Development of an Automated Guided Vehicle for Material Handling in an Aeronautic Environment

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Aerospace Engineering

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To my family that always believe in me and give me the best education I could ever have. To my best friends that have always stayed with me in the good and bad moments throughout my life. I dedicate this thesis and, therefore, the completion of my university studies, to all of them.

Resumo

Esta tese pretende focar-se no desenvolvimento de protótipo de um veículo guiado automatizado (AGV) a ser introduzido na oficina de componentes da TAP Maintenance and Engineering. O veículo autónomo tem como função o manuseamento de materiais ao longo da oficina, o que actualmente é feito de forma manual, rebocando o carrinho que transporta as peças através de uma fita magnética.

A construção é feita depois de um estudo preliminar realizado em anos anteriores, que envolve uma pesquisa aprofundada e um projecto. Em primeiro lugar o carrinho é construído de acordo com o design e as diferentes modificações são exploradas, para que o acoplamento entre o carrinho e o suporte funcione correctamente. Para além disso, o projeto das estantes são também abordados.

Em seguida é desenvolvido o código de movimento e controlo do AGV usando o MicroBasic Language. Este código, por sua vez, é simulado com um software para verificar se a operação do veículo ocorre de forma adequada e segura.

Em termos de hardware, a interface e as conexões entre todos os componentes elétricos são abordadas, assim como a configuração do sensor a laser. O dispositivo de pinos de reboque que permite a conexão do carrinho ao AGV é projectado utilizando atuadores lineares elétricos. É ainda explorado o design da configuração de duas rodas motrizes como uma alternativa à configuração, inicialmente selecionada, de rodas direcionáveis.

Finalmente, o sistema de carregamento da bateria é seleccionado após comparar os diferentes métodos de carregamento. As vantagens e desvantagens de cada um são avaliadas e a decisão é tomada com base em diversos fatores com relevância diferente para esta aplicação.

Keywords: AGV, Manuseamento de materais, Desenvolvimento de protótipo, Código de movimento e controlo, Sistema de carregamento da bateria

Abstract

This thesis intends to be focused on the prototype development of an Automated Guided Vehicle (AGV) to be introduced within the components shop at TAP Maintenance and Engineering. This autonomous vehicle will perform the material handling task along the shop, currently done manually, towing the cart that transports the pieces following a magnetic tape.

The construction is made following the preliminary research and design done in the previous years. Firstly, the cart is built according to the design and different modifications are explored to make the coupling between cart and stands work correctly. In addition to this, the design of the group stands is also addressed.

Next, the movement and control script of the AGV is developed using MicroBasic Language. This code is, in turn, simulated with a software to verify the correct and safe operation of the vehicle.

In terms of hardware, the interface and connections among all the electric components is approached as well as the laser sensor configuration. The towing pins device that allows the attachment of the cart to the AGV is designed using electric lineal actuators. Moreover, the design of a two drive wheels configuration is explored as an alternative to the steerable wheel configuration initially selected.

Finally, the battery charging system is selected after comparing the different charging methods. The advantages and disadvantages of each one are brought face to face and the decision is taken based on several factors with different relevance for this application.

Keywords: AGV, Material handling, Prototype development, Movement and control script, Battery charging system

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Nomenclature

$u(t)$ Control variable of the controller

Kp Proportionality constant of the controller

Ki Integral constant of the controller

Kd Derivative constant of the controller

$e(t)$ Error input of the controller

Acronyms

AGV Automated Guided Vehicle

WLAN Wireless Local Area Network

TAP M&E TAP Air Portugal Maintenance and Engineering

HP Hydraulic and Pneumatic

R/E Reception and Expedition

PID Proportional Integral Derivative

BMS Battery Management System

DOD Depth of Discharge

GND Ground

FET Field Effect Transistor

AC Alternating Current

DC Direct Current

1 Introduction

1.1 About TAP Air Portugal

TAP Portugal, acronym of Transportes Aereos Portugueses, is a Portuguese airline born in 1945 after World War II coinciding with the commercial aviation development being Humberto Delgado the mentor of this foundation. The first route inaugurated was Lisbon-Madrid in September 1946 operated by a DC-3. On the next years more national and international routes were opened and the jets evolution allowed the first TAP transatlantic flight, destination to Rio de Janeiro in 1955. Nowadays TAP flies to more than 80 destinations within 4 continents. The last year it transported about 17 millions passengers with over 100 aircraft, as well as more than 80 tons of cargo. The group employees reach more than 14 thousand and the headquarters are placed in Lisbon as the main hub [1].

TAP fleet has changed over the years, starting with DC models, in 60s the first Boeing is added to the family, however in 90s Airbus becomes the main aircraft supplier setting its supremacy. Currently, it is in process of fleet modernisation aiming for more eco-friendly and efficient aircrafts, being a good example of it the fact that TAP became the first airline to fly the A33O Neo. The current fleet is composed of the Airbus family (A319, A320, A321, A330), Embraer (E190, E195) and ATR72 for regional flights [1].

Regarding the Maintenance and Engineering division, it has over 50 clients all around the world. For more than 50 years TAP has offered engine maintenance service, in fact, in 1974 it was the first airline to undergo major complete overhauls of the PW JT9-D reactors of the B747 and in the 80s it stand out as maintenance and repair company of aircrafts and engines of other airlines being one of the most recognised one in this term. Nowadays, it offers aircraft maintenance (Airbus), engine repair and overhaul, components repair and overhaul, continuing airworthiness management, engineering services, technical laboratories and training. Located in Lisbon with a total workforce of around 2000 people, including highly qualified technicians and engineering staff [2].

1.2 Project motivation

We live in a globalised world where all the companies of any sector fight against its competitors to reach the most efficient production methods and productivity in order to reduce costs and time. In particular, in the manufacturing and maintenance frame it is important to optimize the processes to get the final product with the best quality not penalizing the costs and time involved, which implies being competitive and improving the market share. The customer wants it cheap and good and the company has to do efforts to be able to offer the final product in time with a competitive price and top quality. Thus, it seems essential to adopt strategies that allow this, and here it is where the continuous improvement philosophy plays a crucial role.

One of the most important tasks in this framework is the material handling, which has huge influence on the production process and potential profits. Material handling is a remarkable source of wastes. For many decades the handling operations has been done manually with workers carrying or driving vehicles transporting the material. Nowadays a lot of companies have decided to implement AGVs (Autonomous Guided Vehicles) to make this tasks without the need of relying in humans.

The benefits of the introduction of the AGVs are unquestionable since it reduces the labor costs in terms of salaries and taxes, increases safety and gives the possibility of working in hazardous environments for the human. Moreover the AGV does not need to respect work shifts since it does not get tired and distracted which implies a reduction in the number of errors committed. Of course, the implementation of this technology leads to a higher initial investment , complexity in terms on control and software development and less flexibility due to the lack of decision making.

The AGVs are widely used in automotive industry, logistic and warehousing companies, and the component shop seems to be an ideal place to implement this technology. Hence this project aims to the development of an AGV prototype for the material distribution within the Hydraulic and Pneumatic component shop.

1.3 AGV history

An AGV is a mobile robot that follows a path described by markers or wires on the floor, or it uses vision cameras, magnets, radio waves or lasers for navigation. They are mostly used in industrial applications that required the material handling as well as in hospitals to transport medicines, food and bed linen [3].

The creation of the first AGV dates back to the early 50s in USA when T Arthur Barret, Jr. made some adaptations to a man-driven tow truck in order to follow a wire in the ceiling. He named his invention the "Guide-O-Matic". Afterwards, his company Barret Electronics, currently registered as Savant Automation, started to commercialize the idea [3].

On the following years other versions appeared also in Europe using other ways to follow a path, as optical sensors to following strips on the floor. In the beginings, the AGVs were simple built and able only to follow a specific way and direction relying on bumpers equipped with tactile sensors for safety. The next decades were witness to the advance of the electronics and control which as well as grater batteries. All these advances allowed the improvement of the AGVs precision and navigation. However in the 80s the severe recession made the AGVs less desirable due to the high costs an the Japanese automobile manufacturing industry introduced the Lean Production, lowering operation costs and increasing quality.

From the last decade of the century to the 2010s, AGVs evolved into much more sophisticated, reliable, and flexible. New navigation technologies and advances in sensors made the AGVs extend its performance to more complex scenarios and applications. WLAN (Wireless Local Area Network) also established itself as a means of data transfer [4].

Nowadays, the use of automated guided vehicles still have a clear ascending trend, being introduced in different applications besides the industrial and warehousing.

1.4 Project goal

The final objective of this project is to build a prototype of an AGV meant to work on the HP (Hydraulic and Pneumatic) component shop at TAP Maintenance and Engineering (TAP M&E) based on a preliminary design done in the two previous years by other students. In a first iteration, what it is wanted to achieve is to start up the AGV following a closed path to do the distribution of the different pieces to be repaired in 4 different groups (Pneumatic, Hydraulic, Electrical and Fuel components). The AGV should make the reception operation in an autonomous way following a magnetic tape place on the floor and guaranteeing the safety of all the workers every time at the shop.

Therefore, in order to reach this objective it will be necessary to build the reception stands and the vehicle itself, which in turn consists in a cart that carries the trays with the pieces and the AGV towing it. Some of these elements have been already designed but not tested, thus the prototype will be constructed following the preliminary design and testing if it works or not, making modifications of the design on the go as needed.

The structure and mechanisms of the stands and the vehicle should be built using the TechnoLean materials available on the shop whenever possible, provided by Quimilock, which is the main supplier.

1.5 Thesis layout

This thesis is developed throughout 6 sections broken down on the following:

- **Chapter 1** contains an introduction about the company in which this thesis is carried out as well as a brief exposition about the AGV history. The motivation and objectives are also stated.
- **Chapter 2** presents the project framework introducing the concept of continuous improvement and describing the work area where the AGV will be implemented besides the requirements it must comply with.

- **Chapter 3** outlines the previous thesis where the preliminary research and the design of the AGV were addressed. All the information gathered in this section is used as a start point for this project.
- **Chapter 4** details all the work done in the shop during the stay in TAP M&E. The building of the cart and group stand is done based on the previous design.
- **Chapter 5** includes all the work done concerning the AGV. From the AGV movement and control script development to the AGV chassis design through the electric components selection and connection, sensor configuration and towing pins device design. In this section is also addressed the battery charging system selection.
- **Chapter 6** presents the conclusions of this project and details the remaining steps to achieve the final goal of implementing an Autonomous Guided Vehicle for material handling in the HP shop.

2 Project background

2.1 Continuous improvement

The project is carried out at the Continuous Improvement department at TAP M&E. There the main task is, as the name says, taking actions and doing efforts to improve the efficiency of the different processes and services performed on several areas of the company.

This process of continuous improvement is done according to the "Kaizen" philosophy, Japanese word that means " change for better". The Kaizen method marks the correct strategy to change, fixes what is fundamental and deletes the waste [5]. Moreover, the improvement of the customer service from the production line, to maximize the productivity trying to reach the lowest production cost, and to decrease the inventory investment designating the money to other fields like R+D, all this configure the basis of the change for better strategy.

These actions are taken by every worker of the company no matter the rank or position, it is a responsibility of all. The changes are incremental and constant, that is, small improvements rather than big and ground-braking ones. A big amount of small changes will lead to significant improvements.

On the other hand, in the continuous improvement frame it exists also the concept of "Kairyo" (reengineering) which implies big advances achieved thanks to technological or organisation innovations [5]. If the process is improved in a continuous way the required effort in terms of innovation to carry out a radical change decreases substantially as it is exposed in Fig. 2.1.

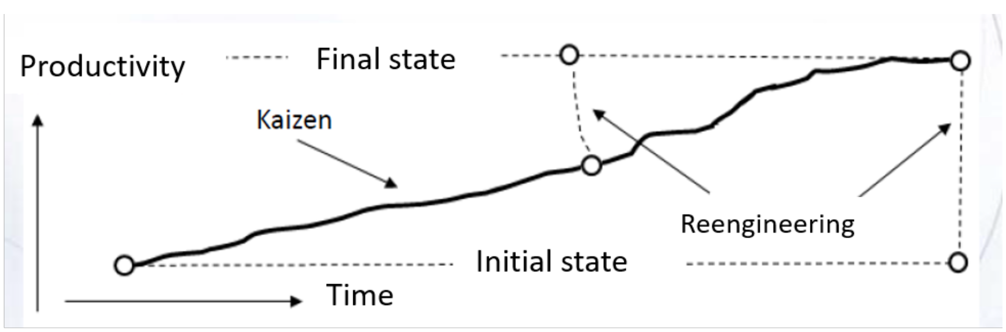


Figure 2.1: Kaizen vs Kairyo philosophy [5]

One of the objectives of the continuous improvement is to identify and eliminate or minimize the wastes, that is, all the things that do not add value to the process, they represent a cost afforded by the company that the customer does not pay for it. This is commonly called Lean manufacturing. Lean is the "antidote" against the wastes ("Muda") [5].

There are 7 wastes: overproduction, unnecessary inventory, waiting times, unnecessary motion, excess of transportation, reworks and over processing. Besides these seven wastes there is another one related to the waste of talent. A non motivated person whose talent is not been used. In order to reduce or eliminate these wastes, the lean methodology makes use of different tools (i.e Value Stream Mapping (VSM), 5s, Total Productive Maintenance (TPM), Kaizen, Andon, Plan-Do-Check-Act (PDCA)...) [5].

In particular, on this project framework, with the introduction of the AGV to perform the material distribution at the component shop, what is expected is to eliminate mainly the wastes of unnecessary motion (related to the physical effort the workers have to do to move the cart and place the pieces on the trays) and the waste of talent.

2.2 Hydraulic and Pneumatic Shop

The AGV will be introduced in the HP shop. This component shop is the place where the workers receive different pieces from the aircraft that need to be repaired. The shop space is divided in several groups, each one for a different kind of component. However, for the seek of simplicity, on this project it is only taken into account four groups, that is, the AGV only performs the route through the mentioned groups: Fuel components, Hydraulic components, Electrical components and Pneumatic components.

About the physical environment, the four groups are separated by a 5 meters wide corridor, being each pair of groups on each side of the corridor. In addition, each group has one reception and one expedition stand with different shelves. In the reception one, the workers responsible of the material distribution put the trays with the components to repair, on the other hand, once the pieces have been repaired, the repairmen put them in the reception shelves ready to be picked up. At the entrance, just on the right hand there is a room called R/E (Reception/Expedition) area (Fig. 2.2) where all the broken components arrived to be distributed among the different groups. This area is also the place where eventually after been totally repaired they will end up. Nevertheless, usually when a component is put in the expedition shelf after been fixed, the next destination is another group or place of the shop where the reparation process will continue and eventually it will end up on the R/E area ready to be sent to the aircraft (Fig. 2.3). Therefore the expedition operation is much more complex than the reception one.

Figure 2.2: Reception / Expedition area [6]

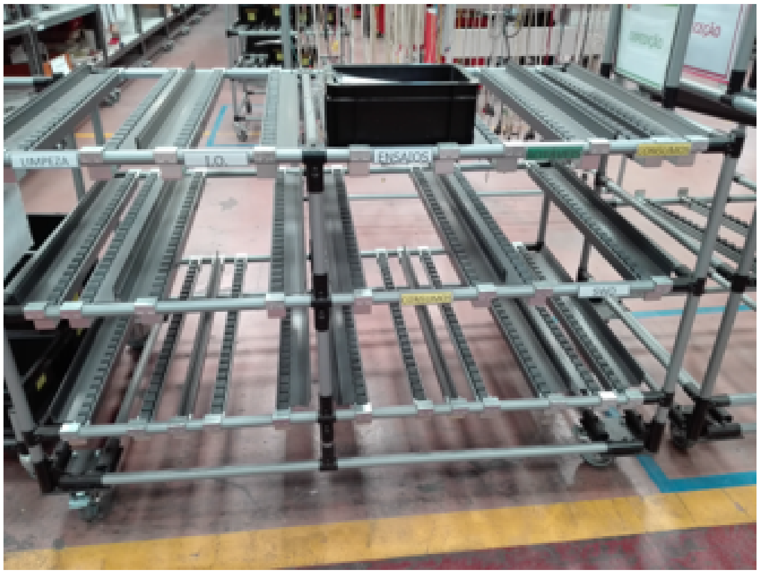


Figure 2.3: Picture of an expedition stand where it is shown the different destinations of each shelf [6].

The Fig. 2.4 shows the distribution of the 4 groups and the R/E area on the shop.

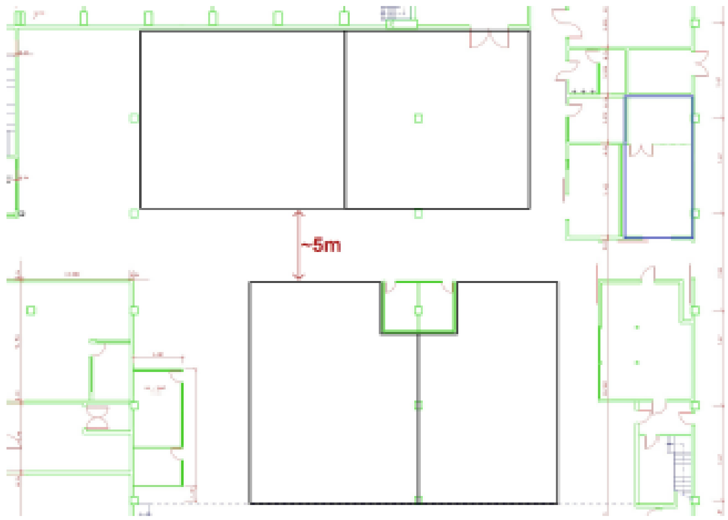
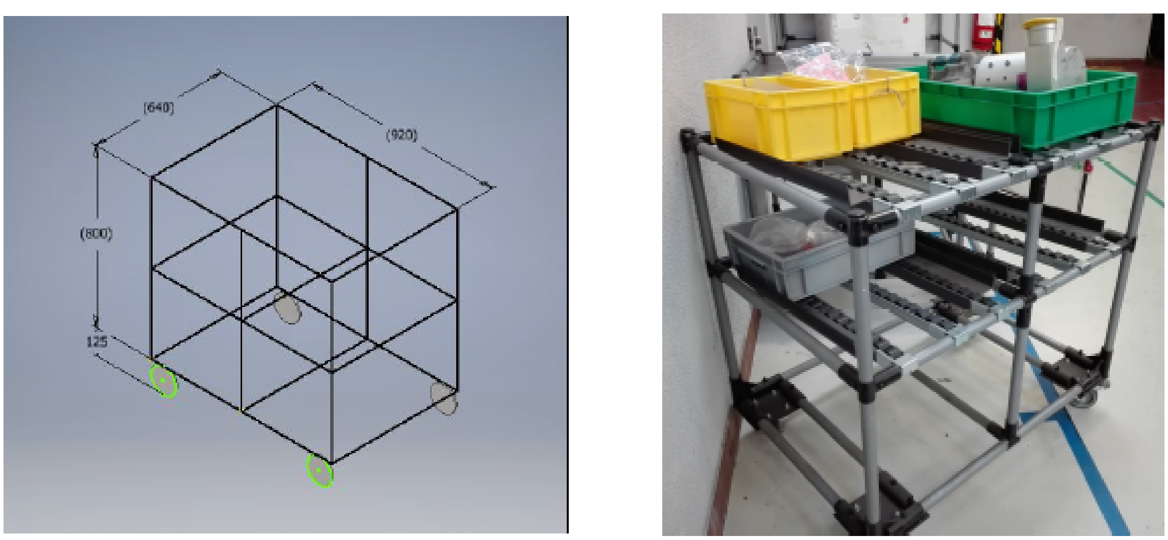


Figure 2.4: Partial plant of the workshop. Areas outlined in black represent the four work groups, and in blue is the R/E area [6].

The worker transports the different parts through the shop wit he aid of a cart. This cart has 4 different shelves as it is shown in Fig. 2.5a and Fig. 2.5b.



(a) Cart dimensions [7].

(b) Cart with trays [6].

Figure 2.5: Material distribution cart

Regarding the trays, to each group is assigned a specific colour to make simpler the task of the worker responsible of the material distribution. In addition, there are three different sizes 600x400 mm (big), 400x300 mm (medium) and 300x200 (small). Each one is used according to the dimensions of the pieces as they can reasonably fit.

In terms of the activity carried out on the shop, there are five different routes and three people with three different schedules who each split their 13 time between performing some of these routes and other activities. Among the three workers there are twenty half-hour shifts dedicated to these routes, which equates to 10 hours per day dedicated to transporting material. Note that these routes include other areas besides the four that this thesis focuses on, so the AGV is not expected to work 10 hours a day, considering the current activity of the workshop [6]. With the introduction of the AGV the tasks will be the same but now not done by humans.

2.3 AGV system implementation requirements

- The idea is that the AGV follows a counter clockwise loop path passing in front of the four groups performing the deliver and pick-up operations autonomously as it is shown in Fig. 2.6. Note that the deliver operation is completely independent from the pick-up one, that is, they are performed in different times. The group numbers correspond to Hydraulic (1), Fuel (2), Pneumatic (3) and Electrical (4) components respectively being the group 1 and 2 the ones whose parts are usually more weighty which will be taken into account later on the design.

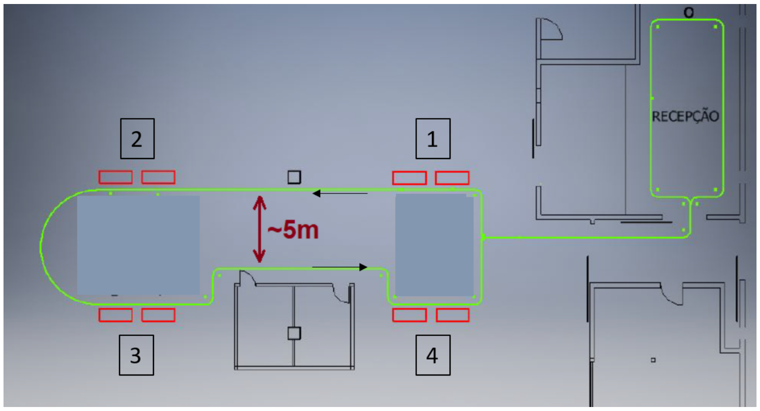


Figure 2.6: AGV single loop path with single unidirectional lane along the 4 groups [6].

