ROBOTICS PROJECT – ROBO3

School year 2023-2024

"GRABBY - the Warehouse robot"

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Introduction

With the constant increase of demand in goods, services and products there is a need to do everything faster and with a lower cost. We asked ourselves where it is possible to win the most time, money and human labor, we concluded that it was storage. Both production and shipping need massive storage places.

We did some research and found out that we can have an automated operating software that has all scheduling, shipping, and timing of products and packages so that warehouses can ensure the ideal timing for such procedures and the timely export of packages at each warehouse.

According to a study by McKinsey, implementing automation in warehouse management can increase productivity by up to 40%, leading to significant cost savings. Companies like Amazon, Honeywell or Zappos have communicated that automation has increased their productivity by 20 to 50%.

Also automated systems can scan and track inventory levels, reducing the risk of stockouts and overstocks.

Seeing these numbers, we started thinking about how we could make a low cost, modulable and flexible way to automatize storage places. We also needed a system that could use the existing infrastructure. So, we came up with Grabby, our logistics warehouse robot.

Grabby the warehouse robot is an autonomous robot that can considerably reduce the cost and time needed for the storage. It can autonomously replace boxes at their place, find a new place for new products and bring you the right box in the less time possible and with incredible accuracy. The goal is to make our robot compatible with the most storage shelves and boxes possible. It will also have an advanced obstacle avoidance system to make it possible to access the storage shelves for humans while it is doing its job. It will also be easy to add or remove robot due to the flexible operation system and the good communication between the robots.

In today's world where warehouses, logistic centers and e-commerce become more and more present, there is a real need for automation, either in the delivery process or the packing process. Our Grabby robot will help during this process inside the warehouse. Grabby will do GTP (good to persons), meaning it will retrieve a box from the warehouse and deliver it to a person at a packing station so it can be packed and shipped.

I. Mechanical analysis and solutions.

I.1 Movement

I.1.1 Overview

In order for our robot to be able to retrieve goods and deliver them to the user, it has to be able to move around the warehouse. Most warehouse robots are composed of two main parts: a movable base and a grabbing system.
Let's look at different types of movable bases used by different manufacturers. The two main types are AGVs (Automated Guided Vehicle) and AMRs (Autonomous Mobile Robot).

I.1.1 - Figure 1 - Movable Base Concept

I.1.2 AGV

AGVs have their pros and cons when compared to AMRs.
They are useful in environment with fixed installations that don't tend to vary a lot, so where there are a lot of repetitive tasks etc. Their need for fixed paths is also what makes them limited in their application. They also have minimal onboard intelligence which makes them able to follow simple instructions as well as cost less. However, they can only detect obstacles and not navigate around them.

I.1.3 AMR

AMRs are a lot more versatile than AGVs, but this can also make them overpowered and over-engineered for their application.
Firstly, AMRs don't rely on fixed routes and can therefore be used in flexible environments. Also, their intelligent navigation, which often relies on vision and laser scanners, they can detect obstacles and navigate around them.

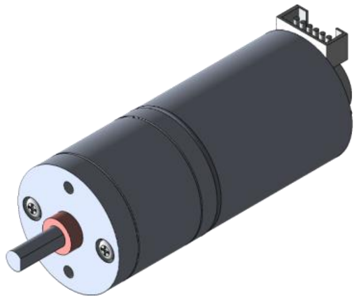
I.1.4 Grabby's motorization and locomotion

For the purpose of our Grabby robot, we will have two main development phases. While the motorization will remain the same, the navigation system will vary but more on that in the Navigation section of this document.

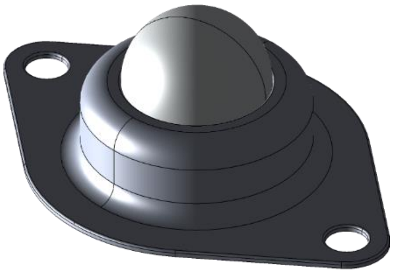
The motorization and locomotion systems on AGVs and AMRs are mostly the same, meaning the components don't tend to vary a lot between these two systems.
Most manufacturers producing robots similar to our idea, use between 2 and 4 motorized wheels with additional non-motorized wheels for stability.
"Grabby" will use 2 motorized wheels and an additional set of 2 wheels (not powered) for stability.

