ROBOTICS PROJECT - ROB3

School year 2023 - 2024

Farming Mars with the PolyMartian

Students : WAELES-DEVAUX Adrien, LEROY Loïc

Supervisors : MASSON Pascal, PETER Christian

Ecole Polytechnique Universitaire de Nice Sophia-Antipolis, formation robotique (systèmes autonomes)

930 route des Colles, 06410 BIOT

Table of contents :

1) Introduction :

The French National Robotics Cup is a competition that entails the development of an autonomous robot centered around a specific theme. These robots are tasked with executing a set number of actions within a defined time frame, while competing against other robots. This event stands as the largest assembly of engineering schools in France and grants three teams an access to participate in the European Eurobot competition.

The primary objective of this project is to unite students from various specialties on a huge project, fostering mutual learning and allowing us to develop fundamental skills in autonomous Robotics under challenging constraints. Concurrently, it serves as a means to represent our institution, Polytech Nice Sophia, and promote awareness of its specialization in Robotics and Autonomous Systems.

2) Rules analysis :

First of all, let’s introduce the theme of this year’s competition. In order to make life on Mars possible, the robots are tasked with running an autonomous greenhouse so astronauts will be able to harvest fruits and vegetables, and then survive. To do this, two rival robots will perform on a table of 3m per 2m and accomplish different missions.

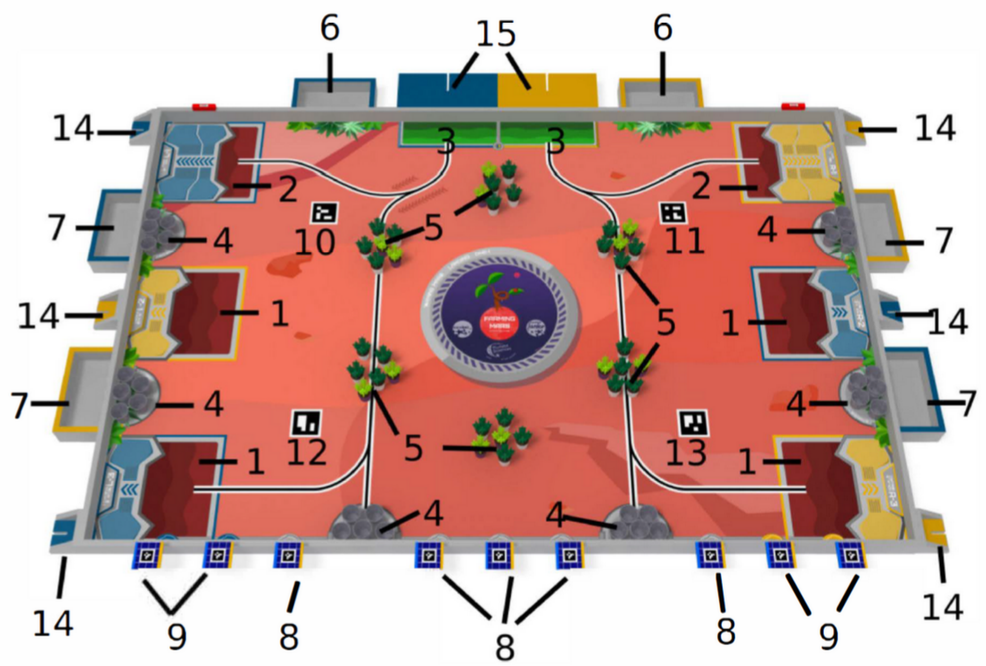

Figure 1 : Playing area

1. Departure/arrival and drop-off areas
2. Departure/arrival and reserved drop-off areas
3. Departure areas SIMA (ladybug hive)
4. Pot supply
5. Plant supply
6. Planters
7. Reserved planters
8. Solar panels
9. Reserved solar panels
10. ArUco marker number 20
11. ArUco marker number 21
12. ArUco marker number 22
13. ArUco marker number 23
14. Fixed beacon supports
15. Remote computing area

At the start of the game, each team is assigned a color : yellow or blue. The team will have to place its robot in one of the three square surfaces on the playfield's extremities delimited by its color line (areas number 1 or 2 on *figure 1*). Then each robot will have 100 seconds to mark as many points as possible without any human intervention. To mark points, robots can realize some of the following actions :

- Repot the plants and put them in cultivation,

Thirty-six plastic plants and thirty-six metallic pots are arranged by groups of six on the playfield (areas 5 and 4 on *figure 1*).

(a) Two delicate plants

(b) One resistant plant

Figure 2

Each group is made of two types of plants : four fragiles with white pots and two resistants with purple pots (*figure 2*).

The team will earn points for each plant dropped off upright in a valid area.

There are three different dropping areas :

- standard drop-off areas (areas number 1 on *figure 1*) where plants can be stolen by the other team;
- reserved drop-off areas (areas number 2 on *figure 1*) that are protected from theft;
- planters which are outside and separated from the playfield by a border (areas number 7 on *figure 1*).

While resistant plants can be dropped off in any dropping area, fragile ones can only be dropped off in planters unless they are in pots.

In addition, each plant dropped off in a pot or in a planter will provide additional points.

