SMART SHOPPING CART

Final Report

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MAMOA

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1. EXECUTIVE SUMMARY

With the proliferation of technology especially in the last three decades, traditional means of daily activities have changed significantly. Shopping, one of these activities since the dawn of commodities, has had its fair share of evolution in the face of ever-growing technology. Nowadays, the question about shopping is whether the product is available online. This tendency stems from some burdens of shopping in person, which only worsen with the growing population and demand for new products. Hence, engineers of today should come up with solutions for the future with the help of technological advancements.

As a group of engineers with the goal of being the future's solution to today's problems, MAMOA comes with a smart shopping cart that solves some major contemporary problems of shopping. When people need to visit a store in person, the image of long waiting lines at the cashier compels them, and it only gets worse with a loaded cart to carry around. The smart shopping cart, on the other hand, follows its designated customer inside the shop and gives the total price to be paid with a display, with no need for reading the barcodes of each item at the cashier. Along with these innovative features, it avoids collisions and soothes the shop owner by having an abuse prevention utility to avoid theft.

The design of the smart shopping cart consists of 4 main parts that cover the mentioned utilities, separated in their operation but intertwined in the workflow. These parts will be called systems from now on, and they are customer detection, collision avoidance, product identification and abuse prevention, and cart control systems. The design approach, block diagrams, flowcharts, illustrations, and detailed explanations for these systems will be demonstrated in this report, together with the actual assembly and test results.

2. INTRODUCTION

In the smart shopping cart project, the main functionalities of the cart according to the needs of customers can be listed as

- Successfully detecting the customer in the shop and following him/her,

- Successfully identifying the products and keeping a list along with the total price,
- Avoiding collisions with people, other carts, or the environment,
- Having measures to prevent theft.

For the implementation of these functionalities, the cart design is divided into 4 different systems, namely customer detection, collision avoidance, product identification and abuse prevention, and finally the cart control systems. These systems cover all the functionalities listed and will be clearly detailed.

The customer detection system is designed as a custom image detection system using an on-cart camera. The video from the camera is used to detect the designated customer among other people. For this purpose, the logo of our company is used as a dedicated object to be found. This system is implemented with a Raspberry Pi 4B together with a Picam mounted on the CSI interface of the cart. The coordinates of the customer are sent to the cart control system through Bluetooth since wired solutions require a long wire going through the basket to the chassis.

The collision avoidance system is designed with ultrasonic sensors so that the cart has an understanding of its environment. Using the distances from nearby obstacles the cart can anticipate and avoid collisions. Since these sensors are not capable enough to depend on, several of them are used simultaneously to cover the inadequacies.

The product identification and abuse prevention system should identify and list the products placed in the cart while preventing theft. This system is designed with an affordable RFID reader and two load cells. The RFID reader has a quite short range, in the order of several centimeters, hence the customer must scan the products to be bought to the customer. The two load cells act as the abuse prevention mechanism, continuously checking for the total weight of the registered items with the actual total weight of the cart. If there are any discrepancies, the system uses an annoying buzzer until the discrepancy is resolved.

Finally, the cart control system is the brain of the cart, getting inputs from all the other systems and deciding on an action, using motors as actuators. This system is not actually a physical part, although it relates to the motors, it is rather an algorithm that decides what to do according to the outputs of other peripheral systems. Hence, it is developed and implemented as an embedded code in the project. It gets the customer position input using Bluetooth as mentioned before, and it gets the ultrasonic sensor readings using UART.

In this report, we will first explain the general working algorithm of the smart shopping cart system. Then the individual systems are explained in detail. After that, the requirements of the project are clarified. The design modifications made since the last report to get to the final product are then clarified. Then, the compatibility of the systems among themselves is explained. The test results for the final product are then illustrated. After that, various resource plans such as the budget or power usage will be analyzed, followed by a standardization section for the cart in terms of different social and ecological aspects. Finally, we conclude the report.

3. OVERALL SYSTEM DESCRIPTION

First of all, we will start by illustrating the overall functionality of the cart as a block diagram, as given in Figure 1. This figure is giving a high-level perspective on the interactions between the systems.