This kind of path may seem not optimal in terms of path length and time spent, but is the simplest one because it is not easy to predict what type of material is going to be available to deliver or pick up at a certain moment, which would mean that the AGV would need to get new instructions constantly to know what path must follow.

- As it has been mentioned before, regarding the expedition operation, when a repaired part is expedited, its destination sometimes is another group until the piece is eventually totally fixed. Since this adds a lot of complexity to the project, this is only going to be taken into account in the first design in order to allow a future implementation of an advance system able to recognise or read the destination and order the AGV to go there. Thus, the prototype of the AGV and material distribution system has to be build in order to allow the implementation of this recognition feature in further work.
- Relative to the mechanism that allows the exchange of trays between the transport cart and the reception or expedition stations of each group, the process is based on the ”Karakuri” method, widely used on ”Kaizen” applications. This method states the use of automated mechanisms that rely only on physical principles, in this case, mainly the gravity. Hence, it is not necessary to introduce electrical engines or similar.
- In terms of safety, the AGV must be able to recognise obstacles that could eventually appear in the middle of the path and stop, avoiding crashing into them. Furthermore it must count with an emergency stop button to shut down the AGV whenever an emergency occurs and stop automatically in case of sensor failure.
- Finally, related to the building process, as long as possible, the idea is to use the TechnoLean material available in the shop, provided by the supplier QuimiLock to build the different structures. However, if some necessary pieces are missing, they will be ordered to the supplier. On the other hand, the different elements that constitute the AGV (Batteries, sensors, engine...) will be ordered to the corresponding manufacturers.

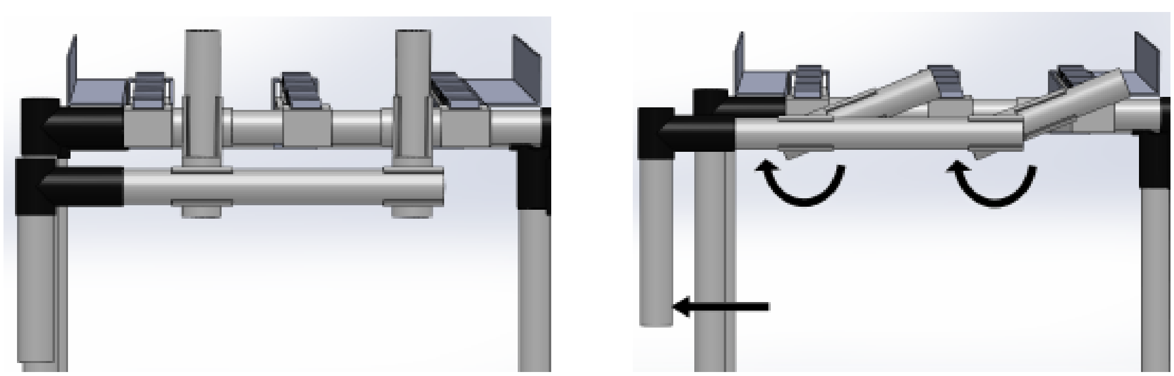
3 Design overview

In the following section an overview of the design done by Cheira [6] is presented. In her thesis, it was made a design of the cart and the AGV that tows it based on the preliminary design and ideas previously presented by Serrano [7], changing some relevant aspects of his first idea.

3.1 Material distribution system design

3.1.1 Reception system design

The cart towed by the AGV is similar to the ones currently used by the workers on the material distribution task. It has the shelves inclined towards the right side. They are only built using TechnoLean material. it was introduced some modifications to the cart coming up with a mechanism formed by two stoppers for each shelf that unlock when the cart makes contact with the stand. The exchange takes place since the reception shelves are also inclined (see Fig. 3.1a and Fig. 3.1b). The contact is produced between a ramp placed on the reception stand and a protrusion wheel situated on the locking mechanism of the cart. To ensure the release of the trays on the right group shelf, both the ramp and the roller wheel are placed at different height for each group. Therefore the wheels of each of the four shelves of the cart will be adjustable in height depending on the destination group of the trays contained on each shelf (see Fig. 3.2).



(a) Closed setting [6].

(b) Opened setting [6].

Figure 3.1: Locking settings

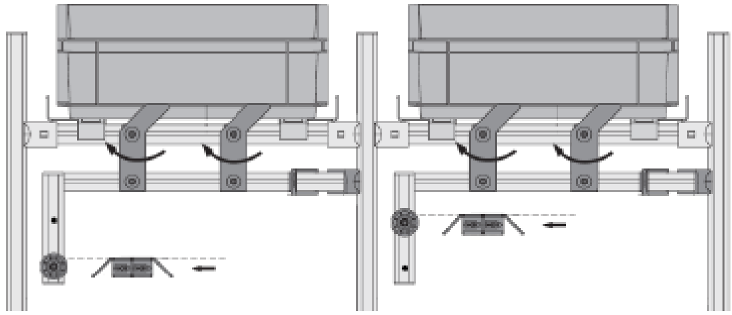


Figure 3.2: Adjustable roller wheels [6].

Moreover, to avoid that two shelves of the same level were activated twice on the same group Maria stated that it would be necessary to introduce an horizontal offset between the front and the rear rollers/ramps. Due to this, the front cart shelf roller avoids the contact with the rear stand shelf ramp but makes contact with the front one which is the correct one. When the trays are delivered and the cart moves away from the station, the rear lock is activated by the front ramp but there are not trays to deliver anymore so it does not matter. A scheme of this is shown in Fig. 3.3.

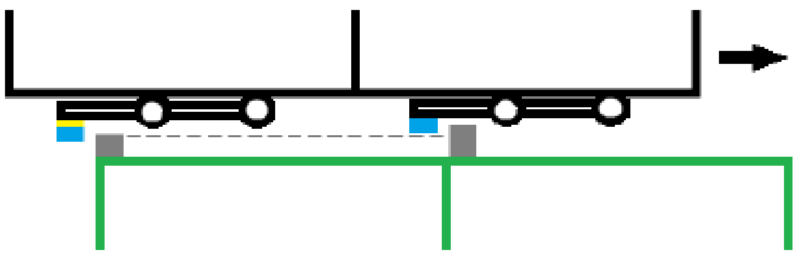


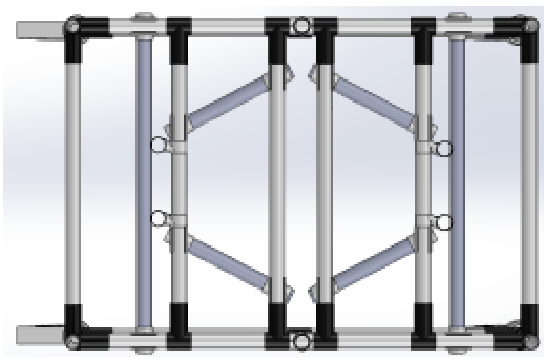
Figure 3.3: Schematic top view of the horizontal offset. Reception shelves in green, ramps in grey, rollers in blue and offset in yellow [6].

3.1.2 Expedition system design

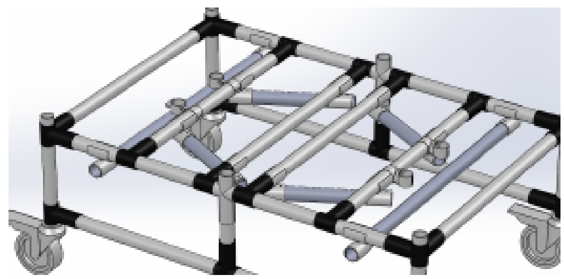
Even though Maria did not have enough time to develop the expedition system, she presented the idea of being similar to the reception process but on the opposite way. Now the cart has the ramps and the station shelves have the stoppers. The AGV will tow the cart turned around and the trays will slide from the station to the cart when the unlocking system was activated. In this way the cart will have on the right side the stoppers for the reception process and on the left side the ramps for the expedition process. The reception and expedition stations are different one from the other because of the shelves inclination direction and due to the fact that the reception one has ramps and the expedition one has the locking mechanism.

3.2 Coupling device

Since the AGV tows the cart, it is necessary a coupling structure between them. The coupling between the two parts must be done automatically. The AGV will go just beneath the cart which has been previously placed in a delimited outlined area and by means of two pins it will be attached. There should be markers to instruct the AGV to activate the towing pins. The coupling structure of the cart is symmetric to allow the introduction of the AGV below it from the two fronts, which is needed to perform the reception and expedition operations with the same cart as mentioned before (see Fig. 3.4a and Fig. 3.4b).



(a) Top view [7].



(b) Perspective view [6].

Figure 3.4: Coupling structure

3.3 AGV design

The type of AGV selected is underride AGV, it places itself under the cargo. The drive configuration chosen consists in a the tricycle configuration, with one steerable drive wheel and two caster wheels. It provides a higher level of steering precision than the other alternative considered which is a two front drive wheels configuration supported by two rear caster wheels (Fig. 3.5). However its complexity is slightly higher.

The steerable drive wheel model is MRT05.D0101 of C.F.R company that consists in a wheel connected to a drive motor and a steer motor responsible for making the vehicle advance and turn respectively. In addition it has two supporting rear wheels forming a tricycle configuration. The batteries selected are Lithium-Ion PowerBrick batteries from the company PowerTech with 12 V and 70Ah as main specifications. The requirements suggest the use of two batteries placed in series giving a total capacity of 140Ah.

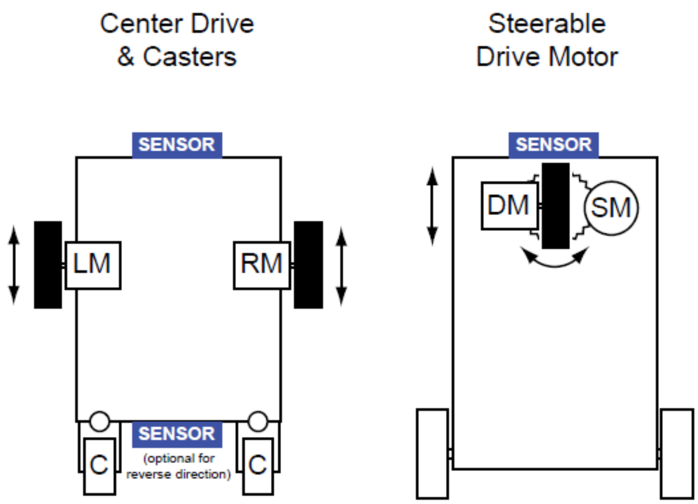


Figure 3.5: AGV wheels configurations [8]

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Regarding the sensors, the AGV counts with a laser sensor to detect obstacles (model S3000 from Sick company) and a magnetic sensor (model MGS1600GY from ROBOTEQ company) to detect and follow the magnetic tape.

The chassis is designed using again only TechnoLean materials (see Fig. 3.6).

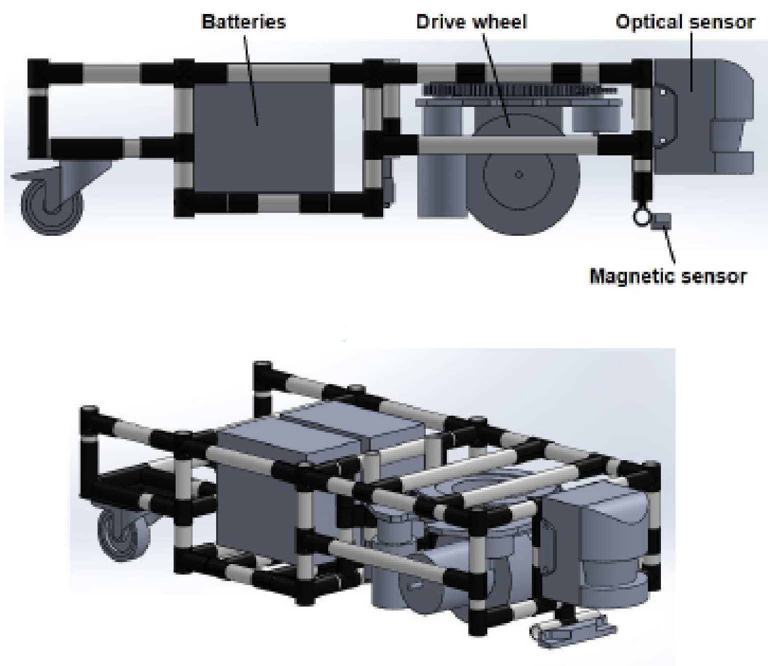


Figure 3.6: 3D model of the AGV [6].

On the next figure it is shown a general view of the AGV coupled to the cart containing a 600x400 mm tray (Fig. 3.7).

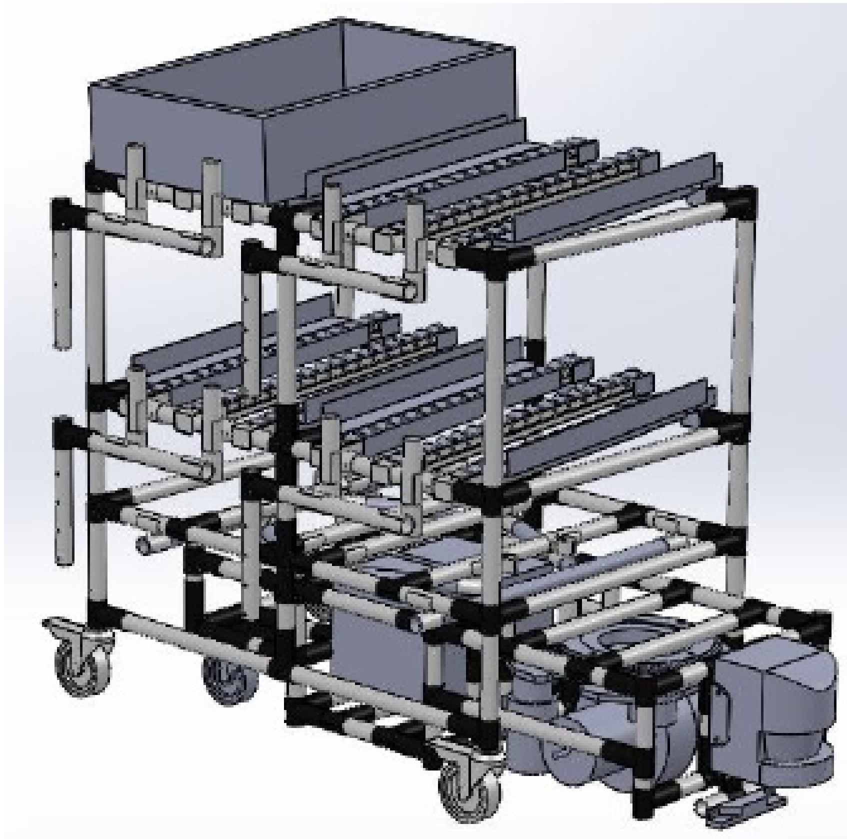


Figure 3.7: 3D model of the AGV coupled to the cart [6].

4 Distribution system development

The project can be divided in two different parts, the first one has to do with the building of the cart and the different group stations and the second part with the AGV prototype development. In this section it is going to be presented the first of the parts, the development of the distribution system. The idea is to follow strictly the design and check if it works as it is suppose to. If not, some modifications will be introduced to the initial design in order to make it work.

4.1 Reception system

To get started, the efforts have been focused on the construction of the cart and the reception stations. The 3D CAD files sketched using Solid Works have been examined to know the number of TechnoLean pieces and the measures of the tubes needed to build the cart. The main measures were verified comparing to the existent carts in use and an inventory of all the elements was made just as a sketch numbering the different tube segments that compound the structure. The tubes available in the stock storage have a length of 4 meters and 2 mm of thickness, therefore it was necessary to cut off them in different segments with the measures wanted (see Fig. 4.1). Of course, since there were a lot of tubes segments of different measures result of the excess of previous cut operations, these tubes were also used in order to take advantage of all the material. The cut operation was performed following all the safety procedures with the mandatory use of protection headphones, gloves, and glasses besides the use of boots, compulsory all over the shop.

Figure 4.1: Cut operation

Once all the tube segments have been cut, they are assembled with the aid of different TechnoLean joints and connectors (TA, TB , TC, TD and TE) and screws and nuts whose pictures and information can be found in the TechnoLean catalogue [9]. On the following pictures it is is shown the cart structure during the assembly process (Fig. 4.2) and the locking system closed and opened setting (Fig. 4.3a and Fig. 4.3b).

Figure 4.2: Picture of the cart during the assembly, coupling structure shown

(a) Closed setting (b) Opened setting

Figure 4.3: Cart locking system

Unfortunately the locking system is tested simulating a contact and it did not open unless a strong force is applied forcing it. The TE connectors responsible of providing relative movement between the tubes forming a "T" (see Fig. 4.3b) are not ideal since there is not a pure rotation around one axis but an additional not wanted tilt around the other two axis (Fig. 4.4) direct consequence of the momentum produced by the contact force which is misaligned from the tube where the TE connector is placed. This tilt blocks and complicates the natural rotation around the main axis, thus the locking system gets plugged while trying to open (see Fig. 4.5 and Fig. 4.6).

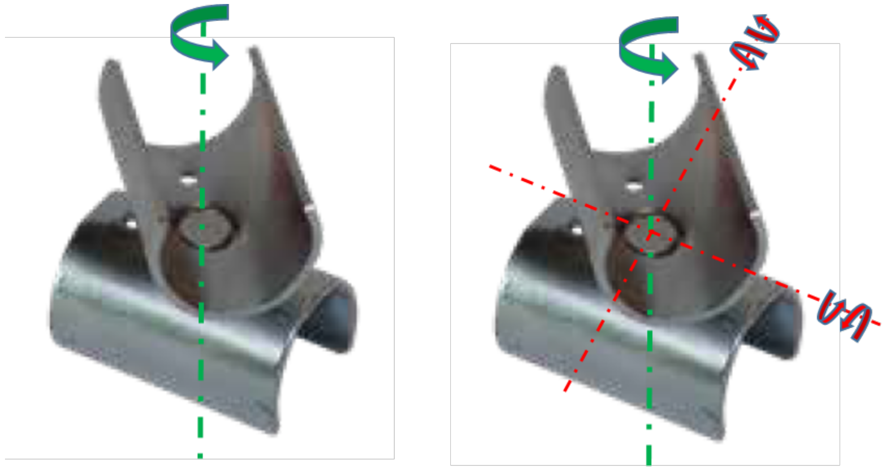


Figure 4.4: TE connector ideal (left) and real (right). Rotation around main axis in green and not wanted tilt around axis in red.

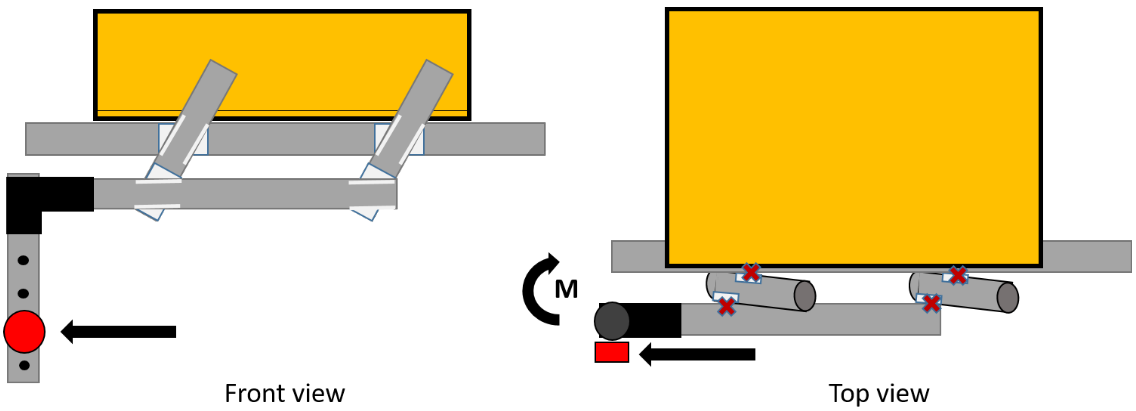


Figure 4.5: Scheme of the locking system aperture problem. The red crosses represent the block in the TE connectors rotation axis

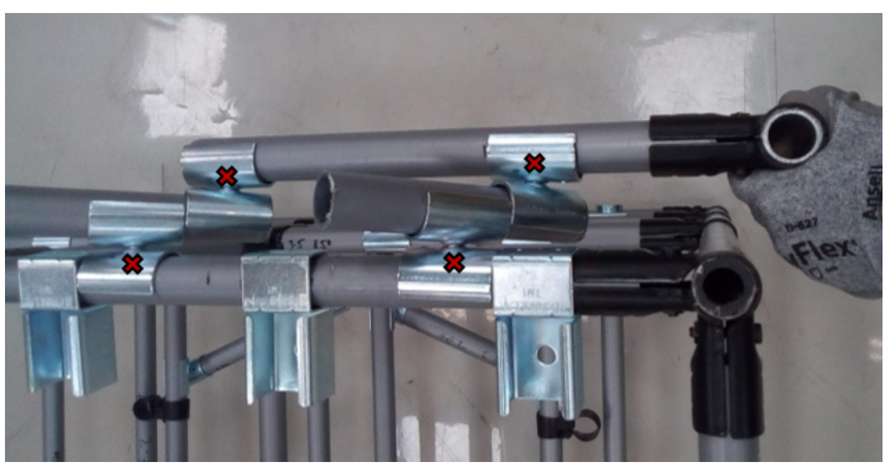


Figure 4.6: Picture of the locking system aperture problem

4.1.1 Failed alternatives

Once it is known that the designed locking system does not work as it was suppose to, the search of an alternative seems obligatory. Several alternatives have been tested in a trial and error process before coming up with the final idea. On the following, it will be exposed some of them.

The first alternative consisted in removing one of the two stoppers because actually it was verified that only one is necessary to block the trays no matter the size. This would allow to simplify the mechanism getting rid of the two tubes that formed the arm in which the roller wheel was placed. Instead of this, the roller wheel would be placed directly in the stopper tube. The roller will make contact with a ramp built by an inclined tube placed properly in the reception stand. Each group station has a different length ramps in order to avoid the aperture of the stopper in non desired group shelves. Moreover, for the same level shelves of each group stand, the front shelf ramp is shorter than the rear one and the cart front stopper is larger than the rear one to prevent from the completely aperture of the cart front stopper when makes contact with the front stand shelf ramp. To understand better this solution a scheme is presented in Fig. 4.7 and some real pictures in Fig. 4.8a , Fig. 4.8b (note that a connector TD is used as wheel).