The most used type of motor used in these kinds of robots are Brushed DC motors, in our case, with encoder (I.1.4 – Figure 1), so that we can monitor the speed, the power etc. better with than without. The amount of torque needed depends on the overall weight of the robot with and without a box on top. Since the boxes will be empty, we'll only take into consideration the dry weight of the robot.

The 2 motorized wheels (I.1.4 – Figure 3) will be semi-slick to slick rubber wheels to offer maximal grip on the warehouse floor.
The non-motorized wheels will be ball caster wheels (I.1.4 – Figure 2). These offer movement in all directions with minimal resistance and will allow the robot to not tip over.



I.1.4 – Figure 1 - DC Motor with Encoder



I.1.4 – Figure 2 - Ball caster wheel

I.1.4 – Figure 3 - Rubber Wheel

The connections between the different components will be made using wheel hubs and shafts as well as a specially designed holding mechanism for the motor.

I.2 Lifting system

I.2.1 Technical specifications

- ✓ Big height range (30cm-100cm equivalent to a 3-5 box shelve)
- ✓ the system must be retractable: it must be small and compact when at the lowest position.
- ✓ Stable even at the highest position
- ✓ Reliable

I.2.2 Stacker like

I.2.2 - Figure 1 - Stacker

Mostly used in pallet stackers (I.2.2 – Figure 1), they use hydraulic or electric power to lift a platform from the side of it.

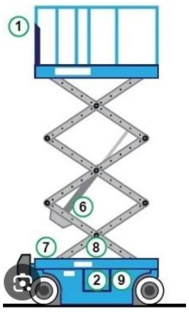
Positive aspects

- can lift heavy loads.
- Very low pickup point, even from the ground

Negative aspects

- Lift from the side, need for a very solid and heavy structure to be stable.
- Low height range
- Complex mechanism doesn’t allow easy range augmentation.

I.2.3 Scissor lift



I.2.3 - Figure 1 - Scissor Lift

Mostly used in scissor lift (I.2.3 – Figure 1) or lifting tables, they use hydraulic, pneumatic or electric power to lift a platform from under it.

Positive aspects

- very big range, up to 22m for some industrial gondola
- stable, light and good weight distribution on the robot
- variable power sources

negative aspects

- need a lot of power to start when at the lowest position.
- lowest pick up point is determined by the system that is fold under the platform.
- Not made for really heavy weight

I.2.4 Adopted solution

Our goal is to lift boxes that aren't usually heavy and to put them in high shelves. So, the best solutions are the scissor lift with an electric motor for a more silent robot.

I.3 Grip system

I.3.1 Technical specifications

- ✓ fast and reliable pick up and drop off.
- ✓ no need for specific boxes
- ✓ light, because it will be on the lifting platform.
- ✓ space saving

I.3.2 Vacuum gripper

Vacuum grippers are composed of a vacuum pump, pipes and suction cup, they are used for delicate handling of objects that have flat surfaces. This system is placed on a sliding arm, this one extends to put the suction cups and the box in contact then the vacuum pump is turned on and the box has been pulled as the arm retracts.


I.3.2 - Figure 1 - Vacuum gripper

Positive aspects

- gentle handling, they don't warp or deform the object.
- speed and efficiency, the pick-up and drop off are nearly immediate.
- minimal maintenance because they have less or no moving parts

Negative aspects

- limited surface suitability, it needs a flat surface to create vacuum.
- weight limits, the weight is limited by the size of the vacuum pump, heavy object will need much more power.
- energy consumption, a vacuum pump needs to be active during the whole pick-up phase, compared to a servo motor that only needs to turn once.
- Noise, vacuum pump and suction cup are very noisy.

I.3.3 Box gripper

Base on multiple servo motors to encage or compress a box to create grip (I.3.3 – Figure 1). This system is composed of two arms that extends at each side of the box, at the end of each arm there is a servo motor that acts as a hook. When the arms retract the box is pulled by the hooks.

I.3.3 - Figure 1 - Box gripper 1

Positive aspects

- Low energy consumption, energy is only used during the first part of the pick-up phase.
- Less noise, only small noise when servo motors are on
- More reliable, no leakage due to air system and motors are less used which means a longer lifetime.

Negative aspects

- Slower, time needed for arms to extend and servo to turn.

I.3.4 Adopted solution.