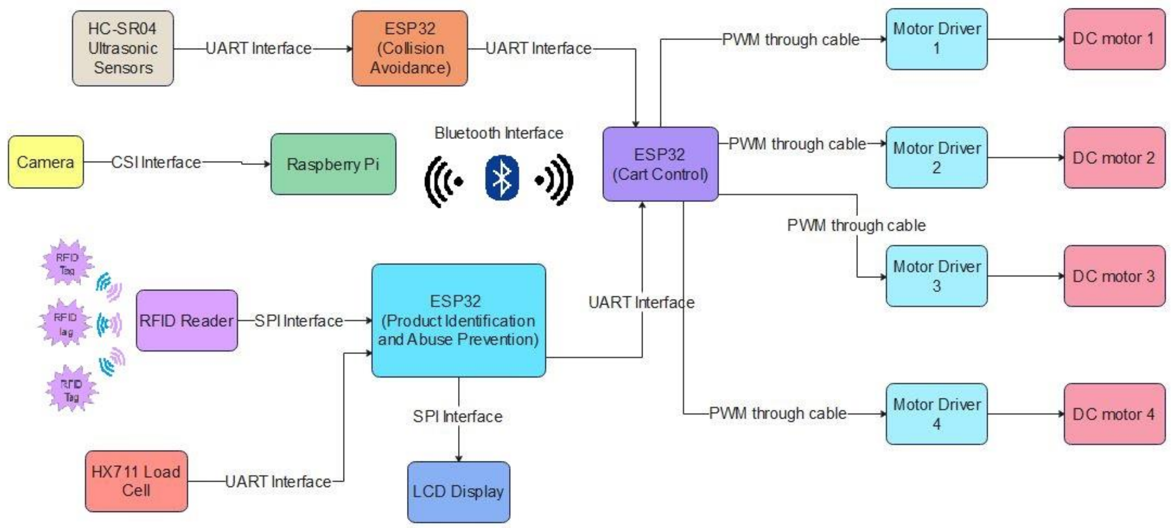


Figure 1: The block diagram of the overall project

As can be seen from the figure, the customer detection system is employed as a Raspberry Pi connected to a camera via a CSI interface. This Raspberry Pi collects video data from the camera and utilizes custom object detection algorithms to detect a specific image linking to the designated customer. This specific image is given to the customer to be carried at their back.

For the product identification and abuse prevention system, the customer scans the desired product to the RFID reader so that it is detected, then he/she places the product inside the cart so that the load cell can check the integrity of the scan by comparing its previous total weight with the updated one, and checking the weight of the scanned product. The total price is continuously displayed via an LCD display. All these are controlled by an ESP32 microprocessor.

For the collision avoidance system, HC-SR04 ultrasonic sensors are connected to a dedicated ESP32 microprocessor. This ESP32 sends the sensor ultrasonic sensor readings to the cart control ESP32 through a UART connection. The cart control system is actually the control algorithm applied in another ESP32 according to all the inputs identified in the figure. Then, according to its decision, it drives the four DC motors using the L298N motor drivers.

At this point, we will delve into the details of all four systems in the cart, by explaining how the aforementioned methods or functionality will be achieved.

3.1 Customer Detection System

As stated before, the customer detection system uses a camera to gather visual data from the front of the cart to detect the designated customer. Detecting an object in an environment requires that object to have some unique trait. A random customer's unique traits cannot be known beforehand, hence a predetermined image is given to the customer to be carried on their back. The pretrained detection model running on the Raspberry Pi detects these predetermined images, which are unique to their carts. A flowchart of this system workflow is given in Figure 2.

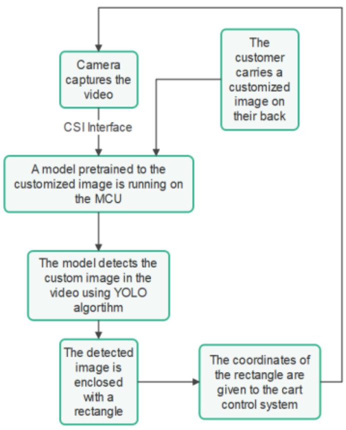


Figure 2: The flowchart of the customer detection system

Before the operation of the cart, the tinyYOLO model to be run in the Raspberry Pi is trained with the image to be followed. Then, the model knows what to detect in the video feed from the camera. Of course, running this trained deep neural network approach may not seem favorable at first, but detection methods without the overhead of this approach such as color detection or shape detection perform very poorly in a similar situation, which would severely affect the tracking performance.

After the detection of the image in the video feed, the code derives the coordinates of the detected object by putting a rectangle around it and provides this information continuously to the cart control system, which is an ESP32 connected to the Raspberry Pi via Bluetooth. An illustration of this detection and rectangle coordinates is given in Figure 3, by using our company logo as the image to be detected.

Figure 3: The MAMOA logo is detected with the pre-trained model

The main design criterion for this approach is the FPS rate of the coordinates given to the cart control system. The FPS of the camera video feed is typically very high, but the tinyYOLO algorithm running on a Raspberry Pi CPU is quite exhausting, hence the update rate of the customer detection system to the cart control system turns out to be around 3-4 Hz. This value, despite being low, is enough to follow the customer since in a shopping scenario the customer does not move fast or abruptly.

This system is powered by a dedicated power bank since 18650 batteries cannot supply stable power to Raspberry Pi and cause low voltage error. A photo of the connections for this system is given in Figure 4.

