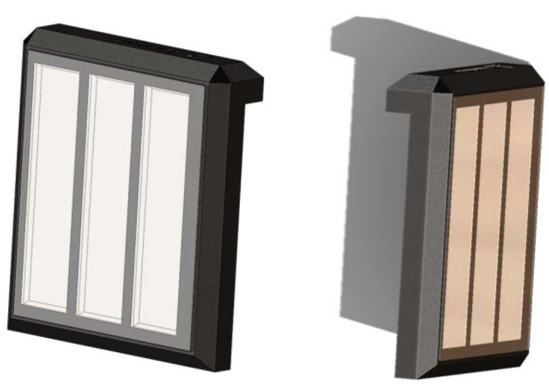
Figure 78: All wheel and stationary configurations mounted on the base with the motors.

An extra protective cover is also added under the motors, to creating space for carrying objects.

Figure 79: An extra protective cover is also added under the motors, to creating space for carrying objects.

Head lights:

Head lights on the front and the back, a custom LED design with 3D Printed case, but ready to buy solutions could be integrated too.



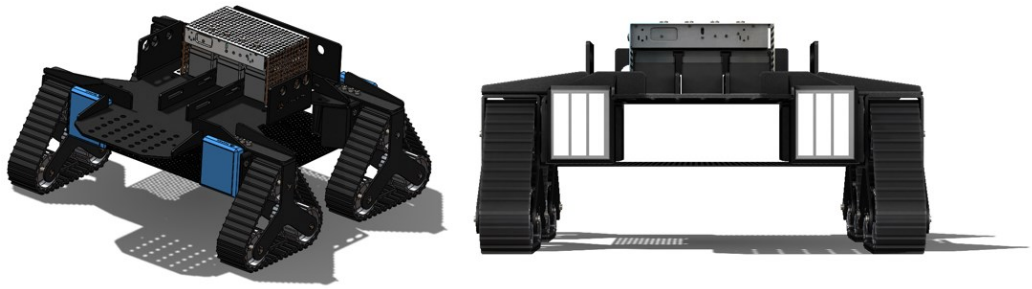
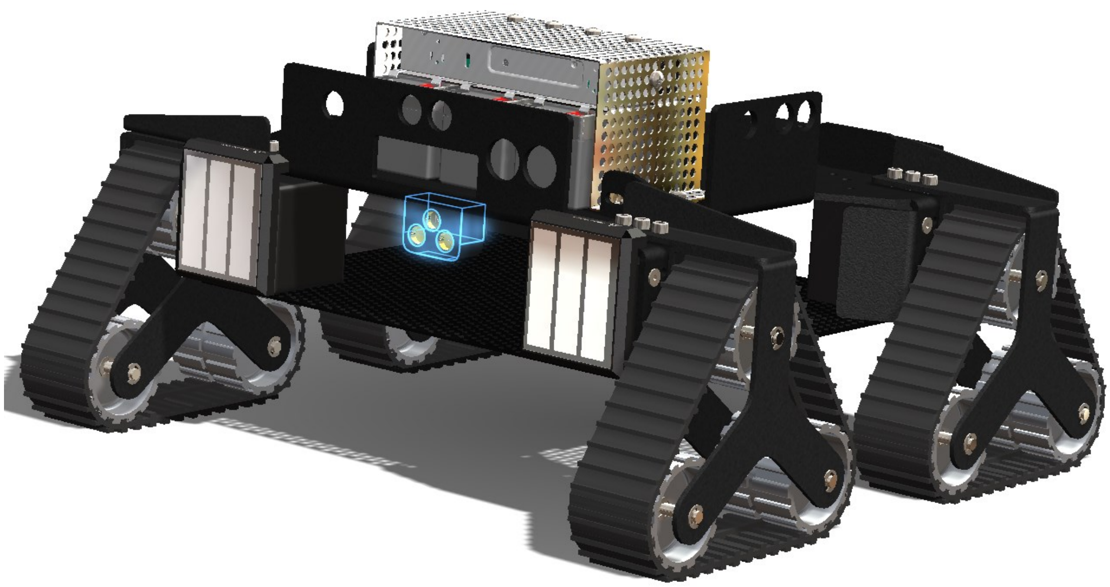


Figure 80: Headlights custom design, 4 integrated covering the motors.

__Magnetic Charging connect:__

Simple connect, incorporating phase, neutral and ground. The idea is to charge directly from the grid, while the robot will head autonomously to the charging point once the battery is drained below the threshold.



__Central Electronics:__

The idea is to use open-source electronics like the Arduino mega. The design incorporates two Arduino mega enclosed to standard cases, with the shield to drive other modules, allowing for fast connection and disconnection of electronics components.

The design goal was to have these electronics compact and protected within boxes, securely mount on the base. Cables are not showed for the sake of simplicity in the design, while most of the electronics shown are for representation purposes. Some specs can be found in the appendix. We shall start with the core electronics, the processors, wifi and Bluetooth modules, voltage adapters, LTE antennas, GPS etc. DC 12V standard ventilation fans in each side will maintain the temperature in cases it rises.

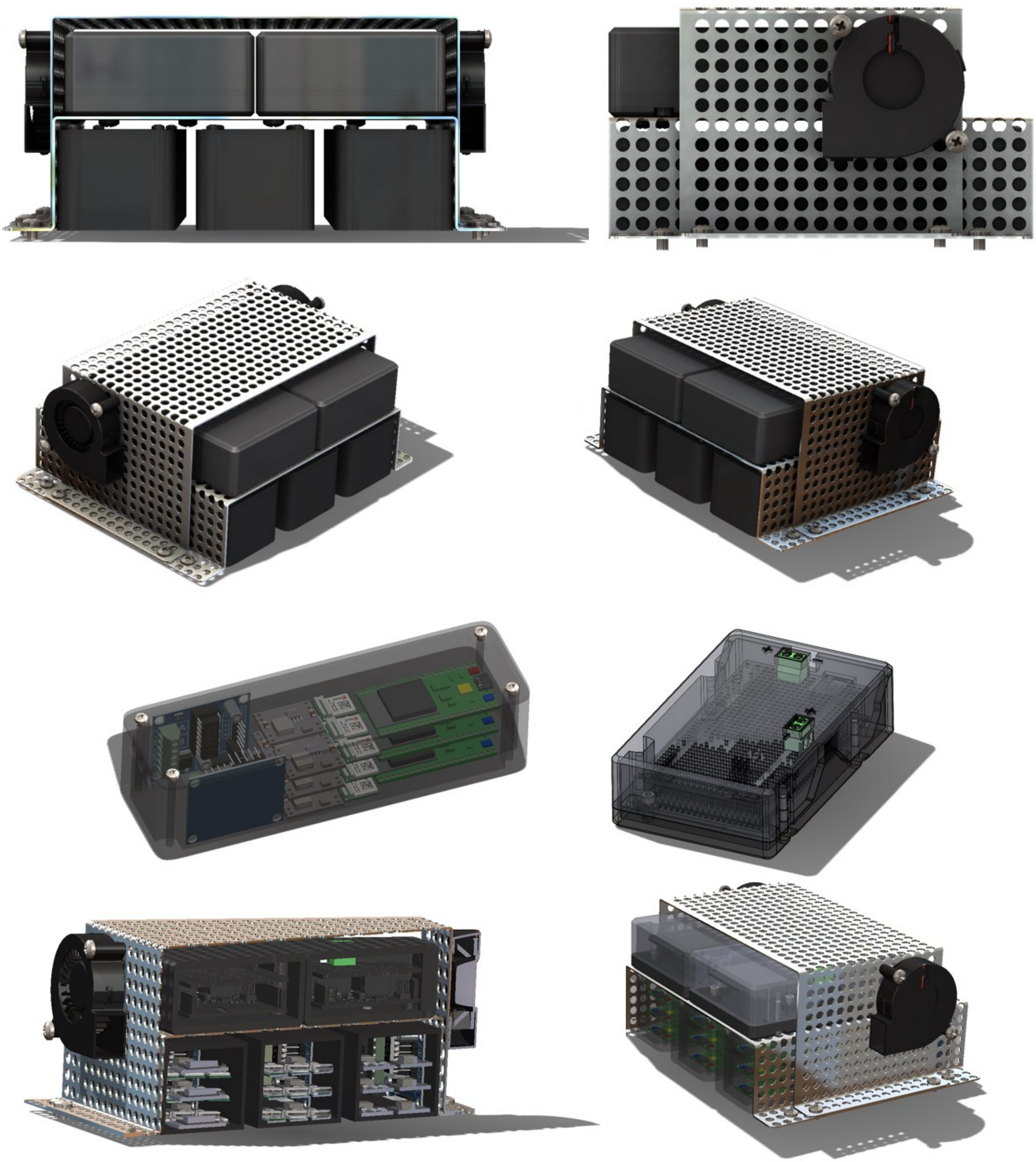


Figure 81: Central electronics enclosed and protected.

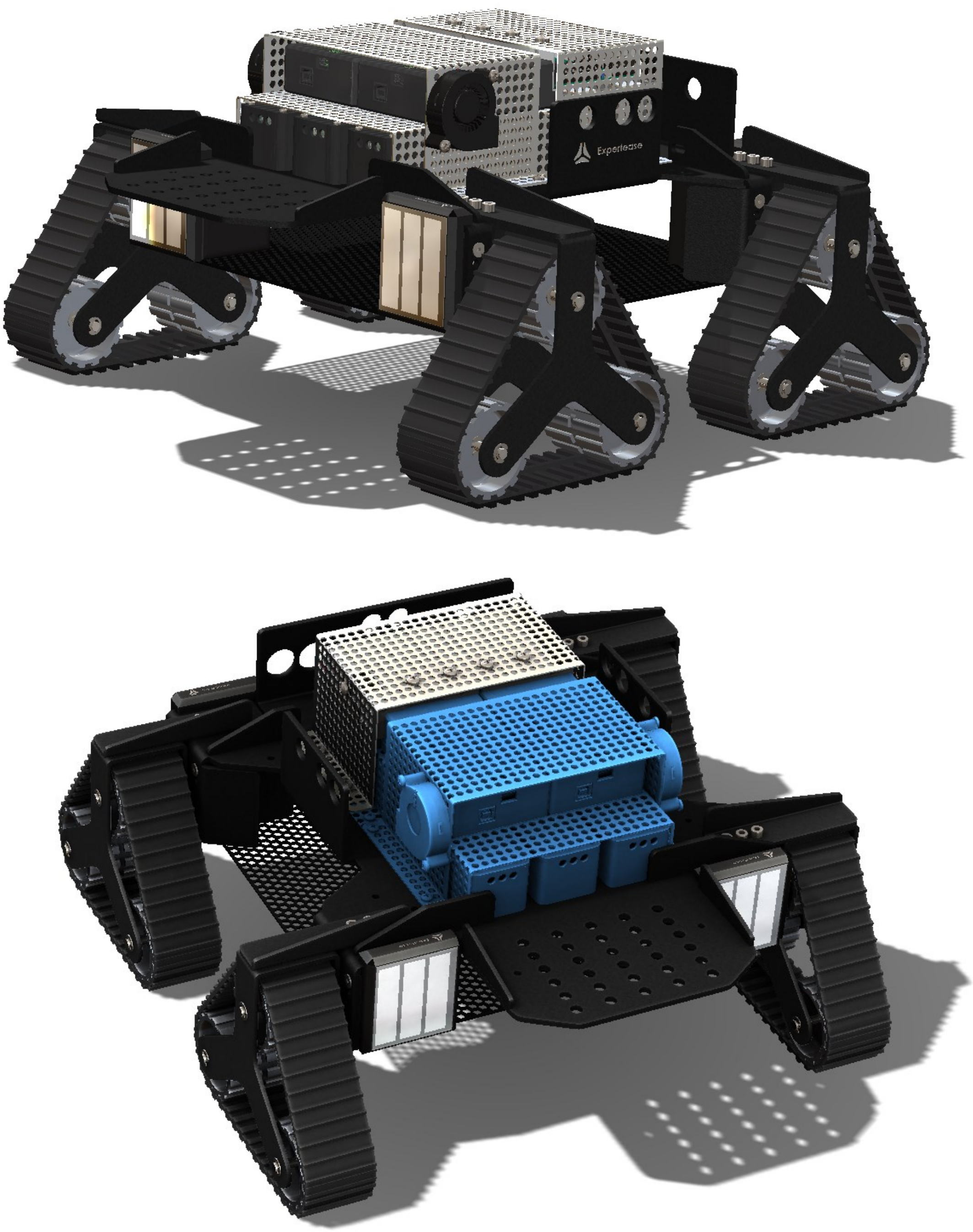


Figure 82: Central electronics mounted on the base.

<u>Side electronics:</u>

Four more electronics boxes added in the four sides of the robot. The front is mounted with a special mount bracket, and the other three are directly bolted on the base. All of them will incorporate a camera, ultrasonic distance sensor, Bluetooth connection, shields, temperature sensor, gas sensor, fire sensor, IPR sensor, microphone, while the one in the back will also have 2 speakers and two extra 12v DC ventilation fans, and also an LCD screen for quick messages. Boxes can be 3D printed.

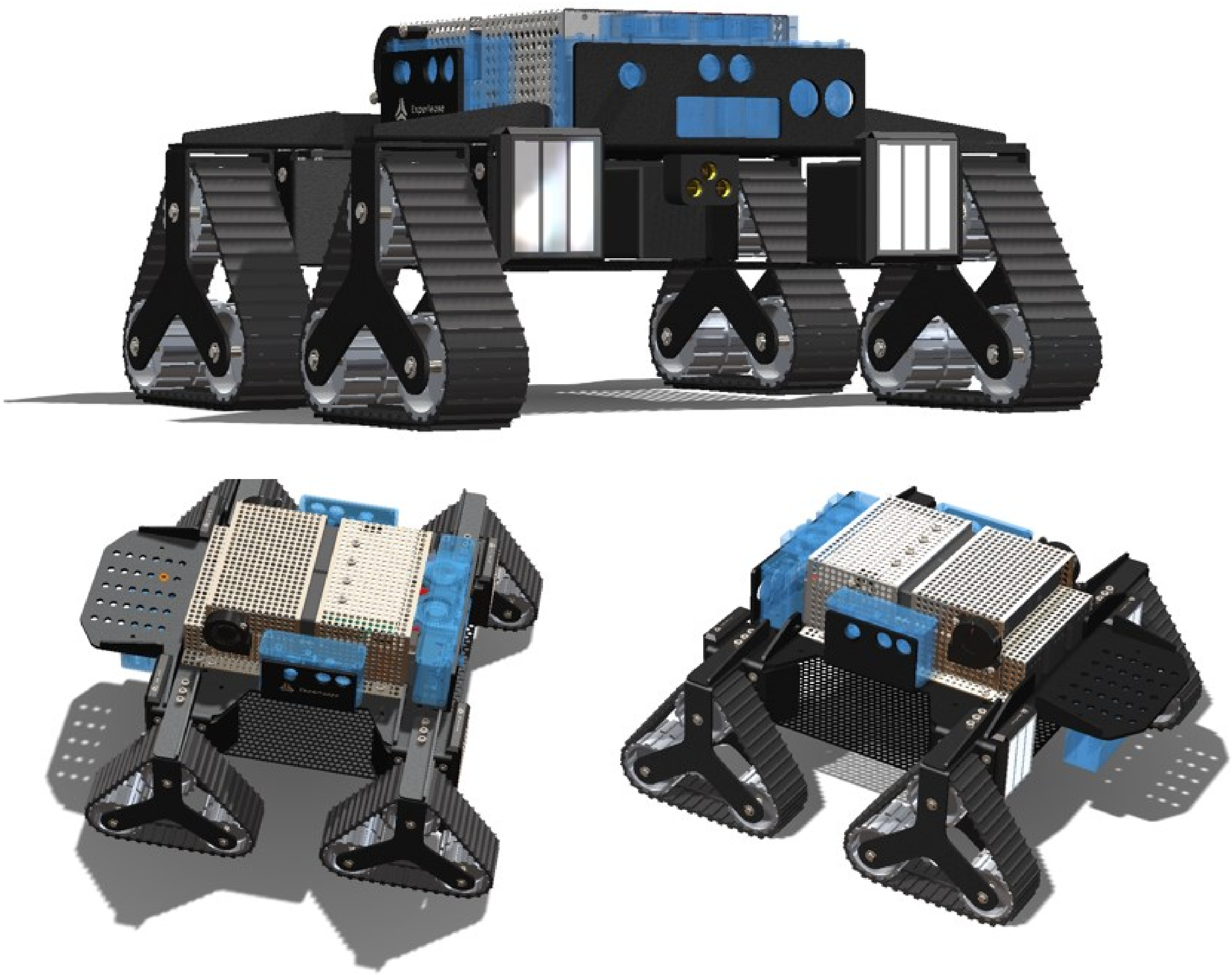


Figure 83: Side electronics boxes incorporated into the robot.