- **Orient the solar panels so that the greenhouse does not lose energy:**

The greenhouse is also made up of nine solar panels (components 8 and 9 on *figure 1*). Among them, each team has 2 reserved solar panels on the table's extremities which cannot be manipulated by the opponent's robot (components 9).

Figure 3

A solar panel is a 3d printed square component which rotates on an axis. Each solar panel has two sides, one yellow and the other one blue (*figure 3*). At the beginning of the match, they are all oriented towards the outside of the table.

To mark points the robot has to manage to turn the solar panel in order to put a part of the vertical projection of the edge with the team color inside the table. If both color edges are inside the table, both teams gain the points.

- **Ensure the pollination of plants,**

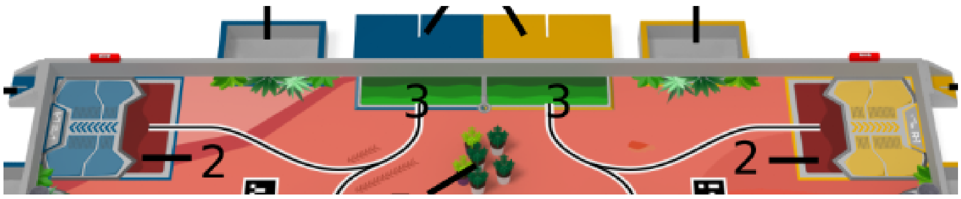

Figure 4

To ensure pollination of plants each team must create Small Independent Mobile Actuators (SIMA) also called ladybugs. These SIMA will start the game from the ladybug hive (areas number 3 on *figure 4*). A team can have as many ladybugs as they want as long as they all fit in their starting zone.

The main constraint is that they can only be released between the 90th and 100th seconds of the match and will have 10 seconds to accomplish their goal.

A team wins points for each plants' deposit area occupied by at least one ladybug at the end of the match. Extra points are granted for each plants' deposit area where at least one ladybug is in contact with a plant or a pot containing a plant.

However, if one ladybug is in an opponent's area, it will score points for the opposing team.

- **Return to recharge the batteries, at the end of the working day,**

The team will also score points if the robot is in an arrival area, which has to be different from its departure area, before the end of the match.

- **Anticipate future crop yield.**

Finally the robot has to estimate its score (excluding the score produced by ladybugs), either at the beginning of the match on a static display or during the match with a dynamic display. A bonus, proportional to the difference between the score estimated and the real performance will be granted.

3) Technical specifications:

- Move forwards and backwards with a precision of less than 1 cm and turn around very quickly,

- To be able to pick up plants, place them in pots and take them to the various storage areas,

- Identify the type of plant (fragile or resistant),

- Point the solar panels in the right direction,

- Comply with the robot's design constraints:

A perimeter (vertical projection on the ground) below 1200 mm at the start. The deployed perimeter must be less than 1300 mm during the match.

A total height less than 350mm (375mm with the emergency stop button) excluding the beacon support mast.

- Must include a start-up cord which will be used to launch the autonomous robot

- Avoidance system for opposing robots to prevent collisions between robots during a match.

- Safety conditions: All robots must be equipped with a red emergency stop button which has to be at least 20 mm in diameter

- Return to its base before the end of the 100-second match.

- Estimate the score produced

- Include a beacon mast

- All ladybugs must enter inside the SIMA starting area (15 cm by 45 cm), have a height limit of 15 cm and must be larger than a 60mm cube and each ladybug’s weight must not exceed 1kg.

4) Main robot’s conception :

a - The rolling base / chassis :

Choice of base type (shape, wheel type) :

For our rolling base we first considered a triangle shape to use three omni wheels as driving wheels.

Figure 5

These three wheels spaced with the same angles allow movements in all directions to gain time and avoid the opponent's robot with more efficiency *(figure 5)*. Indeed with standard wheels we can only go forward and backward so to go to any other direction the robot will have to rotate on itself. On the other hand, with omni wheels, it's harder to handle displacements and it is often unstable. For this competition we only need small displacements, and for a first participation it was more reasonable to concentrate our efforts to create a great stable rolling base.

<u>Motor selection and sizing :</u>

To choose the best adapted motors for our robot we did motor sizing. First of all we estimated the weight of our robot. But many sites don't indicate the exact weight of the components they sell, so to not underestimate our needs we have framed the weight of each component between a minimum and maximum value.

Componant	Min Weight (g)	Max Weight (g)	Details	
2 motors	1000	2000		
2 wheels + ball freewheel	130	200		
Nvidia Jetson	240	240		
4 aluminium profiles 300mm	560	560		
2 stepper motors Nema17	560	560		
Threaded rod (clamp)	20	20		
Servomotor (clamp)	20	20		
2 Lipo Batteries	600	1000		
Stop emergency button	50	50		
300mm linear guide rail (clamp)	270	270		
3 cameras	90	240	30 grams for a raspberry pi camera	80 grams for "Je vois Pro" camera
2 Cytron electronic boards	45	45		
Total	3585	5205		

Figure 6

Here are our estimated weights on *figure 6*.