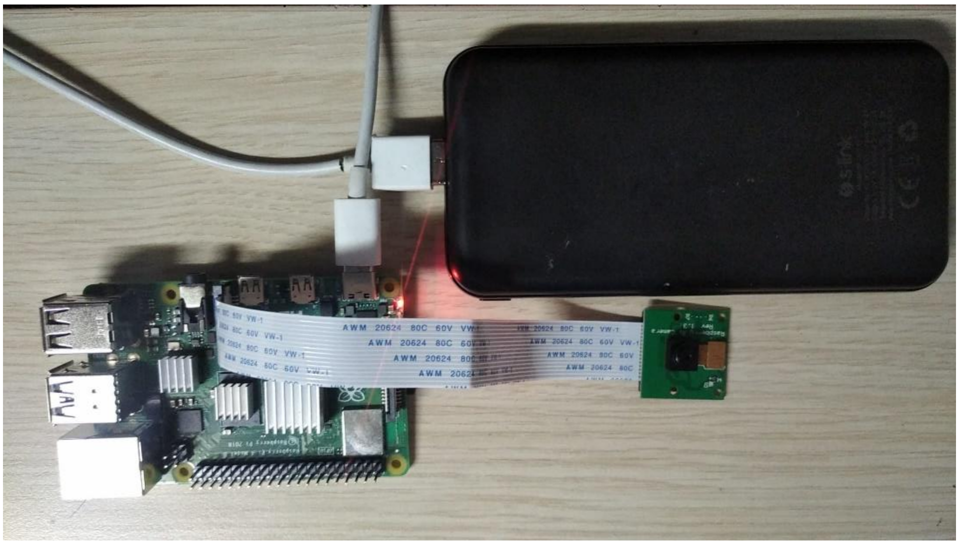


Figure 4: The physical connections for the customer detection system

3.2 Collision Avoidance System

For the collision avoidance system, HC-SR04 ultrasonic sensors will be used to detect the surrounding topology, so that any possible collision can be anticipated and avoided. In the prototype phase, a small prototype car was used with three HC-SR04 sensors for testing this system, and the results suggested that we had to use more sensors to cover all the surrounding space since the angle of vision for these sensors was quite low. Hence, the final product has 5 of these sensors on the basket for full coverage. A typical appearance and the pinout for the HC-SR04 sensors are given in Figure 5.

As usual, the VCC and GND pins are for powering the sensor module, whereas the Trig and Echo pins are used to UART interface the module with the ESP32, or any other microprocessor so that the distance values can be communicated. The Trig pin is the Rx and the Echo pin is the Tx pin of this module.

Figure 5: The typical appearance of an HC-SR04 sensor

Another challenge in this system is that these sensors sometimes erroneously detect close objects which are not there or fail to detect close objects in small time intervals. For evading the effects of these problems, the outputs of these sensors are filtered before being given to the cart control system algorithm. This filter checks if the reading is valid since erroneous readings give distances such as 12 meters. Fortunately, these sensors can update their distance value quite rapidly, hence this filtering operation does not cause any stalls in the movement. The flowchart of the workings of this system is given in Figure 6.

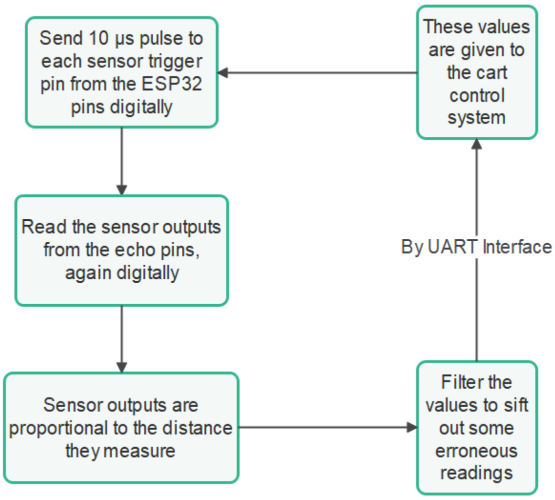


Figure 6: The flowchart of the collision avoidance system

From the flowchart, we see that the working principle of these ultrasonic sensors is quite simple, the microprocessor sends a 10 µs pulse to the sensors trigger pin, which triggers the sensor to send an ultrasonic signal to the air. Once the signal bounces back to the sensor, i.e. it echoes, the time difference between the trigger and the echo is given back by the sensor from the echo pin, where a pulse is given whose duration is proportional to the distance since it is the time that the sound ultrasonic signal took to propagate and bounce back.

The only design challenge to tackle in this system is regarding the cart control algorithm, namely, how will the control algorithm act according to the input from the collision avoidance system. Our design idea is to use it as an interrupt to the customer tracking since it only matters when a collision is anticipated, which should not occur very often. Indeed, the actual operation of the cart confirms this approach.

The physical structure and connections for this system on the basket are given in Figure 7.

Figure 7: The physical connections for the collision avoidance system

3.3 Cart Control System

While the rest of the systems in the project are peripherals, which sense or detect the environment, the cart control system is the brain of the cart, which takes all the outputs from the other systems as inputs and decides on how to drive the motors. This means that the cart control system, although being attached to the motors physically, is actually an algorithm, which has decisions on the behavior of the motors according to the sensor inputs.