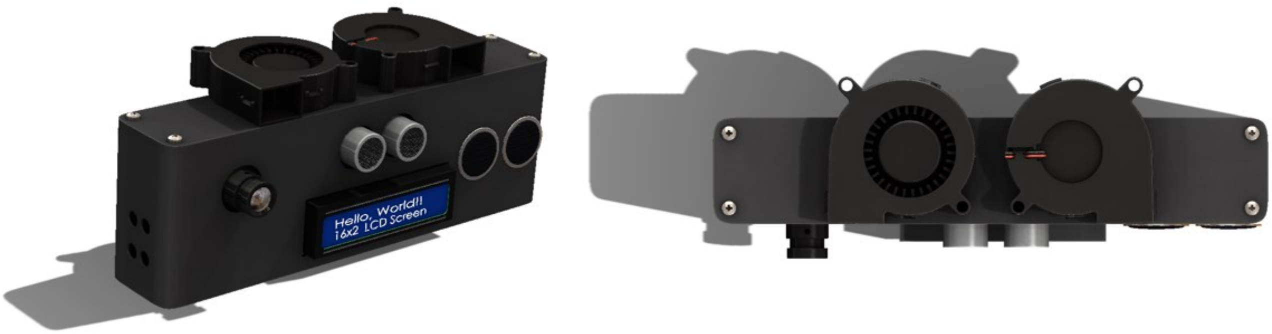


Figure 84: Box incorporating electronics of the back side.

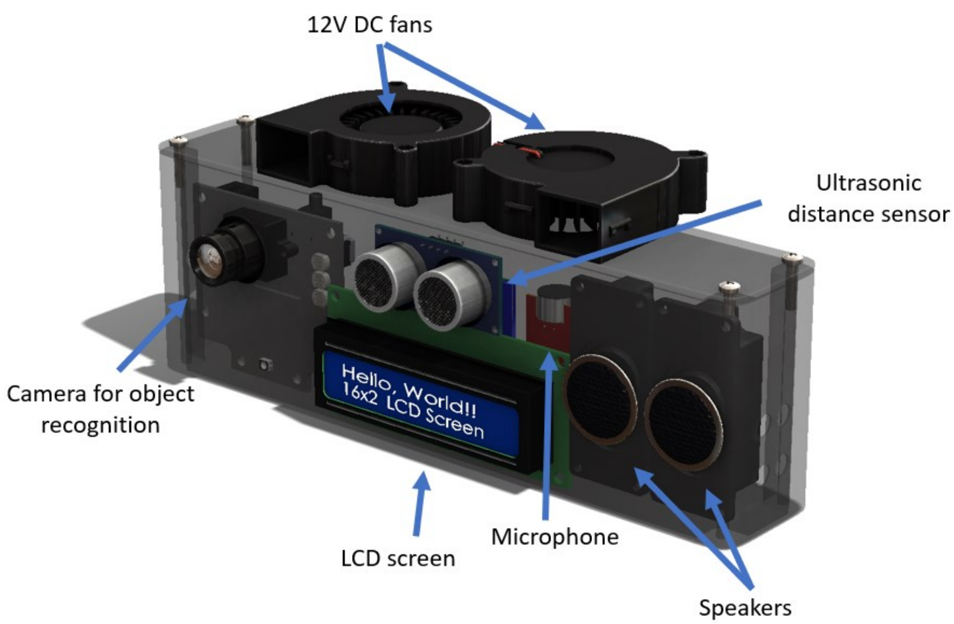


Figure 85: Inside oh the rear electronics box.

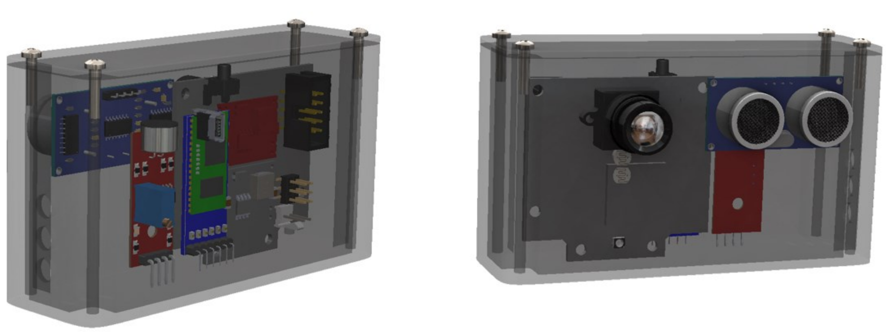


Figure 86: Side electronics in their box. Three of them, identical, will be place on the robot.

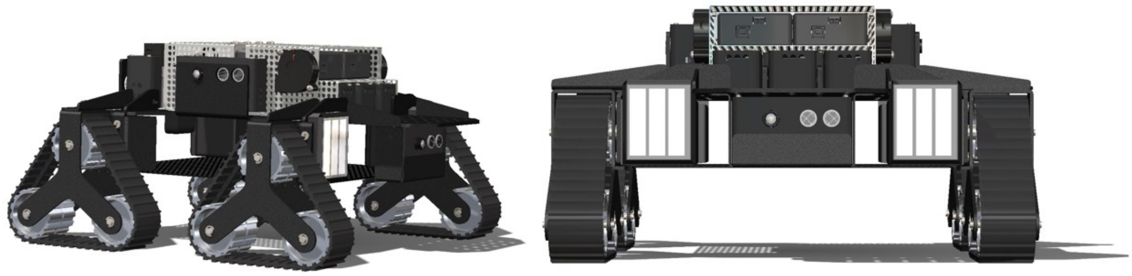


Figure 87: Electronics boxes on the sides, mounted on special openings o the frame.

<u>Up cover:</u>

Finally, a 1.5mm steel cover will protect all the electronics from the elements. On the surface, a solar panel is mounted. Eight solar panel, 5v and 200mA each, can provide of 50W clean energy, enough to keep up the standby processes, communications of the robot when it is not moving. The cover has openings for the other components, bases so it can be fixed on the chassis and, the logos, and a push button for on/off function. Moreover, other pars can be mounted on top, like chariots, a basket to collect thinks, or transport goods, supplies, parts etc.

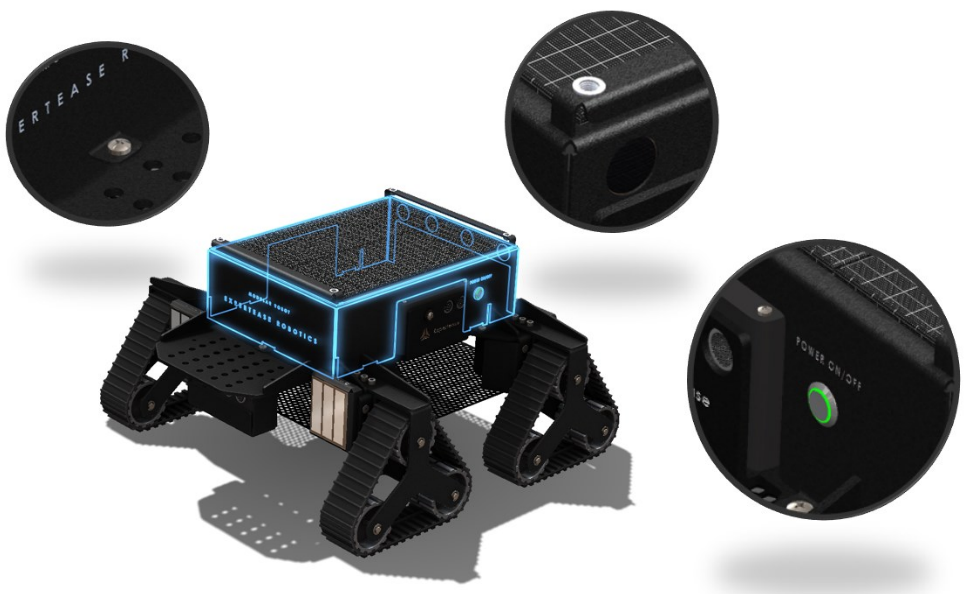


Figure 88: Up cover with its features.

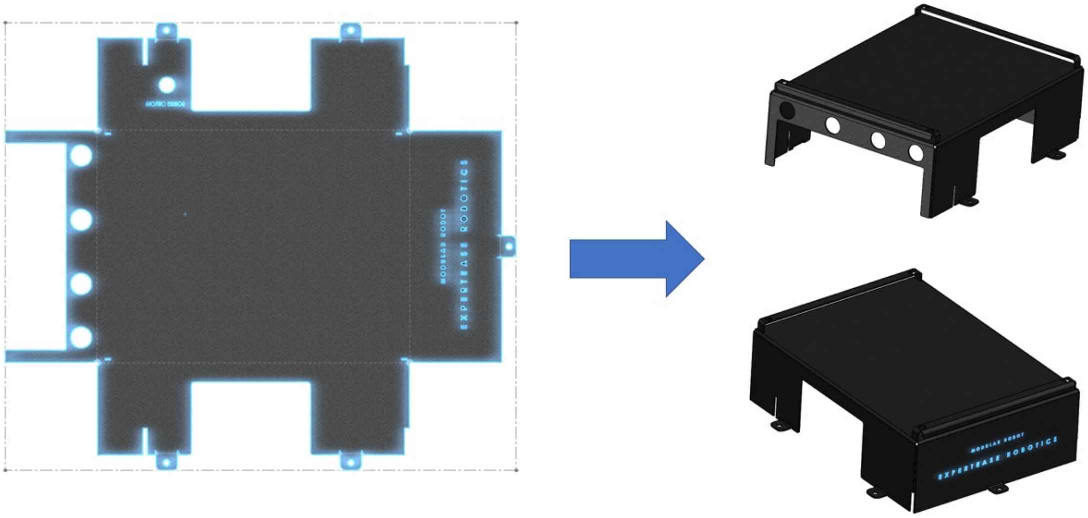


Figure 89: Up cover from 1.5mm steel with supportive brackets. 1.54kg, 295 x 220 mm

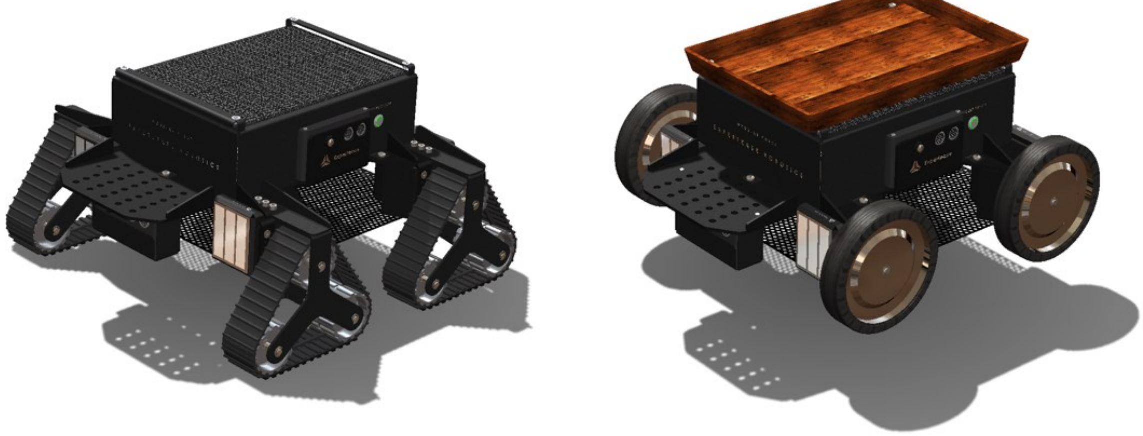
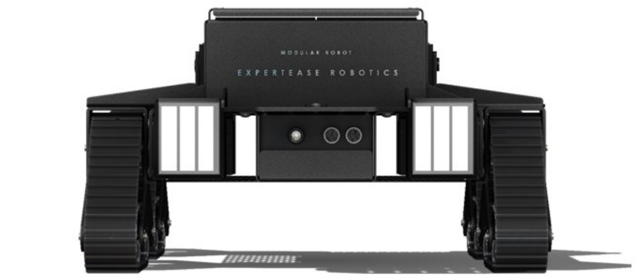
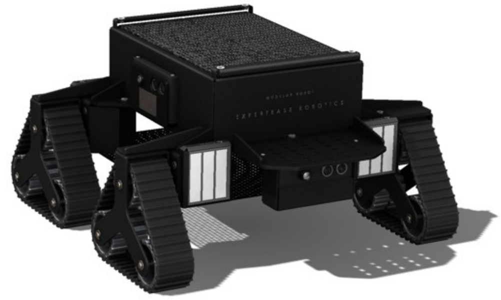
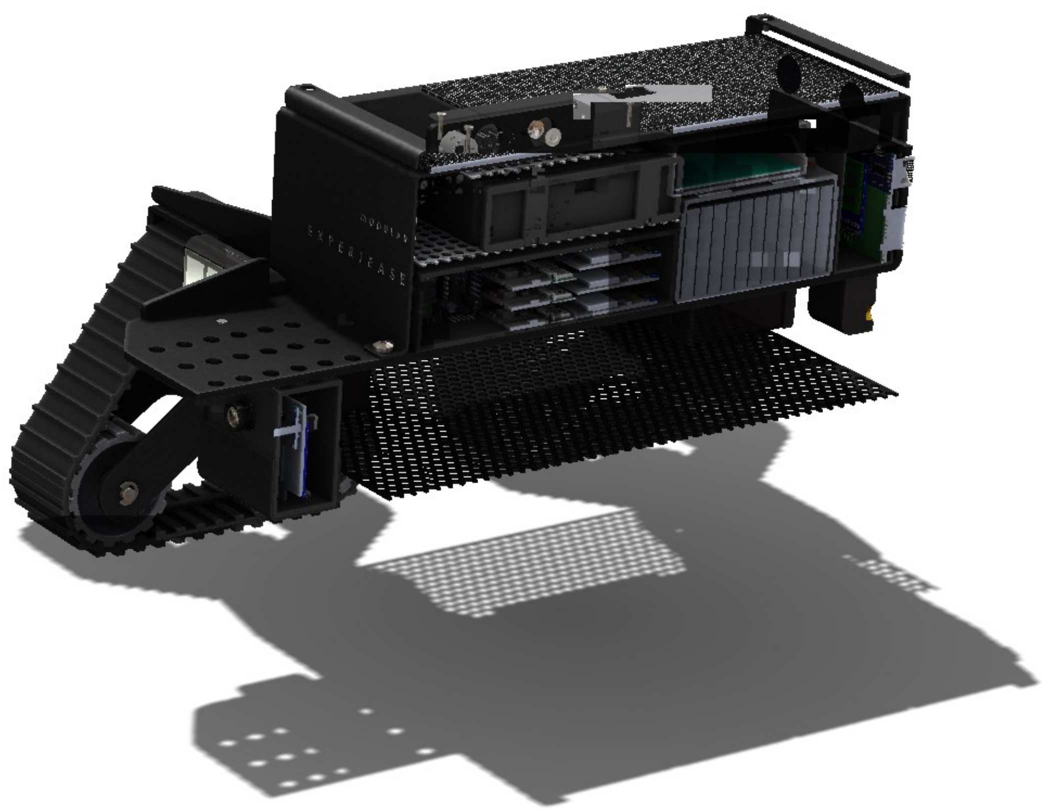


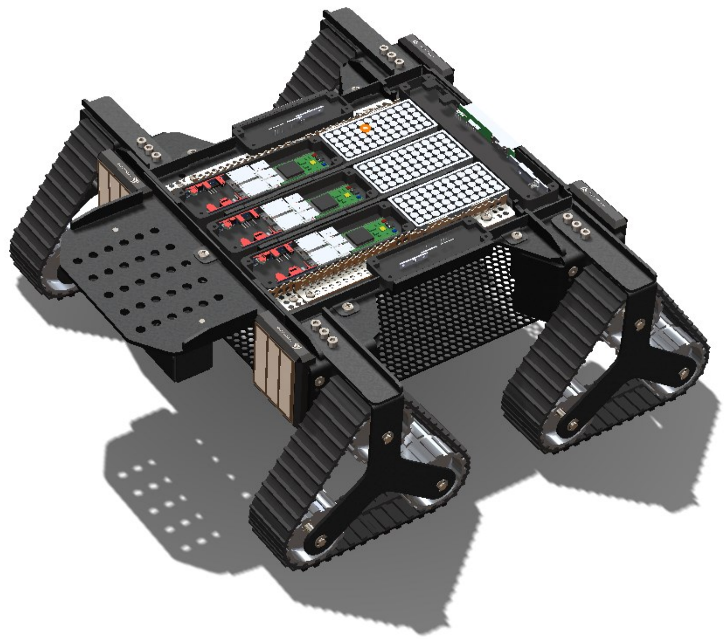
Figure 90: Two different use of the modular robot, one on the left incorporating a wooden basket on its top and having normal wheels, while on the left we have tracked wheels and solar panels on its top.