We chose to opt for a vacuum gripper because of the pick-up speed, it will help to reduce time in every tack the robot has to do. Also there will be no need to have space between boxes because it only interacts with the front of the box. Last, the system is compatible with most boxes.

I.4 Power

Our warehouse robot will need to navigate around the warehouse. Since it is not mounted on conductive rails or other real-time power supply like other robots that exist, to be fully autonomous Grabby will need a battery. Either a swappable battery that can be replaced rapidly or a battery that lasts long enough for the robot to complete its tasks and after the shift it would go back to the charging station to charge.
So, Grabby will feature a battery with enough capacity and voltage to supply power to the robot for about an hour of operation since it is a prototype. The fact being that we have a multiple sensors, computers and motors aboard the robot, we’ll need a lithium battery that is not to heavy but still has enough capacity.

I.5 Navigation

I.5.1 Overview

Grabby’s navigation system will be one of the complex parts of this project. Since the navigation system between AGVs and AMRs varies a lot, Grabby’s navigation system will be developed over two phases.

I.5.2 Phase 1

In the first phase of the project, Grabby will behave more like an AGV, meaning that its navigational capabilities will be minimal.

I.5.2.1 Navigation systems

- Laser Guided Navigation, used on AGVs makes them LGVs (Laser Guided Vehicle), is easy to install, doesn’t need a lot of space, has accurate positioning, and allows for high speeds of the robot. However, this system can be very expensive.
- Magnetic Spot Navigation uses, as the name suggests, magnetic spots located on the warehouse floor. When the robot passes over them, a sensor detects them and knows that it is on the right path. The advantages are a free environment and accurate positioning. However, modifying the system can be difficult.

- QR Code Navigation is similar to magnetic spot navigation, using QR codes instead of magnetic spots. It can be easier to install but the codes need to be read and interpreted.
- Magnetic Tape Navigation has different advantages like easy installation, easy modifications, accurate positioning, reliable navigation. On the other side, there is the maintenance of the tape, the costs and the fact that it only works for simple paths.
- Inductive Wire or Line Navigation (I.5.2.1 – Figure 1) is the preferred navigation method for AGVs. Since the system is similar to Magnetic Tape navigation, is has mostly the same advantages / disadvantages but costs less and is easier to install.

So for the first development phase, we'll use Line Navigation (completed with additional ultrasonic sensors to detect obstacles) as it is a cheap and reliable method of navigation and allows us to test all the other aspects of the robot: the grabbing system, box detection, QR code scanning etc.

I.5.2.1 - Figure 1 - Line Following

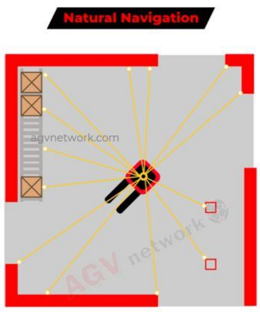
The line will be followed by using infrared sensors to detect the black tape on the warehouse floor.

I.5.3 Phase 2

During phase 2, our robot will have similar capabilities to an AMR from a navigational point of view.

I.5.3.1 Navigation systems

The only navigation system used for AMRs, and therefore giving them these unique capabilities, are Natural Navigation Systems (I.5.3.1 – Figure 1).
This system is based on vision through cameras and other types of sensors. Costing a lot of money and being quite complex, this system is not adequate for every robot.



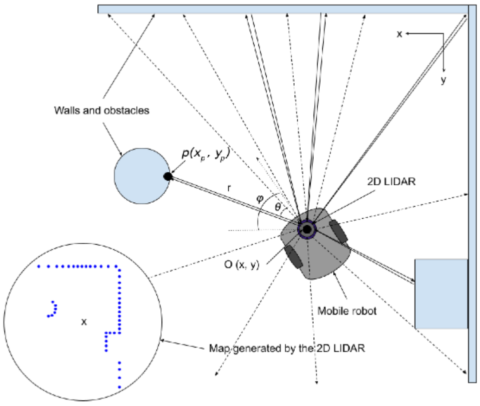
I.5.3.1 - Figure 1 - Natural Navigation

Grabby will utilize Natural Navigation in phase 2 making it be able to know exactly where it is inside the warehouse. Equipped with a LiDAR (Ligh Detection and Ranging) system and ultrasonic sensors to monitor the sides and the back, it will be able to drive though the warehouse, either by following a saved map of it, created during a previous scan or through manual coding, or drive around by discovering the entire warehouse anew.