In a way, the motors are the actuators of this system, and the ESP32 is responsible for the computations of this algorithm. The main input to the algorithm is the customer position data from the customer detection system, which is supplied by the Raspberry Pi through a Bluetooth connection. Other than that, this system uses the collision avoidance system data through a UART connection with the collision avoidance ESP32.

The general workflow of data in the cart control system is given in Figure 8 as a flowchart. This flowchart uses the customer position data to steer the cart in the right direction and controls the collision avoidance input in each iteration. If it has an interrupt to make, which is an anticipated collision according to the ultrasonic sensor readings, the control algorithm jumps to that branch and serves that branch's dedicated functionality.

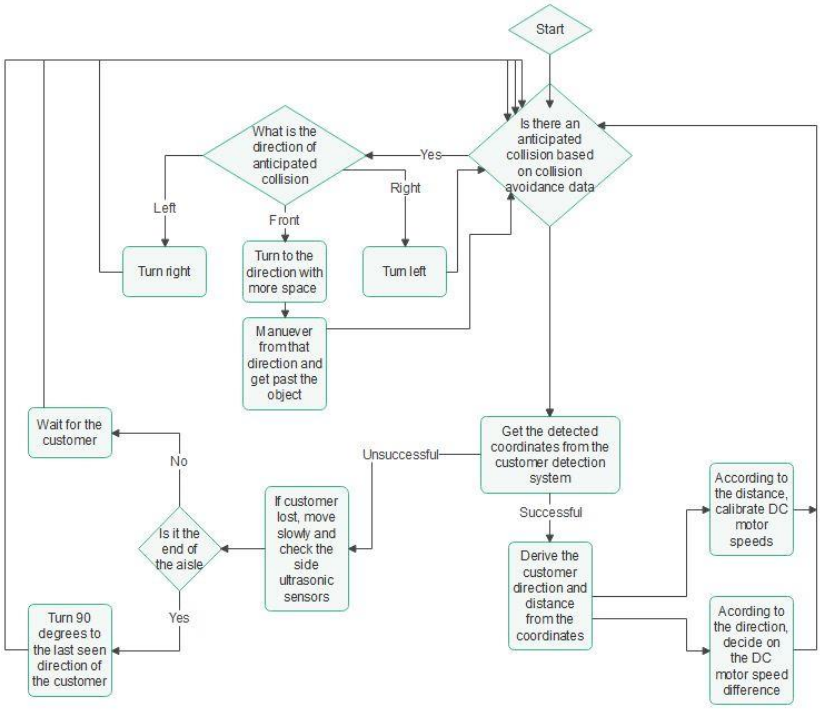


Figure 8: The flowchart of the cart control system

From the flowchart, it can be seen that the algorithm always starts by checking if there is any collision anticipated. If there is no collision possibility, it tries to collect the customer position data from the customer detection system, which are the coordinates of a rectangle, which can be specified by 4 numbers in units of pixels, which are the coordinates of the left top and right bottom corners.

In the case that the coordinates are successfully obtained, the cart uses the area of the rectangle to deduce the distance to the customer, since the rectangle shrinks as the customer gets further away. Also, the horizontal position of the customer is used to determine which way to steer the cart. The distance derived is used to determine the speed of the DC motors without the difference between the sides. Then, the direction value is used to determine the speed difference between the sides.

When the coordinates of the customer could not be obtained, possibly because the customer detection system has lost the customer, the cart first tries to see if it is at the end of the aisle, in which case it makes a predetermined 90 degrees turn to the last seen direction of the customer. If this is not the case and the customer is really lost, he/she can simply show their back to the camera again to make the system flow as usual.

In the case that a collision is anticipated, the direction of the collision is determined by the same modules that detect the collision, the ultrasonic sensors. If the collision is anticipated from the sides, the cart simply steers in the other direction, proportional to the danger. If the collision is from the front, the cart tries to bypass the obstacle by maneuvering around it, which could sometimes be impossible, in which case the cart has to wait for an opening.

The physical connections on the final product for this system are as given in Figure 9.