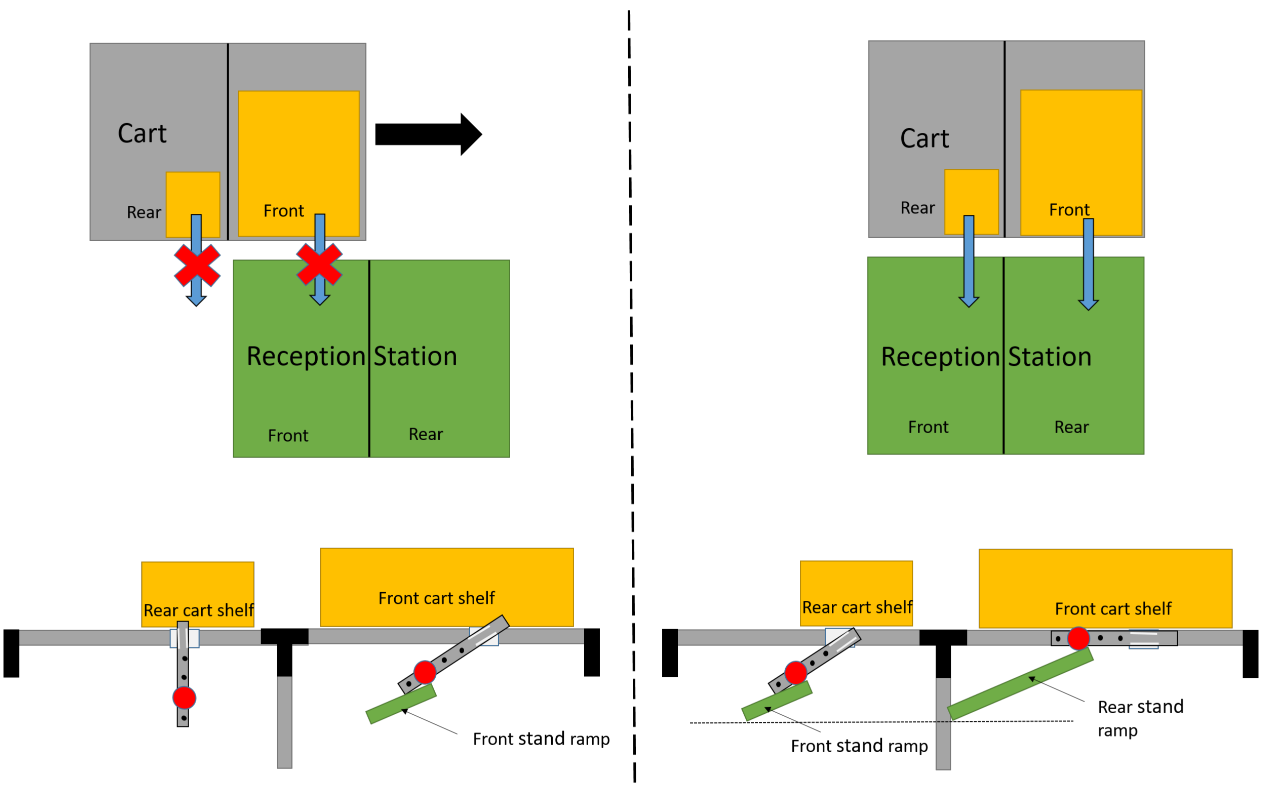


Figure 4.7: Scheme of the simple stopper alternative

(a) Front and rear cart stoppers

(b) Ramp

Figure 4.8: Simple stopper alternative

However, testing this solution it is observed that again it appears the same problem related to the momentum produced because of the force applied in the protrusion wheel (TD connector in this case) which is not aligned with the connector TE causing a deficient aperture of the stopper.

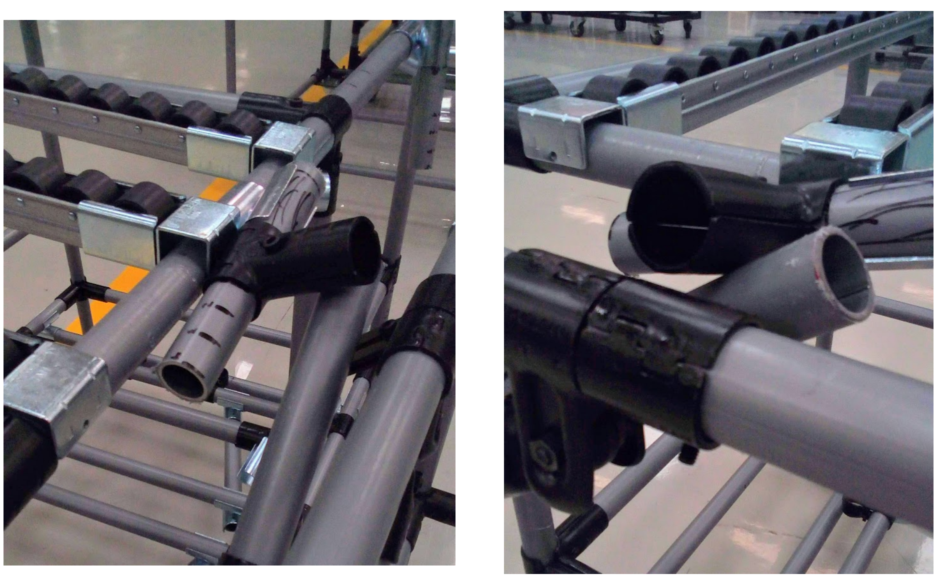
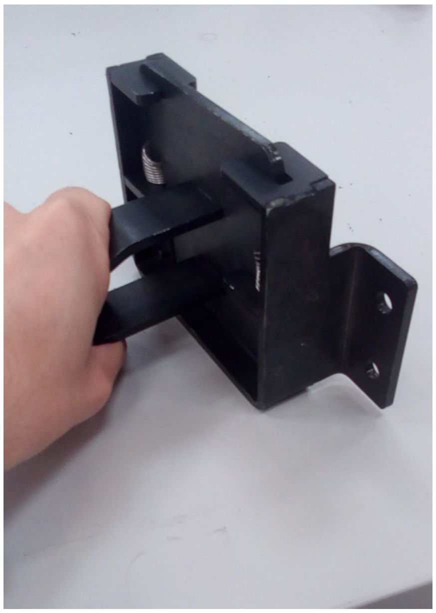


Figure 4.9: Simple stopper aperture problem

Another alternative, this time changing completely the locking system concept, was trying to make use of the Technolean SH-1 piece (Fig. 4.10a, Fig. 4.10b) which is a stopper that opens when there is a frontal contact between the cart and the stand. With the aid of two springs, the stopper returns to the initial position after the trays exchange.



(a) SH-1 device opened

(b) SH-1 mounted on the cart

Figure 4.10: SH-1 device

The main problem encountered to implement this solution was that the contact has to be lateral so it is necessary to place in the stand a protrusion triangle made by tubes as it is presented schematically in Fig. 4.11.

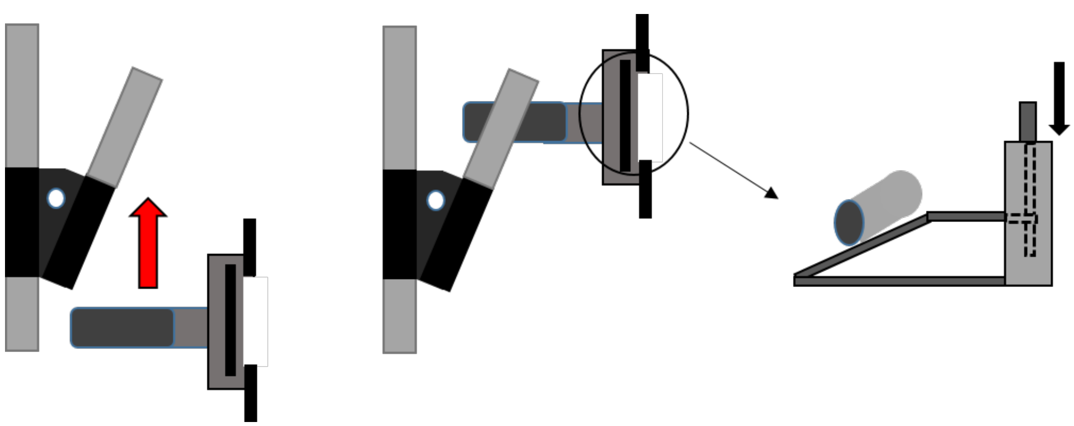


Figure 4.11: SH-1 scheme

After testing, it was concluded that the contact force required to make the stopper go down is too big and also the stopper gets stuck because the contact direction is tangential and not frontal. Therefore the attempt to implement the SH-1, meant to frontal docking, failed.

4.1.2 Final solution

All the failed solutions as the original one meant to keep the multi-usage of the cart in all the groups. Selecting the position of the adjustable roller, each cart shelf could be used for every group station giving to the cart the possibility of eventually carrying trays to one single group using all the shelves for that group. This multi-usage feature, despite the fact that it added complexity to the design, was considered convenient due to the heterogeneity of material distributed on each route, that is, in one specific route the parts to repair may be destined only to some of the groups and not the four groups. Therefore if each of the cart shelves is reserved to a different group more often than not the AGV would perform routes with some empty shelves and thus it will be needed to raise the number of routes. Nevertheless for the sake of the project feasibility it was decided to change the concept and assign each of the cart shelves to one specific group. Now the four cart shelves have different heights just as the reception stands.

The difference of level between the two upper shelves (same for the two lower ones) is established in 95 mm to avoid the activation of the shelves stoppers in wrong groups. In the Fig. 4.12 it is presented an example of the cart delivering a tray for the group 1. Note that the station ramp passes just above the stopper of the group 2 shelf avoiding any contact (marked by a circle in the figure). The same happens when a tray is delivered to group 3. In addition during the group 2 and 4 deliveries the activation ramp will make a slight contact with group 1 and 3 shelves stoppers partially opening them, but these shelves will be already empty since the trays contained have been delivered previously.

The station activation ramp consists in a TechnoLean TD connector that stands out making contact with the cart shelf stopper. Since the contact is produced in the stopper tube itself the problem of the momentum disappear and the TE connector does not tilt not getting stuck.

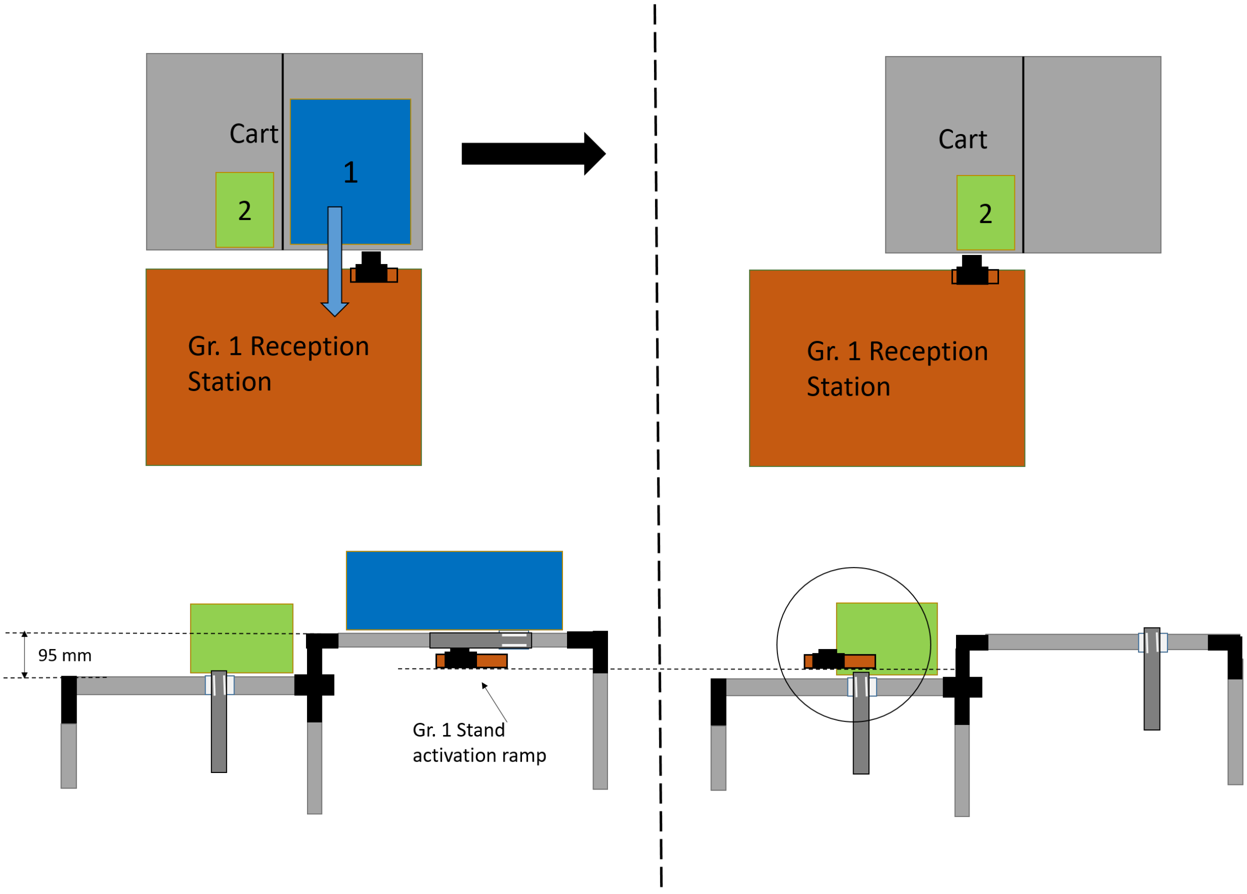


Figure 4.12: Scheme of a tray delivery to group 1

The cart now is not symmetric anymore, thus it turns out that it can be removed half part of the coupling structure. The AGV will just be able to get attached from one side. Pictures taken during the new cart building process are shown below (Fig. 4.13 and Fig. 4.14).

Figure 4.13: Group 1 (right) and 2 (left) cart shelves

Figure 4.14: Group 3 (right) and 4 (left) cart shelves

Regarding to the reception station, it was important to design a stand that allows to receive and keep several trays waiting to be picked up and repaired. Sometimes when a tray is placed in the reception stand, immediately a worker picks up the tray to repair the pieces. However, specially in some groups more often than not the trays remain a certain time in the station awaiting to be taken (Fig. 4.15).

Figure 4.15: Several trays awaiting to be repaired in Gr.3 reception station

Since the cart will always make the tray exchange in the same shelf, in order to guarantee that several trays fit in the stand it is necessary that each delivered tray moves automatically following a series of inclined rollers rails occupying the empty spaces of the reception station surface. To understand better this design, schematic pictures of the delivery process between the cart and the stations 1 and 2 are presented in Fig. 4.16 and Fig. 4.17 respectively. The change of direction of movement in 90º is possible thanks to the gravity, the trays fall by its own weight and start to follow a series of inclined rails perpendicular to the initial ones.

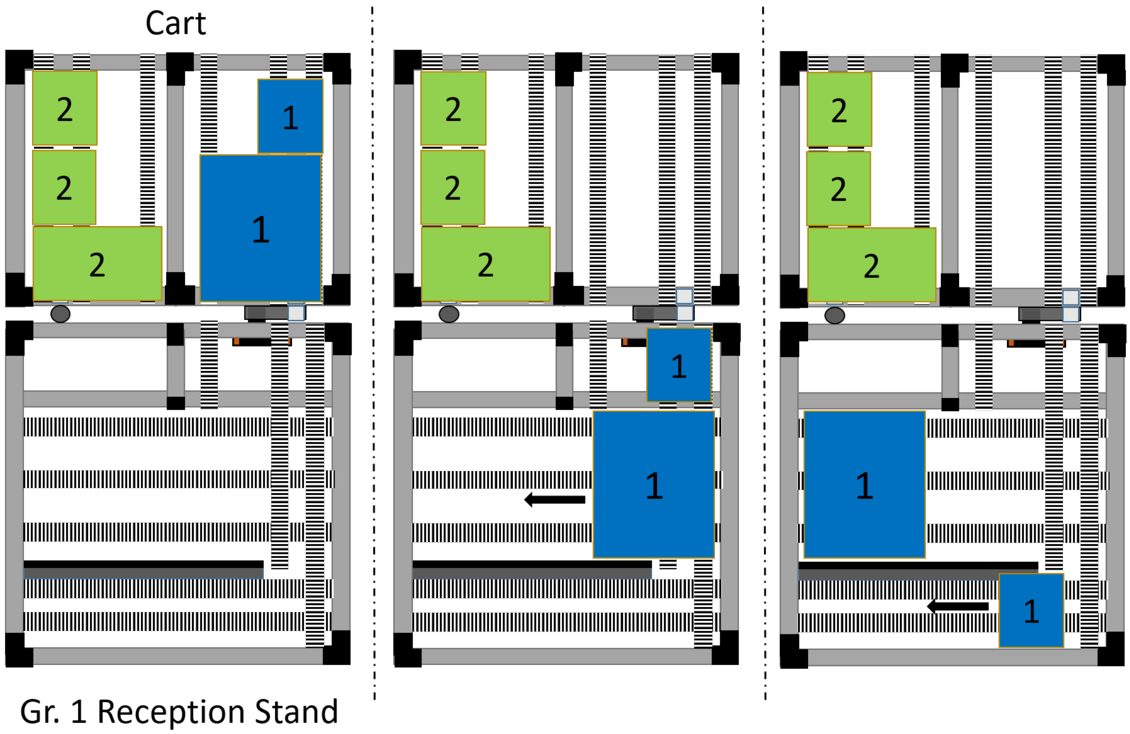


Figure 4.16: Scheme of the reception process in group 1 (Top view)

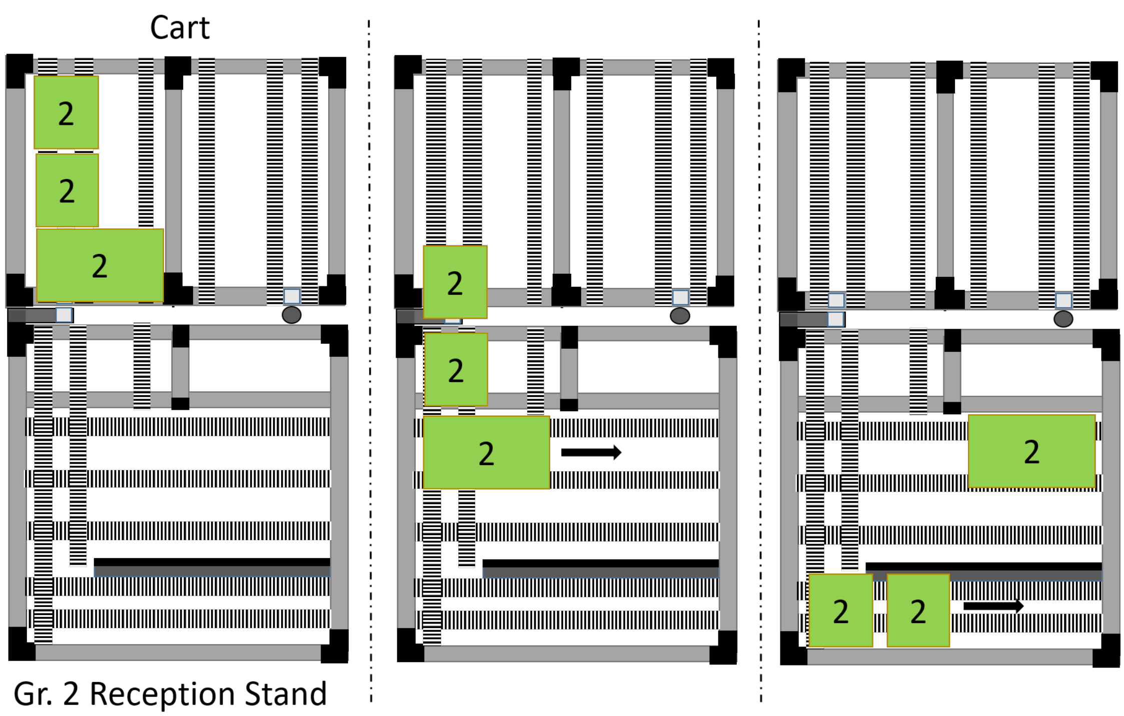


Figure 4.17: Scheme of the reception process in group 2 (Top view)

Note that in order to admit the reception of the small size trays (200x300 mm) a specific thinner path is described, on the other hand, the medium and big size trays share the other rail path.

The group 3 reception stand is exactly like the group 1 stand and the group 4 equal to the group 2 stand but of course with different height given by the correspondent cart shelf level.

On a first attempt, it was intended to use the available roller rails which are unidirectional (Fig. 4.18a), nevertheless the trays got stuck when trying to perform the corner by gravity fall, thus it was decided to order a special multi-directional rails which allow sliding transversely to the initial flow (Fig. 4.18b).

(a) TR-400 rail (b) ROM-50 rail

Figure 4.18: Unidirectional Vs Multi-directional TechnoLean roller rails

In the following Fig. 4.19 it is shown a first version of group 2 stand built with unidirectional roller rails that did not work, with the goal of illustrating how the final version of group stand using multi-directional roller rails would look like.

Figure 4.19: First non-working version of the group stand

Unfortunately, the exceptional and unexpected circumstances that surrounded this project caused by the pandemic did not allow to finish the construction of both, the cart and the group stands. Therefore the building and testing of the reception stands using the multi-directional rails will be done in further work.

4.1.3 Expedition system

As it was mentioned in Section 2.3 when a repaired part is expedited, its destination sometimes is another group until the piece is eventually totally fixed. This extra complexity suggests that the AGV used for the expedition operation should be different from the one used for the reception task. The expedition stations have different shelves with different destinations each one, the AGV should read or identify somehow the destination of the trays in order to know where to bring each tray.

Unfortunately due to the lack of time and complexity, the design of the expedition system goes beyond the objectives of this thesis and will be addressed in further work. However, this has been taken into account in the design of the magnetic tape path and the AGV movement and control script development, addressed in Section 5.2, trying to favour that further modifications of it will be easy to implement and the complex expedition system features comply with the requirements.

5 AGV development

5.1 Path design and navigation system

According to previous research done [7] a close path was selected instead of an open one based on implementation, flexibility and cost factors. Even though the flexibility of the closed path is lower, the much easier implementation in terms of programming and low cost makes it the best option.