Photos of the robot without the robotic arms



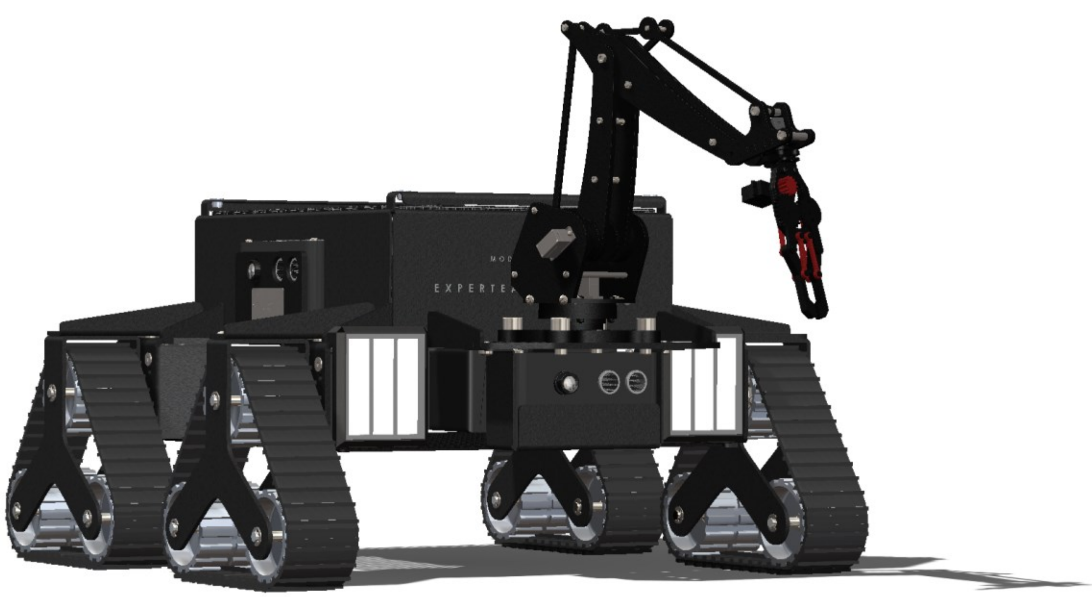


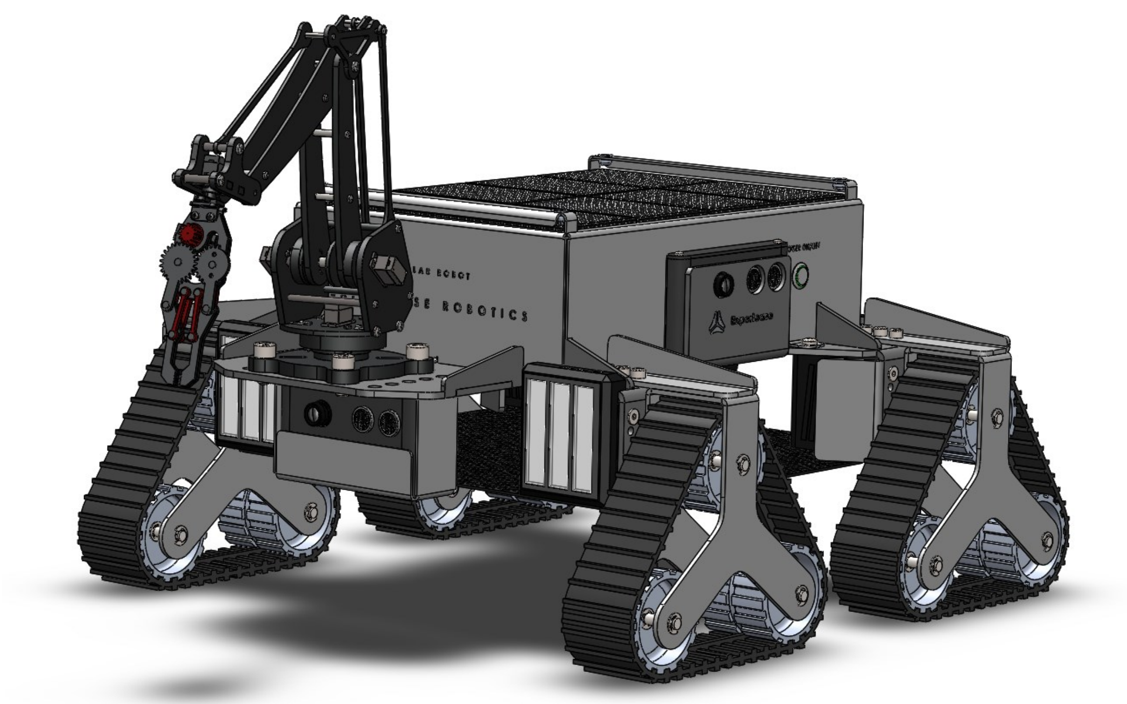


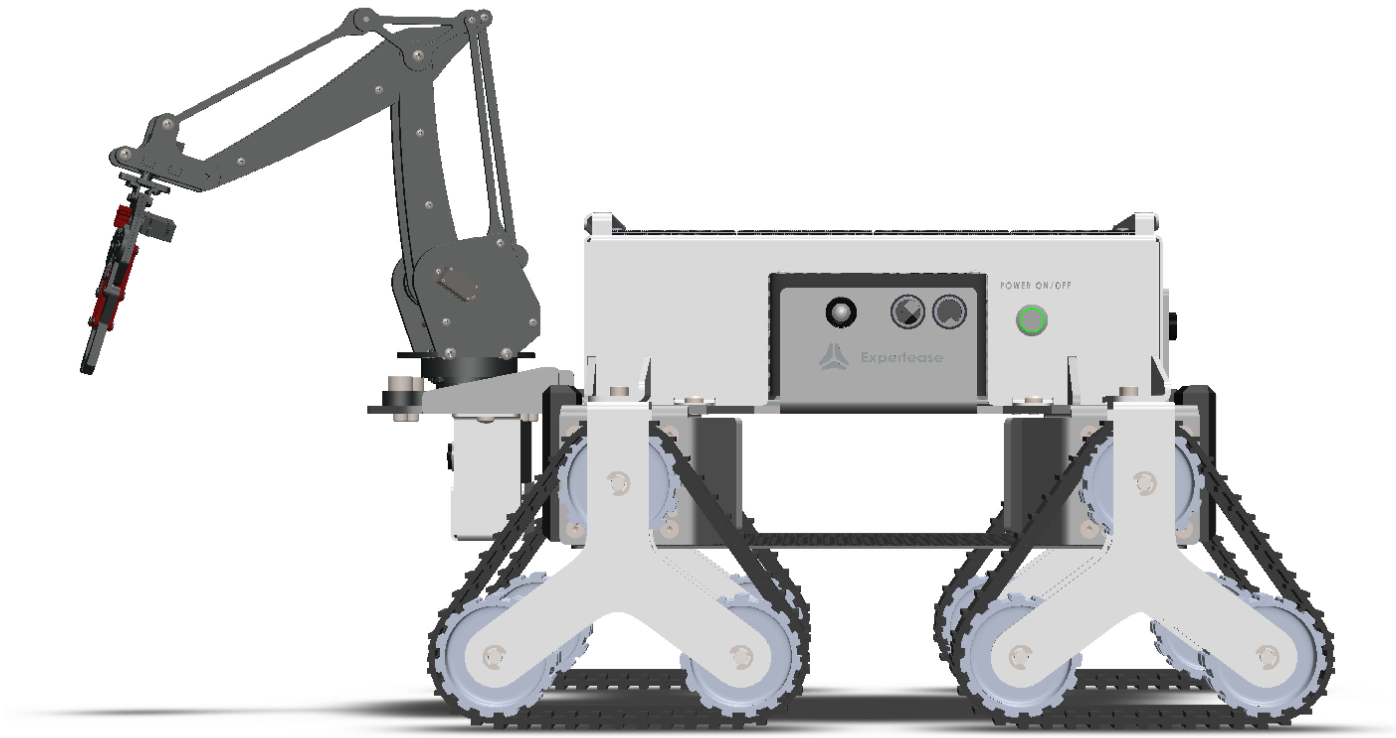


Robotic Arms 1:

Different types of arms and of grippers can be mount on the base and get connected to the board. There are enough electronics power to drive even a 6-axis arm. We will see some of the designed concepts in different combinations below. The first one, a simple articulated arm, having rotating base, lift up, and rotating gripper, all moved with servomotors. This configuration is ideal for consuming less power, exploration, search and rescue, but it can be slow for repetitive operation where speed is key or in cases where there is great need for high accuracy movements.



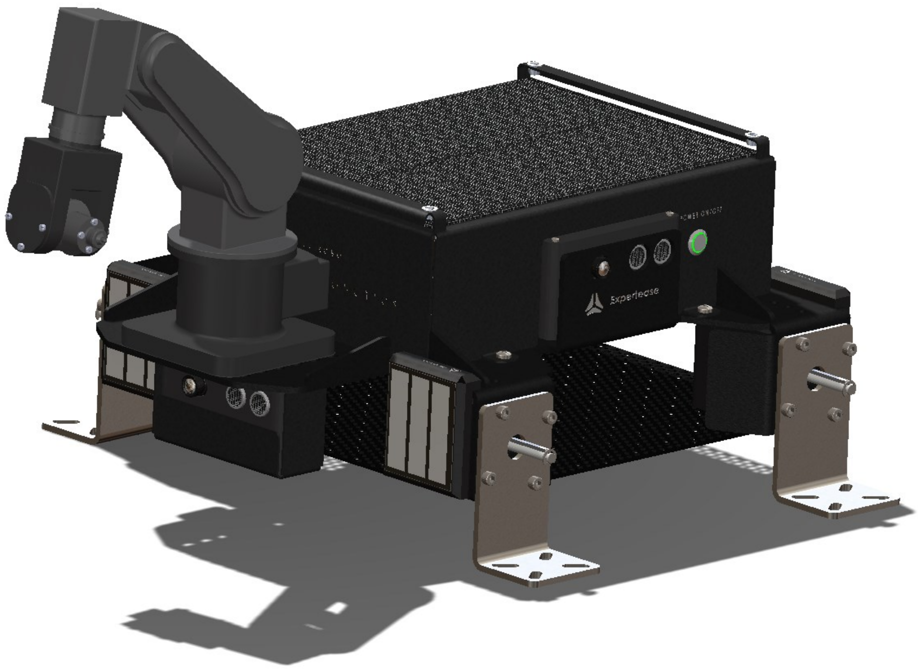


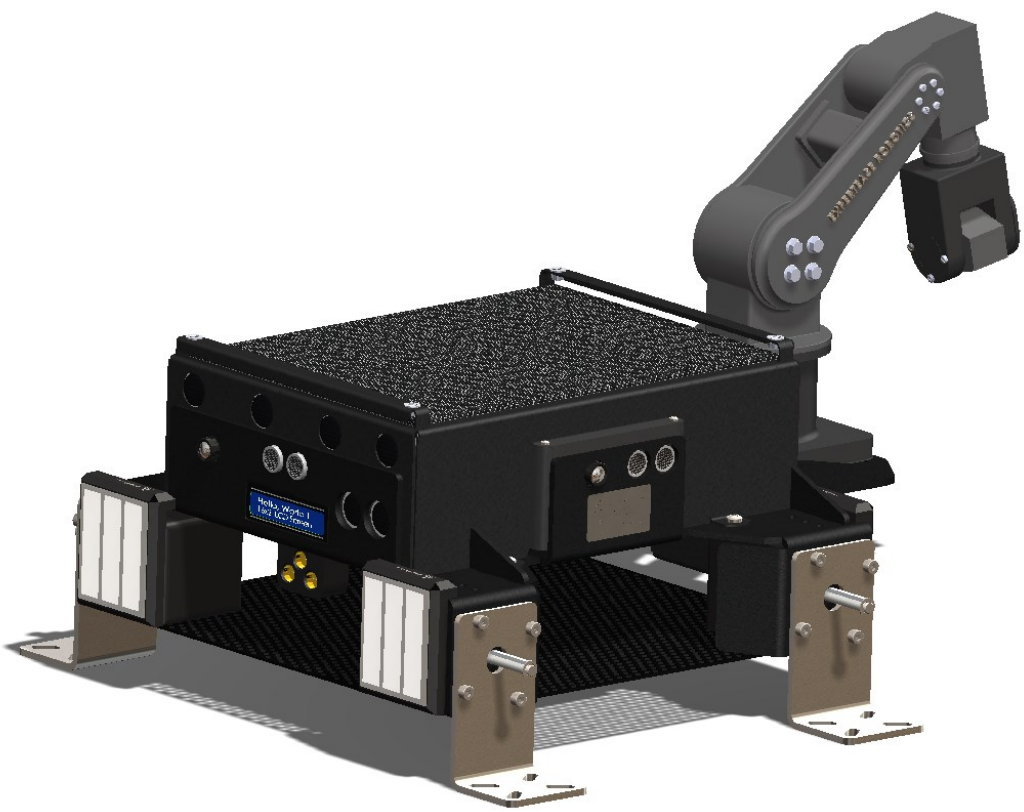

POWER ON/OFF
Expertease


Expertease

Robotic Arm 2:

A more expensive, more sophisticated arm suitable for fast response projects, and also for the stationary configuration. An idea would be to mount the robot on the special bases, and allow it to perform a repetitive task fast, or do precision work, handle tools etc.

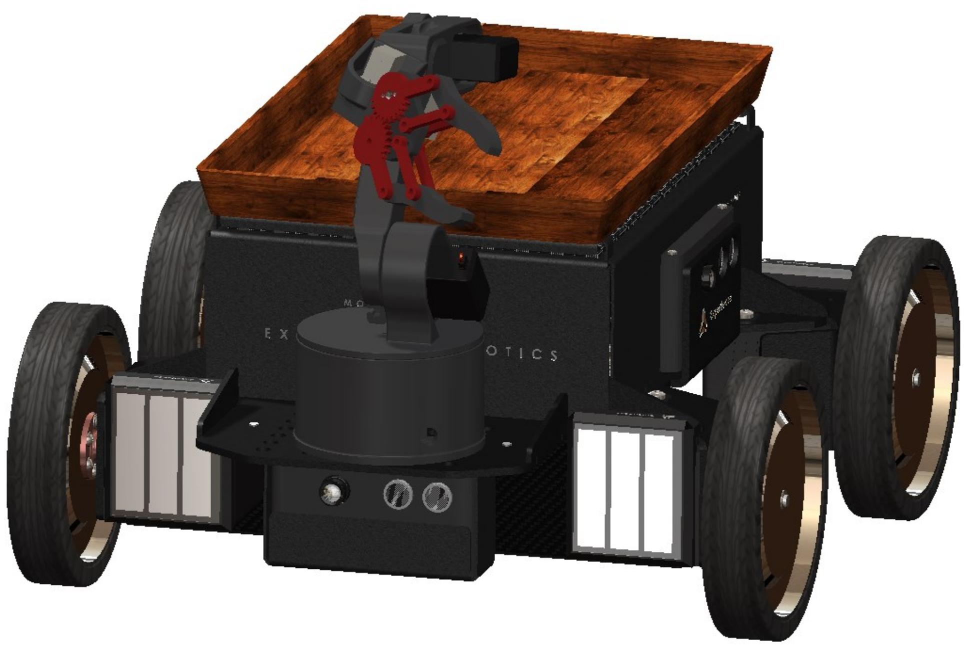




Robotic Arm 3:

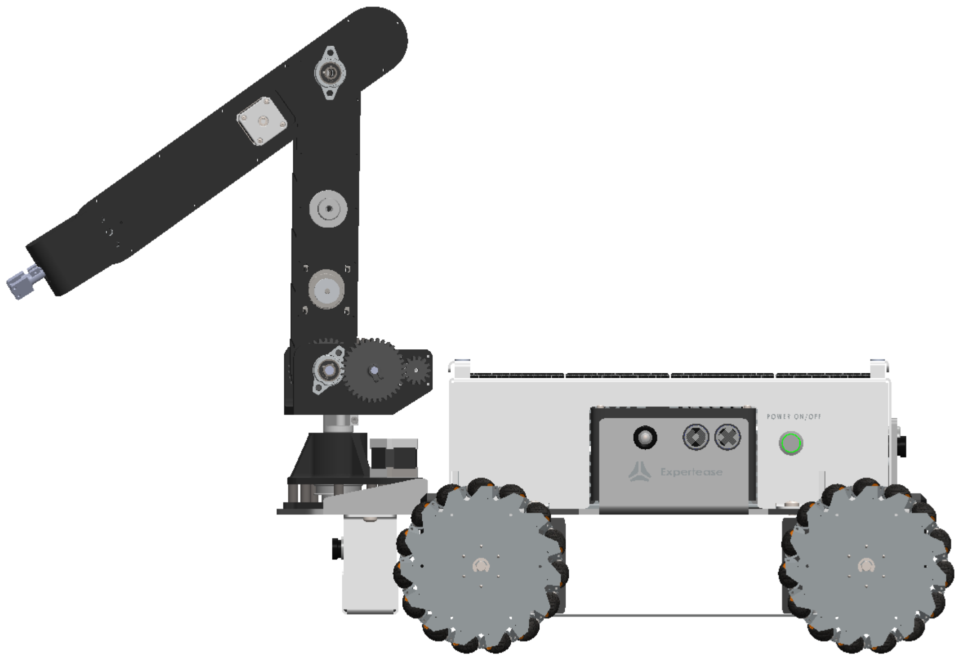
A robotic arm with bigger servomotors, rotating base and 6 axis movements. Suitable for pick and collect operations.