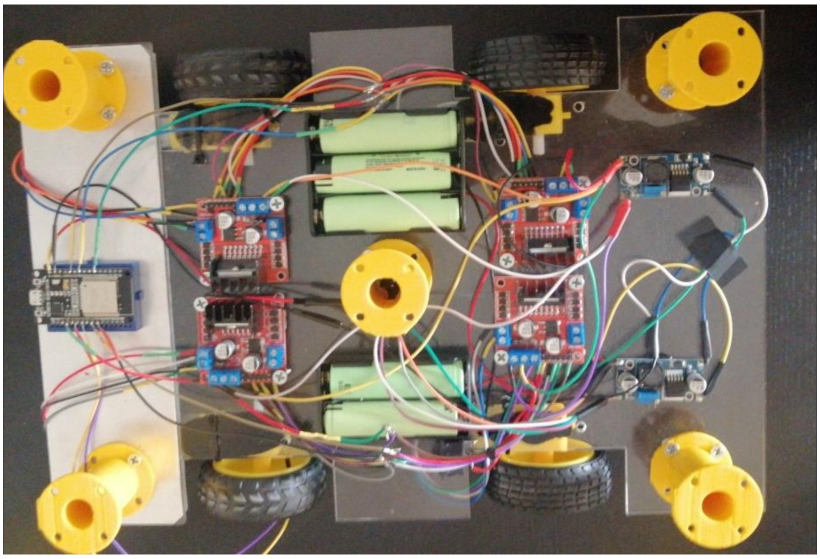


Figure 9: The physical connections for the cart control system

3.4 Product Identification and Abuse Prevention System

Two essential functions are handled in this system of the cart as mentioned before. In this system, we are aiming to identify at least 10 different kinds of products placed on the cart without any false identifications. Used hardware includes one microprocessor one RFID reader, one LCD, one load cell, one speaker, and one RFID tag for each product. The working principle and usage of this system are quite simple. Identification of the products will be done by using an RFID reader and tags on the products. LCD will be used to show the total price and other relevant information or warnings. In addition to the LCD, a speaker will be used to offer the customer a better shopping experience with sound signals in successful and unsuccessful product additions or removals. Finally, two load cells have been used to obtain weight data of the products inside the cart that will be compared with the products' ID. While doing so, the abuse prevention part weighs the cart with two load cells combined in parallel for physical stability and compares its results to the list in order to detect discrepancies.

From our perspective, using RFID techniques for the product identification system is affordable, reliable, and consistent. We can extract, analyze, and actuate data from the tag reader to accomplish the identification task.

A small size card with low power consumption, capable of reading and writing on tags operating at high frequency, is suitable for our system. Thus, we chose the RC522 RFID card because it is a low-power, small-sized card that can be used easily with many microcontroller platforms, capable of reading and writing on tags operating at 13.56 MHz, which is the NFC frequency. Since NFC modules work at this frequency, they can be used with NFC tags.

In our tests, we found that RC522 is able to read up to 5 cm when there is no obstacle in the way and it can read MIFARE tags and tags that use ISO 14443A protocol.

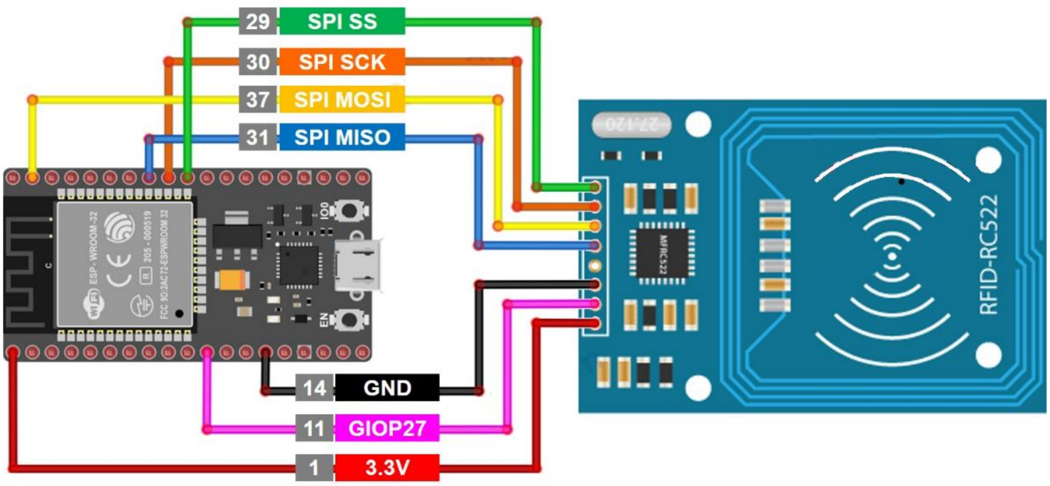


Figure 10: The physical connections for the RFID system

A load cell is a force transducer or force sensor. It is mainly used to measure weight, although it can be used to measure other forces such as torque, compression, and pressure. It is important to choose a load cell that not only fits the type or direction of load we want to measure but can handle the maximum expected load.

Considering the possibility that the load cell is being used in an environment containing corrosive gases, water, steam, etc., we should use a load cell rated as corrosion resistant. Bar type load cells are commonly used for industrial weighing applications. A force is applied to the free end of the sensor while one end of the rod is secured to a structure. The structure can be seen clearly in Figure 11.