For the navigation system, it was selected one from those that fit in the close path. The possible systems were: inertial guidance, magnetic grid, magnetic tape guidance, wire guidance and optical guidance. The accounted factors were: control simplicity of the system, flexibility, introduction of the navigation system inside workshop and maintenance. In this way, the two best options seemed to be optical and magnetic tape guidance but the maintenance difficulty of the optical guidance (the lines coloured in the floor must be kept cleaned) suggested the use of the magnetic tape guidance. A market study was conducted to find a magnetic sensor and the magnetic tape. Both elements are from the company Roboteq.

The magnetic sensor is the MGS1600GY and the magnetic tape is the MTAPE25NR. It is capable of detecting an reporting the position of a magnetic field a magnetic field along its horizontal axis. The sensor uses signal processing to accurately measure the lateral distance from the center of the track with millimeter resolution. It can detect and manage up to two way forks and merges other than crossings being instructed to follow the right or the left track. Besides that, the sensor can detect magnetic markers which are pieces of magnetic tape of opposite polarity placed on the left or right side of the track used to indicate specific locations such as a stop position, or a battery charging station.

In terms of connections, the sensor can be interfaced with any robotic motor controller. It may also be connected to any PLC using analog PWM RS232 or CanBUS interfaces and of course to a laptop using USB link (Fig. 5.1). [10]

Figure 5.1: MGS1600GY connection options

For this application, it has been decided to connect the sensor to a ROBOTEQ FBL2360 dual channel motor controller. The steering rotates head to follow the tape and drive motor stops when tape is no longer or magnetic markers are placed on both sides of the path. A demo is shown in the following video link [11].

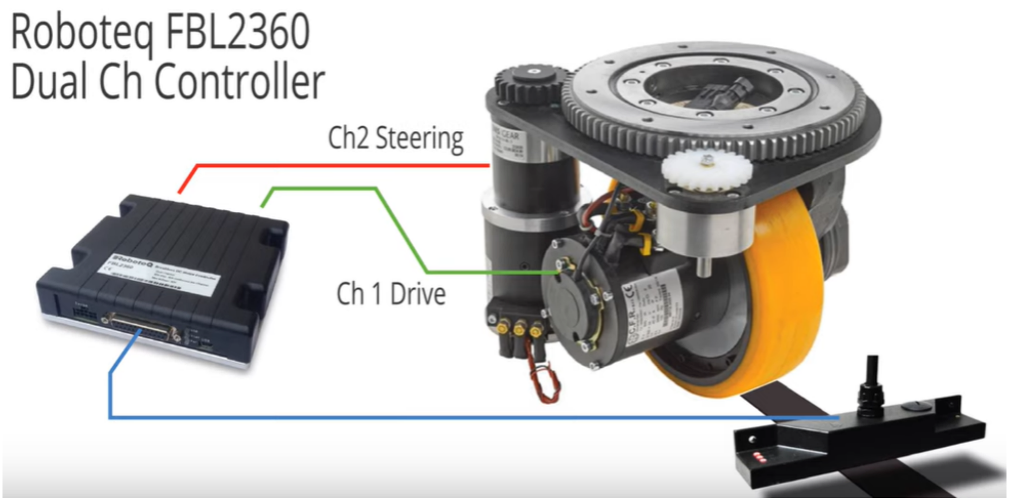


Figure 5.2: MGS1600GY sensor interfaced with a FBL2360 controller connected to the C.F.R MRT05.D0101 wheel.

5.2 AGV movement and control script implementation

All the computation is done in the motor controller using the MicroBasic scripting language. Roboteq's MicroBasic is high level language that is used to generate programs that runs on Roboteq motor controllers. It uses syntax nearly like Basic syntax with some adjustments to speed program execution in the controller and make it easier to use.

In order to develop the code it has been used the MicroBasic script manual found in Roboteq website [12] as well as a code example for a basic application AGV application [8]. This language uses only two kind of variables, boolean and integer. The boolean variables admit only two states, true or false (1 or 0), whereas the integer ones admit an integer number.

The code must be developed in a way that allows the AGV to follow the magnetic tape and stop on each reception / expedition station for a brief time to perform the trays delivery or pick up besides going and stopping at the charging station when the battery is low. Besides these, the AGV must comply with the safety protocols as interrupting the running when an obstacle is detected by the laser sensor or whenever any sensor fails or even in case of emergency.

In order to check whether the code architecture makes the AGV perform the desired task, a free AGV simulator software is also provided by Roboteq in its download center [13] and its user manual can be found in the following link [14]. This simulator gives the possibility of sketching the path, place magnetic markers wherever necessary and configure the AGV characteristics like dimensions, engine specifications, type of motor controller used and so on and so forth. Of course, it also has a tab to write or upload the code that drives all the simulation. It is very useful because it allows to simulate the AGV movement and performance along the drawn path while writing the MicroBasic script and therefore check if there are any errors.

5.2.1 Script development for simulation

The code is divided in several parts that will be explained in the following section. Firstly it is specified the assignation of the digital inputs which simulate buttons or certain states of the AGV. For this application it will be used 7 digital inputs to simulate the start/ resume button (Go Button), the emergency stop button (Stop Button), the low battery state, the sensor failure, the obstacle detection, both in protection and warning fields, and finally an input to select reception or expedition operation (Fig. 5.3).

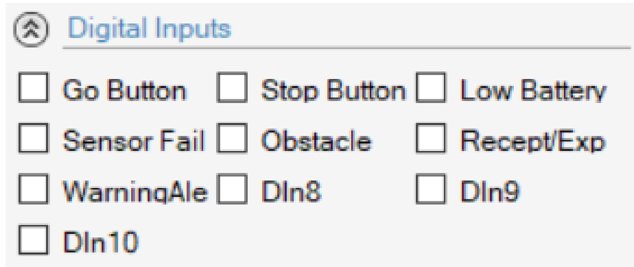


Figure 5.3: Digital inputs of the simulator

In real life, the ”Go Button” input would be, as its name says, a physical button that when pushed sends a digital impulse input to the motor controller in order to start the AGV route from the base or after an emergency stop. In the same way the ”Stop Button” sends an impulse to stop the AGV movement in case of emergency. Regarding the ”Recept/Exp” input in the simulator, it simulates what in reality would be an on/off switch that when turned on it will send a digital step input indicating that the AGV must perform a reception operation (Trays delivery) and on the contrary, when turned off the AGV will perform the expedition operation (Pick up).

The other four digital inputs simulate different situations or states. When the battery drops under a certain level a step input is sent to the motor controller. The same happens whenever an obstacle is detected by the laser sensor due to the fact that range finders typically provide a digital signal which can easily be connected to an input on the motor controller. Finally the sensor failure input represents when the magnetic sensor fails, which in real life is directly detected by the motor controller. An extract of the code where the declaration and reading of the digital inputs is done is shown in Fig. 5.4.

```
'DIGITAL INPUTS

#define GO_BUTTON_INPUT         1
#define STOP_BUTTON_INPUT       2
#define LOW_BATTERY_STATE       3
#define SENSOR_FAULT_STATE      4
#define OBSTACLE_FOUND_STATE    5
#define RECEPT_EXPED_OP         6
#define WARNING_ALERT           7
```

```
' READ BUTTON OR STATES

GoButton = GetValue(_DI, GO_BUTTON_INPUT)
StopButton= GetValue(_DI, STOP_BUTTON_INPUT)
LowBattery = GetValue(_DI, LOW_BATTERY_STATE)
SensorFault = GetValue(_DI, SENSOR_FAULT_STATE)
ObstacleFound = GetValue(_DI, OBSTACLE_FOUND_STATE)
Operation = GetValue(_DI, RECEPT_EXPED_OP) 'true when reception
WarningAlert = GetValue(_DI, WARNING_ALERT)
```

Figure 5.4: Declaration and reading of the digital inputs on the script

Afterwards, all the variables are declared as boolean or integer as well as its initial values or states are stated. The AGV will walk only when there is magnetic tape detection and the timer is set in 0 milliseconds (Fig. 5.5).

```
'PAUSE TIME SETTING

TimerStopped = GetTimerState(1) ' true if the timer is stopped (0 ms)
```

Figure 5.5: Timer status on the script

The timer initiates a countdown when the AGV stops in a station and it resumes the movement when the timer countdown is over marking 0 ms. Whenever the AGV is running, the towing pins must be deployed to ensure the attachment between AGV and cart. The towing pin mechanism will be connected to two of the digital outputs available on the motor controller as it will be explained later.

```
' RUNNING CONDITION

if (TimerStopped = true)

'When AGV is running the towing pins keep deployed
Setcommand (_DRES,1) 'Turn off digital output 1

Setcommand (_DRES,2) 'Turn off digital output 2

end if

if (TimerStopped = true and MarkerLeft = false and MarkerRight = false) then OnStation = false
 ' The OnStation state is set again in false  when the AGV moves away from the stop markers.


' Use TapeDetect and Pause Timer to apply throttle or not

if (TapeDetect = true and TimerStopped = true and EmergencyStop = false)

'if there is presence of tape (true) and the timer is stopped then apply throttle

       Throttle = DefineThrottle

else 'if something of both is not complied

       Throttle = 0

end if

''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
' STATION STOPS

If (OnStation = false and MarkerLeft = true and MarkerRight = true and PrevLeftMarker = false)

       OnStation= true ' Stop marker is not detected again until AGV moves away

       SetTimerCount(1, PauseTime) ' Load stop timer timout value in milliseconds

       RunState = false
end if

if (OnStation= true) then Setcommand (_DRES,3)
'Turn off warning alert sound when AGV is on group stations

end if
```

Figure 5.6: Running condition and station stops implemented on the script

In order to make the AGV stop in the different group stations two magnetic markers will be placed on both sides of the path being the right one ahead. When the sensor detects that both markers are present, the AGV stops and it starts the countdown to resume the motion. During this brief pause time the trays are exchanged between the AGV cart shelf and the group stand. The laser sensor will detect the group stands into the warning zone when approaching, this will cause the emission of an alert sound. Hence, this is used also as an alert for the workers to indicate that the AGV is arriving to their group station, but this alert will be switched off automatically once the AGV comes to a full stop in order to not be annoying (Fig. 5.6 above).

To identify the Base position , where the AGV is meant to start all the routes, and the Battery Charging Station, both in the R/E room, it is necessary to place the markers in a special way, different from the one used for the stations stops. It has been decided to place an unique left marker and short right markers separated, forming a dashed line as shown in Fig. 5.7.

Figure 5.7: Group station (left), Base position (middle) and Charging station (right) markers

Therefore, the code is build in a way that allows to count how many right markers there are and thus identify whether the AGV is at the Base position (4 right markers) or at the Charging Station (3 right markers). When the AGV has fully charged the batteries in the charging station, it automatically returns to the base position. In addition, to start every route from the base, it is necessary to push the ”Go Button”.

The towing pins are retracted when the AGV stops in the base and deployed again when a new route is started after pushing the ”Go Button”. They keep deployed until the AGV returns to base. There is a time delay (”PinsTime”) between pressing the button and starting the movement to make sure that the pins have enough time to deploy before the AGV starts moving. The pins mechanisms consists in a pair of electric linear actuators connected both to digital outputs 1 and 2 of the motor controller in a way that when the digital output 1 is active the linear actuators deploy, and on the other hand, when the digital output 2 is active the linear actuators retract. The code fragment where all these things are implemented is presented in Fig. 5.8 and Fig. 5.9 below.

The details and explanation of the towing pins mechanism and electric circuit architecture is stated in Section 5.3.3.

```
' R/E AREA STOP BASE
if (MarkerCount = 4 or MarkerCount= 5) then
Throttle = 0 'The AGV stops in the base
RunState = false
end if
if ((MarkerCount = 4 or MarkerCount= 5) and OnBase=false) then
Setcommand (_DSET,2) ' activate digital output 2 (towing pins go down)
SetTimerCount(1, PinsTime) ' Load pins retrieving timer timout
OnBase=true
end if

if ((MarkerCount = 4 or MarkerCount= 5) and GoButton = true) then
Throttle = DefineThrottle
RunState = true
Setcommand (_DSET,1) ' activate digital output 1 (towings pins go up)
SetTimerCount(1, PinsTime) ' Load pins deployement timer timout
MarkerCount= 0 'Clear counter when AGV goes away from R/E base
OnBase = false
end if
```

Figure 5.8: Base Station stop declared on the script

```
' CHARGING STATION STOP (for low battery condition)
if (MarkerCount = 3 and LowBattery = true) then
Throttle = 0
   'if low battery and AGV in charge station, then stop to charge
ChargingBattery = true 'Charging state updated to true
end if
if (MarkerCount = 3 and LowBattery = false and MarkerLeft= false and ChargingBattery = true) then Lineselect = 2
'When the AGV is totally charged and goes away (digital input 2 turned off) it returns to base taking the right pat
if (MarkerCount = 3 and LowBattery = false and MarkerLeft= false ) then Markercount= 0
 'Clear counter when AGV goes away from charging station
if (MarkerCount = 0 and LowBattery = false and MarkerLeft= false ) then ChargingBattery = false
'When the AGV is totally charged and goes away ChargingBattery status updated to false
```

Figure 5.9: Charging Station stop declared on the script

Regarding the type of operation, the AGV must follow a different path whether it is performing a reception or an expedition operation. As told before, the state (true or false) of the correspondent digital input decides which of the two operations the AGV is performing. Therefore, in the two points where the path is split for each one of the operations it is necessary to place a marker similar to the ones in the Charging Station and Base but this time with only two right markers. The code is similar to the previous case but adapted to this new scenario (Fig. 5.10).

```
'TYPE OF OPERATION (Reception or Expedition)


if (Operation= true and MarkerCount = 2)
lineselect = 2 'select the right path to follow the reception operation path
OnOperationMarker = true
end if

if (Operation= true and MarkerLeft = false and OnOperationMarker = true)
MarkerCount = 0 ' reset the counter to 0
OnOperationMarker = false
end if


if (Operation= false and MarkerCount = 2)
lineselect = 1 'select the left path to follow the expedition operation path
OnOperationMarker = true
end if

if (Operation= false and MarkerLeft = false and OnOperationMarker = true)
MarkerCount = 0 ' reset the counter to 0
OnOperationMarker = false
end if
```

Figure 5.10: Path selection in function of the type of operation declared on the script

In any case, whenever the AGV approaches to a fork or merge it will take the left or the right path depending on whether the last marker detected was on the left or right side. This implies that in the group station markers, the last marker in disappearing will be the right or the left as needed to take the correct way in the next fork or merge.

Furthermore, in terms of safety checks, as told before, the AGV must comply with some safety requirements like stopping when an obstacle is detected by the laser sensor or any sensor fails. There are two kind of fields detected by the laser sensor, the warning field and the protection field. Whenever an object is detected in the warning field the AGV must emit an alert sound, however if the obstacle is detected into the protection field the AGV must stop immediately and wait for the blockage clearance. Once this happens, it resumes the walk after a few seconds (”ResumeTime”). On the other hand, whenever a sensor stops working the AGV immediately stops. After repairing or substituting it, the AGV must be placed in the base position and the ”Go Button” be pushed to restart it. The extract of the script where all these safety checks and measures are implemented is shown in the following figures Fig. 5.11, Fig. 5.12.

```
' SAFETY CHECKS

'Called when a fault state raised in sensors.

    if (SensorFault = true) then SensorStatus = 0

    if (SensorStatus = 0) then 'Sensor fault. ('Sensor status unequal 0 means working)

    Throttle= 0

    MarkerCount=4 'To resume it is necessary to press Go Botton

    end if

'Called when an obstacle is found.

   if (ObstacleFound = true)

   Throttle = 0

   ObstacleRemoved = true 'Obstacle removed updated to true in order to set AGV go on after 10 seconds

   end if

'Resume of AGV after obstacle removed 10 seconds later

   if (WaitingToResume = false and ObstacleRemoved = true and ObstacleFound = false)

    SetTimerCount(1,ResumeTime) 'Load the resume time in the counter

    WaitingToResume = true

   end if

   if (TimerStopped = true and WaitingToResume = true)

    ObstacleRemoved = false 'After resuming movement, ObstacleRemoved status updated to false

    WaitingToResume = false 'After resuming movement, WaitingToResume status updated to false

   end if
```

Figure 5.11: Safety checks and measures implemented on the script

```
'Called when an obstacle is found in warning field

   if (WarningAlert = true and OnStation = false) then Setcommand (_DSET,3)
   'Activate digital output 3 (warning sound)

   else

   Setcommand (_DRES,3)

   end if
```

Figure 5.12: Warning field alert implemented on the script

Besides these, an additional button is installed for emergency stops ("Stop button"). Pushing this button makes the AGV stop immediately and it can only resume the motion when the "Go Button" is pressed (Fig. 5.13).

```
'EMERGENCY STOP

   if (StopButton = true)
   Throttle = 0
   EmergencyStop = true
   end if

   if (GoButton = true) then EmergencyStop = false
```

Figure 5.13: Emergency stop implemented on the script

Finally, concerning the control of the AGV it has been tested two ways of control (Proportional Control and Proportional–Integral–Derivative Control or PID). The sensor outputs a value that is the tape's distance from the center of the track. This information is then used to correct the steering. If the tape is centered, the value is 0 and no steering correction is needed. The further the track is from the center, in one or the other direction, the stronger the steering change.

The first and simplest control method consists in a proportional control. The steering of the wheel (control variable ”u(t)”) is proportional to the distance between the sensor and the center of the magnetic tape, which is the error e(t) between the desired value (0) and the actual value. The steering is applied to decrease this error until it reaches a null value.

$$u(t) = Kp \cdot e(t) \tag{5.1}$$

The proportionality constant is defined as ”Kp” or ”Gain” in the code, the larger it is, the quicker is the response but it increases the oscillations (Fig. 5.14). Therefore choosing the value of this gain is a trade off between swiftness and stability. Increasing the speed of the AGV or making sharper curves will required the use of a higher gain which can lead to larger oscillations.

```
' CONTROL

 Tape_Position = getvalue(_MGT, LineSelect) 'read Read Left or Right Track position (value)

' A) Proportional control (Use tape position multiplied with gain as steering )

 Steering = Tape_Position *Gain
```

Figure 5.14: Proportional control implemented on the script

For best precision and response time, the control algorithm may be improved to a full PID. The proportional–integral–derivative controller adds two new terms to calculate the control variable, in this case, the steering. These two terms are the integral (I) and derivative (D) terms. The integral accounts for past values of the error and integrates them over time seeking to eliminate the residual or stationary error after the application of proportional control. The derivative predicts the future trend of the error based on its current rate of change helping dampen any overshoot and oscillation. The ultimate goal in a well tuned PID is a motor that reaches the desired position quickly without overshoot or oscillation.

$$\mathsf{u(t)} = \mathsf{Kp} \cdot \mathsf{e(t)} + \mathsf{Ki} \cdot \int_0^t e(\tau)d\tau + \mathsf{Kd} \cdot \frac{de(t)}{dt} \quad (5.2)$$

Implementing the PID control algorithm directly in the MicroBasic script is a very difficult task due to the fact that it is necessary to compute the integral and and derivative terms. The calculation of the integral implies storing all the previous values of the error each loop iteration in an array and the derivative operation seems to be hard to program in this language. Therefore, since the Microbasic script manual does not explain how to do these things or even whether it is possible or not it has been decided to implement only the proportional control in the code. Fortunately, the PID is already implemented in the motor controller, there is no need to program it on the MicroBasic script. It is just necessary to select one of the close loop modes and tune the three PID constants in the ”configuration” tab.

5.2.2 Simulation

The Roboteq AGV simulator allows to simulate the performance of the AGV following the code implemented. Thus, it has been decided to sketch an approximate model of the magnetic tape path that will eventually be installed along the shop floor. In addition, every required marker has been placed in the right position. As it is seen, once the AGV arrives to the components shop it encounters the marker that makes it to continue straight or turn left depending on the type of operation the AGV is performing at that moment. For instance, if it is carrying out the reception operation the AGV will only make contact with the reception stand of each group avoiding the expedition stands describing a ”zig zag” path. The shop magnetic path model is presented in Fig. 5.15 where the blue lines represent the magnetic tape.

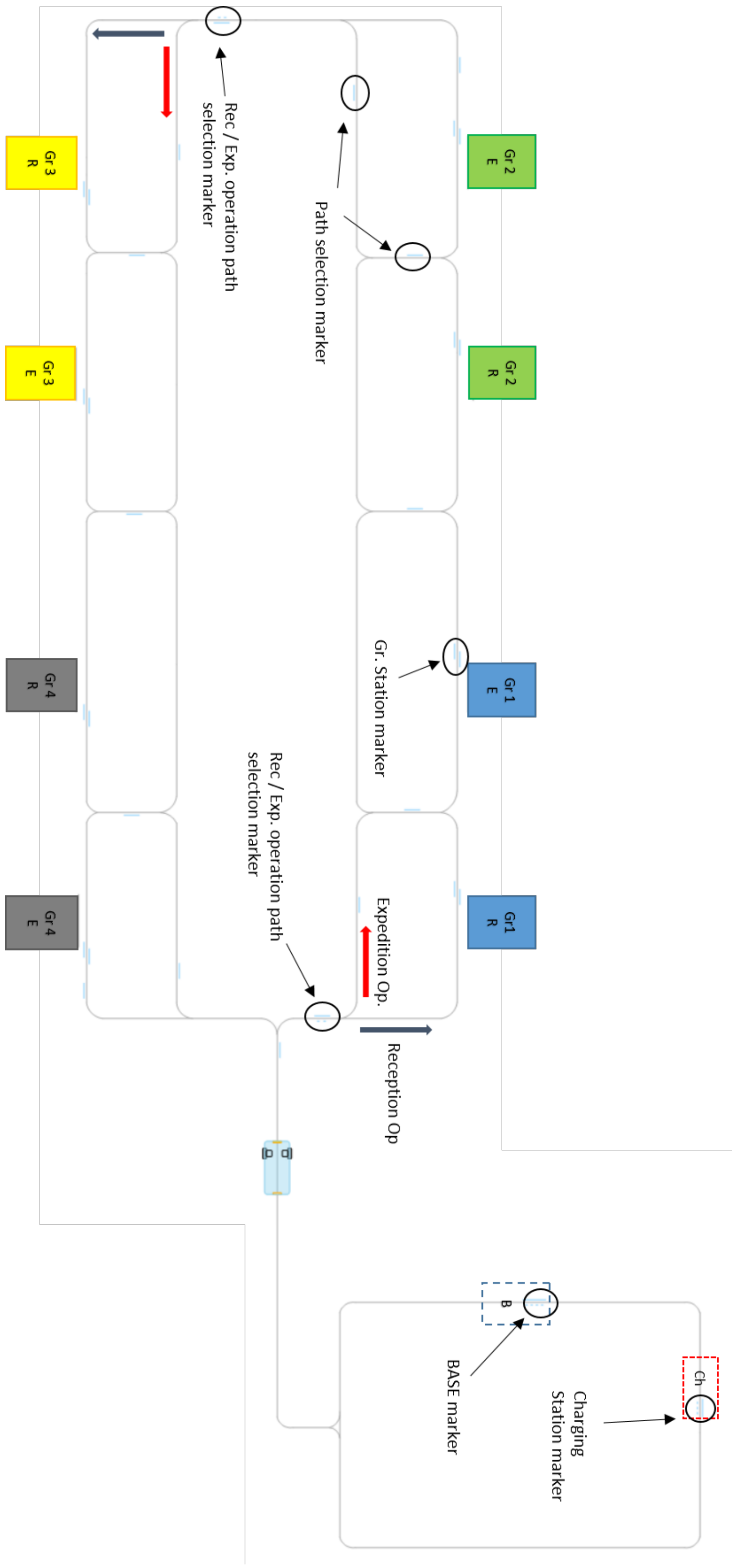


Figure 5.15: Shop magnetic tape track

It is important to remark that once the magnetic tape path is installed in the shop as well as the corresponding stop markers, it will be necessary to run the AGV and check the exact position where it stops in every group. Then, after that, it will be possible to place the stands in the right place to ensure a perfect coupling or alignment between the AGV cart and the group stand. The markers will be installed before the stands and not afterwards because the AGV does not stop immediately, it has a certain deceleration, hence it goes over a small distance after detecting the markers receiving the order to stop.