I.5.3.2 Spatial Recognition

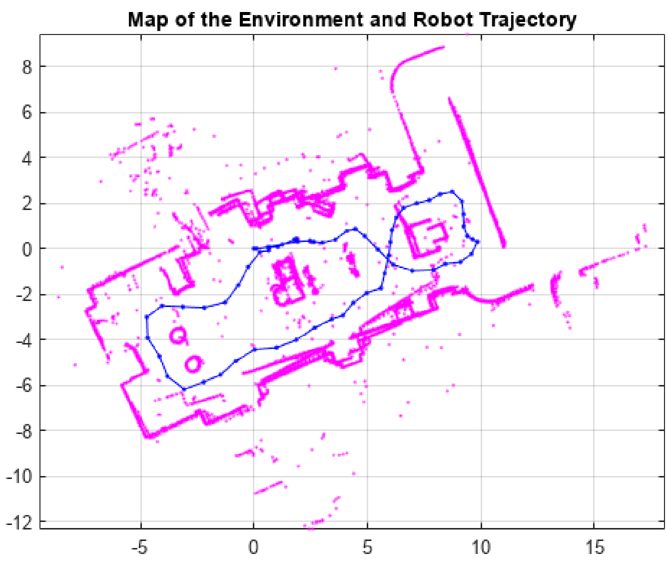
Spatial Recognition will be a key aspect of phase 2 since the robot will need to know exactly where it is either through vision or through a hard coded map of the warehouse.
Grabby will utilize a 2D LiDAR (I.5.3.2 – Figure 1) system with which it could create a map of the warehouse and then navigate around. Since there will be elements on top of the robot, the LiDAR system will only be useful in the front. To take into account the possible presence of glass, and obstacles on the sides, Grabby will feature ultrasonic sensors on the side and maybe on the front to further improve the robot's detection capabilities.

I.5.3.2 - Figure 1 - 2D LiDAR



I.5.3.2 - Figure 2 - 2D Map

Using the LiDAR sensor, which will be a Mechanical Scanning LiDAR (a LiDAR that rotates with an emitter and a receiver), we can create a 2D map of the warehouse (I.5.3.2 – Figure 2). Using this existing map that is saved and by comparing and measuring the real-time data from the LiDAR as well as using the motor encoder data for the wheel turn count etc… we could pin-point the location of the robot inside the warehouse. In our testing environment this will be easier than in a real warehouse where everything is just shelves. This could be achieved by using a 2D-LiDAR SLAM algorithm (Simultaneous Localization and Mapping). So essentially, by using the data received from the LiDAR, the robot would create a so-called HD map (I.5.3.2 – Figure 3). This kind of map is highly detailed containing way more information that normal maps.



I.5.3.2 - Figure 3 – HD-Map

And so, with this map and the real-time data, Grabby would navigate around and know where it is.

I.5.3.3 Obstacle avoidance

Obstacle avoidance is crucial for AMRs since it's one of the key capabilities of these types of robots that make them so versatile and flexible when compared to AGVs.
Our robot now features a LiDAR sensor as well as other sensors and algorithms that will enable it to know where it is and detect a possible disturbance inside the warehouse. Now, when such a disturbance is detected, there are two possibilities. Either come to a complete stop and warn the user that there is something in the way or try to find an alternative route around the obstacle so the robot can still complete its designated task.
Grabby would avoid an obstacle by using the same method that it uses to know where it is inside the warehouse. By comparing the saved HD-map of the warehouse (which also contains distance information) with the real-time data from the LiDAR and the ultrasonic sensors, the computer can calculate a new route around the obstacle. Since the LiDAR can only see in 2D meaning there is no indication of height, the ultrasonic sensors are crucial to determine whether we can go around etc.
Additionally, in the context of our robot, we will only work with stationary obstacles, so obstacles that are fixed and don't move. We do this in phase 2 to limit the risks of collisions between two mobile elements and only concentrate on fixed things.

I.6 Intelligence and communication

I.5.1 Technical specifications

Our goal is to have multiple robots working together, these robots will have to communicate together and with a fix server to receive tasks.
Each robot will also have a relatively complex navigation system and a need to read QR codes to identify boxes and shelves.
Last, we must memorize where the boxes are stored.