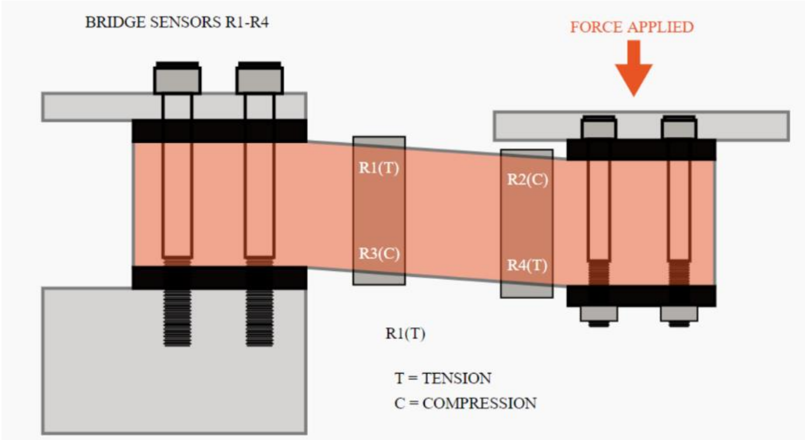


Figure 11: The physical structure of the load cell

The four strains placed on the upper and lower parts of the load cell cause the gage and the structure of the load cell to stretch or compress, depending on how strained it is when this force is applied or lifted. It is important to choose a load cell that not only fits the type or direction of load we want to measure but can handle the maximum expected load. This straight bar load cell that we use can translate up to 10kg of pressure (force) into an electrical signal, which is more than enough for the purposes of the smart shopping cart. Nevertheless, only one of these load cells do not offer enough stability to the basket with only one support point. To solve this problem, two load cells are used in parallel, in which case the output becomes their measurements averaged since they are simple voltage division circuits. With two support points, the basket becomes firm and stable.

The HX711 load cell amplifier is used to get measurable data out from a load cell and strain gauge. The card converts the analog weight value detected in the load cell into digital data and transfers it to our microprocessor. Pin diagram that shows connections between ESP32, HX711 load cell amplifier and load cell can be seen in Figure 12.

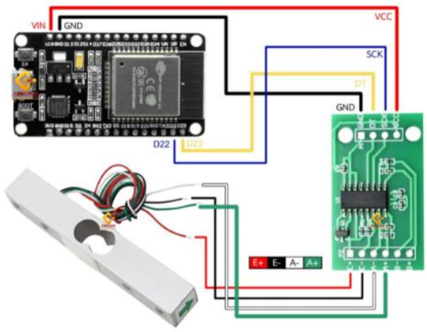


Figure 12: The physical connections of the abuse prevention system

In the light of all the given information, the physical structure of this system consists of two parts, the load cells under the basket and the rest of the components soldered on a pertinax. The resulting pieces on the final product are as given in Figure 13.

Figure 13: The physical connections of the Product ID & Abuse Prevention System

A flowchart that shows how the data coming from sensors are processed inside MCU and outputs are generated can be seen in Figure 14.