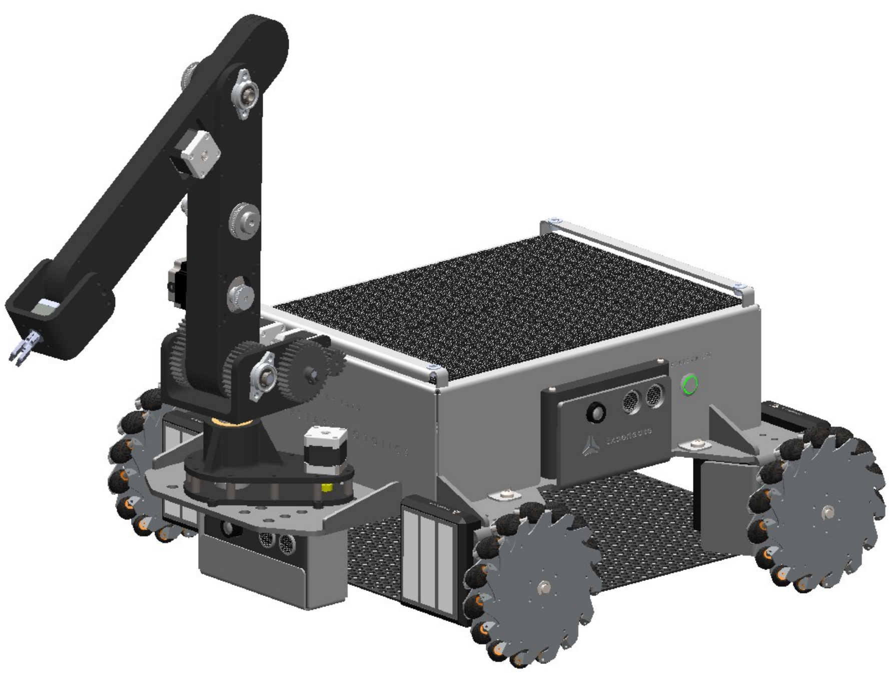

Experlease

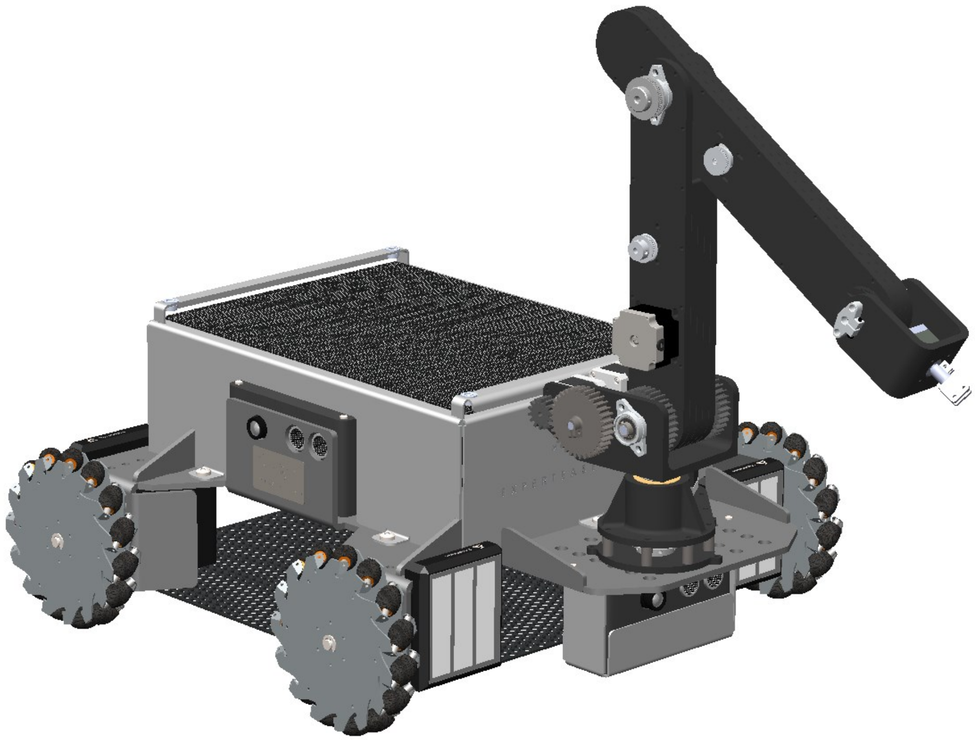


Robotic arm 4:

A final concept, with a solid robotic arm, big stepper motors instead of servo motors, suitable for lifting heavy objects, like a crane. A configuration presented with the omni wheels for representation, and grey colour.







9. Conclusions

An attempt to design a modular robotic system was presented in this thesis. We can see that the final result is exactly this, a system that can be adjusted to the need of the user. We have designed a base with flexibility in electronics, robust, reduced assembly, and versatile design. This design incorporated 3 different types of moving wheels, and 5 different robotic arms. The thesis focuses on the design aspects of the system, and an extensive benchmark of existing products, electronics, parts and sensors used in robotic systems. In some future work, maybe the following aspects that are not touched in this thesis could be also reviewed:

- An overview explaining the products' place in the market and intentions behind its creation
- Performance considerations
- Target audience
- Financial and time restrictions
- Questions/considerations
- Product life span
- Quantity
- Maintenance

- Packaging
- Shipping
- Size and weight restrictions
- Manufacturing process
- Aesthetics
- Ergonomics
  Reliability
- Safety and standards
- Testing
- Disposal/recycling

Moreover, it could be very interesting to raise funding for creating a physical prototype, for industrial, academic, or educational purposes. Certainly, many improvements of the initial design could be spotted after the prototype, and a second improved version could be an actual industrial project for the future. Surely, with further optimization on the shape and more calculations, great weight reduction is possible, since in the current project the goal was to create a concept from scratch, not to optimize all parts to the maximum degree. Another promising idea, it could be to create a version of the device that it can be 3D printed. A smaller 3D printed version can serve as teaching model for universities labs or exhibition model.

As stated in the beginning of this work, it was out of the scope of this project to deal with the accurate control of the electrical and electronic parts. With the creation of a prototype, a team could be focused on the development of the special algorithms and accurate calibration of all the automatic systems. Finally, following the tendency of our times, maybe a smart application could be created to accurately control the device and collect the necessary data. One step further could be to use 5G, upload the data in real time to the cloud and maybe perform real time smart analysis. AI or deep learning models could be created, that would analyze the study the input from the robot in order to produce the right output.

After the prototype creation, if there is any possibility for commercialization of the project, there could be some steps more towards this direction. For example, some good ideas could be to create the necessary CE folder and try to patent the device at least in the European Union Countries.

10. References

1. *Watch out for these Top 10 Micro-Robots that could potentially alter the Future of Robotics*. (2021, January). Found in circuitdigest: https://circuitdigest.com/article/top-10-micro-robots-changing-the-future-of-robotics
2. *2020: The Year Ahead In 3D (Printing)*. (2019). Found in www.forbes.com: https://www.forbes.com/sites/marcoannunziata/2019/12/17/2020-the-year-ahead-in-3d-printing/
3. ACKERMAN, E. (2016, Dec). *MIT's Modular Robotic Chain Is Whatever You Want It to Be*. Found in https://spectrum.ieee.org: https://spectrum.ieee.org/modular-robotic-chain-is-whatever-you-want-it-to-be
4. Adeept. (2022). *Adeept RaspTank Pro Robot Car Kit*. Found in Addept.com: https://www.adeept.com/adeept-rasptank-pro-robot-car-kit-wifi-wireless-smart-robot-for-raspberry-pi-4-3-3b-3-dof-robotic-arm-opencv-target-tracking-video-transmission_p0245.html
5. *Articulated Robotic Arm*. (2020). Found in www.pishrobot.co: https://www.pishrobot.com/en/product-en/pishrobot-arms/
6. Ayari, N. (2017). *A semantic approach to enhance human-robot interaction in Aml Environemtns.*
7. Bernier, C. (2014, Jul). *Magnetic Robot End Effector: Top 5 Pros and Cons*. Found in blog.robotiq.com: https://blog.robotiq.com/bid/65794/Magnetic-Robot-End-Effector-Top-5-Pros-and-Cons
8. BERNIER, C. (2021, December). *Articulated Robots: A Guide to the Most Familiar Industrial Robot*. Found in www.howtorobot.com: https://www.howtorobot.com/expert-insight/articulated-robots
9. Bouchard, S. (2011, Aug). *Servo-Electric Grippers: How does it Work?* Found in blog.robotiq.com: https://blog.robotiq.com/bid/37839/Servo-Electric-Grippers-How-does-it-Work
10. Choset, H. (2022). *Modular Robots*. Found in https://www.ri.cmu.edu: https://www.ri.cmu.edu/project/modular-robots/
11. CLEAR-Lab . (2019, May). *Legged Locomotion*. Found in wzhanglab: https://www.wzhanglab.site/research/legged-robots/
12. Davis, L. (2021, April). *4 Types of robotic grippers and their Pros and Cons*. Found in metapress.com: https://metapress.com/4-types-of-robotic-grippers-and-their-pros-and-cons/
13. Distributed Robotics Laboratory. (2018, Feb). *M-Blocks Modular Robotics*. Found in www.csail.mit.edu: https://www.csail.mit.edu/research/m-blocks-modular-robotics
14. dji. (2022). *robomaster*. Found in www.dji.com: https://www.dji.com/gr/robomaster-s1

15. Geddes, D. (2022). *What is a product design specification (PDS)?* Retrieved from /www.technicalfoamservices.co.uk: https://www.technicalfoamservices.co.uk/blog/what-is-a-product-design-specification-pds/
16. generationrobots. (2022). *TECDRON TC200 mobile robotic platform*. Found in www.generationrobots.com: https://www.generationrobots.com/en/403498-tecdron-tc200-mobile-robot-without-arm.html
17. Goodwin, D. (2022, August). *Technology Differences: Stationary Robots vs Mobile Robots*. Found in control: https://control.com/technical-articles/technology-differences-stationary-robots-vs-mobile-robots/
18. greecehighdefinition. (2017, Junuary). *MEET TALOS, THE KILLER ROBOT FROM ANCIENT GREEK MYTHOLOGY*. Found in www.greecehighdefinition.com: https://www.greecehighdefinition.com/blog/meet-talos-the-killer-robot-from-ancient-greek-mythology
19. Green, T. (2023, September). *What's New in Robotics?* . Found in robotiq.com: https://blog.robotiq.com/whats-new-in-robotics-23.09.2022
20. *Grippers For Robots*. (2022). Found in www.robots.coμ: https://www.robots.com/articles/grippers-for-robots
21. Hauert, S. (2018, December). *Growing bio-inspired shapes with a 300-robot swarm*. Found in robohub.org: https://robohub.org/growing-bio-inspired-shapes-with-a-300-robot-swarm/
22. HENEY, P. (2016, June). *Where are pneumatic grippers used?* Found in www.pneumatictips.com: https://www.pneumatictips.com/pneumatic-grippers-used/
23. heurio. (2022). *Dieter Rams' 10 Principles of Good Design*. Found in www.heurio.co: https://www.heurio.co/dieter-rams-10-principles-of-good-design
24. Huenit. (2022, September). *HUENIT - AI camera & modular robot arm*. Found in https://www.kickstarter.com/projects/huenit/huenit-ai-camera-and-modular-robot-arm
25. HVR MAG. (2021, May). *Electromagnetic Gripper for Robot – The What & How About It*. Found in www.hvrmagnet.com: https://www.hvrmagnet.com/blog/electromagnetic-gripper-for-robot-the-what-how-about-it/
26. ID MTL. (2020). *Medical Nano Robot*. Found in https://ville.montreal.qc.ca: https://ville.montreal.qc.ca/idmtl/en/medical-nano-robot/
27. *igus® Robot Control Software: program and control robots*. (2022). Found in www.igus.eu: https://www.igus.eu/info/robot-software
28. *Industrial Robots*. (2020). Found in www.neptunesystem.in: https://www.neptunesystem.in/industrial-robots.html
29. Jablonski, C. (2011, November). *Soft robot uses air to move*. Found in Zdnet.com innovation: https://www.zdnet.com/article/soft-robot-uses-air-to-move/
30. Javaid, A. (2022, Feb). *Which Arduino board is best for me?* Found in inuxhint.com: https://linuxhint.com/which-arduino-is-best/
31. *Jointed Spherical (Articulated Arm) Robots*. (2008, August). Found in www.industrial-electronics.com: https://www.industrial-electronics.com/industrial-electricity-com/7_Jointed_Spherical.html
32. K, H. P. (2020). *Choosing Batteries for Robots*. Found in /www.engineersgarage.com: https://www.engineersgarage.com/choosing-battery-for-robots/

33. Ken, N. (2016). ChainFORM, a linear integrated modulat Hardware sytem fro shape changing.
34. Kent, R. (2016). *Design quality management*. Found in www.sciencedirect.com: https://www.sciencedirect.com/topics/engineering/product-design-specification
35. KINMORE PRODUCTS. (2022). *PMDC Motor*. Found in kinmore.com: https://kinmore.com/product/pmdc-motor/?gclid=EAIaIQobChMI07_K0a3i-gIV1Mc7Ah0cYQYtEAEYASAAEgLsHvD_BwE
36. *Laser cutting as a contact-free slitting process*. (2022). Found in www.trumpf.com: https://www.trumpf.com/en_GB/solutions/applications/laser-cutting//
37. lasered. (2022). *THE HISTORY OF LASER CUTTING*. Found in lasered.co.uk: https://lasered.co.uk/news/history-of-laser-cutting/
38. Le, J. (2017, September). *Robot Arm DIY only $30 CNC shield control stepper and servo motor and first test*. Found in www.youtube.com: https://www.youtube.com/watch?v=vRAaXrJJf6s
39. LSN Global. (2014). *CES: BLOCK BOTS: MODULAR ROBOTICS CREATES SIMPLE ROBOT SET FOR GEN*. Found in /www.lsnglobal.com: https://www.lsnglobal.com/news/article/8770/ces-block-bots-modular-robotics-creates-simple-robot-set-for-gen-i
40. Mayor, A. (2022). *The World's First Robot: Talos*. Found in www.wondersandmarvels.com/: https://www.wondersandmarvels.com/2012/03/the-worlds-first-robot-talos.html
41. mechspdcm. (2021, December). *5 Advantages of Spider Legs Over Other Robot Designs*. Found in mechanicalspide: http://www.mechanicalspider.com/5-advantages-of-spider-legs-over-other-robot-designs/
42. MIKE GUELKER, T. S. (2012, June). *Where, when to apply pneumatic actuation*. Found in www.controleng.com: https://www.controleng.com/articles/where-when-to-apply-pneumatic-actuation/
43. Moravec, H. P. (2022, April). *robot*. Found in Encyclopedia Britannica: https://www.britannica.com/technology/robot-technology
44. Mundrathi, R. (2021, MAY). *DC Motor, Advantages, Disadvantages, Applications, Working*. Found in www.cselectricalandelectronics.com: https://www.cselectricalandelectronics.com/dc-motor-advantages-disadvantages-applications-working/
45. *NIRYO NED ROBOT*. (2022). Found in https://www.robot-advance.com/: https://www.robot-advance.com/EN/art-niryo-ned-robot-3315.htm
46. Ogrodnik, P. J. (2015). *Conceptual Phase*. Found in www.sciencedirect.com/: https://www.sciencedirect.com/topics/engineering/product-design-specification
47. pfa-inc. (2022). *What is a Vacuum Gripper?* Found in www.pfa-inc.com: https://www.pfa-inc.com/what-is-a-vacuum-gripper/
48. Quantum Robotics. (2022). *UNIVERSAL ROBOTS: EASY AUTOMATION WITH COLLABORATIVE ROBOTS*. Found in www.quantumrobotics.com: https://www.quantumrobotics.com.au/universal-robots/
49. Robot Enthusiast. (2022, January). *Magswitch CoBot SmartMagGrip E30 Magnetic Gripper*. Found in www.robothusiast.com: https://www.robothusiast.com/magswitch-cobot-smartmaggrip-e30-magnetic-gripper/

50. robot.cfp.co. (2022). *robots swimming*. Found in robot.cfp.co: https://robot.cfp.co.ir/en/robots/swimming
51. RobotPark Academy. (2022). *MODULAR Robots*. Found in RobotPark: http://www.robotpark.com/academy/all-types-of-robots/modular-robots/
52. *Rover Robot - Arduino and Lasercut Plywood*. (2020). Found in www.instructables.com: https://www.instructables.com/Rover-Robot-Arduino-and-Lasercut-Plywood/
53. SOFFAR, H. (2019, March 3). *Wheeled robots types, uses, advantages and disadvantages*. Found in www.online-sciences.com: https://www.online-sciences.com/robotics/wheeled-robots-types-uses-advantages-and-disadvantages/
54. *Talon Military Robot*. (2020). Found in www.gizmohighway.com: https://www.gizmohighway.com/robotics/talon-military-robot.htm
55. Tameson. (2022). *Pneumatic Gripper - How They Work*. Found in Tameson.com: https://tameson.com/pneumatic-gripper.html
56. *Top 10 sensors which can be integrated into Arduino*. (2018). Found in forumautomation.com: https://forumautomation.com/t/top-10-latest-sensors-which-can-be-integrated-with-arduino/10412/1
57. *Types of Robot Sensors*. (2022). Found in www.robotplatform.com: https://www.robotplatform.com/knowledge/sensors/types_of_robot_sensors.html
58. Uraga, C. (2017). *From connected robots to connected components — Modularity has arrived*. Found in medium.com: https://medium.com/@curaga1/from-connected-robots-to-connected-components-modularity-has-arrived-f8ac9d480cd3
59. *What is Servo Motor – Advantages, Disadvantages Applications*. (2020). Found in robu.in: https://robu.in/what-is-servo-motor/
60. *What Is Stepper Motor?* (2020, April). Found in robu.in: https://robu.in/what-are-the-advantages-disadvantageous-of-the-stepper-motor/
61. *Wheels vs Continuous Tracks: Advantages and Disadvantages*. (2013, May). Found in www.intorobotics.com: https://www.intorobotics.com/wheels-vs-continuous-tracks-advantages-disadvantages/
62. *When Was 3D Printing Invented? The History of 3D Printing*. (2020, May). Found in www.bcn3d.com: https://www.bcn3d.com/the-history-of-3d-printing-when-was-3d-printing-invented/
63. Wikipedia. (2022, September). Found in Wikipedia.com: https://en.wikipedia.org/wiki/Robot
64. www.destaco.com. (2022). *Pneumatic Automation Grippers*. Found in www.destaco.com: https://www.destaco.com/gripping/pneumatic-automation-grippers.html

11. Appendix

Rectangular Concept

A rectangular concept that was abandoned shortly after the first's designs presented, were we tried to reduce welding as much as possible. Welding can save space and weight, but on the other hand, they are stoppers in manufacturing process and require skillful workers. Also, will make the repair more difficult in case of failure, thus by design, we will try to eliminate them and use standard fasteners instead. Moreover, a good design incorporates as many identical parts as possible, and as much symmetry as possible, to facilitate maintenance and assembly process.