I.5.2 Small onboard intelligence and big server

We have a first option where we have a small PCB on the robot (Arduino card) that only has simple tasks to execute and that send all information to the server, server who proceeds to all the calculations needed and then send back the information to the robot.

Positive aspects

- Cheap, Arduino cards are cheap it reduces the costs of one robot drastically.
- Light and small

Negative aspects

- Slower reaction time from the robot => robot is slower
- Huge amount of information needs to be sent and received.
- Good task management is needed by the server to not be overflowed by information.

I.5.3 Big onboard intelligence

Second option is to have a bigger PCB on the robot so that the robot is autonomous for QR code detection and part of the navigation. The server is there to send tasks to the robot, to avoid the robots colliding and memorize where every box is stored.

Positive aspects

- Faster reaction time => robot is faster
- Less communication between the server and the robots

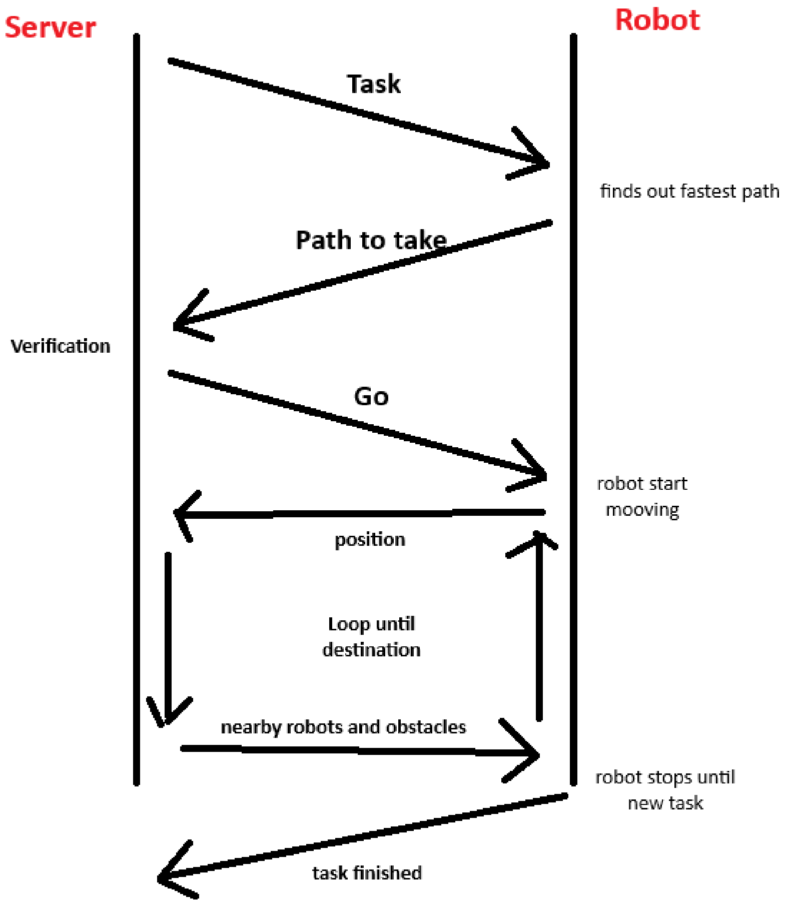
Negative aspects

- More expensive, each robot has a small computer onboard.

I.5.4 Solution adopted

We opted for a bigger onboard intelligence, this means we can have more robots in the same warehouse without saturing the communication frequencies, have a smaller server (also reduces the cost) better adaptability from the robots.

We made a communication timeline between the robot and the server (Img I.5.1).



I.5.4 - Figure 1 - On-board intelligence

II. Manufacturer examples

II.1 InVia Robotics

II.1.1 Introduction

InVia Robotics, a Californian robotics company, is building a robot that resembles our Grabby robot: the InVia Picker robot (II.1.2 – Figure 1). They use only one robot type that has a lifting and gripping system. There are 62kg robots than can lift 18kg crates from 50 cm up to 2.5m. They can pick-up boxes up to 38*61*35cm (standard moving crate 35*55*30cm) there is no minimum size except they need to have a smooth surface for their vacuum gripping system to work. This robot, being an AMR, can navigate autonomously inside the warehouse with a max speed of about 8km/h and that for 10 hours.