From this, we are now able to size our motors. According to our research based on robots built for the Robotics Cup in previous years. An optimum top speed would be between 1 m/s and 1.3m/s . The robot will work only on the playfield so a flat surface with no inclination. We chose a wheel radius of 60mm to fit with the thickness of the rolling base and because a large diameter provides better angular speed than a small diameter for the same motor size. The power supply would be 24V because it corresponds to the type of motor often used in the Robotics Cup and adapted to our needs. Operating time will be 100 seconds cause it’s the match duration so to make a broad estimation we estimate it to 2 minutes. Our research showed us that an optimum top acceleration would be approximately 1.3m/s which is often the case on cup’s robots.

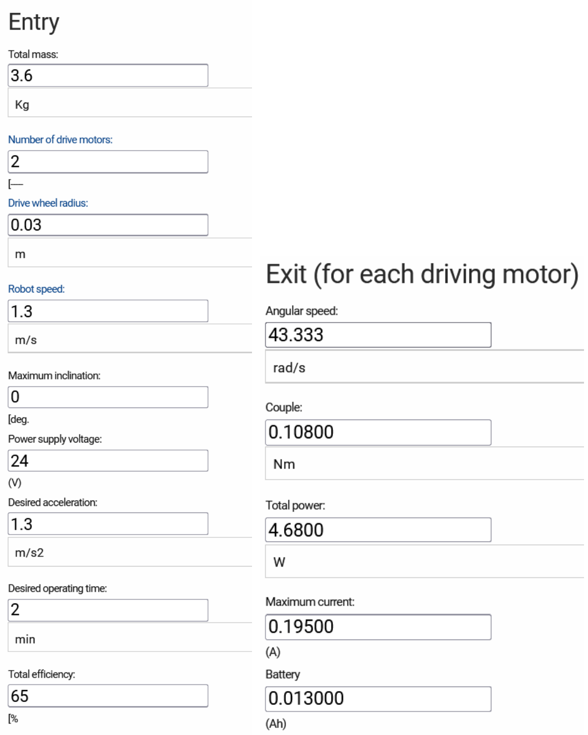

Figure 7

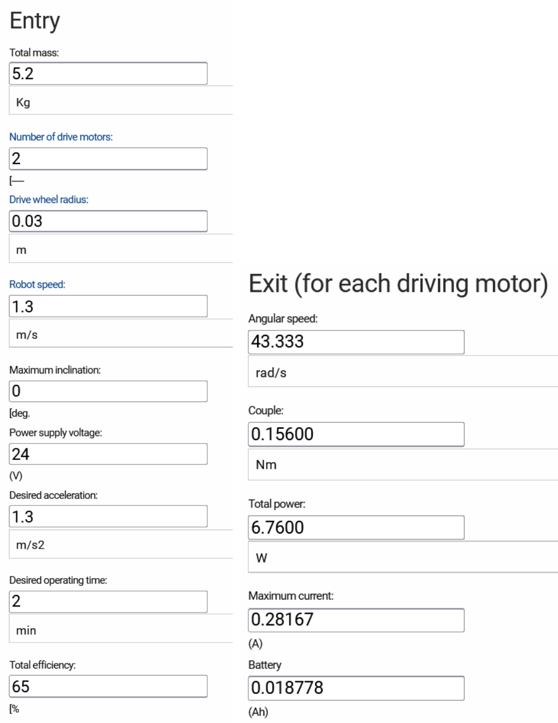

Figure 8

Here are our sizing results for the minimal weight *(figure 7)* and for the maximal weight *(figure 8)* :

The best teams often use very expensive engines because of their performance/compactness ratio. Due to our limited budget we chose large, heavy motors but with great performances. If the above-mentioned engines are too constraining, we plan to acquire Maxon engines which are the most used in the Robotics Cup due to their ratio and performances.

The rolling base or chassis is composed of two main plywood plates (~5mm thickness) assembled together with 3D printed spacers. This configuration offers multiple advantages over a single thicker plywood plate. The first advantage is the possibility to store the batteries, the electronics and the motors into a safe volume between the two plates and still be able to set elements above all these components. In this case, plywood offers a great rigidity but remains lightweight so the robot is solid and easy to accelerate at the same time. Moreover, plywood is an affordable material compared to aluminum and is very easy to process with a laser cutter and usual woodworking tools. Also, plywood lets us make quick modifications on the parts which is very useful for prototyping.