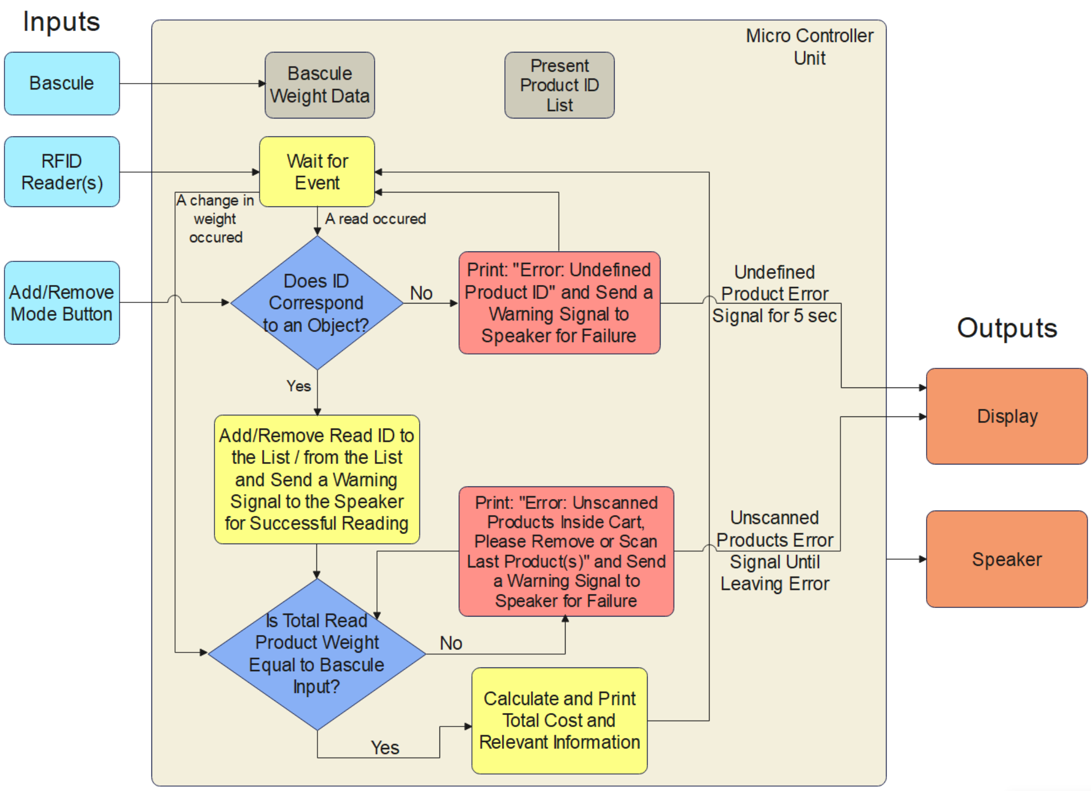


Figure 14: The flowchart of the abuse prevention system

After the customer completes their shopping, they go away from the shelves and to a place where they will complete the payment. Since the customer is now away from the products, the chance of making an RFID reader read other products instead of the products taken out of the basket is eliminated. For the customer to proceed to the payment stage, the customer must take the products out of the basket one by one and have them read by the RFID reader. When a product is removed from the basket, a weight change is detected by the system and if a product equivalent to this weight is not read to the reader, the system gives a warning. In this way, the shopping is completed when all the products in the basket are removed and read. The working principles of product identification and abuse prevention systems are clearly shown in Figure 14. How the payment will be made is out of the scope of this project.

4. REQUIREMENTS

There are some main project-level requirements to be satisfied as given below.

- Following the customer in both the aisles and the corners
- Moving in a controlled manner without any jittery movements
- Identifying the products placed on the cart without any false identifications
- Avoiding collisions from all sides by detecting them and maneuvering
- Being self-contained
- Preventing theft
- Being able to carry 2 kg of product
- Identifying 10 different kinds of products
- Being less than 200 dollars to produce

And with these project-level requirements, the system-level requirements are set as follows

- Customer detection system should frequently update the detected customer position, which quantitatively should have a frequency of at least 2.5-3 Hz
- Cart control system should drive the motors smoothly with no abrupt movements

- Product identification system should only detect objects inside the cart
- Product identification system should always detect objects scanned
- Product identification system should always distinguish between different products
- Abuse prevention system should detect fraudulent activities, which broadly encompasses scanning a product and putting another in the cart or putting nothing at all, as well as not scanning a product but putting one in the cart
- Collision avoidance system should frequently update its readings of distance data, which quantitatively should have a frequency of at least 5-6 Hz
- The systems should not outsource tasks, the cart should be able to handle itself
- The motors should be powerful enough to carry the weight

5. DESIGN MODIFICATIONS

The methods used in the systems have been cemented in the critical design review report, hence they are still implemented as follows

- Custom image detection with a camera for the customer detection system,
- An RFID reader with tags on the products, as well as using the load cell for the product identification and abuse prevention system,
- For the cart control system, using the detected coordinates of the customer and controlling motors to direct the cart
- HC-SR04 ultrasonic sensors for the collision avoidance system.

Since the design proposed in the critical design review report, some minor changes had to be made in the cart to reach the final product. The main differences are as follows

- The 18650 batteries were not giving stable power to Raspberry Pi, hence all the batteries are dedicated to the other parts and a power bank is added to the cart, which only powers the Raspberry Pi 4B.
- The customer position data was planned to be sent to the cart control system from the Raspberry Pi using UART, but this connection was also not stable since the cable for the UART had to cross all the carts to go from the chassis to the top of the basket.

Instead of the cabled UART solution, a Bluetooth connection is implemented between the Raspberry Pi and ESP32, since both are capable of this wireless standard.

- Instead of the proposed number 8, only 5 HC-SR04 sensors are used since 8 of them were unnecessarily crowding the basket and were adding not much sight over 5 sensors
- In the proposed design of the critical design review report, only one load cell was to be used for abuse prevention. This proved to be a mistake, since connecting the basket to only a small point from the middle resulted in an unstable cart with the basket swinging with the cart movement. This was also affecting the load cell readings. To solve this, the number of load cells is increased to 2 in the final product, hence now the cart is more stable with two support points.
- The final change was done to the steering system. The plan in the critical design review report was to use two DC motors in the back to thrust the cart and a servo motor at the front to steer it. Nevertheless, this endeavor was not successful, because the servo motor was not able to steer the cart enough and its 3D printed parts were not stable enough. To solve this issue, the cart is armed with 4 DC motors each connected to a wheel and providing a driving force. When the cart needs to steer, it gives different speeds to the sides and rotates in the desired direction.

6. COMPATIBILITY ANALYSIS OF SUB-BLOCKS

The interfaces in the systems and their description are as given in Table 4.