II.1.2 Technical capabilities and specifications

Every robot is equipped with a pneumatique or hydraulic scissor lift, the utilizes the same system that we anticipated to use. On top a grip system based on a vacuum pump and suction cups, they have two motorized wheels and 4 free rotating. To recognize shelves and boxes they use a lot of QR codes that can be read by a camera place on top of the grip system.

II.1.2 - Figure 1 - InVia Picker Robot

II.2 Caja Robotics

II.2.1 Introduction

They use two different robots, one called Sprynter (II.2.2 – Figure 1) which has a maximum gripping height of 80 cm. This robot is used to pick-up and drop-off boxes from low shelves. They also bring boxes to another robot called Skyler (II.2.2 – Figure 1) which is much bigger, heavier, slower and has less autonomy but has a maximum gripping height of 3.2m. The combination of those two robots allows faster movement, better productivity and lower costs.

II.2.2 Technical capabilities and specifications

Both robots can lift boxes up to 30kg with a size between 49.7*59cm and 40.3*61cm, a standard moving crate is 35*55*30cm, we notice that their robots aren't very flexible concerning the size of the crates. Skyler is a 350kg robot that moves at 1.5m/s and has 6h autonomy. Sprynter is a 55kg robot that travels at 2m/s.
They use a lifting system inspired by the forklifts, the robot Skyler is very wide and cannot turn in the allays, therefor it pick-up and drop off boxes from the side.

They use a grip system based on two arms that grab the crates and each side and one on the underside which means that every box is on a on an iron or plastic support, so they need specific shelves.

They use QR codes on the shelves, the ground and every box to recognize the crate and localize the robot. Every robot is equipped with a camera at the front, they don’t seem to have a captor on the side.

All the robots have two motorized wheels, in the middle for Sprynter and on the back for Skyler, then they have free rotating wheels.