To facilitate assembly, all fasteners will be the same diameter, specifically 6mm X12mm length will be the standard chosen fastener, that is good for most of the applications. Giving tight dimensions to the openings (eg 6.5mm) we will be able to reduce play between parts. We will try to use the same kind of fasteners, and prioritize allen screws, to make sure that simple tools can be used for assembly and repair and also save space. Also, an important detail will be the use of safety nuts, to make sure no nut is going to be loose during operation. Finally, we will avoid the use of washers, when possible, in order to speed up the assembly process and save space and weight. Instead, we shall use washer head nuts in most of the cases.

In the following image, we can see the start of the monobasic, starting to take shape. As stated, the idea is to have bolted parts connected to create a solid structure. In the image we can see an early design of the base, with the four supporting parts (highlighted) to hold the structure together.

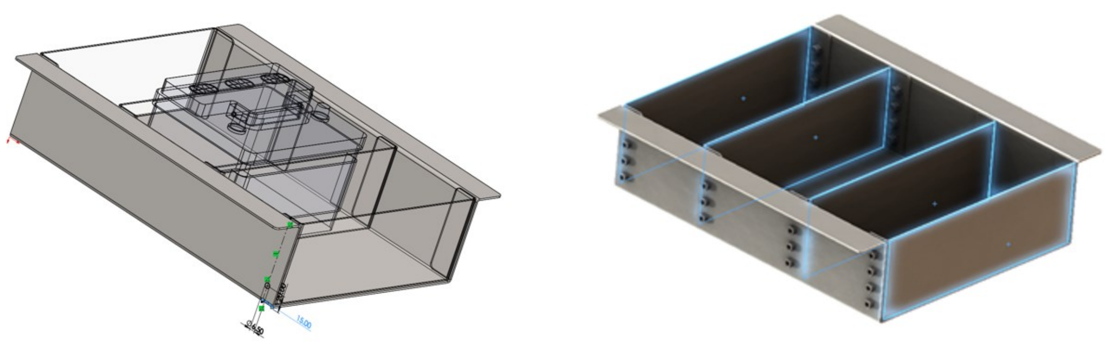


Figure 91: Early design of the base with the supporting flaps.

The base can be made either from standard 2mm carbon steel and then paint it to make it rust free, or directly from stainless steel. Since we will not be using any welding, the robot must operate in palces with moisture and must be rust free, we will choose the solution of the stainless steel. Stainless steel might be more expensive than carbon steel, but we will eventually save from the painting of the parts, gaining in manufacturing time, weight and of course, paint cost.

The supporting flaps will be laser cut and brake pressed as the monobasic. Symmetric openings of 6.5mm at 10mm will be prepared to reduce wight and facilitate bolting parts. Also, openings for the electronics will exist.

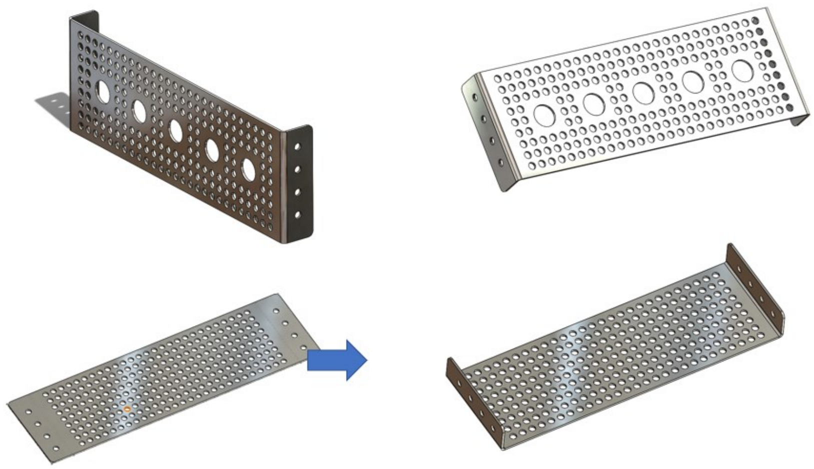


Figure 92: Metal support flaps with openings for electronics, screws, and weight reduction. Stainless steel, 2mm.

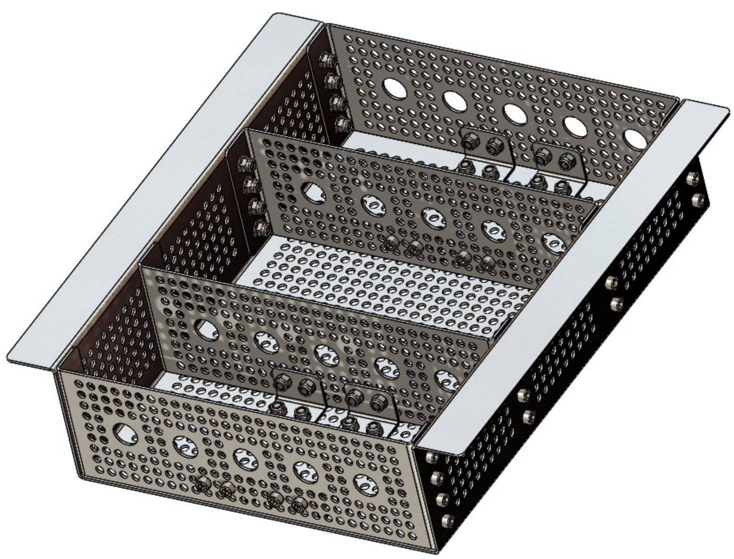
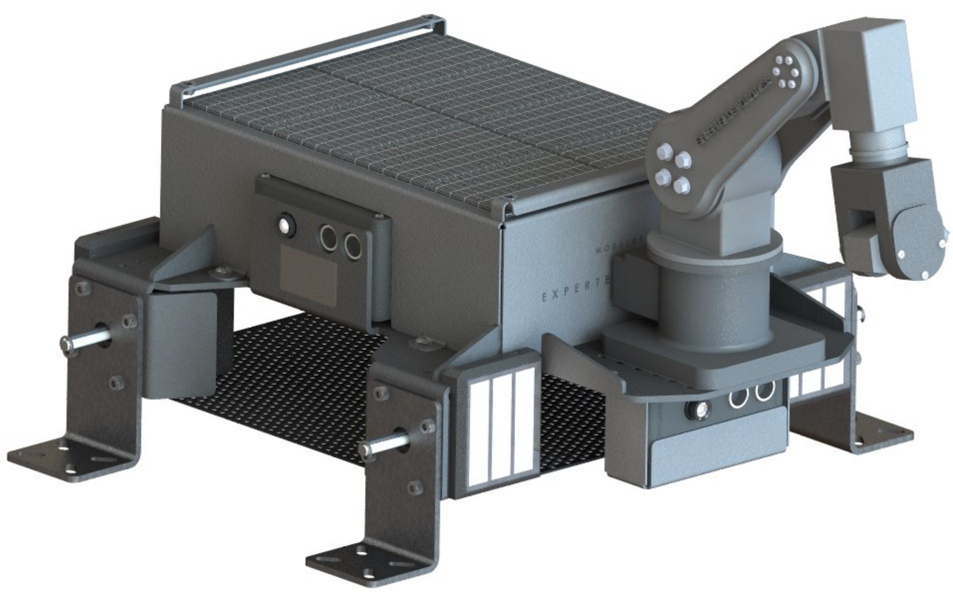
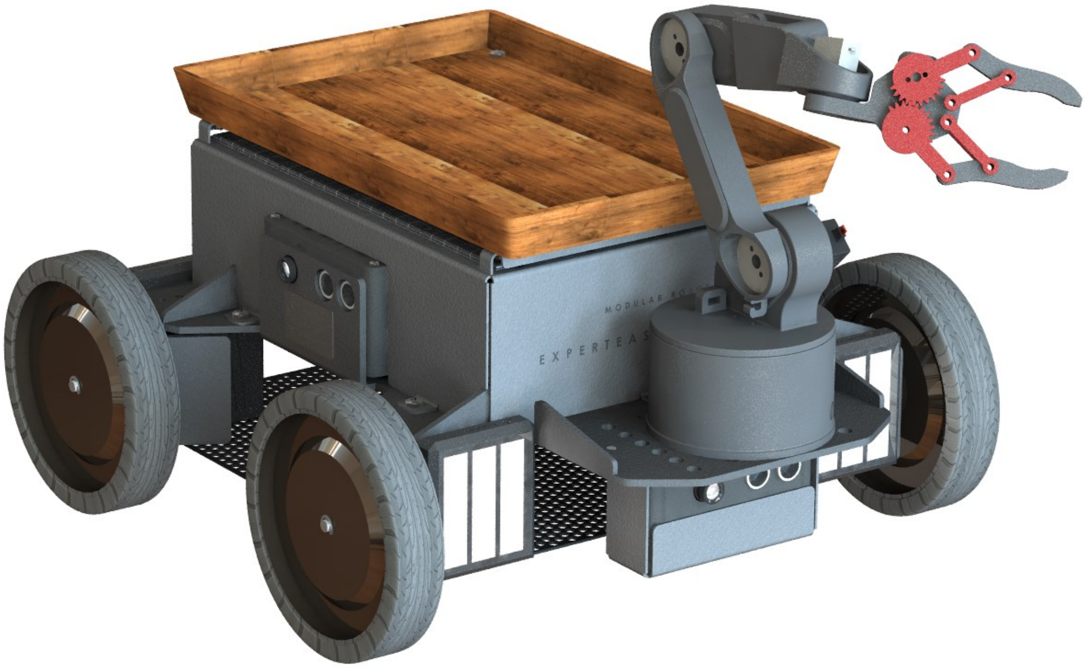


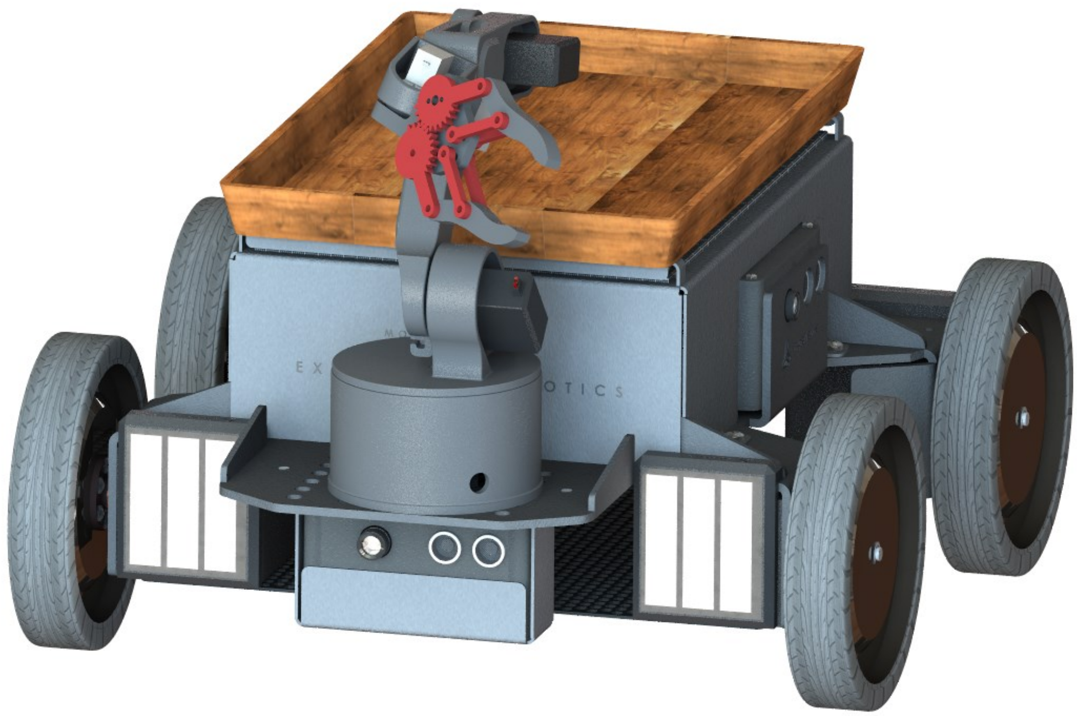
Figure 93: Final monobase design with support flaps and openings, 400mmx300mm from mm stainless steel, weighting 8kg and will be the heaviest of the parts.