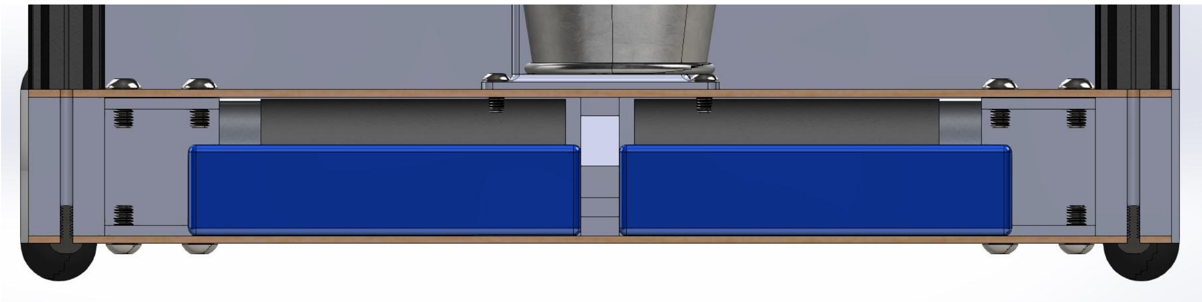

Figure 9

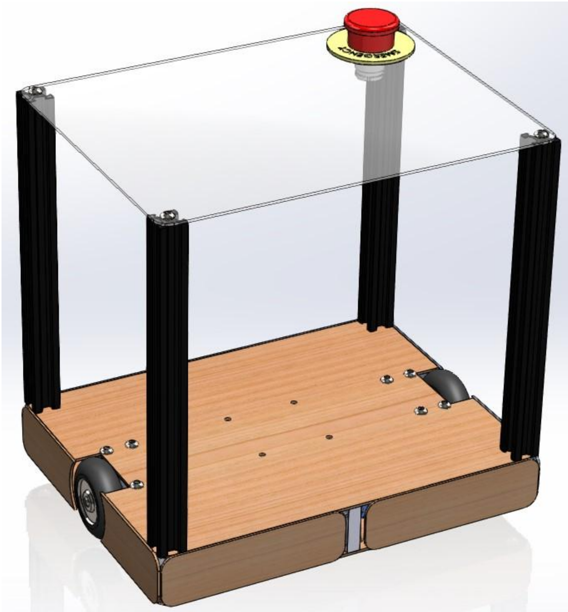

Figure 10

The 3D printed parts are designed to keep a constant spacing between the plywood plates. They are held in place by screws which pass through the plates and the 3D-printed parts and are screwed into the robot's upper structure (*figure 9 & 10*).

Some of the spacers also have the role to maintain the motors in place.

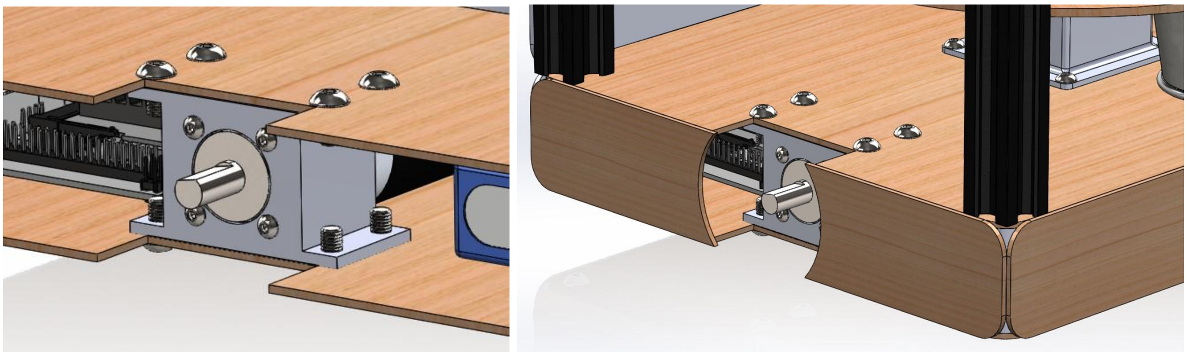

Figure 11

The motors are screwed onto these parts on the side closest to the wheels (*figure 11*).

The other components are directly screwed onto the plywood plates except the batteries which need to be easily and quickly removed from the robot for their replacement and recharge.

Finally, the base is enclosed from every side with smaller plywood plates in order to protect the components inside from dust and chocks (*figure 11*). The panel in front of the batteries might be held in place with strong magnets for easy access.

The wheels are modified rollerblade wheels so we can apply torque to them and mount them directly on the motors' shafts. The original bearing is removed and replaced with a 3D printed adapter which fills the gap between the motor shaft and the inner wheel diameter. The adapter has a flattened surface, like the motor, to transmit torque from the motor to the wheel.

Figure 12

Figure 13

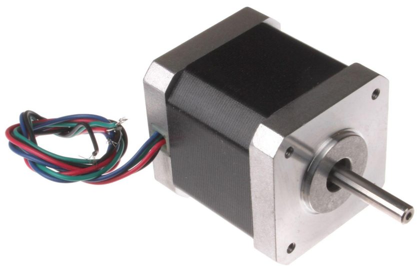

Figure 14

For the motorization of the rolling base, we considered using DC motors (*figure 12*) or brushless motors (*figure 13*) or stepper motors (*figure 14*). The table below shows the mains characteristic of each motor type.