The other important feature of the simulator besides the path sketching and the code compilation is the AGV profile configuration which is done in the ”Tree configuration” tab. This allows to select the motor controller model that will be used, in this case the FBL2360, and afterwards customize the characteristics of the AGV such as the specifications of the motor, the dimensions, the gear ratio and so on and so forth (Fig. 5.16).

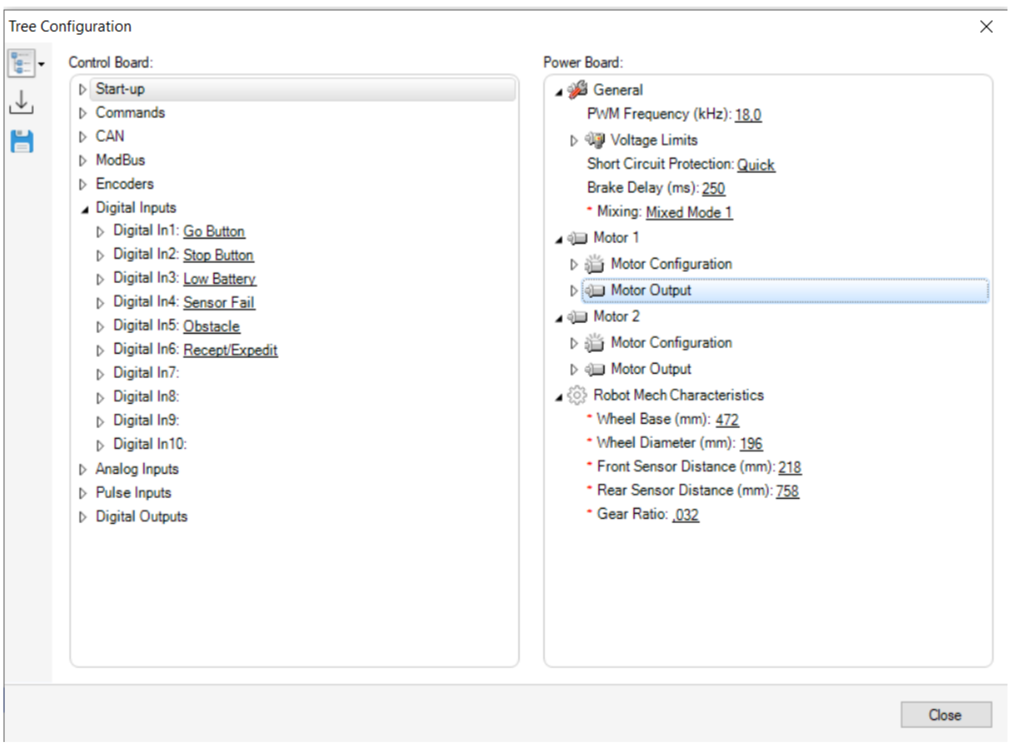


Figure 5.16: AGV profile configuration

Note that unfortunately the simulator is not able to reproduce the AGV that was designed. It is not possible to configure it with only one motor, therefore the simulation is done with two motors and the steering is achieved by a differential power between both (setting ”Mixing Mode 1”). Furthermore, in reality only a front sensor will be used whereas in the simulation there is an additional rear sensor. Due to these things, the results of the simulation in terms of steering response and control may be quite different from the reality. This implies that the selection of the optimal control constants (Gain or PID constants) will be done during the AGV real experimentation, that is, on a trial-error process.

Despite everything, the simulation is carried out with the simple proportional control and according to the results it seems that for this application it is expected to reach a good control level selecting an adequate gain. Thus, probably it won't be necessary to make use of a PID to ensure a satisfactory control of the AGV.

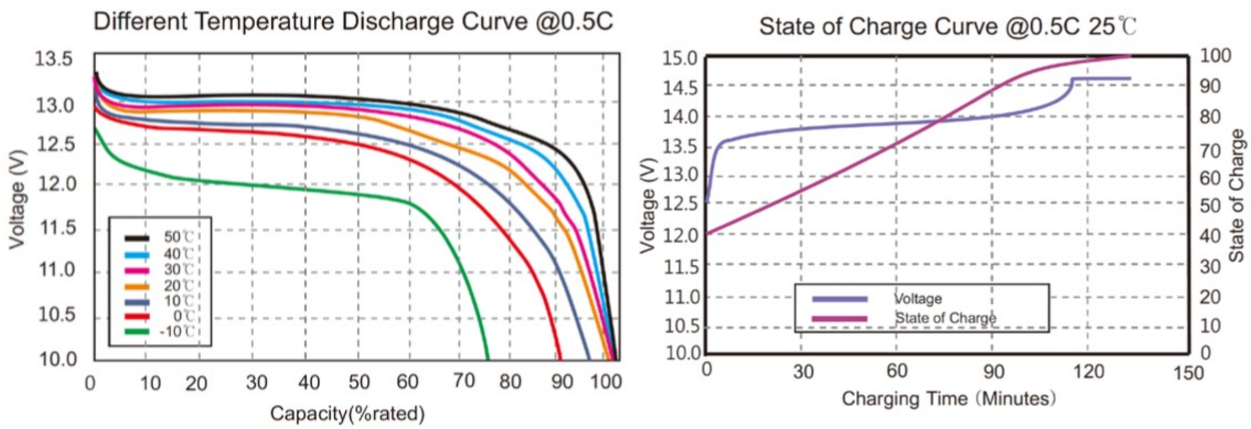
However, since the simulation is performed using a two drive wheels configuration it has been considered appropriate to offer the possibility of building the AGV using this kind of configuration which, even though it provides a bit less steering precision, it is simpler as it was stated in Section 3.3. In this way, the results of the simulation would fit even more to the reality. The selection of the motors of the two drive wheels configuration is addressed in Section 5.3.1.

5.2.3 Script implemented in the motor controller

The code that must be implemented and loaded in the AGV motor controller is similar to the one used for the simulation but introducing a few slight modifications. The low battery condition, which was simulated by a digital input in the simulator, now is given in function of the battery voltage. It is well known that the voltage of a battery decays as long as the state of charge does. Furthermore, when the battery is charging the voltage increases above the nominal voltage reaching a maximum level. These means that it is possible to establish a discharge voltage threshold below which the low battery state is activated and, on the other hand, a charge voltage threshold above which the battery is considered fully charged and thus the AGV can move away from the charging station.

The batteries used are Lithium ion 12V 70Ah $LiFePO_4$ by PowerBrick company [6] whose specifications can be found in the following document [15]. Since, according to the manufacturer, the steerable driver wheel must be connected to a battery voltage of 24 V and the nominal voltage of the battery selected is 12.7 V with a capacity of 70 Ah, it is needed the use of two batteries connected in series. Hence, the total capacity reaches 140 Ah. Due to the fact that the wheel nominal current is 23 A, the run time estimation is roughly 6 hours, that is a discharge rate of around 0.17C.

In the specifications sheet, the manufacturer gives the values of "BMS battery cut off voltage" both for discharge and charge. The discharge cut off voltage is the voltage below which the Battery Management System (BMS) embedded in the battery pack shuts down the device because a further discharge could cause harm. On the other hand the charge cut off voltage is the voltage above which the BMS stops the charging process, the battery is considered fully charged. The values provided by the company are 10 V and 14.8 V respectively. Therefore, base on the curves given in the specification sheet that show the relation between the voltage and the state of charge for discharging (Fig. 5.17a) and charging (Fig. 5.17b) for 0.5C and assuming an ambient temperature of 20 ºC the threshold voltage values that will be used to consider a low battery and a fully charged status are 11.8 V and 14.7 V respectively. The 11.8 V value represents a depth of discharge (DOD) of about 85 % while the 14.7 V indicate a state of charge of almost 100 %.



(a) Discharge characteristic curve

(b) Charge characteristic curve

Figure 5.17: Battery characteristics curves

Thus, whenever the AGV battery voltage drops below 11.8 V, which means a remaining battery of about 15 %, it will stop in the charge station after completing the route. This state of charge should be more than enough to guarantee that the AGV has enough battery to complete a last route since the remaining battery time would be around 50 min considering the discharge rate of 0.17C estimated before. Moreover a DOD of 15-10 % implies prolonging the life time of the batteries up to almost 10000 cycles according to the manufacturer information.

In addition to that, once the battery drops below 11.8 V a light signal turns on indicating low battery condition to inform the workers that the AGV must go to the charging station after arriving and stopping in the base. Hence, the worker will press the ”Go Button” after picking up the repaired pieces from the cart to allow the AGV go to recharge the batteries. The light signal can be a LED or a lamp connected to digital output 4 of the motor controller.

After fully charging the batteries, the AGV will turn off the light signal and return to the base remaining there until it starts a new route. The fragment of the code where the low battery and fully charged condition is stated in function of the battery voltage is presented in Fig. 5.18 below.

```
' BATTERY VOLTAGE

BatteryVolt = getvalue(_VOLTS, 2) ' read the battery voltage (volts * 10)

if (BatteryVolt < 118)  'if battery voltage is below 11.8 V
LowBattery = true  'activate low battery status
 Setcommand (_DSET,4) 'turn on low battery LED
end if

if (BatteryVolt > 147) 'if battery voltage is above 14.7 V then battery fully charged
LowBattery = false
 Setcommand (_DRES,4) 'turn off low battery LED
end if
```

Figure 5.18: Low battery and fully charged condition stated on the script

The other modification of the code with respect to the one used for the simulation is that now it is not necessary to assign a digital input to the sensor failure state. It is enough with the internal function that reads the status of the sensors connected. Whenever the magnetic sensor fails, it will read a 0, otherwise the value read is different to 0 (Fig. 5.19).

```
SensorStatus = getvalue(_MGS, 1) 'read sensor status (0 means failure, not 0 means working)

if (SensorStatus = 0) then  'Sensor fault.
Throttle= 0
MarkerCount=4 'To resume it is necessary to press Go Botton
end if
```

Figure 5.19: Sensor failure declared on the script

After making the simulation and checking that the script does not have any errors and the AGV follows the desire tasks properly, the script can be loaded into the motor controller. In order to do this, it is required to make use of the software Roborun+ provided by the company and downloaded from [13]. On the following, the steps to configure and load the script into the motor controlled are explained.

- Connect the computer to the motor controller through serial communication (USB or RS232).
- In the configuration tab, the AGV profile will be loaded containing all the motor and AGV mechanical characteristics as well as the PID constants and close loop mode in case of deciding to use the PID control (Fig. 5.20). However, this would be used only if the proportional control did not offer satisfactory results .
- Configure the controller to automatically run the script every time the controller starts (Script Auto-Start = enable) and save the profile to controller (Fig. 5.20).
- Open the Microbasic script in the scripting tab and download it to the device (Fig. 5.21). The motor controller now can be disconnected from the computer.

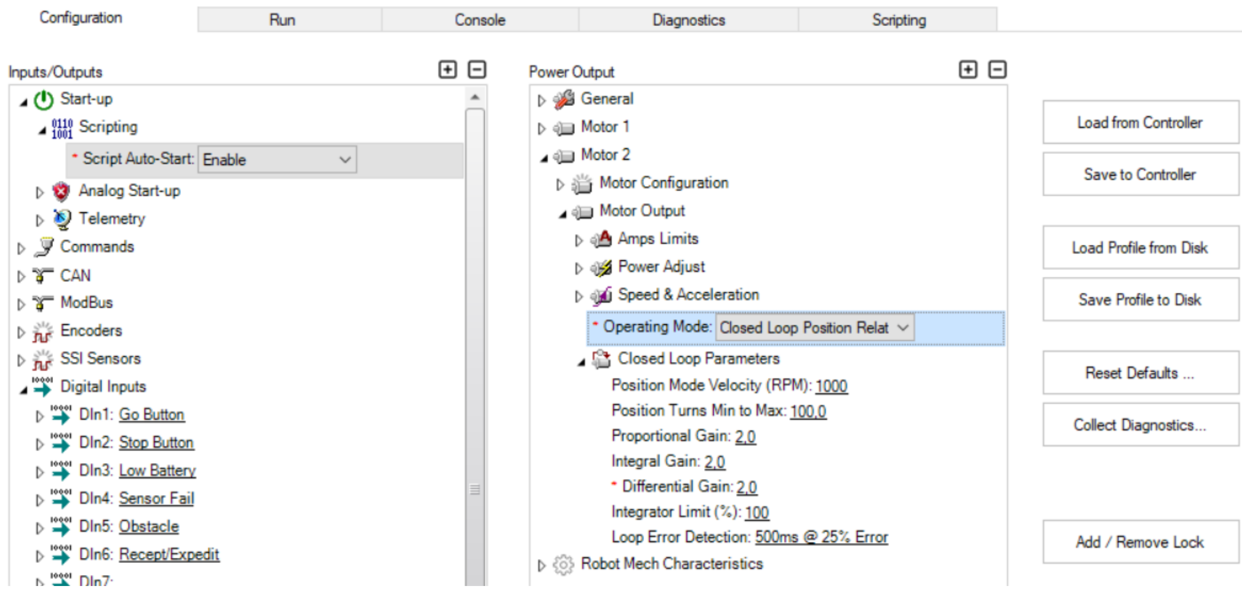


Figure 5.20: Configuration tab, Roborun +

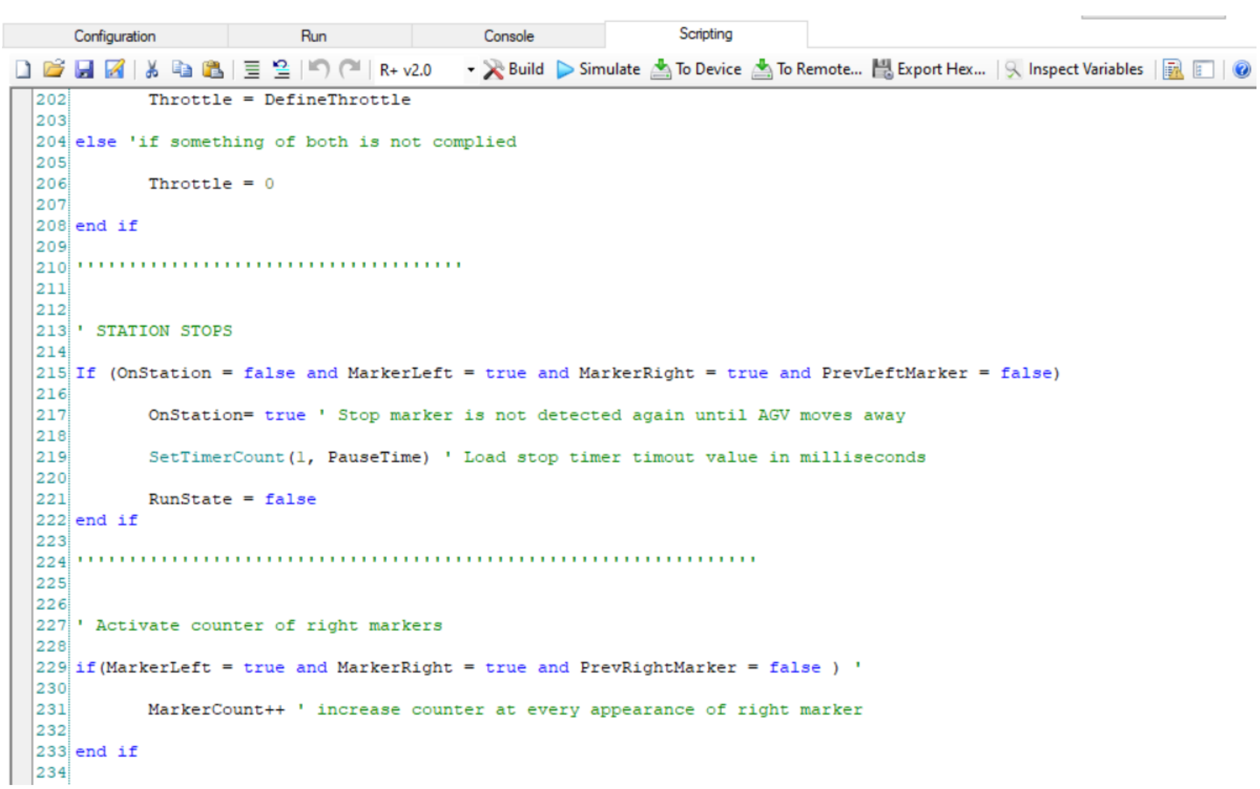


Figure 5.21: Scripting tab, Roborun +

The run tab allows to monitor and visualize all the inputs and outputs of the controller as well as the engines state and performances while the AGV is following the path. It plots in real-time the controller parameters on the PC, and logs it to a file for later analysis. This has to be done with the computer connected to the controller.

In case of using a PID control, so as to make the gains tuning as simple as possible, first start with the Integral and Differential Gains at zero, increasing the Proportional Gain until the motor overshoots and oscillates. Then add Differential gain until there is no more overshoot. If the overshoot persists, reduce the Proportional Gain. Finally add a minimal amount of Integral Gain and vary slightly all the gains from these positions until reaching a satisfactory level of control [16].

5.3 AGV building

5.3.1 AGV electric components

The different electric components that define the AGV are presented in Table 1.

Table 1: AGV electric components

Component	Company and model	Amount
Magnetic Sensor	Roboteq MGS1600GY	1
Laser Range Finder Sensor	Sick S3000 Standard [1]	1
Steerable Drive Wheel	C.F.R MRT05.D0101	1
Towing Pins	Electric Linear Actuator (Company: N/A)	2
Motor Controller	Roboteq FBL2360	1
Battery	PowerTech PowerBrick-LiFePO4 12V 70Ah	2
Go Button	N/A	1
Emergency Stop Button	N/A	1
Operation Switch	N/A	1
Low Battery LED	N/A	1
Alert Sound Horn	N/A	1

As explained before in Section 5.2.2, it is also explored the possibility of using a two drive wheel configuration instead a single steerable drive wheel configuration. A research of the market has been done where different models have been found. These models are gathered in the following Table 2.

Table 2: Drive wheels models

Company and model	Voltage (V)	Power (KW)	Torque (Nm)	Diameter (mm)
Roboteq AGV089A04 [17]	48	N/A	29	156.4
Benevelli WD Serie-125 [18]	24-144	0.3-1	100	125
Benevelli DD1 Serie [18]	24-120	0.6-1.6	800	200
Nidec SU Series [19]	12-60	0.2-0.4	High (N/A)	150

Important remarks concerning the use of these models are stated. All the models output a torque that is more than enough to move the AGV maximum weight which will be lower than 100 Kg. The diameters are different from the steerable drive wheel (198 mm) which implies that slight modifications of the chasis design must be done in case of using the new configuration. Furthermore in case of choosing the Roboteq model, it will be necessary to use 4 batteries in series instead of two.

[1] The system plug is not included, it has to be bought separately. It is recommended to buy the SX0A-B0905G model.

Anyway, despite the fact that the four models comply with the requirements, it is considered that the most suitable option would be the use of the Benevelli DD1 Serie because its diameter (200 mm) is similar to the steerable drive wheel and it consists in a complete assembly of the two wheels (Fig. 5.22) unlike the other models that are independent wheels. In addition, the Roboteq model has the disadvantage of needing a voltage of 48 V, requiring the use of four batteries in series instead of two or the change of the battery model.