II.2.2 - Figure 1- Sprynter & Skyler

III. List of materials

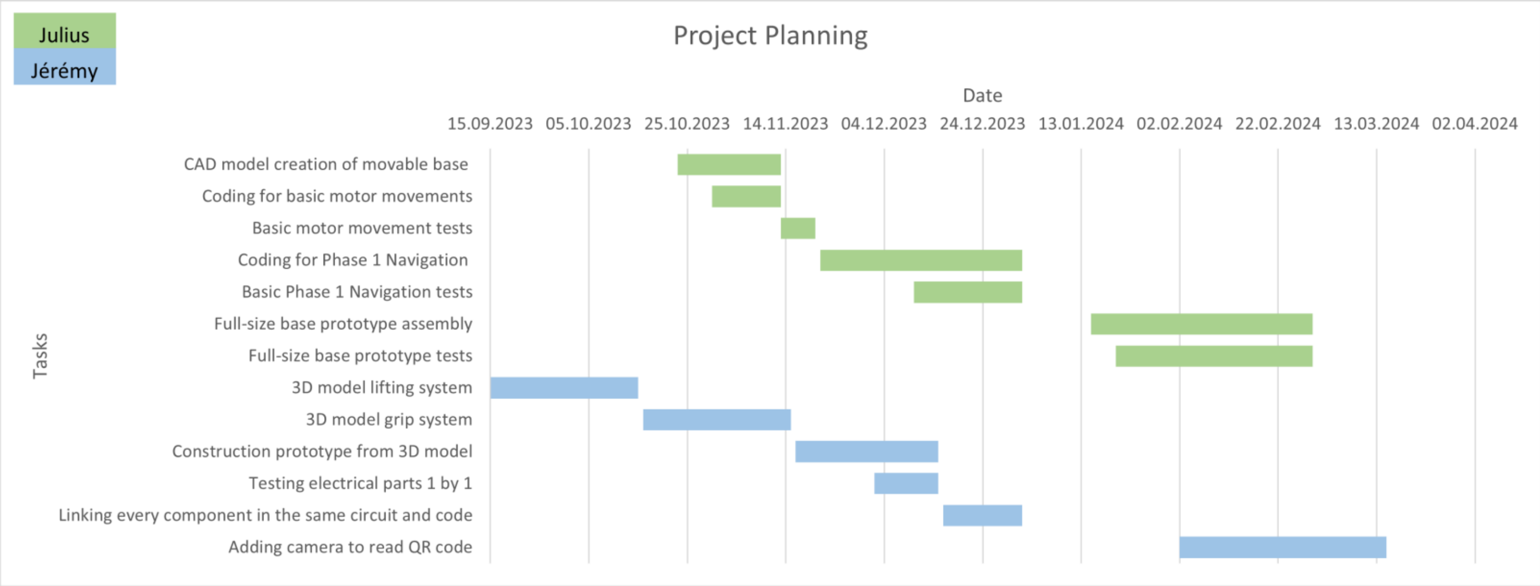
III.1 Electronic components

Quantity	Price (€)	Name	Description	Link
1	3.71	Nema 17	Stepper motor	AliExpress
2	0.5	Limit switch	Limit switch	
1	2	POLOLU-2967	Stepper control module	Amazon
1			Optical encoder	
1	40	HD C505	Logitech camera	Cdiscount
1			Emergency Stop	
1			Orange Led	
1			Red Led	
1	2	L298N	H bridge	AliExpress
1	0.7		IR speed sensor	AliExpress
2	1.3	VL53L0XV2	Laser distance sensor	AliExpress
1	3.7	R385 DC	Vacuum pump 12V	RobotShop
2			Brush DC Motor with encoder	
			Colored LEDs	
4	0.49	TCRT5000	Infra-red sensors	AliExpress
1			LiDAR sensor	
4	0.49	HC-SR04	Ultrasonic sensors	AliExpress
1			Arduino	
1			Nvidia Jetson	
1			Battery	

III.2 Parts

Quantity	Price (€)	Name	Description	Link
2	0.8	SC8UU	Slider 8mm rod	AliExpress
2	0.5	KFL08	Bearing 8mm rod	AliExpress
2	0.5	SHF8	Support 8mm rod	AliExpress
2	1		8*200mm rod	Castorama
1	5		8*200mm screw rod and screw	AliExpress
1	1.5		Link stepper to 8mm rod	AliExpress
2	15		Link motor to wheel	Amazon
2	7.17		Wheels (motorized)	Robotshop
2	3.03		Ball caster wheels	Robotshop

IV. Planning



IV - Figure 1 - Planning

Conclusion

To conclude this bibliographic report, our Grabby robot will be a mix of different existing technologies and manufacturing techniques. Grabby is a special warehouse robot since he combines two different robots into one: a picker robot that takes boxes out of the shelf, and a transport robot that takes this box and brings it to a user. Therefore, Grabby completes Goods-To-Person tasks. As already mentioned, the navigation of the robot will be made operational over two phases. One where line following is used and another where natural navigation is key. As for the lifting system, we chose a scissor lift combined with a vacuum gripper to retrieve the boxes from the shelf at different heights.

Links and resources

- Differences between AGVs and AMRs
    - https://www.mobile-industrial-robots.com/insights/get-started-with-amrs/agv-vs-amr-whats-the-difference/
- Motorization and locomotion
    - https://static.generation-robots.com/media/datasheet-agilex-robotics-tracer-fr.pdf
    - https://acim.nidec.com/fr-fr/motors/motion-control/industries/agv-and-amr
- Navigation
    - https://www.agvnetwork.com/types-of-navigation-systems-automated-guided-vehicles
    - https://www.agvnetwork.com/natural-navigation-automated-guided-vehicles
- Manufacturers
    - InVia Robotics
        - https://inviarobotics.com/our-system/invia-picker-robots/
        - https://inviarobotics.com/blog/goods-to-person-vs-person-to-goods-automation/
    - Caja Robotics

        - https://www.bastiansolutions.com/solutions/technology/goods-to-person/caja-robotics/
        - https://cajarobotics.com/
    - Scallog
        - https://www.bastiansolutions.com/solutions/technology/goods-to-person/scallog/
    - Stäubli
        - https://www.staubli.com/rs/en/robotics/products/AGV-platforms.html#carousel-4de4b361e1-item-c3d6fb5087-tabpanel
    - AMR Robotics
        - Otto Lifter and mover
            - https://www.amrobotics.eu/otto-100/
            - https://www.amrobotics.eu/autonomous-lifter/

- Automation
    - https://www.intellinum.com/top-benefits-of-automation-in-warehouse-management/