	DC	Brushless	Stepper
Rotational speed (no load)	< 540 rpm	< 3000 rpm	< 1500 rpm
max torque	0.72 Nm	1.1 Nm	0.02 Nm

Volume	81400 mm3	88300 mm3	70560 mm3

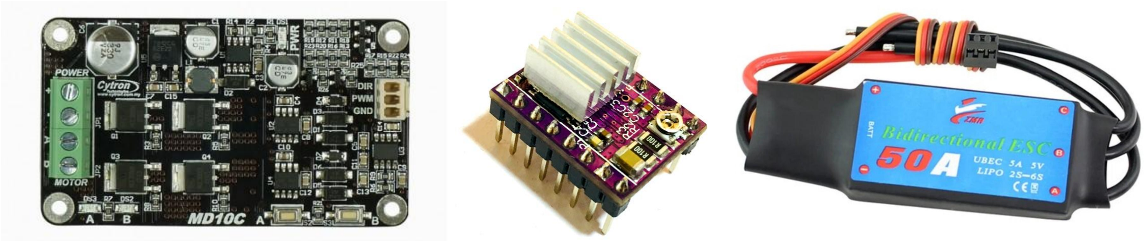

Figure 14

Because of the power these motors consume, we cannot power them directly with the arduino board, we have to use motor drivers (*figure 14*). These electronic boards take in input a command signal from the arduino, the power supply from the battery and they output the correct power signal corresponding to the motor for which they are intended. For example, for a brushless motor it will be a three-phase power supply, for a DC motor, it will be a PWM signal and for a stepper motor it will be a sine wave signal on each phase.

On figure 14 from left to right : a H-bridge for DC motor, a stepper driver, an ESC for brushless motor.

b - The upper structure :

The upper structure (*figure 10*) is the continuity of the rolling base. It supports cameras and other sensors (IR, lidar), as well as the emergency stop button on top of the robot. This structure is made out of standard v-slot 20x20mm aluminum profile sourced on the website www.systeal.com so they came already at the right size and with the threaded ends. This type of profile allows us to easily fix components on them and offers a great rigidity for a minimum weight. Like the base, the upper structure is closed from all sides except the front one so the grabbing system can freely manipulate the pots and the plants. Like the rolling base, we use plywood panels screwed onto the aluminum profiles (hidden on *figure 10*) to close the robot's sides.

c - The storage system :

In order to be as competitive as possible, the robot has to temporarily store the pots and plants it found on the field so it minimizes the number of deplacement which are time consuming. The storage system (*figure 11*) is composed of two main elements : a stepper motor and a laser cutted plywood plate. The latter is directly mounted on the stepper motor shaft. In this system, a stepper motor was chosen for its rotational speed and ease of use in positioning the turntable. The motor is held in place with a 3D printed part screwed onto the plywood panel under it. The turntable has the shape of a disc with six 70mm holes around it. The layout of this part is optimized to store cone geometry like the plant pot, so when the gripping system releases a pot above the turntable, the pot naturally centers and straightens out with gravity. This technique makes the system very simple and repetitive in its task with no use of electronics.

Figure 14

Before opting for this solution, we considered storing the pots and plants on conveyors, but this solution was not chosen because of the problem of potting the plants. A conveyor doesn't have as much stability and repeatability as a turntable, as it can't prevent the movement of pots and plants while the robot is moving. What's more, a conveyor is a more complex system, requiring more moving parts to operate.

d - The gripping system :

To respond to its tasks, the robot will have to manipulate pots and plants. Because of their geometry, we found that using a gripper is an effective solution due to the simplicity of use, the repeatability of movement. The claw shape of the gripper (*figure 12*) allows the grabbed object to self centers and straightens out with gravity. The gripper ‘s claws are actioned with a servo motor, an ES-3054 (in blue on *figure 12*). We chose this motor type for its relative great speed, its ease of use, its reliability and its compactness.

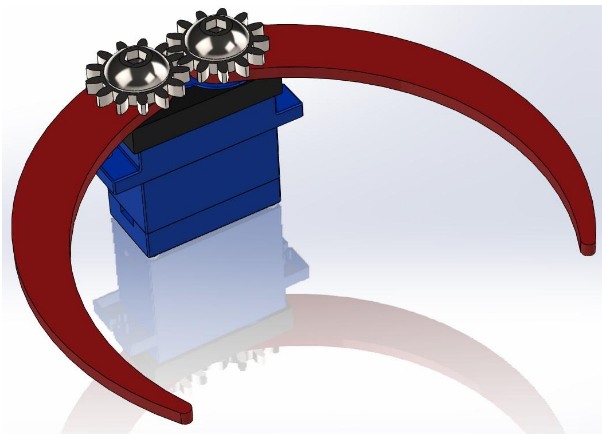

Figure 15

As the pots are metal, we considered using an electromagnet to catch them, but tests showed that the pots are not very magnetic, and the contact between the magnet and the pot was too loose to guarantee sufficient reliability. Moreover electromagnets are big energy consumers.

To grab plants and pots we had also envisaged other alternatives.

First of all, air compression tubes like machines used to transport letters and medicines : https://youtu.be/OPhILg-G7J8?t=31.

This system is very fast but also restrictive in space. A pneumatic compressor would take a huge space on the robot, moreover to transport plants from the ground to the storage platform we need curves with a large diameter otherwise the plant will be stuck in the tube and finally plants and pots would arrive on the storage platform upside-down.

We also discovered a really ingenious grabbing system discovered by researchers at Cornell University. It simply consists of a balloon filled with coffee beans. With an aspiration system, the gripper can transition from a soft state to conform to the shape of any object, to a rigid state to hold it firmly. https://youtu.be/Rna03IlJjf8 This system is really convenient because it can be adapted to the shape of any object such as a plant or a pot. On the other hand, this aspiration system takes a lot of space and can be quite slow compared to a fully electronic system.