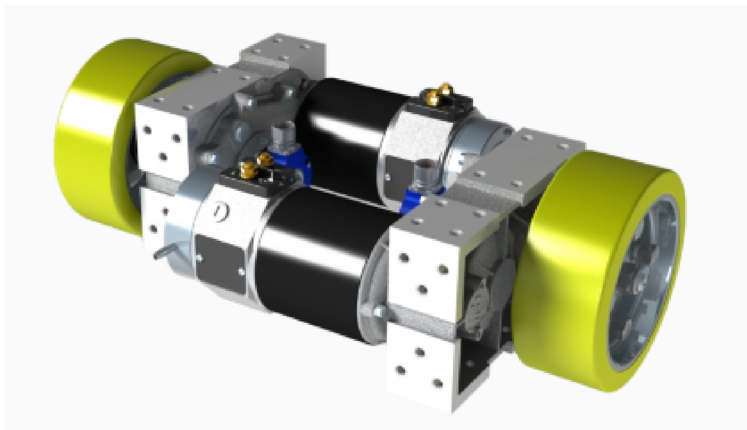
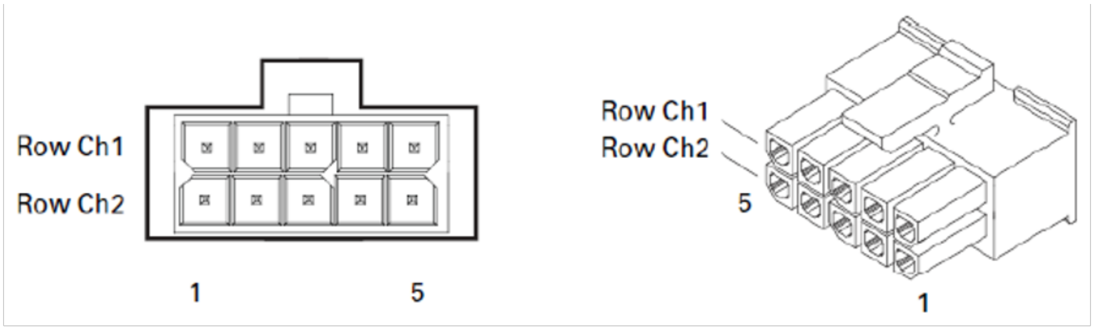


Figure 5.22: DD1 series drive wheels by Benevelli company [18]

5.3.2 Motor controller connections and wiring

The motor controller used for the AGV is the Roboteq FBL2360. All the information about the electrical wiring is detailed in the datasheet [20] and summarised below:

- The battery terminals must be connected to the VMOT and GND entries.
- The power wheels are connected to each output tabs of the same letter (U, V, W). In the case of using the 2 drive wheels configuration, the left engine is connected to U1, V1, W1 and the right one to U1, V1, W1. On the other hand, using the single drive steerable wheel configuration, the drive motor is connected to U1, V1, W1 and the steering motor to U2, V2, W2.
- The magnetic sensor is connected to the hall sensor connector which has 10 pins, 5 for each sensor (it admits up to 2 sensors connected). The power wires are connected to 5V and GND pins and the signal wires to the rest of the pins (Fig. 5.23).



Pin Number	1	2	3	4	5
Row Ch1	5V	Hall1 C	Hall1 B	Hall1 A	Ground
Row Ch2	5V	Hall2 C	Hall2 B	Hall2 A	Ground

Figure 5.23: Hall connector pins [20]

The location of each connection tab in the motor controller is shown in Fig. 5.24.

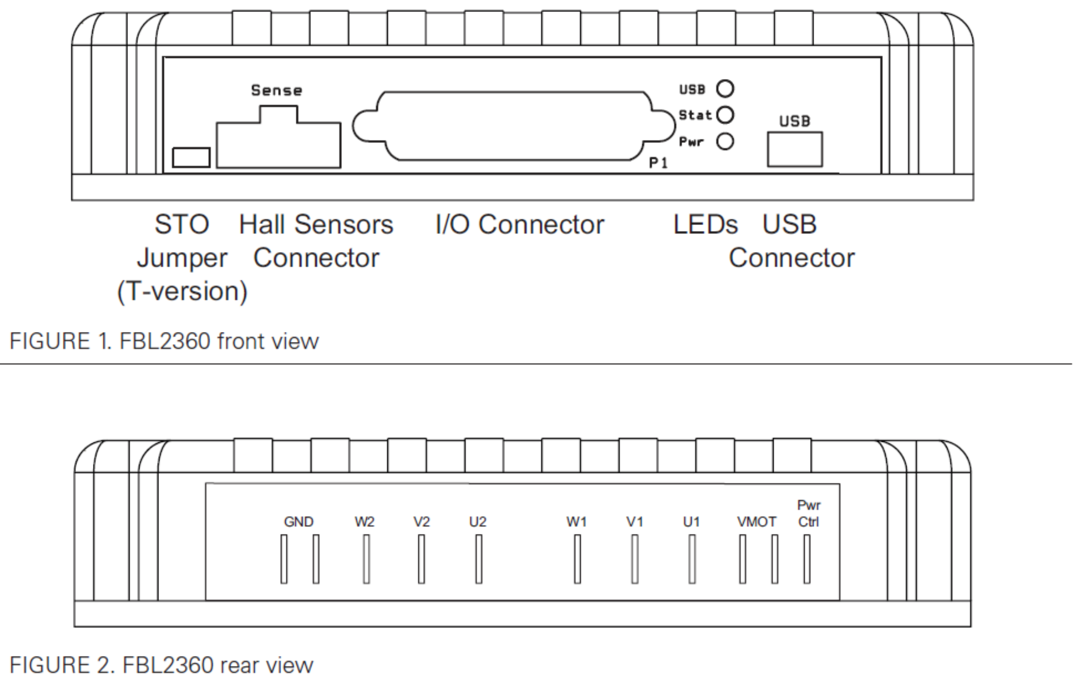


Figure 5.24: FBL2360 wires identifications and connections [20]

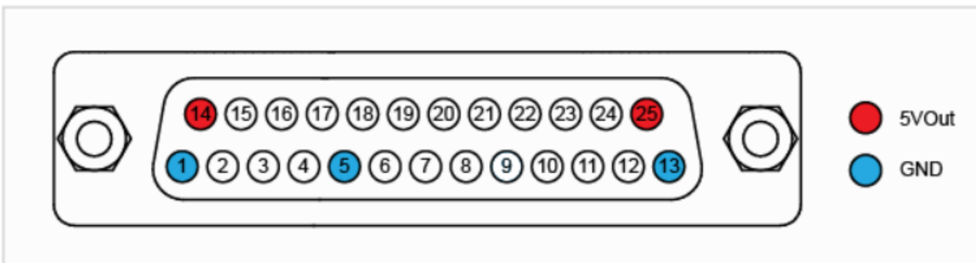
Regarding the I/O connector, there are several components that will send digital signals to the motor controller to make the AGV perform a certain action. These digital inputs, as told before, are the Go action, the Emergency stop, the Towing Pins activation, the Obstacle Found alert and the type of Operation (Reception/Expedition). Hence, following the connection pinouts of the FBL2360 motor controller (Fig. 5.25) both, the Go Button and the Stop Button, will be connected to pins 15 and 16 respectively. In addition, the

Laser Range Finder Sensor will be connected through its output signal wire to pins 21 and 24. Finally, the Operation Switch connection is assigned to pin 22.

FBL-Type Pinout

25 Pins | 10 Pins

Pin	15	16	17	18	19	20	21	22	23	24
Digital In	Go	Stop	DIN4				Obstacle	Recept/E		WarningA
Pulse In	RC1	RC2	RC4				RC5	RC6		RC7
Ana In	ANA1	ANA2	ANA4				ANA5	ANA6		ANA7
Sin/Cos In										ASIN2
Digital Out				TPinsUp	WarnSou					
Encoder							Enc2A	Enc2B		Enc1A
Com						CANH			RS485+	



Pin	2	3	4	6	7	8	9	10	11	12
Digital In			DIN3				DIN9	DIN10		DIN8
Pulse In			RC3							RC8
Ana In			ANA3							ANA8
Sin/Cos In							ASIN1	ACOS1		ACOS2
Digital Out				TPinsDo	LowLED					
Encoder										Enc1B
Com	TxData	RxData				CANL			RS485-	

Figure 5.25: FBL2360 digital inputs / outputs connection pinouts

The information about the activation of these digital inputs is gathered in Table 3.

Table 3: Digital inputs activation

Digital Input	**Type**	**Description**
Go	Impulse	Sent when button pushed
Emergency Stop	Impulse	Sent when button pushed
Obstacle Found	Step	Sent when laser sensor detects any blockage in protection field
Warning Alert	Step	Sent when laser sensor detects any blockage in warning field
Type of Operation	Step	Sent when the switch is active (Reception Operation)

In relation to the digital outputs, the towing pins device is connected to the digital outputs pins 18 and 6 (Fig. 5.25) to receive the digital step signal from the motor controller when they must be active. In order to deploy the towing pins, the digital output 1 (pin 18) is activated, on the other hand to retract the towing pins, the digital output 2 (pin 6) must be activated. The device that emits the alert sound when an object is detected into the warning zone is connected to digital output 3 (pin 19). Finally, the low battery light LED or lamp is connected to digital output 4 (pin 7).

5.3.3 Towing Pins device

Each towing pin is an electric linear actuator which is compounded of a DC motor, a gear box and a lead screw (Fig. 5.26).

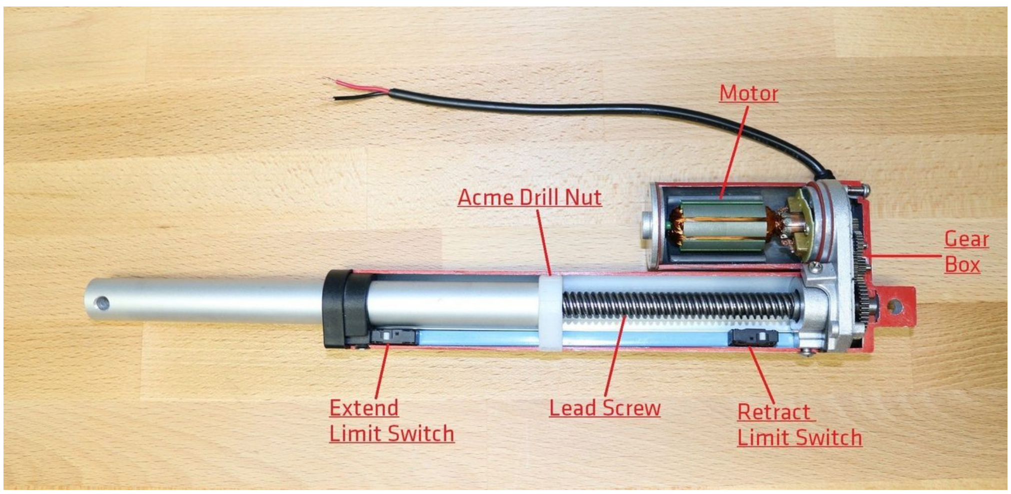


Figure 5.26: Example of an electric linear actuator

The piston rod extends or retracts depending on the direction of rotation of the motor, that is, the polarity. Therefore, if there is no current applied to the motor, the piston keeps the position.

Regarding the specifications of the actuator, since its purpose differ from the normal use of this kind of devices which is to apply a force to move something, for this application the maximum force that the actuator can exert is not important. Nevertheless, other parameters like the voltage, dimensions, stroke and piston extend / retract speed take on relevance. Therefore the selection of the actuator will be taken trying to minimize the cost and weight, complying with the requirements of stroke and rod diameter as well as 24 V feeding voltage. The stroke has to be large enough to ensure that its extension allows the correct AGV-cart attachment and a rod diameter which fits inside the TechnoLean T-E piece (28.6 mm diameter). In addition, the actuator speed will be selected trying not to be very slow.

Due to the fact that there is a wide market of electric linear actuators, the selection and purchasing of it will be done in the future when the AGV building will be carried out.

Initially, it was meant to connect the actuator to only a sole digital output and write instructions in the script to change the polarity of the actuator motor when it was required. Unfortunately, it could not be found the way to implement the change of polarity using the MicroBasic language, thus another solution had to be explored. The use of a spring return linear actuator was also considered, it extends the piston when current is applied and retracts when not, with the aid of a spring. The problem of the latter is that it would be necessary to applied current constantly to keep the towing pins deployed and in addition after exploring the market it has been observed this kind of actuators are used for heavy loads industrial applications being not adequate at all to use them as towing pins.

For this reason, as told before, it has been decided to connect the linear actuators to two different digital outputs. To achieve that the piston rod extends or retracts depending on which digital output is active, it is necessary to design an electric circuit compounded of two simple relays. The relays are connected between the digital outputs and the power source (Fig. 5.27). The digital output is actually a FET (Field Effect Transistor) switched to ground. When active, the digital output pin is grounded closing the circuit and switching the correspondent relay.

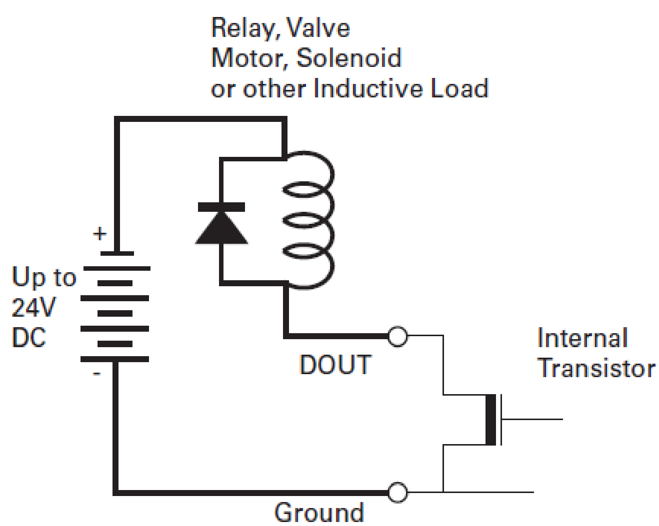


Figure 5.27: Motor controller digital outputs connections [16]

Making use of two simple relays it is possible to change the polarity of the motors connected to these relays depending on which digital output is active. The circuit architecture is presented in Fig. 5.28.

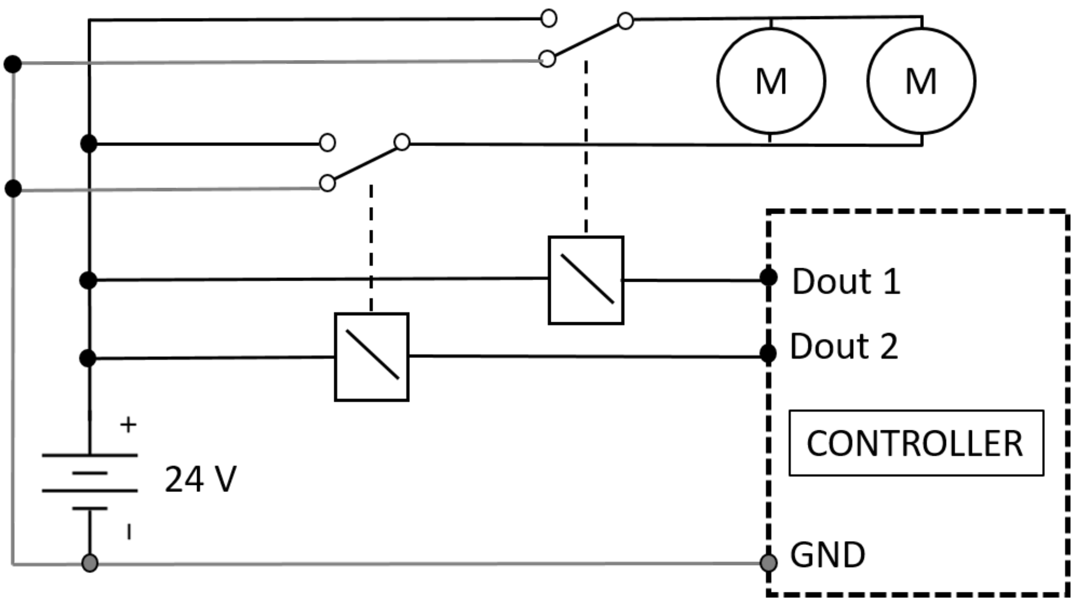


Figure 5.28: Linear actuators electric circuit scheme

The correct working has been tested using a simple creator and simulator of electric circuits available online called "DCACLab" [21] (Fig. 5.29).

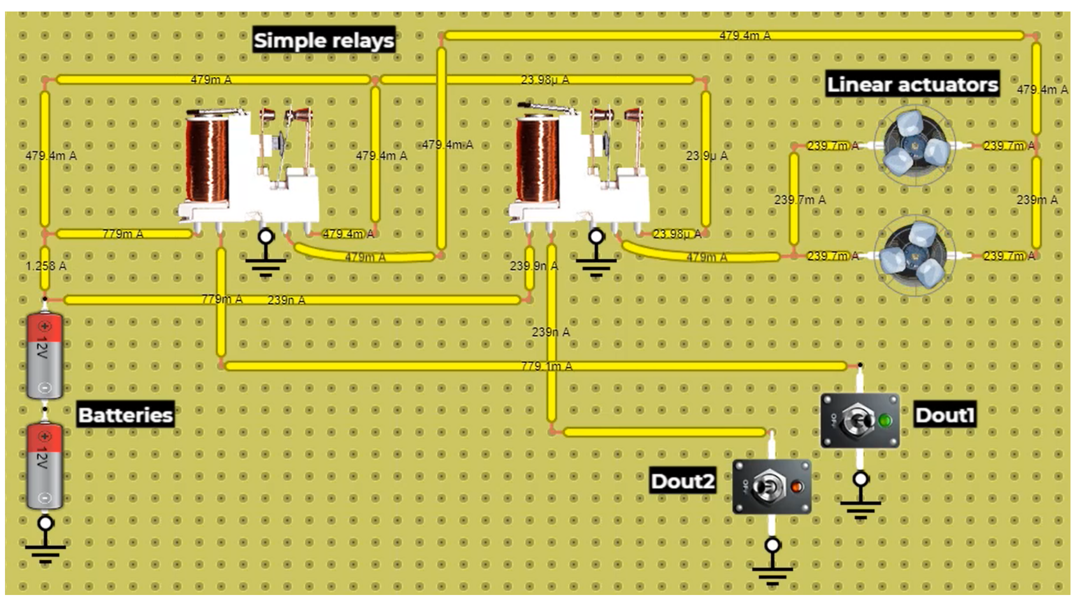


Figure 5.29: Linear actuators electric circuit testing, DCACLab

5.3.4 Laser Range Finder Sensor

The laser range finder sensor is configured with the SICK Configuration and Diagnostic Software (CDS) downloaded in the manufacturer website [22]. The main feature of this software is that it allows to customize both the warning and protection fields of the sensor. This can be done in an offline mode, that is without connecting the sensor to the computer. In order to do that, firstly it has been added the S3000 laser scanner device with I/O module standard and short range sensor head (up to 4 m range). Afterwards the device has been configured step by step. In the "resolution/ field type" tab it has been selected the following settings shown in Fig. 5.30. The dual field mode allows to set one protection zone and one warning zone.

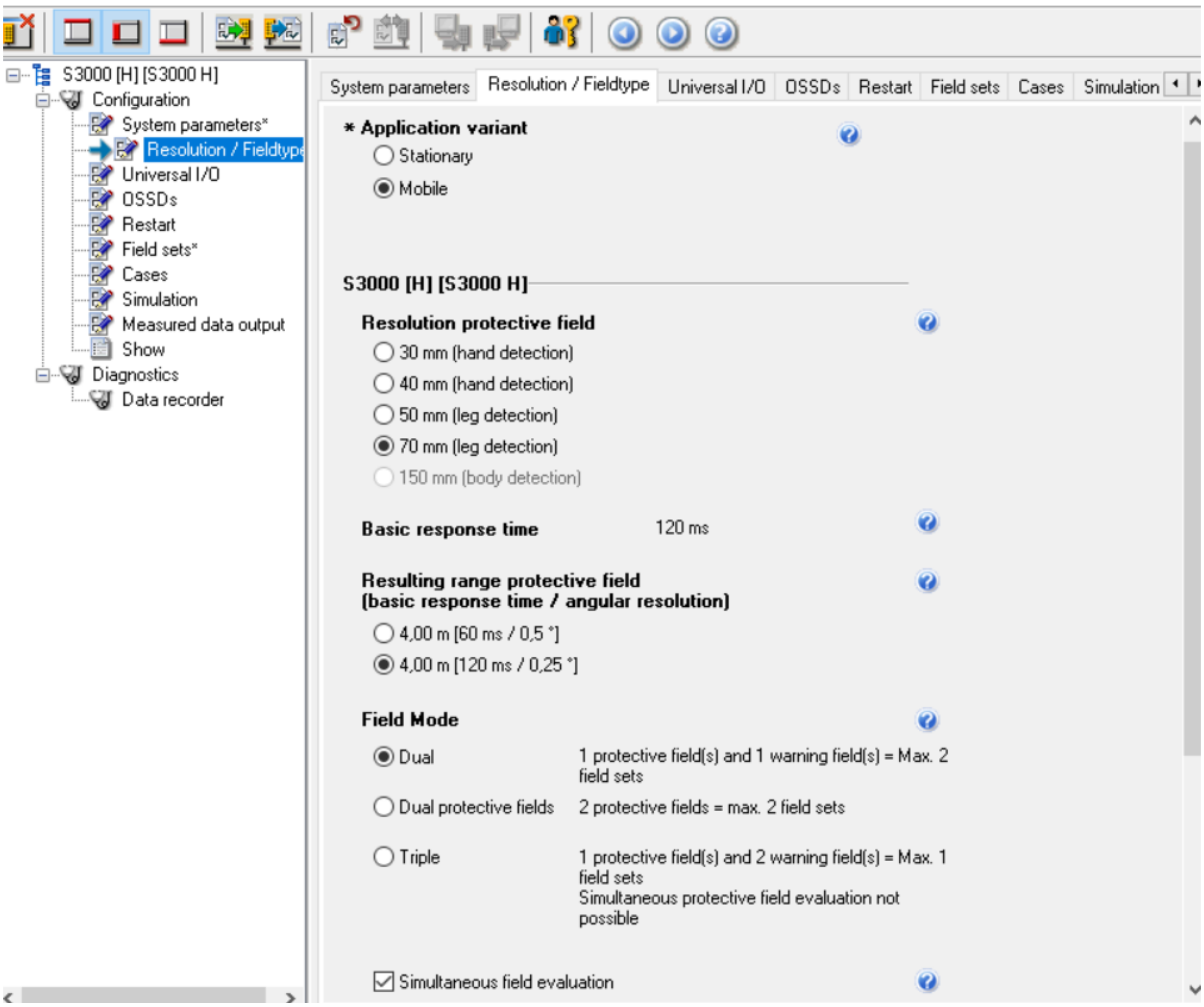


Figure 5.30: S3000 resolution and field type settings

Besides this, in the "Field sets" tab the customization of the shape and dimensions of the protection field has been done according to the dimensions of the AGV cart. The cart width is 64 cm, therefore the width of the protection field is set in 64 cm . Since the lateral distance between the AGV cart and the group stands will be around 10-15 cm during the trays exchange, it is necessary to set a protection field width not larger than 64 cm to avoid that the optical sensor detects the stands inside the protection field. On the other hand, the field length is set in 1.5 m forming a rectangular shape. Furthermore, regarding the warning field, the dimensions have been set in 50 cm on each side of the protection field. Therefore the total dimensions of the detection field are 164 x 200 cm. The field customization is shown in Fig. 5.31.