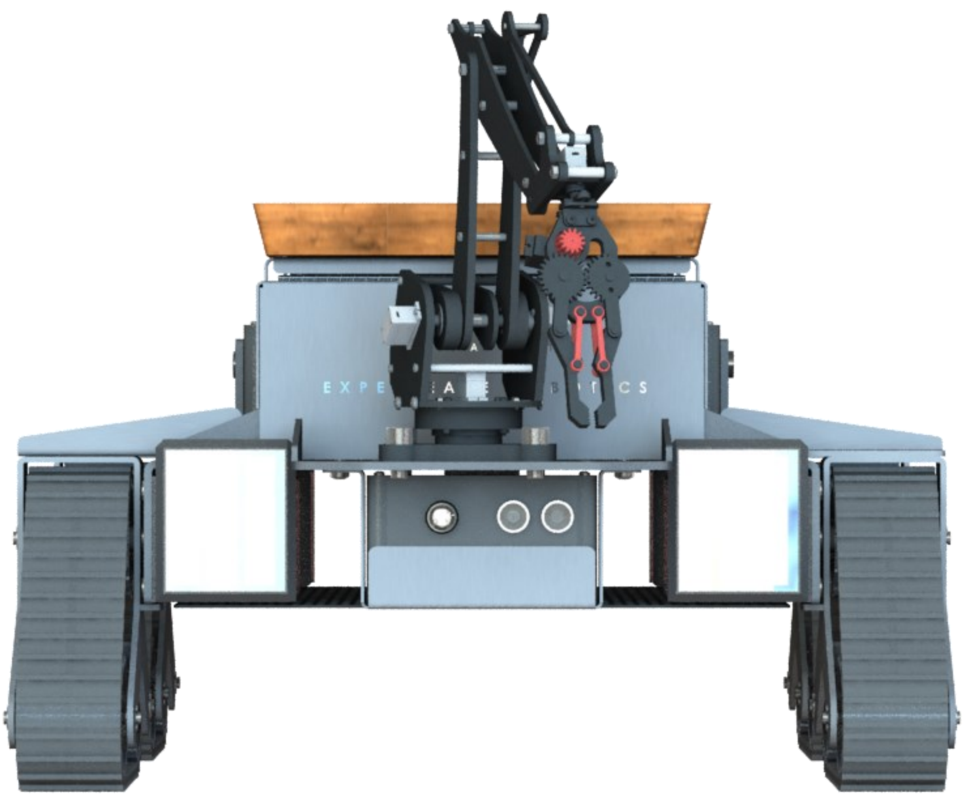
High Resolution images



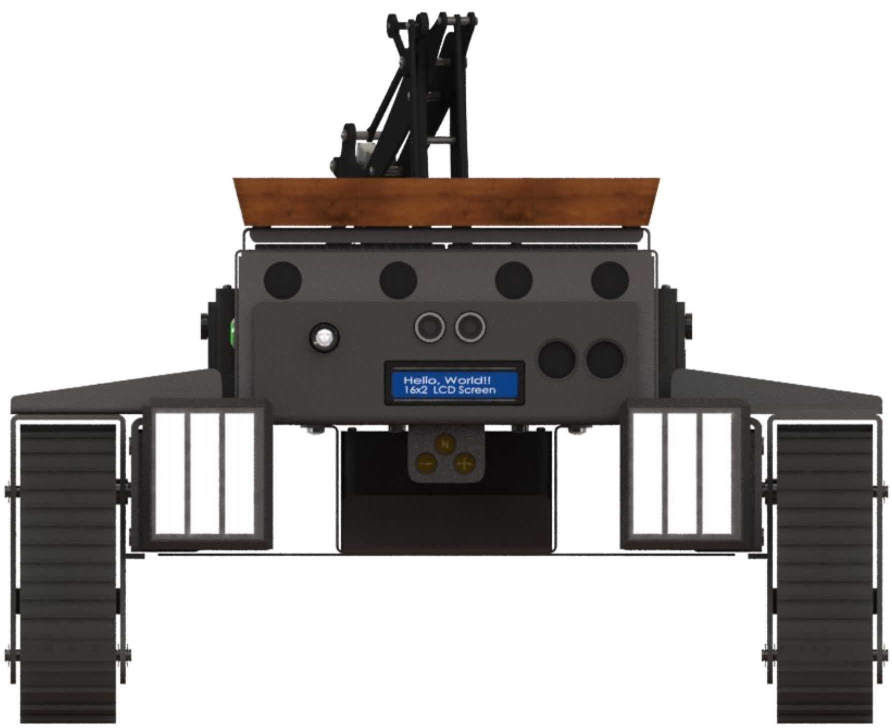



Hello, World!!
16x2 LCD Screen

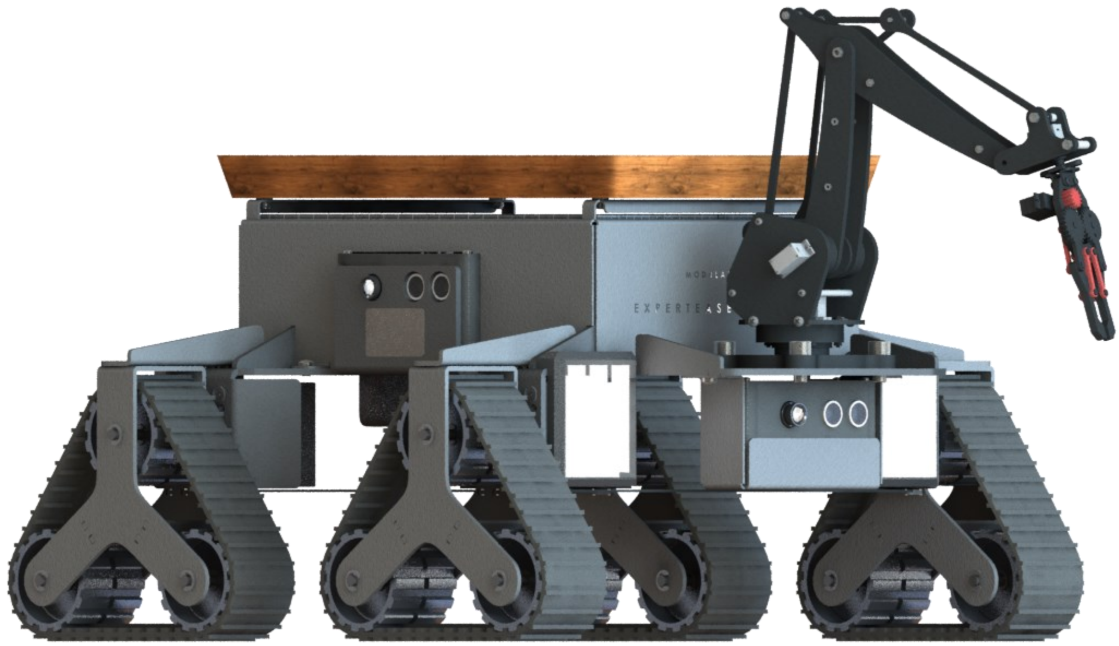


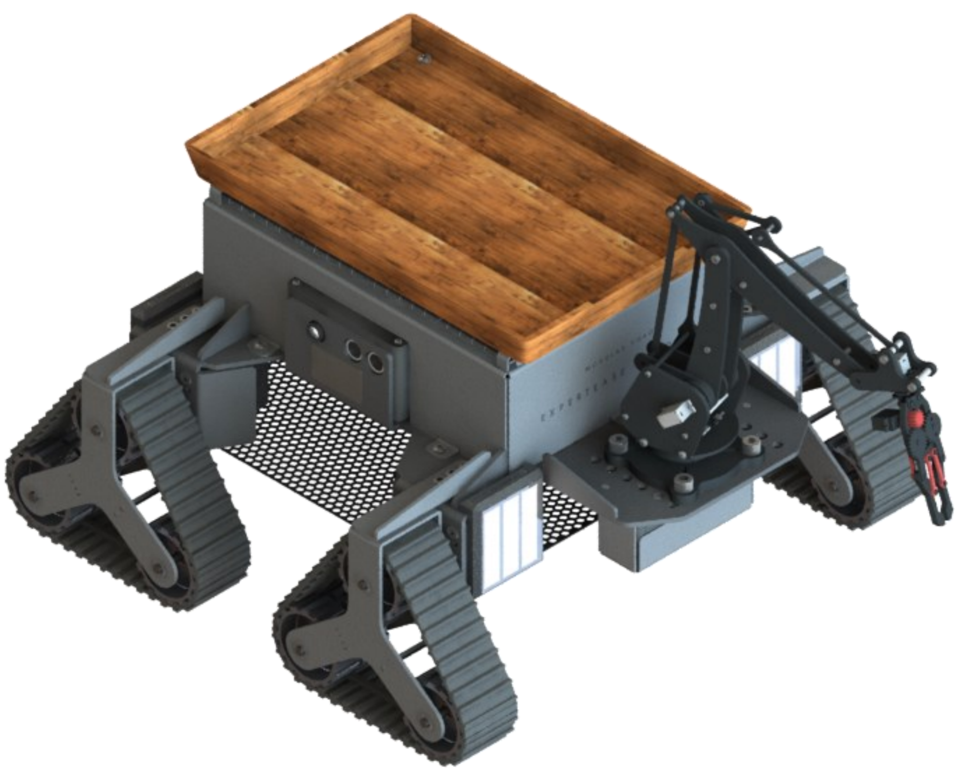


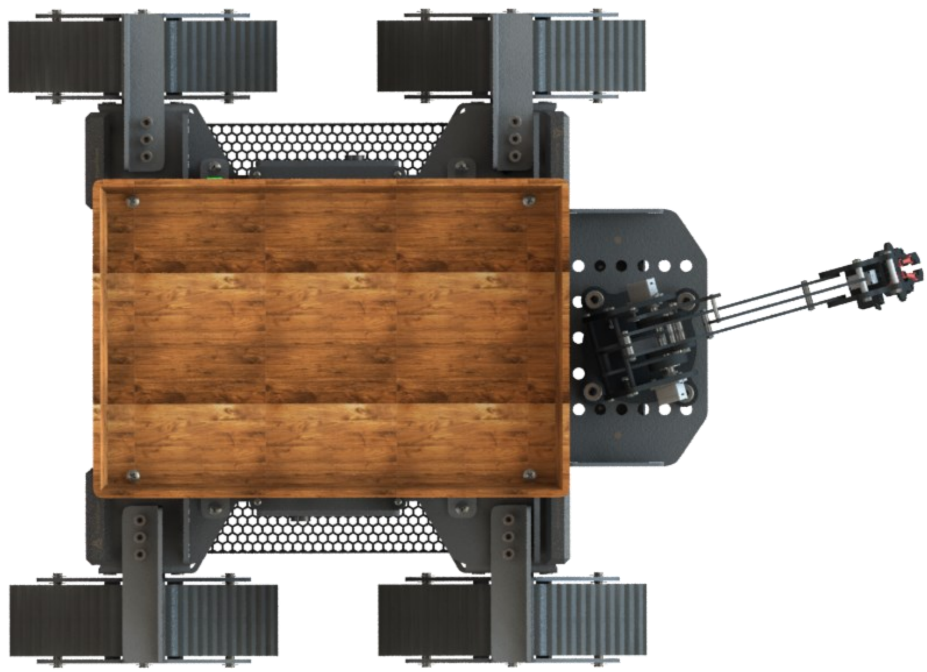

POWER ON/OFF
Expertease

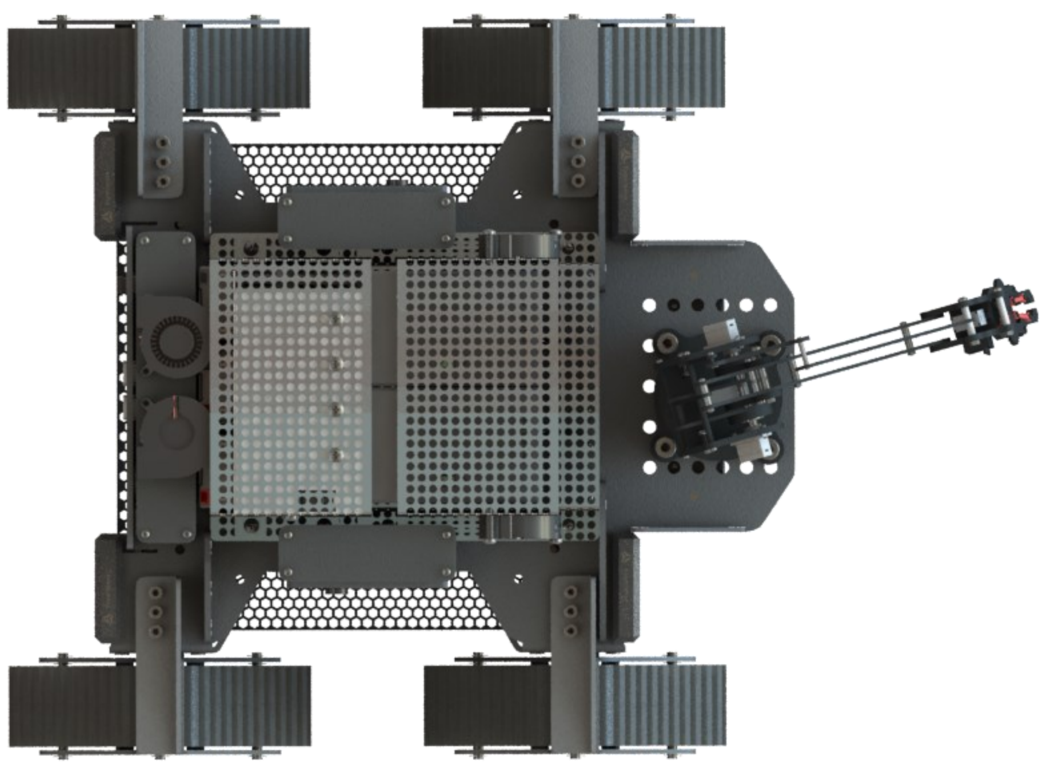

Hello, World!!
16x2 LCD Screen

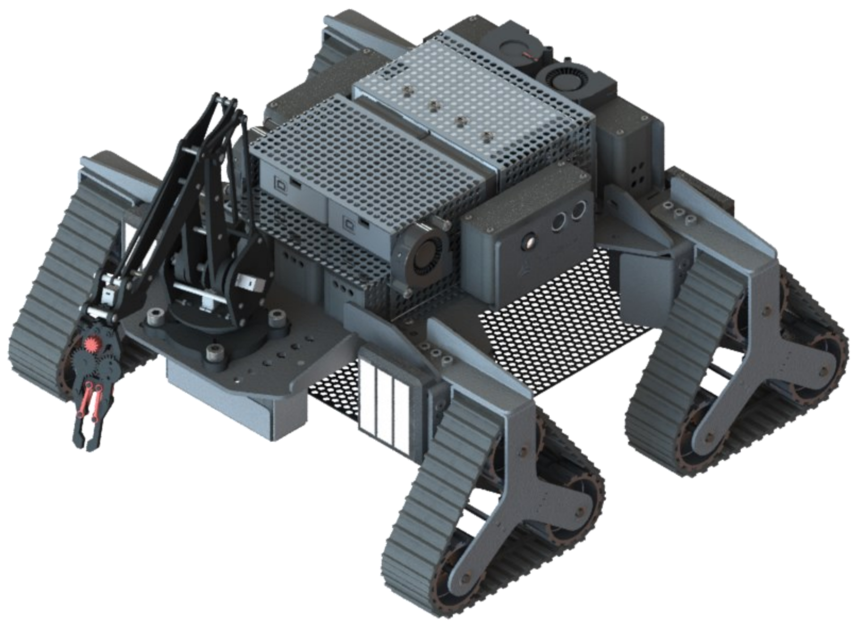

Hello, World!!
16x2 LCD Screen

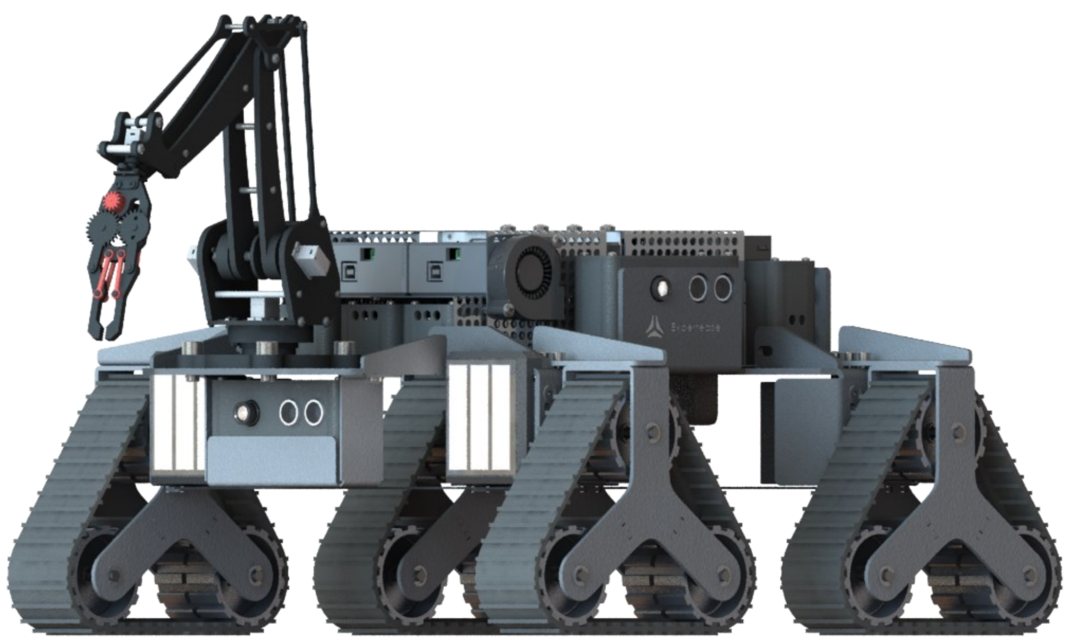


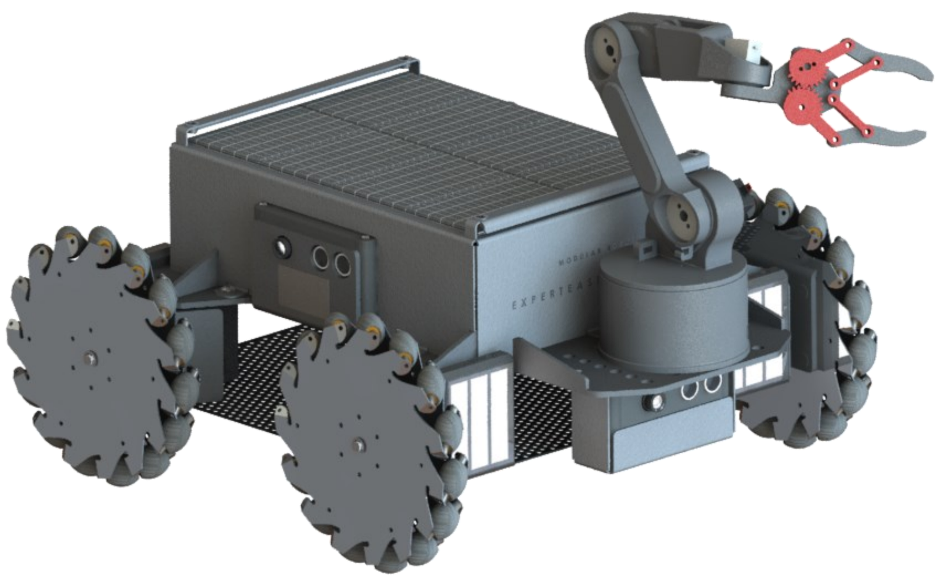


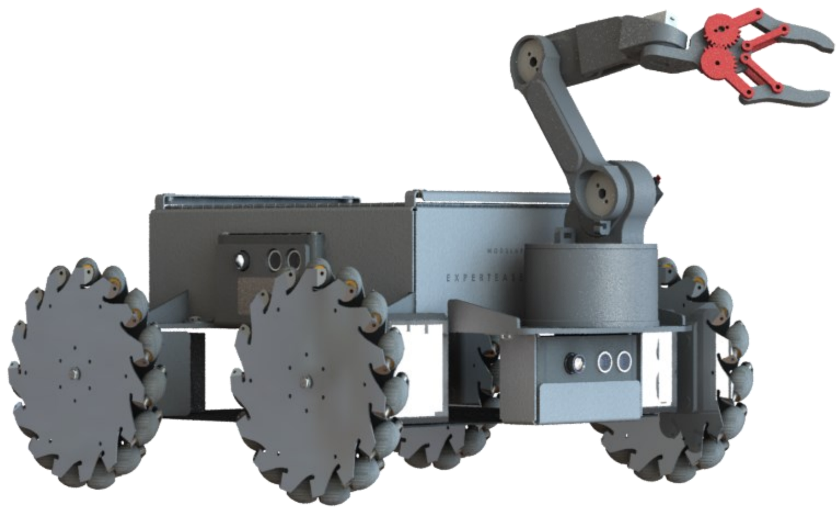


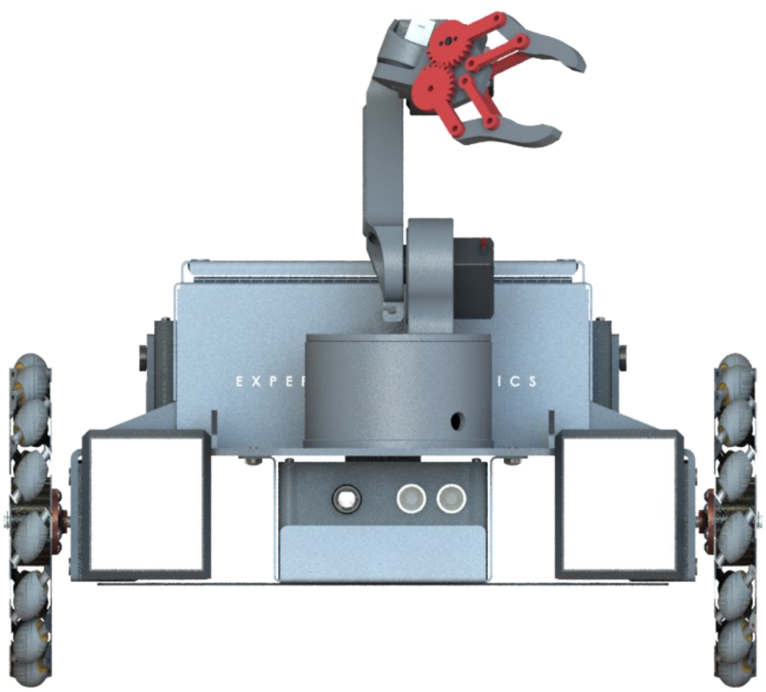


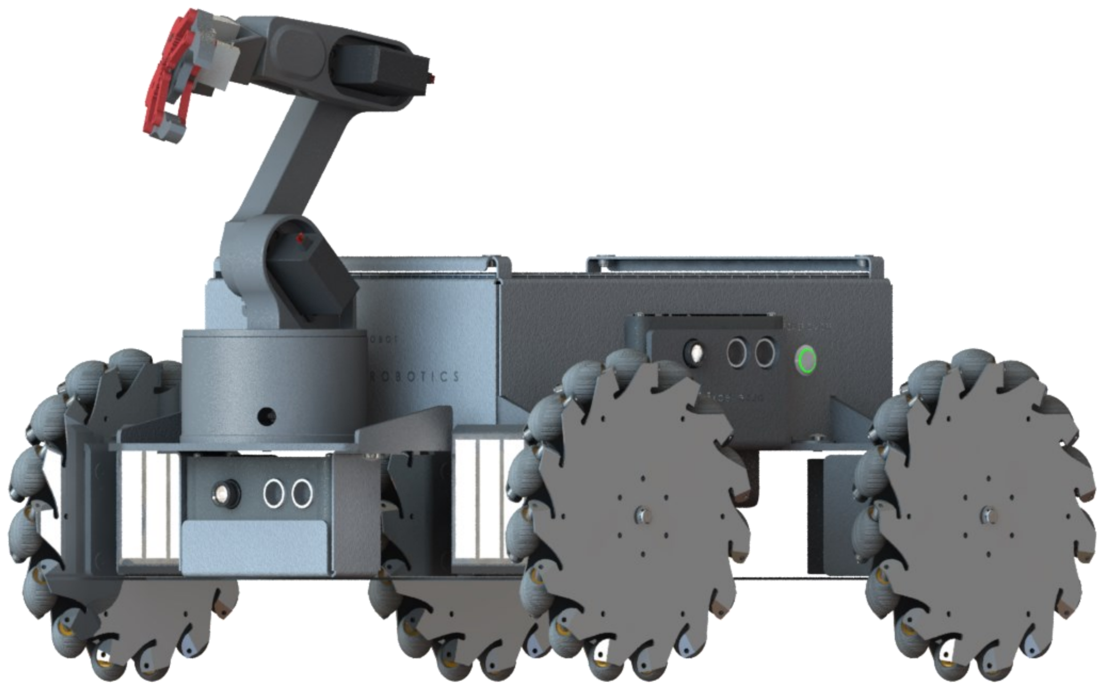






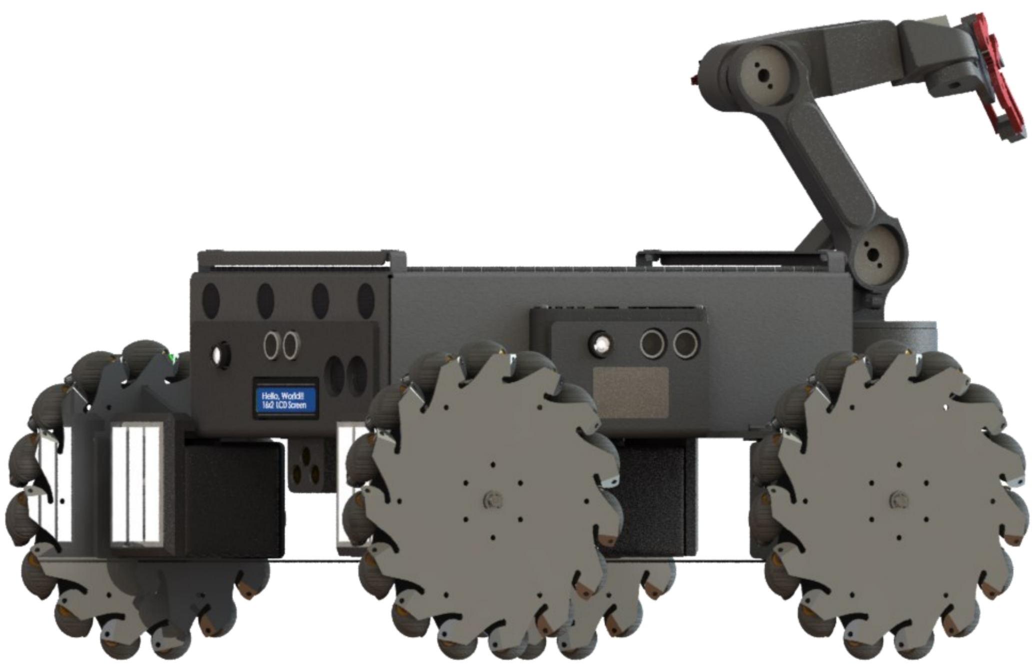


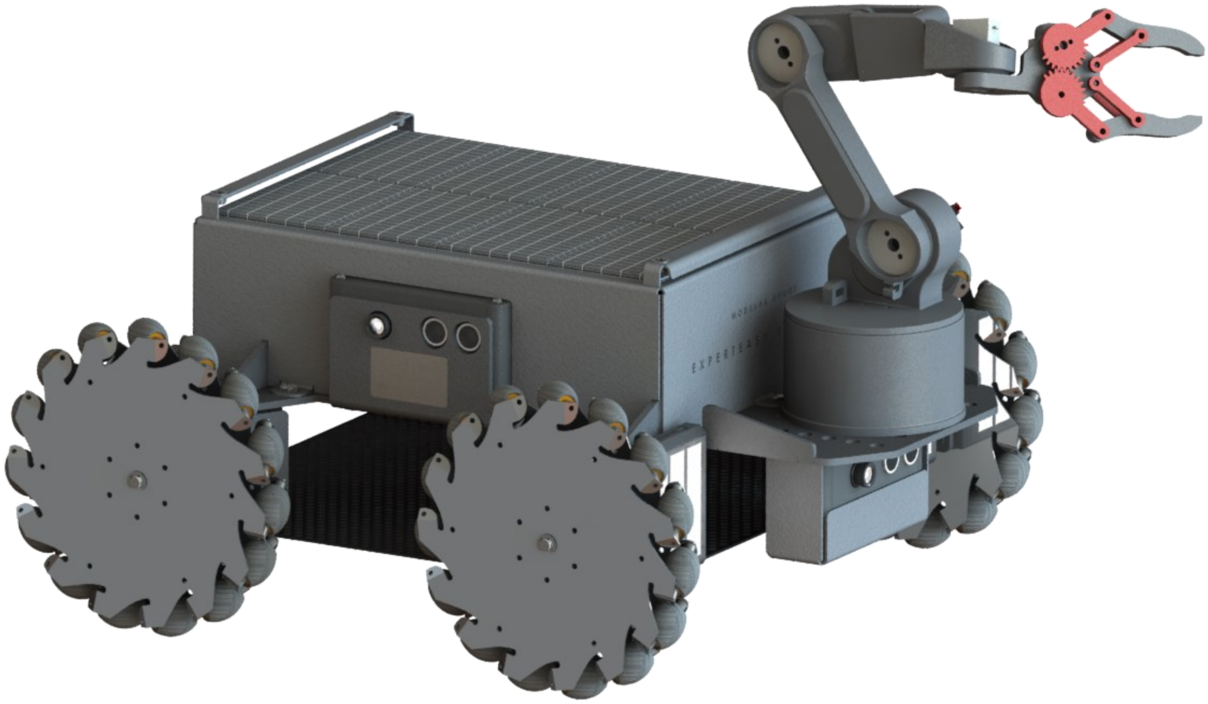




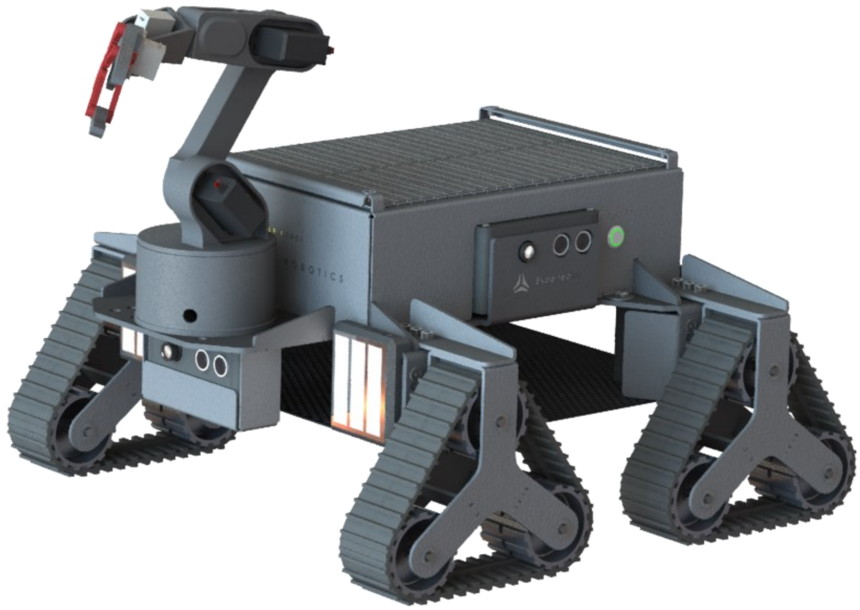

POWER ON OFF
Hello, World!!
16x2 LCD Screen

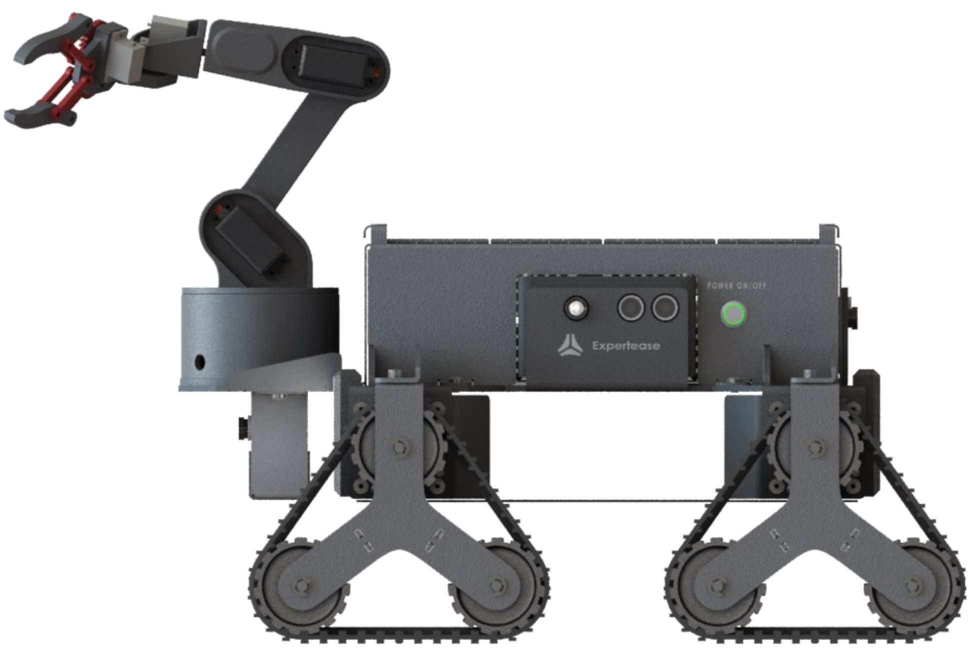

Hello, World!!
16x2 LCD Screen



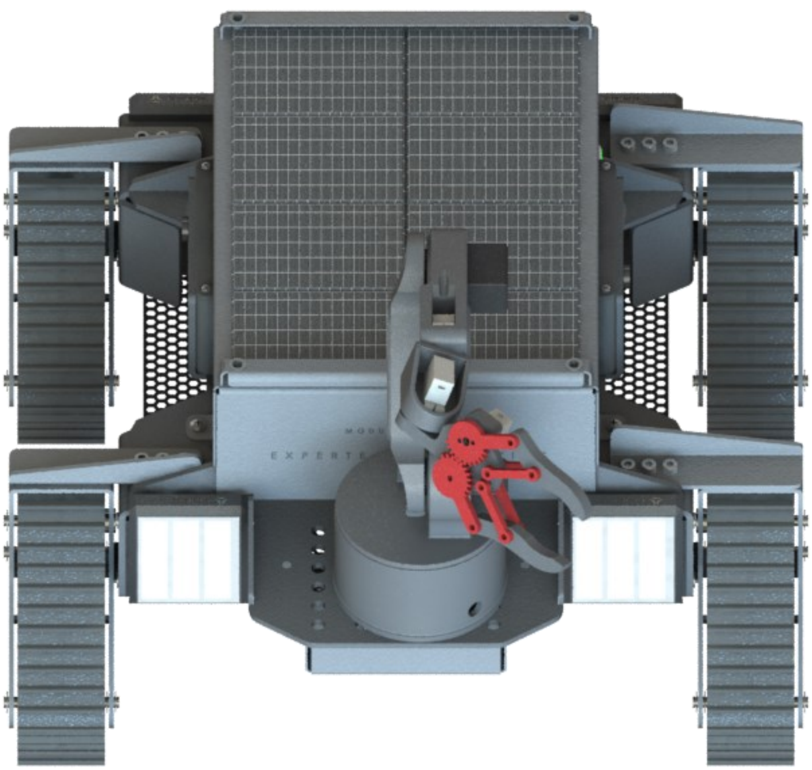


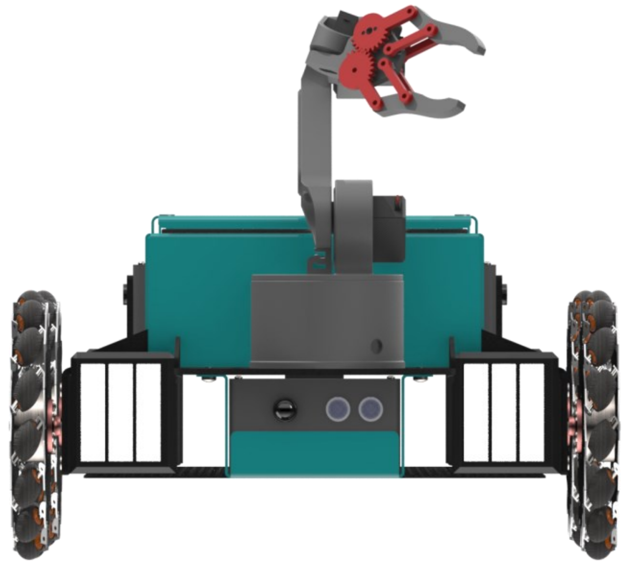

Hello, World!!
16x2 LCD Screen

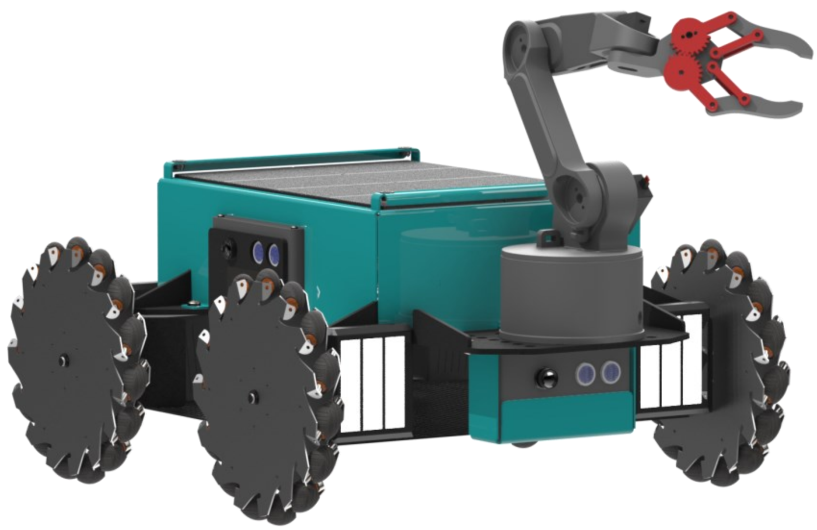



POWER ON/OFF
Expertease

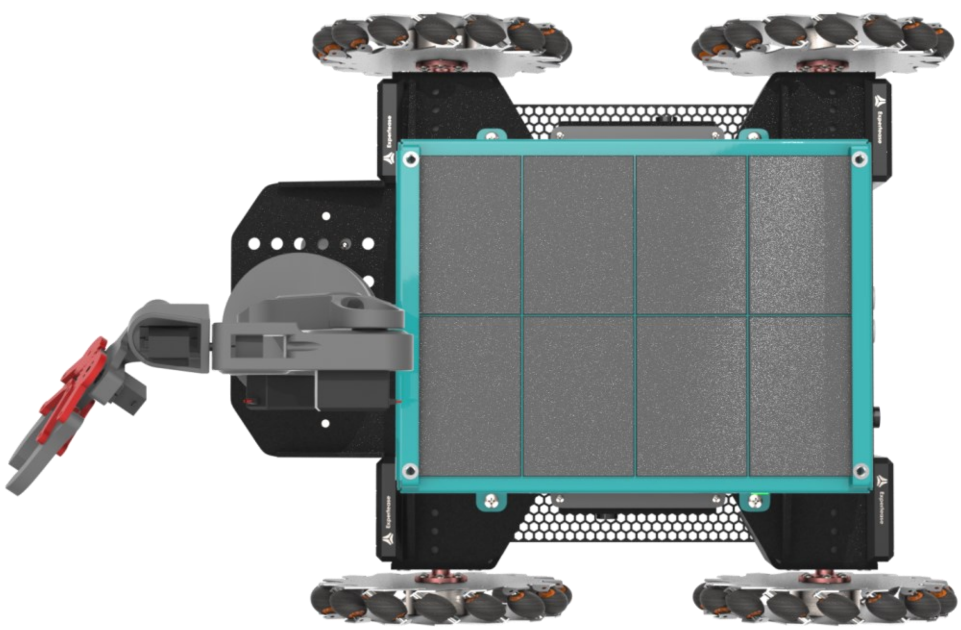

POWER ON OFF
Experteose
Hello, World!!
16x2 LCD Screen

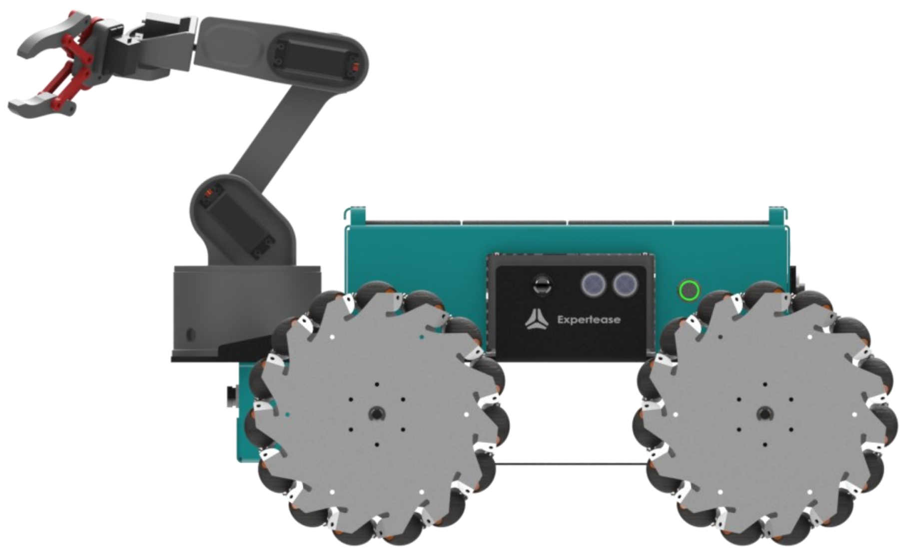




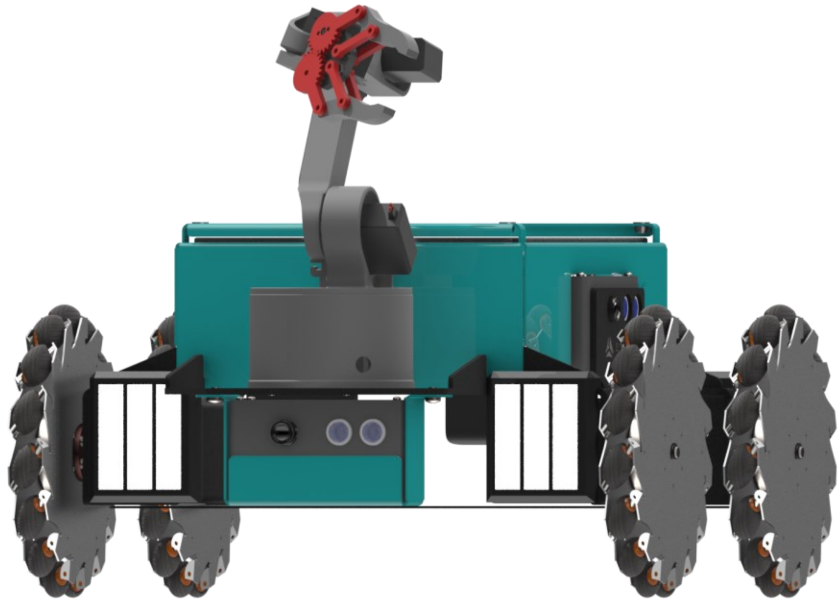


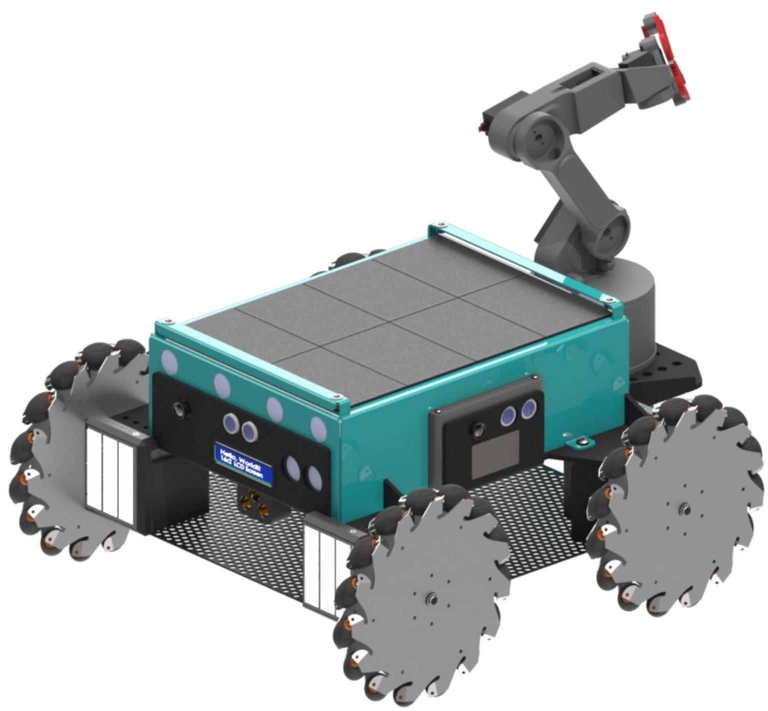

Hello, World!!
16x2 LCD Screen

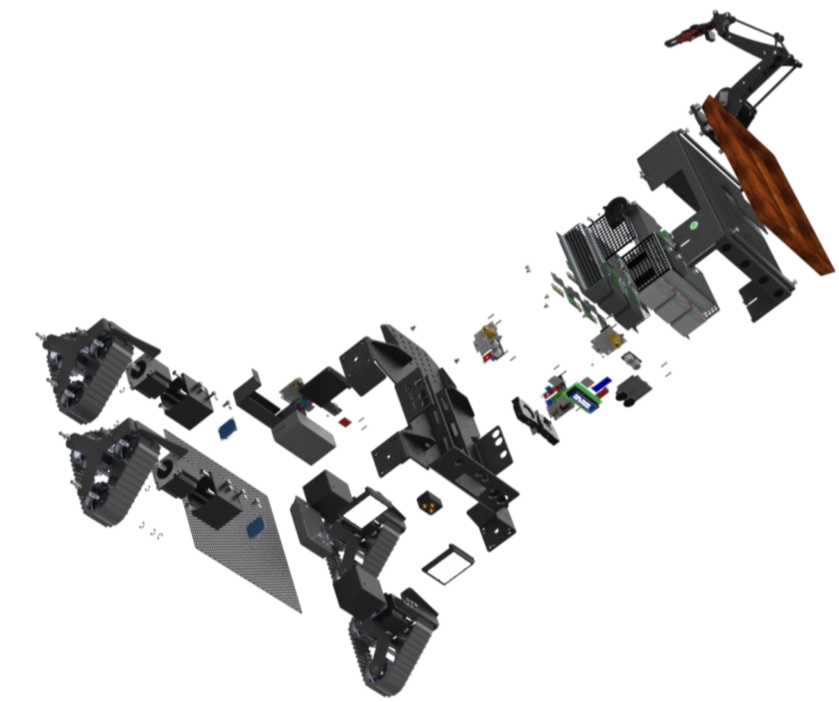



Expertease


Hello, World!!
16x2 LCD Screen







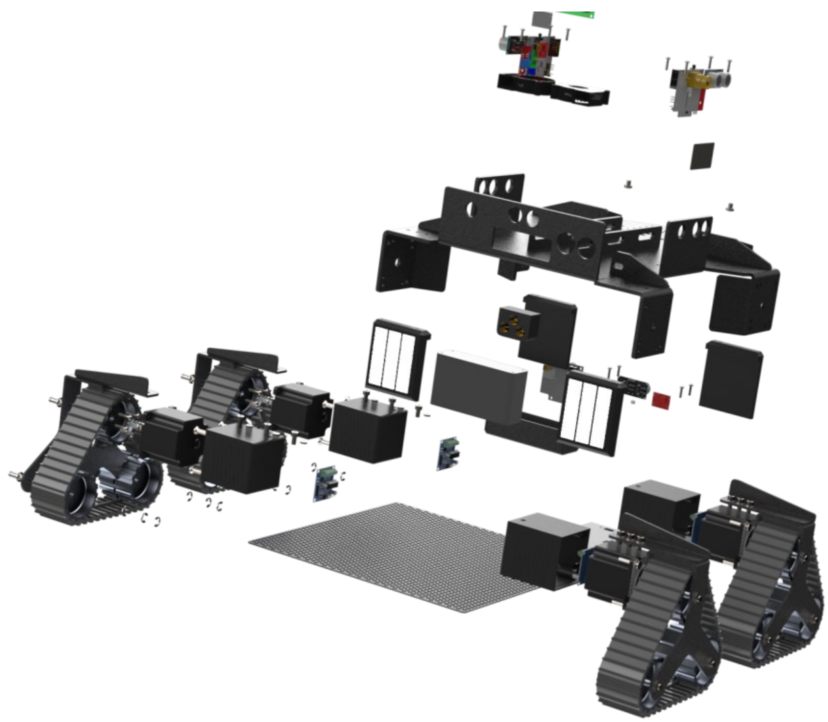
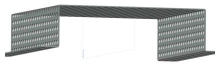
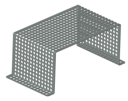
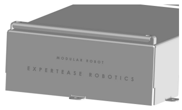
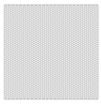
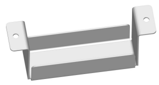
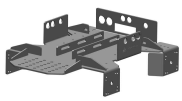