In case the plant the robot wants to catch falls to its side, the grabber will be mounted on an extra pivot so it can bend forward and grab it. The motor used for this extra pivot is the same servo motor as the one used to close the gripper's claws because this model is very reliable and compact.

The whole grabber is mounted on a linear rail guide so when an object is caught, the linear guide is lifted to the top with the object. The rail guide can be set in position with both a system with a belt and a stepper motor, and a screw-nut system actuated by a stepper motor as well (*figure 13*). The belt system offers a lot of speed, less noise and less friction than the screw-nut one but it might break under heavy load. In our case, pots and plants are very lightweight (only a few tens of grams) so the belt solution appears to be well adapted for our use. In both systems, the compactness seems identical so it was not a critical parameter.

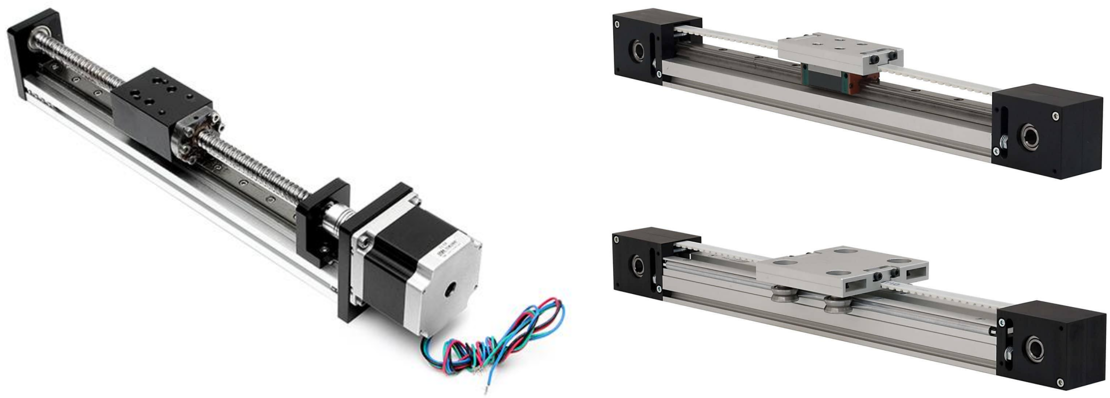

Figure 16

For the rail itself, we considered two different technologies, a roller system and a ball system (*figure 13, right*). We first thought about the roller system but the complexity and the compactness were not good enough so we moved to the second choice which also has the advantage of being easy to source in a fully assembled format.

e - Power supply:

During use, the robot will have to accelerate and brake a great deal. It is therefore essential to choose a power source capable of supplying a high current (~80A). The following types of battery can supply sufficient current: LiPo (on the right, *figure 14*), lead-acid (on the left, *figure 14*), LiFePo4 but LiPo and LiFePo4 remain the best choices based on their longevity, their capacity and their performance. For our purposes, NiMh, NiCd, Li-ion (on the middle, *figure 14*) and lead-acid batteries are not an option, either because their capacity is too low, or because their discharge current is too low, or because of their mass capacity.

Figure 17

We therefore choose li-Po batteries, although they are more dangerous than other types. In fact, these batteries must be charged with an appropriate charger that controls the charging voltage and current, to avoid overcharging and thus overheating the battery, or even causing it to explode.

f - Sensors:

During its movements, the robot must avoid obstacles (plants, pots, other robots, walls). To achieve this, it will be equipped with several types of sensors (*figure 15*) to increase information redundancy and limit the risk of misinterpreting its environment. These include infra-red proximity sensors for nearby obstacles, RGB cameras to read QR codes and detect plants, and lidar to measure the distance between the robot and distant obstacles.

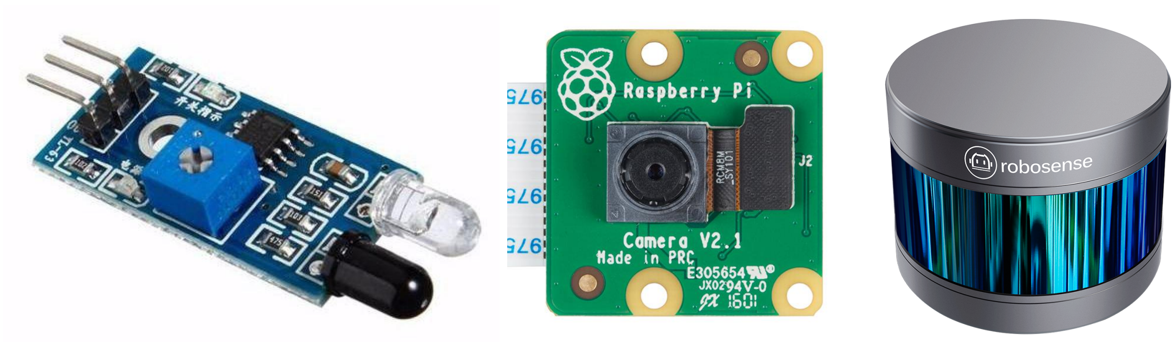

Figure 18

It is very important to have redundancy because sensors may be subject to external disturbances, for example, IR proximity sensors are sensitive to sunlight and heat, and cameras and lidars can be tricked by reflective or transparent surfaces.