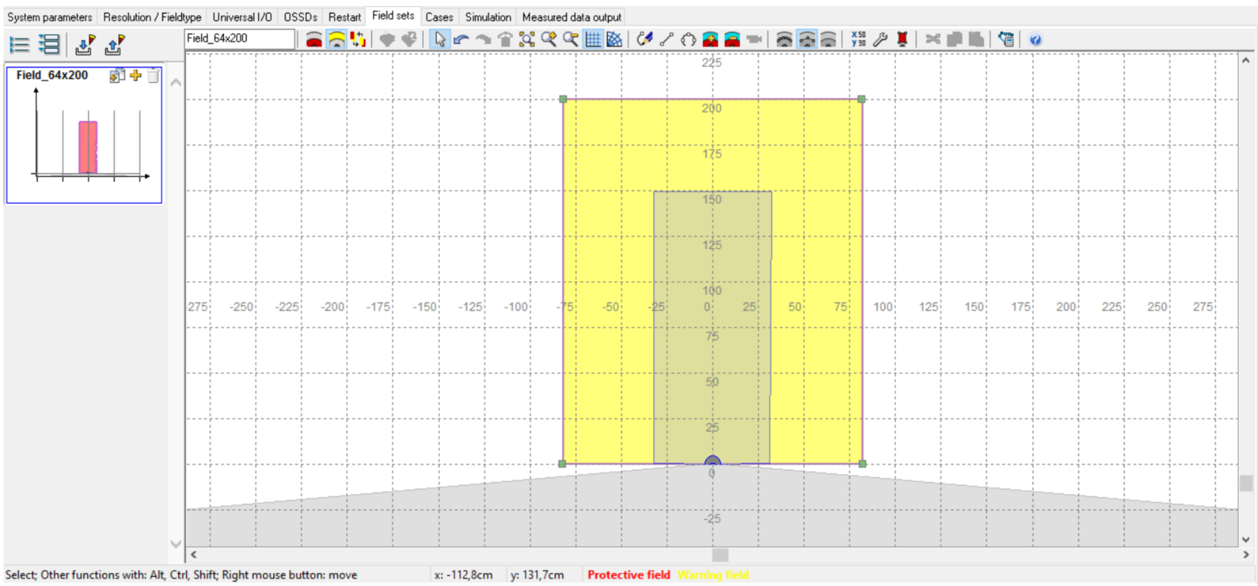


Figure 5.31: S3000 protection (red) and warning (yellow) fields customization

In this way, whenever an object enters in any of the zones, the output signal (OSSD) is switched and sent to the controller connected to the sensor.

The sensor configuration is exported to the device after connecting the sensor to the computer using an USB cable (not included with the product).

Regarding the sensor mounting and wire connections or electrical installation, all the detailed information can be found on the S3000 operating instructions [23].

5.3.5 AGV chassis building

The structure of the AGV is designed to support all the electric and mechanical components as well as offering a correct coupling with the cart. Again, it is completely built using TechnoLean materials which provides a wide flexibility to do modifications easily if necessary. A picture of the 3D model of the AGV is shown in Fig. 5.32.

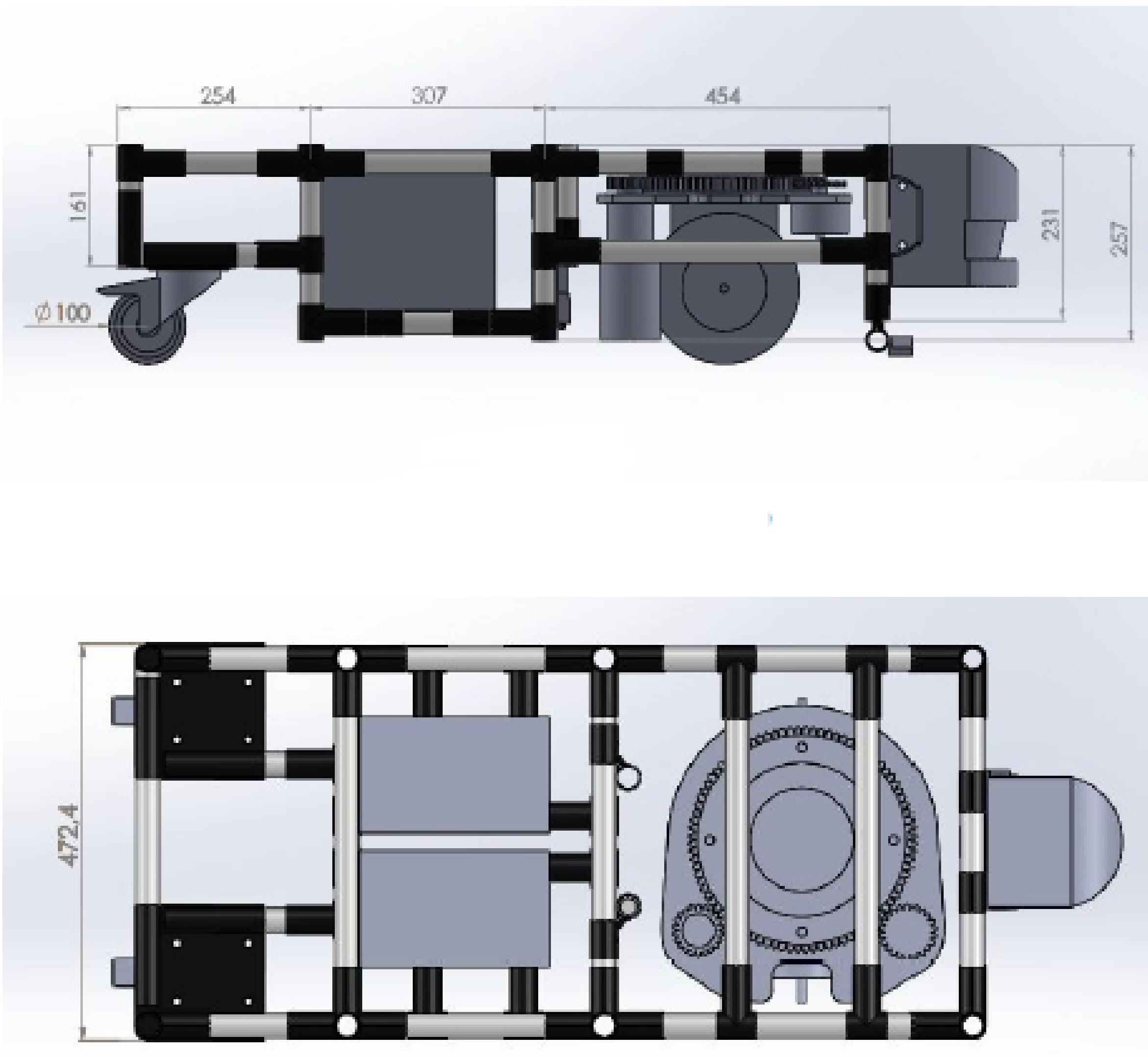


Figure 5.32: AGV 3D model main dimensions [6]

The attachment of both sensors to the structure will be intended to be done with the aid of TechnoLean connectors and joints, however, if it is not possible, it will be used the mounting kits offered by the manufacturers. Furthermore, the structure is susceptible to suffer all the required modifications to ensure the correct placement and attachment of each component avoiding any displacement of them when the AGV accelerates, decelerates or turns.

The battery charger collector will be placed on the bottom of the chassis. Its installation requires some modifications of the structure that will be shown later in Section 5.4.4.

Regarding the steerable drive wheel, it is easily fixed to the structure through four screws M10 that pierce the tubes located just above the wheel attaching the wheel to them as shown in Fig. 5.33.

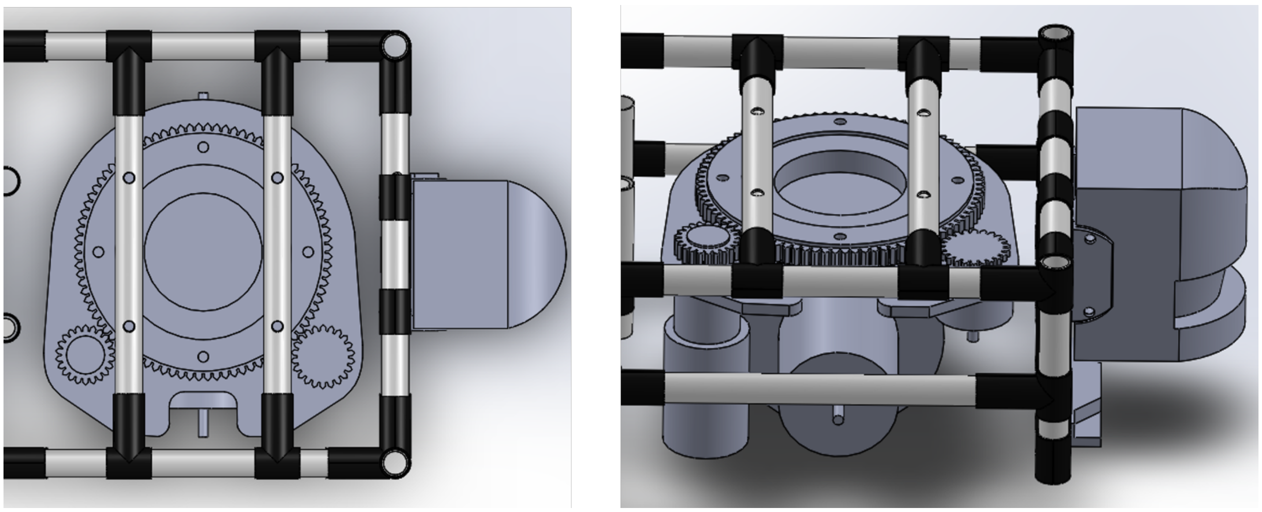


Figure 5.33: AGV 3D model steerable drive wheel attachment

In case of changing the single steerable drive wheel to the 2 drive wheels configuration some modification must be done in the front part of the structure. However, the use of this configuration would imply a more complex attachment to the structure due to the characteristics of the wheels selected. It has been tried to do the attachment using only TechonLean materials and, in order to achieve this, the front part of the chassis has been redesigned. The length has been increased and the width decreased to align the support tubes with the wheels holes allowing the fastening of the wheels assembly to the structure through M8 screws.

This new AGV structure is meant to fit the Benevelli DD1 series drive wheel, nevertheless, it could also be used to attach the other wheels models making height adjustments of the support tubes as well as modifying the width and length of the front part structure as necessary. The design of the AGV chassis for the 2 wheels configuration is presented in Fig. 5.34 and Fig. 5.35.

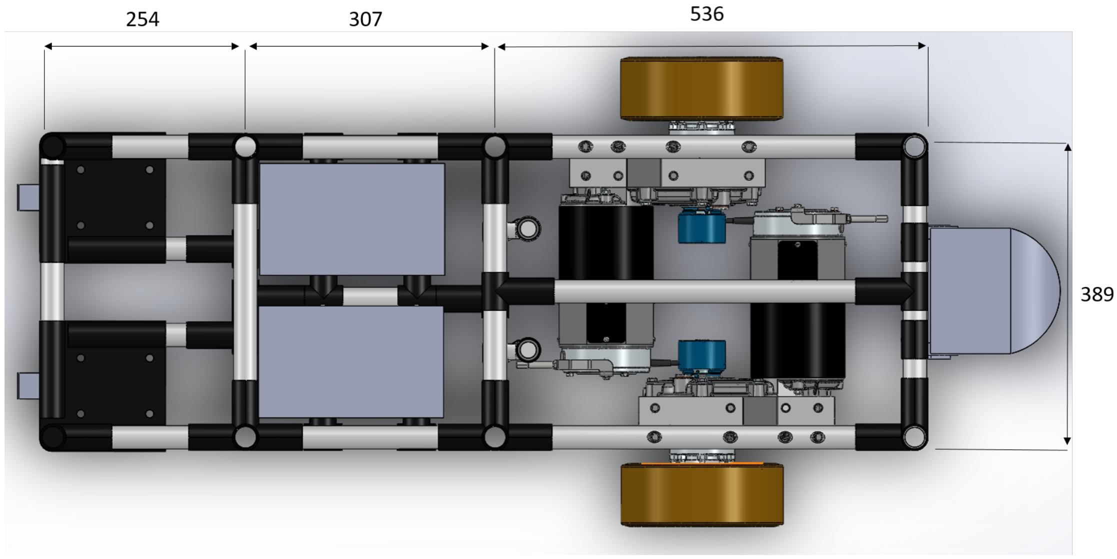


Figure 5.34: Two drive wheels configuration, AGV 3D model top view

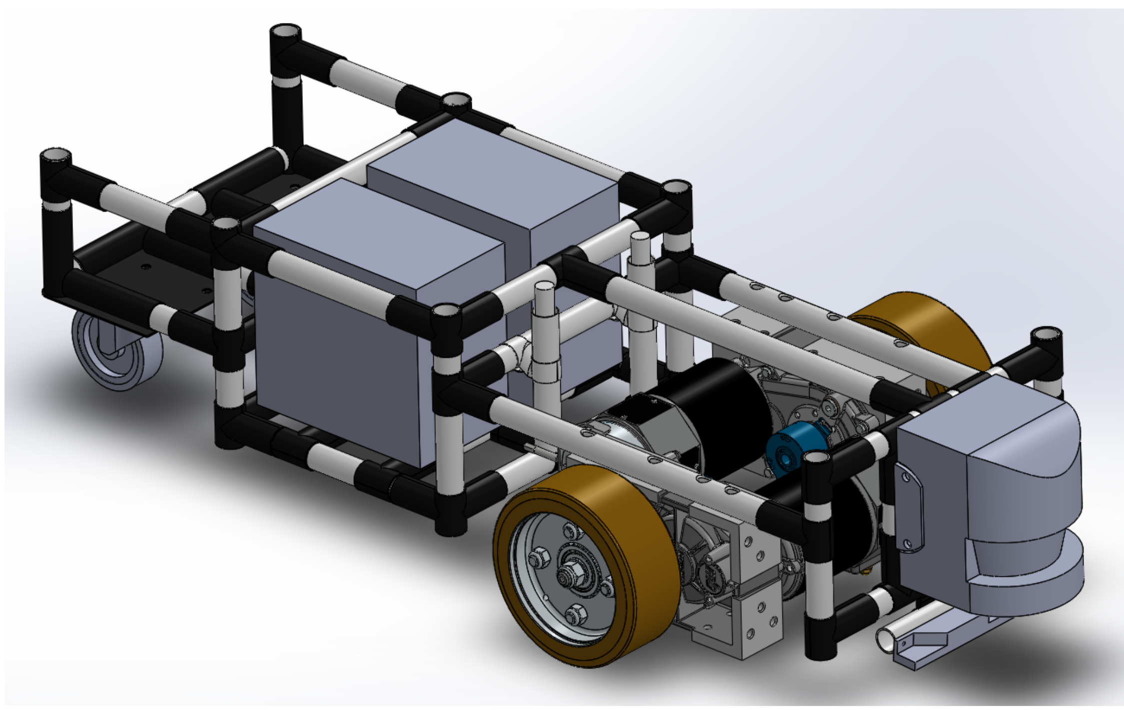


Figure 5.35: Two drive wheels configuration, AGV 3D model perspective view

5.4 Batteries charging system

The charging methods for AGV batteries can be classified essentially in two types, contact and contactless. Both of them are widely used and each one has advantages and disadvantages with respect to the other one. Therefore, the selection of the best system will be done comparing them and deciding which one fits better to this specific application. The system selected must comply with some important requirements:

- The AGV must charge its batteries in a certain location along the route, there is not a specific path diversion meant to this purpose. Hence, the charging station must be able to be placed in the main route.
- The charging operation must be done in an autonomous way, not needing the human intervention.
- Since the AGV pass over the charging system each time it performs a route, the system has to be resistant, for instance, to the friction in case of contact to reach thousands of cycles until failure.
- It has to be guaranteed that the system works correctly needing the less maintenance possible.
- Avoid or reduce as much as possible the interference between the charging system components and the warning field of the laser sensor.
- Maximize the efficiency and ensure that it does not decreases due to slight misalignment that could occur between the AGV stop position and the charging station.

5.4.1 Contact charging

The contact charging methods, as its name indicate, works making direct contact between the battery terminals and the charger. For AGV applications, these systems are typically compounded of two parts. A base plate placed outside of the AGV fixed generally to the floor or any lateral support and connected to the battery charger, and a current collector which is mounted in the AGV connected to the battery terminals. When the collector makes physical contact with the plate, the current passes from the charger to the batteries. An example of this system is shown in Fig. 5.36.

Several companies offer this contact charging system specially designed for AGV applications. Among all, in this case it has been selected three to focus on: Roboteq, Vahle and Conductix-Wampfler.

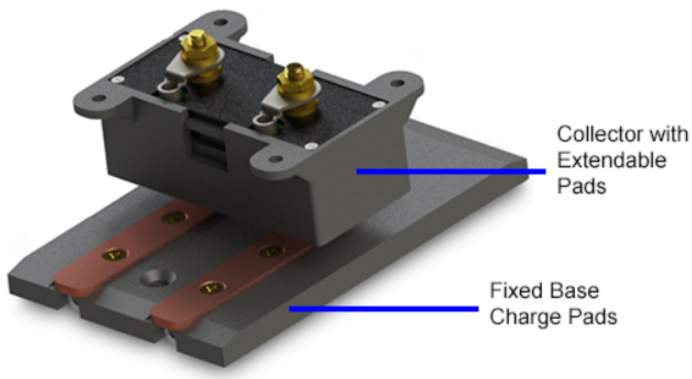


Figure 5.36: Contact charging system example by Roboteq [24]

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5.4.2 Contactless charging

The contactless charging makes use of the magnetic induction to charge the batteries not requiring physical contact between the battery terminals and the charger. The system consists in a transmitting unit and a receiving unit. The transmitter (Tx side) is connected to the AC (Alternating Current) electrical grid and contains a coil that generates a magnetic field when the AC current passes through it. Next, this magnetic field induces an AC current in the coil contained in the receiver (Rx side) existing an air gap between both coils. This AC current is converted to DC (Direct Current) by a rectifier and smoothing circuit and regulated before supplying the batteries.

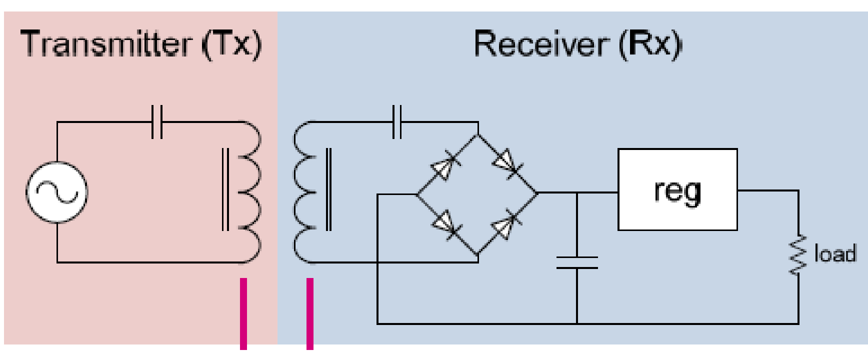

Figure 5.37: Contactless charging, Tx and Rx electric circuits[25]

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In Fig. 5.37 (above) is presented the electric circuit scheme of the Tx and Rx sides. The AC-DC converter consists in a rectifier diode bridge and a filtering capacitor. Afterwards the DC voltage is regulated by a regulator to obtain the battery supply voltage.

Delta company offers contactless chargers base on this technology. Their system consists in a transmitter side, that includes Wall-Box and Base-Pad, and a receiver side containing On-Board-Pad and On-Board-Electronic (Fig. 5.38).

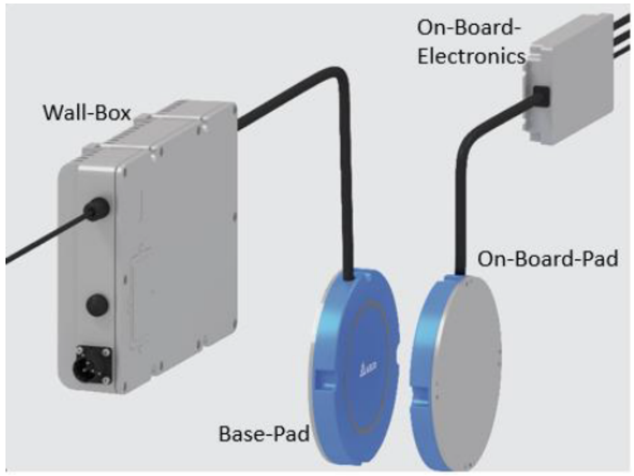

Figure 5.38: Delta wireless charging system [26]
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The magnetic field generated by the primary coil radiates approximately equally in all directions, hence the flux drops rapidly with distance obeying an inverse square law. Consequently, beyond a few centimeters, the flux becomes so weak that power transfer eventually stops. This implies that in order to maintain a high efficiency and a correct working of the system, the gap between both pads must not be larger than 2 cm as well as the horizontal misalignment.

Nevertheless, it exists an advanced wireless charging technique called magnetic resonance, that even though it is based exactly on the same principle than the latter, it increases the alignment flexibility avoiding the severe efficiency drop for larger gaps and misalignment between coils. To achieve this the coils must operate at identical resonant frequencies taking advantage of the strong coupling that occurs between resonant coils even when separated by tens of centimeters. The physics of resonant power transfer is complex, but can be roughly explained as the energy is transferred forming a ”tunnel” from one coil to the other instead of spreading omni-directionally (sphere). Therefore, the energy attenuates less with distance, and actually the primary source of attenuation is the Q factor (gain bandwidth) of the coils which can be improved with a good design [27].

A company that offers wireless chargers based on magnetic resonance is Daihen with the D-Broad wireless Power Transfer System Fig. 5.39.