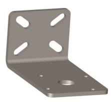
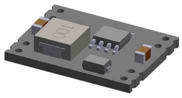
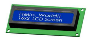
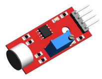
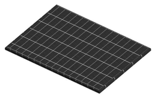
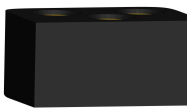


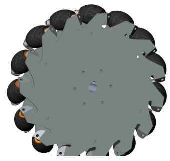
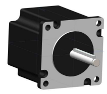
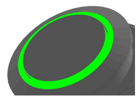
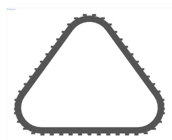
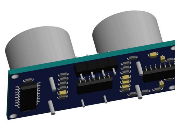
Table of parts

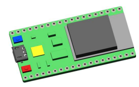
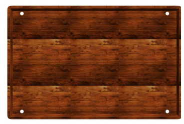
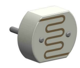
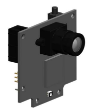
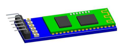
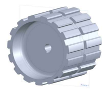
	Number of Constructions	1	Total Parts per Construction	Total Parts
	Number of Different parts:	45	121	121

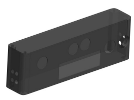
N.	Laser Cut	Width [mm]	Material	Parts per Constr.	Total Parts	Pic.
1	MR2_IHU_LOGO_1PART_1MM_INOX_LAZER	1 mm	INOX	1	1	
2	MR2_ARDUINO_METAL_BASE_1MM_1PART_ST37_LASER	1 mm	ST37	1	1	
3	MR2_BATTERY_HOLDER_1MM_1PART_ST37_LASER	1 mm	ST37	1	1	
4	MR2_ELECTRONICS_METAL_BASE_1MM_1PART_ST37_LASER	1 mm	ST37	1	1	
5	MR2_COVER_1.5MM_1PART_ST37_LASER	1.5 mm	ST37	1	1	
6	MR2_DOWN_COVER_1.5MM_1PART_ST37_LASER	1.5 mm	ST37	1	1	
7	MR2_FRONT_BOX_SUPPORT_1.5MM_1PART_ST37_LASER	1.5 mm	ST37	1	1	
8	MR2_TRACK_WHEELS_SUPPORT_BASE_3MM_1PART_ST37_LASER	3 mm	ST37	4	4	
9	MR2_MONOBASE_4MM_1PART_ST37_LASER	4 mm	ST37	1	1	
10	MR2_STATIONARY_BASE_4MM_4PARTS_ST37_LASER	4 mm	ST37	4	4	

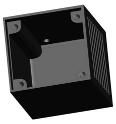
11	TW_WHEEL_SUPPORT_4MM_4PARTS_ST37_LASER	4 mm	ST37	4	4	

N.	Shop	Link	Purchased yet?	Parts per Constr.	Total Parts	Pic.
12	DC_VOLTAGE_REGULATOR_5PARTS_BUY		NO	5	5	