In order to detect nearby objects, different technologies exist, for example we could use a bumper like on the vacuum robots with switches behind so when the robot encounters an obstacle, the bumper deforms and the closest switch from the impact commutes. By looking at which switch commuted, the robot can determine if the object was on its right, on its left or ahead. In our situation we cannot accept touching obstacles. On top of that, plants are too lightweight to be detected using this technique. This is why we chose to use IR proximity sensors. They are able to detect an obstacle from a few centimeters so no need to make contact with it, they are very affordable and easy to use, the output is a digital signal “0” or “1”.

Because the robot will have to “see” objects from one side to another of the field, we need to use cameras. Cameras to have a global view of the area and if we add a Nvidia Jetson Nano board to the robot, it would be able to process images from cameras. Then, by using computer vision, the robot will determine by itself where plants are and drive right up to them while avoiding obstacles. The bad side of using cameras is that they require a lot of computing power so it might make the robot slow but from another side, it is the only solution to see colors from “long” distance which is necessary for the robot to know where its camp is. To reduce the computing power required to process the images, we will use JeVois Pro cameras which have integrated accelerator Hailo8 to optimize AI use with these cameras.

During a match, obstacles will be all around the robot so in order to detect them and know how far they are from the robot, we chose to use a lidar. A lidar allows the robot to scan at a 360 degree angle and measure distances with each point. Based on this 3D scan of its environment, the robot will be able to calculate a free path between him and its goal. We could also use a radar instead of a lidar but it is not precise enough for our use.

5) <u>Alternative design :</u>

To design the first version of the robot, we only based on tasks the robot will have to do but since, we received the points awarded to each action so now we have to modify our conception to suit better our new strategy. We found out that putting plants in pots is not worth it so we decided to just swipe as many plants as we can without potting them.

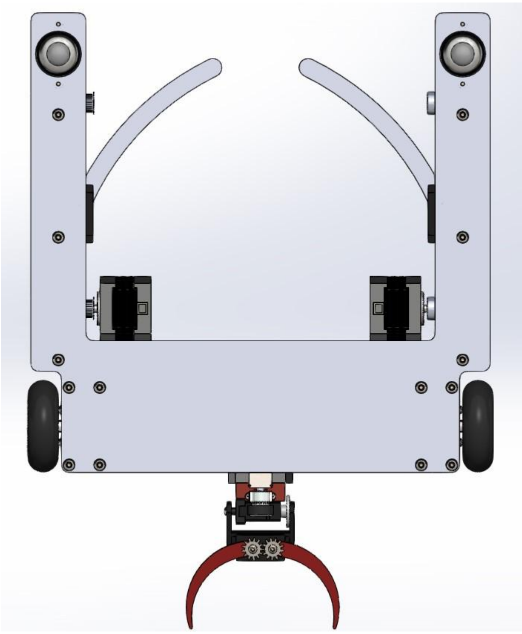

Figure 19

To do so, the next version will not have any storage system; instead, the rolling base will have a U shape with rear-mounted motors (*figure 16*). The robot will not have to take each plant individually but just to push them with its body. To avoid plants from falling down while the robot is pushing them, we designed a system with two long claws which will hold plants together. Steps are the following :

- The robot moves towards the plants and surrounds them
- The claws close
- The claws slide backward to squeeze plants against the robot's
- The robot moves to the next plant location

The claws system is shown on *figure 17* where we can also see the stepper motor which actuates this system. We can also see that each claw is actuated by a servo motor (the same model as the grabber) in direct drive, and each system servo + claw is mounted on a linear guide to ensure an efficient translation motion.

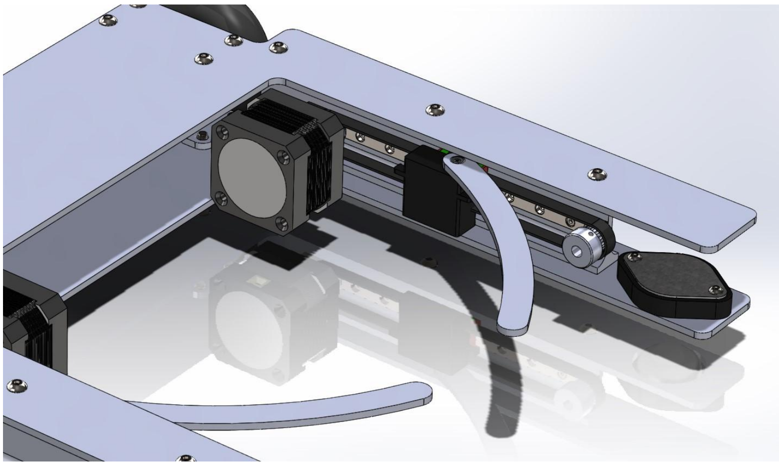

Figure 20

The grabbing system is also a bit different on this version, indeed, the linear guide cannot rotate on itself anymore because we do not need it anymore. To unload the plants, the robot opens its claws, moves backwards and turns half a turn, then handles the plants with its gripper (*figure 18*).