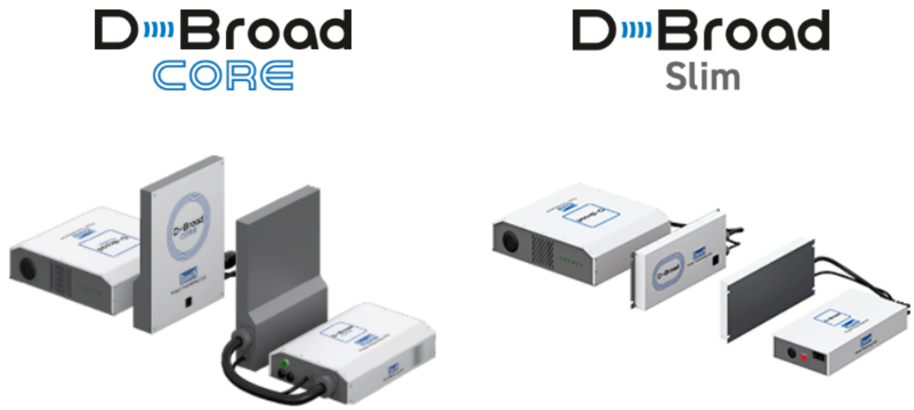


Figure 5.39: Daihen D-broad wireless chargers [28]

5.4.3 Charging system selection

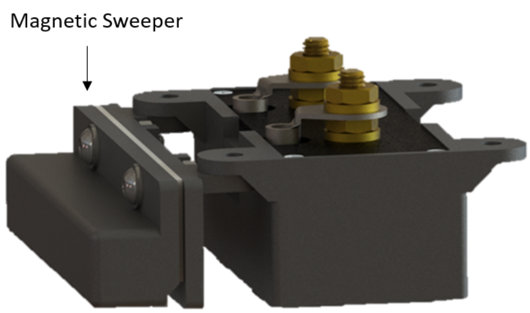
The selection of the most appropriate charging method for this application will be done based on the advantages and drawbacks of each, which are gathered in Table 4.

Table 4: Charging systems comparison

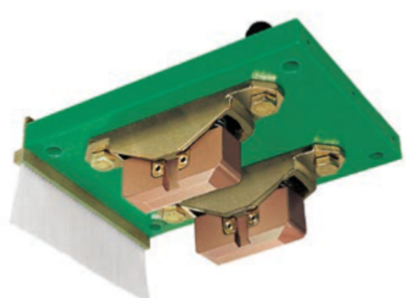
Charging Method	**Advantages**	**Disadvantages**
Contact charging	• High efficiency • Simple functionality • Cheaper • Moderate alignment flexibility	• Friction wear • Dirt or dust settled
Magnetic induction	• Moderate efficiency • No friction wear • No dirt or dust	• Low alignment flexibility • More expensive • Efficiency drop with misalignment
Magnetic Resonance	• Higher alignment flexibility • Low efficiency drop • No friction, dirt or dust	• Lower efficiency • More expensive • More complex functionality

The contact system provides the higher efficiency because of the physical contact and also is simpler than contactless methods. Moreover it allows a larger misalignment between the collector and the ground pad which is very important to avoid efficiency losses if the AGV stops a few centimeters away from the ideal position for some reason. However, since it exists friction wear, it is important to ensure that the contact charging device endures a high number of cycles and minimize the dirt or dirt deposition in the ground pad. Regarding these concerns Vahle and Roboteq companies offer contact chargers that besides claiming that their charger pads are designed and made to last a very high number of cycles minimizing the friction wear, they also avoid the deposition of dust and particles.

Vahle offers models with a bristle brush placed in the collector plate that cleans the ground plate every time the AGV passes over it (Fig. 5.40b). On the other hand, Roboteq pads fit with the optional sweeper assembly. Composed of a magnet holder and a nylon brush, the sweeper cleans the track ahead of the pad's motion and attract metallic particles or objects keeping them away from the collector's pads (Fig. 5.40a).



(a) Roboteq Magnetic Sweeper



(b) Vahle bristle brush

Figure 5.40: Roboteq and Vahle collectors with sweeper accessories

On the other hand, contactless methods besides being more expensive and complex, they have less efficiency due to transmitted power losses because of the air gap and dropping severely if there is not a precise alignment between the coils in the case of magnetic induction. Magnetic resonance charging method has the lower efficiency and higher complexity and costs but also it has the widest alignment flexibility allowing air gaps of several centimeters and moderate horizontal misalignment.

Once they are known the advantages and drawbacks of each charging technology it is time to decide which option fits better in this specific application. To do this, it will be taken into account 4 factors (efficiency, alignment/ air gap flexibility, costs and maintenance [2]). Next, it is assigned a specific weight to each factor in function of its relevance (1: important, 0.6: normal, 0.3: less important).

[2]Maintenance refers to the need of keeping cleaned and replace the ground plate due to friction wear

- Efficiency and maintenance have a weight of 1, due to the fact that efficiency marks the power consumption and time required to charge a battery, and the maintenance could imply the necessity of having a worker in charge of keeping clean the ground plate and frequent replacements.
- Alignment and air gap flexibility have a weight of 0.6 because. Even though it is very important to have a precise alignment in the case of magnetic induction, it is expected that the AGV will be able to stop more or less accurately in the exact position.
- Cost has been considered to have a weight of 0.3 because it is expected to have only one charging station.

Nevertheless these weights can be reassigned afterwards in the way the company considers, which could eventually affect to the charging system solution selected.

Finally, the quality of each charging solution for each one of the factors is evaluated assigning three levels (3: good, 2: normal, 1: bad). For instance, in terms of costs if the solution is the more expensive one, it means a 1, while in terms of maintenance in case of not requiring any, it will mean a 3. In this way, the final mark of each solution is computed multiplying the level of quality by the relevance factor and adding up. The chosen solution is the one with the best mark. The inputs and results are presented in Table 5.

Table 5: Charging systems selection

Charging Method	**Efficiency**	**Flexibility**	**Maintenance**	**Cost**	**Overall Mark**
Contact Charging	3	2	2 [3]	3	**7.1**
Magnetic Induction	2	1	3	2	**6.2**
Magnetic Resonance	1	3	3	1	**6.1**

According to the results, the chosen solution is the contact charging. Both Vahle and Roboteq offer contact chargers with a good resistance to friction and able to keep the ground plate cleaned, free of dust and particles.

The Vahle model working principle is based on the use of springs to make contact. The contacts or pads are normally extended until they make contact with the ground plate ramp contracting the springs and therefore it appears a contact pressure between the ground plate and the collector pads and the current pass through them.

Roboteq uses a more advanced mechanism consisting in high force magnets with opposing polarities placed in the charging base and charging contacts that causes the appearance between them of a strong

[3] In the case of using the sweeper accessory, otherwise it would be a quality grade = 1

repulsion force during both, entry and exiting of the ground plate, and a strong attractive force in the center electrically active area of the plate allowing a solid electrical connection between collector contacts and ground plate. This attractive force is enough to ensure that the AGV batteries acquire full charge at the maximum rate possible.

One of the advantages of the Roboteq chargers against the Vahle conventional spring charging contacts is the less tight height tolerance because the spring contacts must physically slide up a ramp on the base which implies that if they are mounted too low, they will touch the floor or hit the side of the base and, on the contrary, if they are mounted too high, the will have weak spring pressure or not make contact at all (Fig. 5.41).

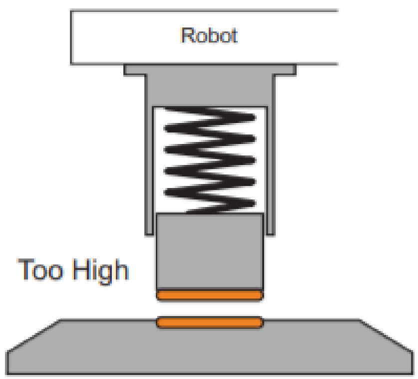


Figure 5.41: Conventional spring contacts [29]

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Another important advantage is the lower friction wear suffered by the magnetic contacts. The Roboteq magnetic pads only extend and make contact with the ground plate in the center area, whereas the conventional spring contacts slide all over the base plate ramp and surface (Fig. 5.42).

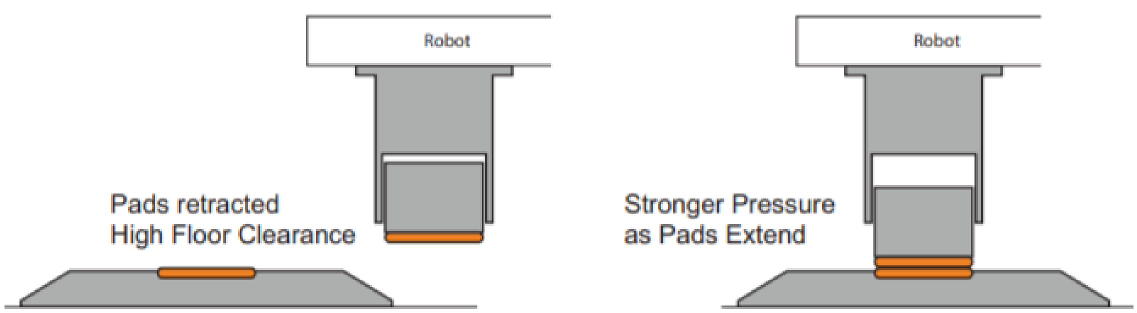

Figure 5.42: Magnetic contacts [29]

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For all this reasons, it seems more appropriate to select the Roboteq Robopad charging system rather than the Vahle models.

The base plate will be placed in one side of the track as it is shown in Fig. 5.43, and the collector will be mounted on the AGV in a way that the maximum vertical distance between ground plate and collector is 20 mm.

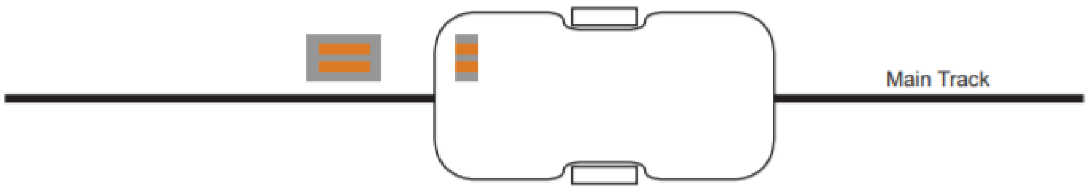

Figure 5.43: Magnetic contacts [29]

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Finally, in terms of charging amperage, the charger offered by Roboteq is capable of 100 A maximum (75 A continuous) which implies that the time required to fully charge the two batteries connected in series, each one with a capacity of 70 Ah, would be almost two hours in case of setting a DOD around 90 % as it has been considered before. In order to decrease the required time to charge the batteries, two options are considered:

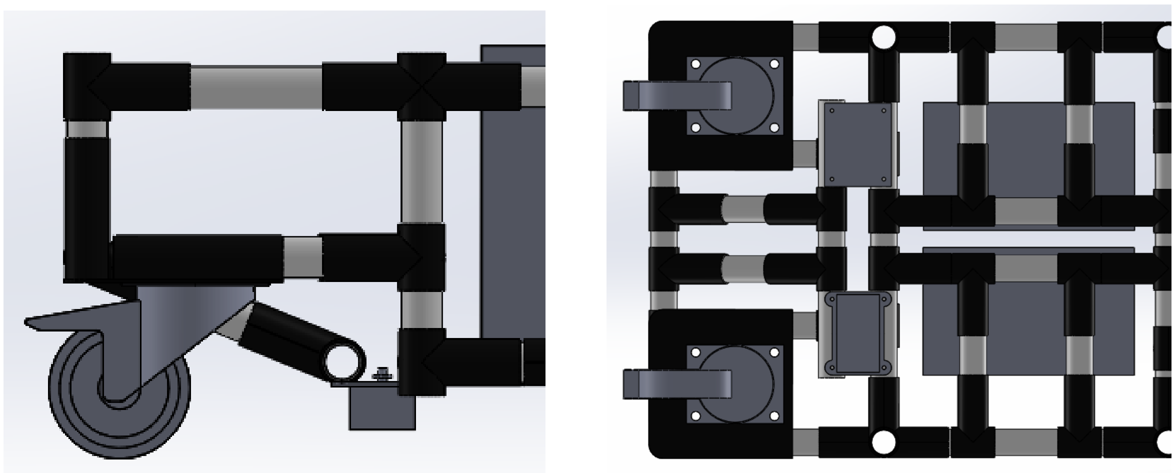
- To set a lower DOD to make the AGV charge the batteries more often. Lithium-ion batteries do not have memory effect hence it would be possible to charge the batteries during the not working time intervals between routes selecting an appropriate DOD. For example, if the charging time is required to be lower than 45 min, it could be selected a DOD of 40%. Changing the threshold voltage below which the low battery condition is activated on the script, the AGV will be programmed to stop in the charging station when its battery charge level is lower than 60%.
- Asking Roboteq for tailor made to user's charger with higher amperage or ordering to Vahle that have models up to 600 A.

5.4.4 Charger collector attachment

As told before, the Roboteq contact charger consist in two parts, one of them mounted on the AGV, which is the collector, and the other one fixed on the floor. The gap between the collector and the floor must be lower than 20 mm because, both the ground plate thickness and the stroke of the magnetic contacts, are 10 mm.

The attachment of the collector to the bottom of the AGV chassis is done through four M4 screws, however some modifications of the structure must be done to fix the collector. The design is presented in

Fig. 5.44a, Fig. 5.44b and Fig. 5.45 for the steerable drive wheel configuration. For the two drive wheels configuration the design of the attachment structure would be similar adapting the tubes dimensions. The gap between the collector and the floor has been set in 1.8 cm.



(a) Lateral view

(b) Bottom view

Figure 5.44: Charger collector attachment

Note that in order to avoid any possible rotation around the perpendicular axis of the support structure, it can be added a 90x64x3 mm metallic plate used as joint between the two parallel tubes that support the collector through four M4 screws.

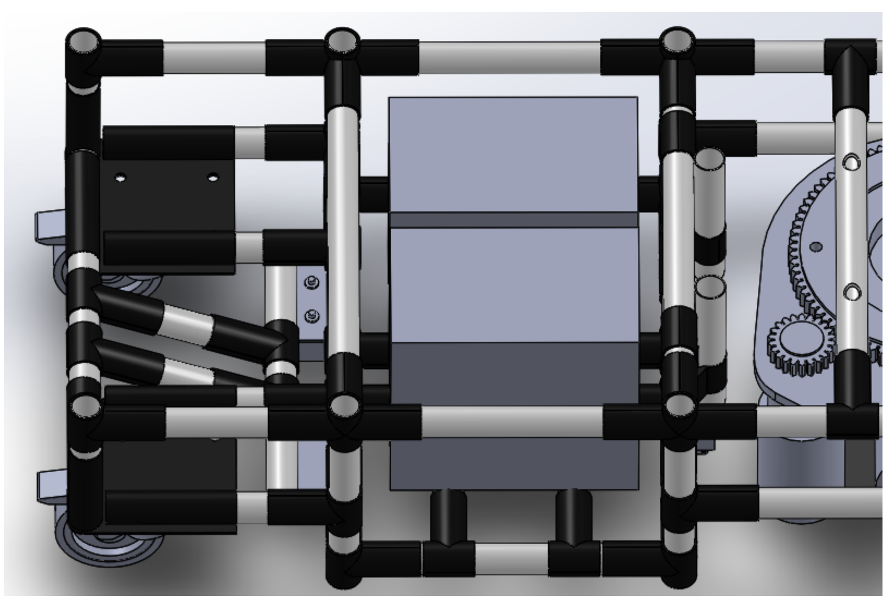


Figure 5.45: Charger collector attachment perspective view

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The complete view of the AGV structure design is presented in Appendix A.

6 Conclusions and further work

6.1 Conclusions

This thesis have covered different aspects of the process of building an Automated Guided Vehicle to be implemented in the components shop to perform the task of material distribution in an autonomous way. On each part of the building process some difficulties has been encountered requiring appropriate solutions which are addressed in the thesis.

The first design of the cart did not offered a correct functionality in terms of coupling between cart and group stand causing problems in the opening of the stoppers mechanism that allows the trays exchange. Therefore, after testing several concepts and solutions, a simpler stopper mechanism was implemented but it required that each one of the four shelves was assigned unequivocally to one group. This new concept reduces the flexibility in the usage of the cart compare to the initial idea.

On the other hand, the design of the reception group stands has been carried out in a way that makes them capable of storing several trays of different sizes waiting to be gathered up and repaired by the workers.

Regarding the programming and script development, it has been written using MicroBasic language specially conceived to be easily interpreted by the Roboteq motor controllers. This code commands all the movements and steering control of the AGV and has been simulated using a software that simulated the performances of the vehicle. Since the simulator does not allow to configure the AGV with only one steerable drive wheel, the results of the simulation are valid in terms of movements and task performances, but not in terms of steering control. In order to get a better match up between the simulations outputs and the real life, it is also proposed the use of a new AGV configuration consisting in two driver wheels instead of one. This configuration can be perfectly set in the software. Anyway, since the tuning of the control parameters must be done during the AGV testing no matter the type of wheel configuration used, the initial steerable drive wheel configuration is recommended because of its higher precision.

The towing pins device has been entirely designed. It consists in two electric lineal actuators connected to two simple relays that allow the inversion of the motors polarity in function of which one of the two digital outputs is active. In this way the rod of the actuator is deployed whenever the AGV is running allowing the cart towing, and retracted when the AGV is stopped in the base.

Unfortunately, due to the exceptional situation that surrounded the realization of this project caused by the pandemic, the building of the AGV structure and installation of all the components could not be carried out and will remain to further work.

Finally, concerning the batteries charging method, the contact charging method has been selected above the magnetic induction and magnetic resonance methods because of presenting the highest efficiency besides enough alignment flexibility and not requiring a periodical maintenance. It is also the cheaper and simpler option. The model chosen is the Roboteq Robopads that uses magnetic contacts instead of the conventional spring contacts allowing a higher endurance due to the reduction of friction wear. It is important to remark that it will be necessary to purchase the magnetic sweeper accessory that keeps the ground plate cleaned, free of dust and particles.

6.2 Further work

Despite the fact that initially the main objective of this thesis was the building of the AGV and testing it, the special circumstances that surrounded the realization of the project made impossible to be present in TAP the most part of the time. Thus, there was only time to build the cart and part of the group stand remaining the building of the AGV to do. However, instead of this, a deeper work was done concerning the script development and simulation as well as exploring some wheel configurations alternatives and getting into detail in the charging system methods and selection. That said, on the following all the further work is detailed:

- Complete the building of the reception group stands using the multi-directional roller rails and verify that the tray exchange with the cart is performed correctly.
- Build the AGV structure and fix all the electric and mechanical components with the necessary elements.
- The connections and interface between all the electric components will be made following the information available in the documents and manuals provided by the manufacture companies.
- Put the magnetic tape drawing the desired path and place markers in the correct positions.
- Start testing the AGV, tune the control parameters and verify its correct performance.
- Place the group stands and the battery charging ground plate in the exact positions where the AGV stops to ensure perfect couplings.
- Once the AGV is capable of performing the reception operation correctly, start working on the expedition operation which will required improvements in sensors and more complex programming as well as a new design for the expedition stands.

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A AGV structure

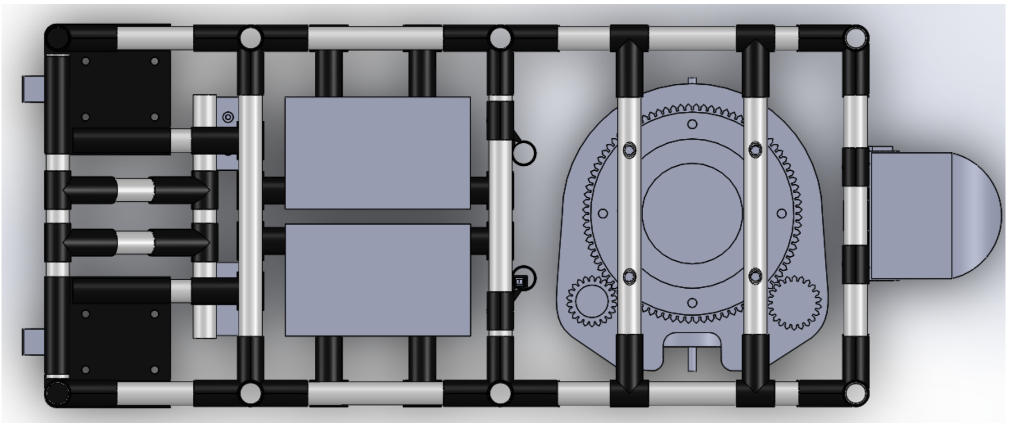

Figure A.1: AGV top view
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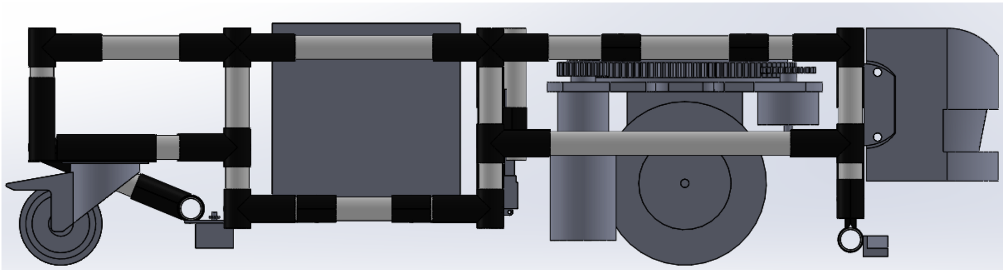

Figure A.2: AGV lateral view
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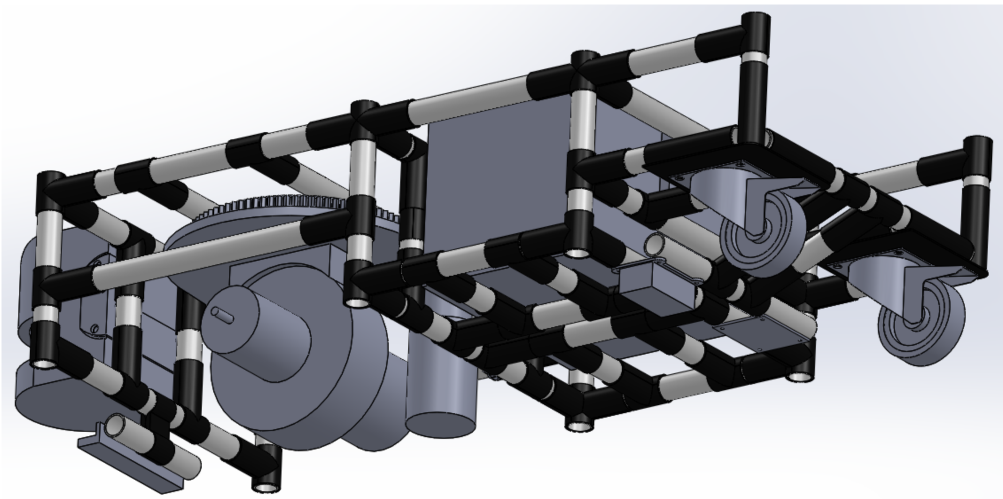

Figure A.3: AGV perspective view
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