13	LCD_Screen_1PART_BUY		NO	1	1	
14	Microphone_Module_4_PARTS__BUY		NO		0	
15	Monocrystalline Solar Panel_5V_200mA_8PARTS_BUY		NO	8	8	
16	Mono_Enclosed_Speaker_3W_4Ohm_2PARTS_BUY		NO	2	2	
17	MR2_3PARTS_BUY_KT_1213_12V_1.3 Ah_ AGM_Lead_Acid_Battery		NO	3	3	
18	MR2_ARDUINO_MEGA_AND_CASE_2PARTS_BUY		NO	2	2	
19	MR2_DC_FAN__12V_4_PARTS_BUY		NO		0	
20	MR2_DC_MAGNETIC_CHARGING_1_PART_BUY		NO		0	
21	MR2_LTE_ANTENNA_1PART_BUY		NO	1	1	

22	MR2_Mecanum_Wheels_4PARTS_ADAPTERS_BUY		NO	4	4		
23	MR2_Mecanum_Wheels_4PARTS_BUY		NO	4	4		
24	MR2_Nema_23_PHB57M56_430_4PARTS_BUY		NO	4	4		
25	MR2_POWER_SUPPLY_CL_C500W24V_PFC_1PART_BUY		NO	1	1		
26	MR2_Push_Button_M19_1PART_BUY		NO	1	1		
27	MR2_RA2_1PART_BUY		NO	1	1		
28	MR2_RA_1_1PART_BUY		NO	1	1		
29	MR2_Speaker_Grill_6PARTS_BUY		NO	6	6		
30	MR2_TRACKED_Wheels_4PARTS_ADAPTERS_BUY		NO	4	4		
31	MR2_Triangular_Track_Wheel_4PARTS_BUY		NO	4	4		
32	MR2_ULTRASONIC_SENSOR_4PARTS_BUY		NO	4	4		

33	MR2_WHEELS_4PARTS_BUY		NO	4	4	
34	MR2_WIFI_BLEUTOOTH_1PART_BUY		NO	1	1	
35	MR2_WOODEN_BASKET2_1PART_BUY		NO	1	1	
36	MR5_GL55_PHOTORESISTOR_4PARTS_BUY		NO	4	4	
37	MR_2Pixy(CMUcam5)_4PARTS_BUY		NO	4	4	
38	MR_SHIELD_BT_1PARTS_BUY		NO	1	1	
39	TW_WHEELS_ALUMINUM_12PARTS_60MM_BUY		NO	12	12	

N.	3D_printed	Wieght [g]	Material	Parts per Constr.	Total Parts	Pic.
40	MR2_ELECTRONICS_BOX1_100GRAMS_PLA_3PARTS_3DPRINT	100	PLA	3	3	
41	MR2_ELECTRONICS_BOX2_PLA_1PARTS_3DPRINT_170GRAMS	170	PLA	1	1	
42	MR2_ELECTRONICS_SIDE_BOX3_90GRAMS_PLA_2PARTS_3DPRINT	90	PLA	2	2	
43	MR2_HEADLIGHTS_4PARTS_ADAPTERS_PLA_50GRAMS_3DPRINT	50	PLA	4	4	

44	MR2_MOTOR_COVER_4PARTS_50GRAMS_PLA_3DPRINT	50	PLA	4	4	

N.	Machined	Raw Material	Material	Parts per Constr.	Total Parts	Pic.
45	MR2_TRACKED_Wheels_4PARTS_PINS_MACHINED		-	4	4