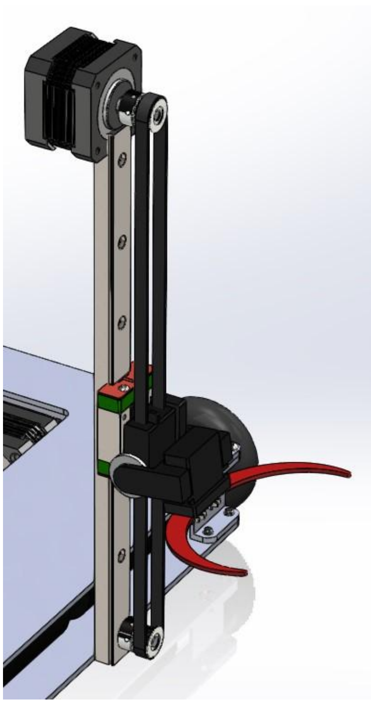

Figure 21

6) **Material list :**

1 sheet of 5mm plywood 300x600mm

2 brushless motors

Emergency stop button

2 pairs of roller wheels

300x600mm linear guide

3 belts 5mx6mmx2mm

2 DC 24v 35w 220 rpm motors

3 NEMA 17

3 GT2 pulleys

Stepper driver arduino

2 Cytron DC drivers 5v-30v 10A

Arduino mega

Nvidia jetson nano

4 aluminium profile 250mmx20mmx20mm v-slot

Various screws

Vinyl play mat + 36 plastic plants + 36 steel pots

Construction wood

3 JeVois Pro Cameras

7) <u>**Gantt diagram with work distribution :**</u>

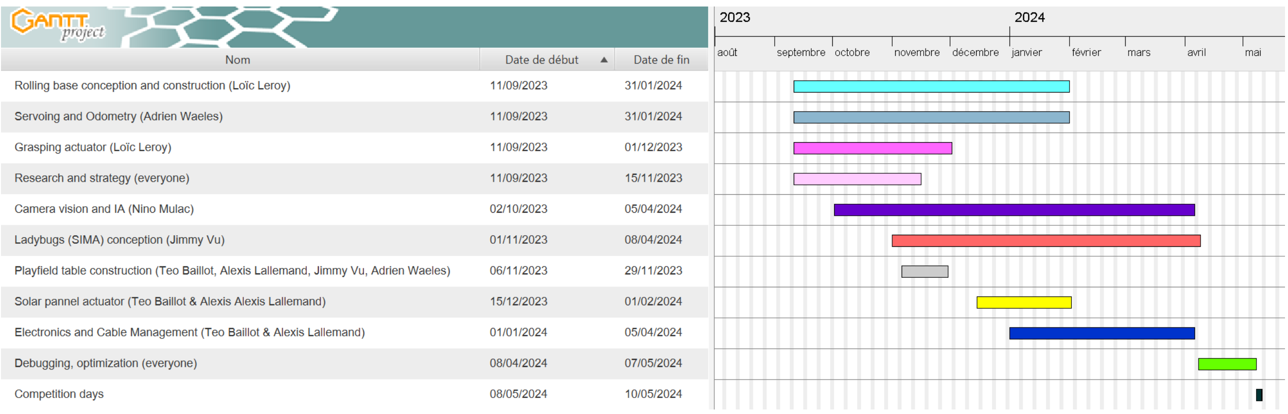

Figure 22

Due to the project's scope we have to share tasks between the participants. Thus, we will focus our work on the rolling base conception, its servoing, odometry and the grasping actuator which are fundamentals for the rest of the project.

8) Conclusion

To conclude on the technological choices we made, the main body of the robot is plywood plates assembled with 3D printed parts and screws, the structure is made out of aluminum profiles. The motors are DC motors positioned in the middle of that body. Wheels are roller wheels. To interact with plants and pots, the actioner is a grabber with two claws actuated with a servo motor, the grabber system is mounted on a linear guide which can rotate on itself thanks to a stepper motor and the chariot is actuated by a stepper motor and system pulley / belt. The robot stocks plants and pots on itself in a storage unit. This unit is a plywood plate with holes to hold the plants and the pots. It is mounted on a stepper motor shaft. The storage unit is screwed on top of the rolling base inside the aluminum structure. In terms of sensors, the robot is equipped with IR proximity sensors, cameras and a lidar. The whole system is supplied in energy by a LiPo battery stored into the rolling base.

9) Sources :

https://www.coupederobotique.fr/edition-2024/le-concours/reglement-2024/

https://community.robotshop.com/blog/show/dimensionnement-dun-moteur-dentranement

https://www.eurobot.org/wiki/fr/home

https://github.com/VRAC-team/la-maxi-liste-ressources-eurobot/

https://spectrum.ieee.org/universal-jamming-gripper

Rafli, Fouzi. (2020). LES BATTERIES AUX LITHIUM.

Guillaume Borschneck, Alexandre Janot (2015). ANALYSE ET APPLICATION POUR DIFFÉRENTES COMMANDES DE MOTEUR BRUSHLESS

Adel Dahdouh (2013). COMMANDE EN VITESSE D'UN MOTEUR À COURANT CONTINU PAR BACKSTEPPING