Table 4: The interfaces and their description

Source	Destination	Protocol	Description
Camera	Raspberry Pi	CSI	Provides visual data flow from the camera to the Raspberry Pi
Raspberry Pi	ESP32	Bluetooth	Sends coordinate information

			obtained from visual data to the ESP32 which controls the movement of the cart, both Raspberry Pi and ESP32 are capable of Bluetooth connection
RFID Reader	ESP32	SPI	Provides an interface to ESP32 to drive RFID Reader to read tags and get data from it
HC-SR04 Sensors	ESP32	UART	Carries distance information read by sensors to the ESP32
HX711 Load Cell	ESP32	UART	Converts analog weight information to digital and gives it to the ESP32
ESP32	Motor Driver	UART	Gives control signals to drive the rear motors
ESP32	Servo Motor	UART	Gives control signals to steer the cart from the front
ESP32	LCD Display	SPI	Outputs the product identification-related data to the display

7. TEST PROCEDURES AND RESULTS

After the final assembly of the cart, the systems are tested according to the requirements of the project. The results of these tests are tabulated as given in Table 7.

Table 7: The test plans and their relation to the requirements

System	Test Description	Test Result	Requirement	Is the requirement met?
Customer Detection	A customer will move around the screen and the accuracy of detection will be tested	The system is able to detect the customer at 3-4 FPS	Customer Detection should frequently update the detected Customer data	✓
Cart control system	The cart will follow a test customer and the movements of the cart will be noted	The cart follows the customer with appropriate speed and direction, and it can turn shelf corners when the customer changes shelves	The cart should follow the customer without abrupt movements	✓
Product Identification	The range and the accuracy of the RFID Reader will be tested using different	10 different products with various casings (plastic, metal, etc.) are tagged	The products should be detected without fail, and the objects	✓

	product casings (paper, metal-plastic, etc)	with sticky RFID tags and their tests showed that the detection range for the RFID reader is at most 5 cm, hence it never detects objects outside the cart	outside the cart should not be detected.	
Abuse Prevention	The customer will try to steal the object inside the cart without scanning it through the RFID reader to test if the system detects misuse.	In the tests, when a product is placed in the cart without scanning the buzzer turned on. In the normal course of events the buzzer was off, and when a scanned product was taken away without rescanning the buzzer again turned on.	The abuse prevention system should detect all fraudulent activities	✓
Collision Avoidance	Some scenarios will be applied to see if the cart sends the distance data continuously	The distance sensor data was updated by collision avoidance ESP32 with a frequency of around 10 Hz,	The collision avoidance system should frequently update its readings of distance data	✓

	and avoids colliding.	which was enough for the cart to avoid collisions. Nevertheless, the capabilities of these sensors are limited and when the obstacle is narrow like a gas pipe, it cannot detect it.		
Motor System	The cart will be loaded with a 2kg load to see if it can reach the desired maximum speed of 1.4m/s in a short time	In the tests, the motors were able to carry the fully loaded cart, even with excessive speed, in a way that the speed had to be limited in software. Hence, this requirement is clearly met.	The motors should be powerful enough to carry the weight	✓

8. LIST OF DELIVERABLES

For the final product, a list of deliverables is given as

- The smart shopping cart
- 5 Panasonic 18650 batteries
- 18650 battery charger
- 10 Sticky RFID tags (more can be bought by the shop owner)
- User Manual

Images for these items and the user manual are given in the Appendix section of this report.

9. RESOURCE MANAGEMENT

In the critical design review report, cost and power analyses were done for that time's design proposal. In this part, we will provide the resource management for the final product in terms of cost and power.

9.1 Cost Analysis

In Table 8, the cost analysis is provided for the final product. It can be seen that the design satisfies the 200 $ budget constraint for the project.

Table 8: The cost analysis for the smart shopping cart

	Cost ($)
Raspberry Pi 4B 4 GB	90
Xiaomi Mi 10000 MAh Power Bank	12
ESP32 x 3	19.5
HC-SR04 x 5	2.5
Camera	6
RFID reader	2
RFID tags	2
NCR18650b Battery x 5	15
18650 Battery Charger	6
DC motor x 4	4
Basket	3
Chassis x 2	6
Wheel x 4	2
Motor driver x 4	8
HX711 Load Cell x 2	6

Miscellaneous (Converters, 3D printed pieces, etc.)	10
Load	0
Total	**194**

The main change in the cost since the critical design review report is that now Raspberry Pi is powered by a power bank and the number of batteries supplying power to the rest of the cart is increased to 5. In addition, the number of DC motors is increased to 4 with cheaper motors, the servo motor is discarded, the number of motor drivers is increased to 4, and the number of ESP32 modules increased to three, where the collision avoidance system operates on its own module and sends data to the cart control ESP32 through UART. The number of load cells increased to 2 for basket stability and the number of HC-SR04 sensors dropped to 5 for convenience.

9.2 Power Distribution and Weight Analysis

In Figure 15, the power distribution diagram for the final product is given, where the power dissipation for all the parts is identified. It can be seen that the total power dissipation for the project is 41.75 W.

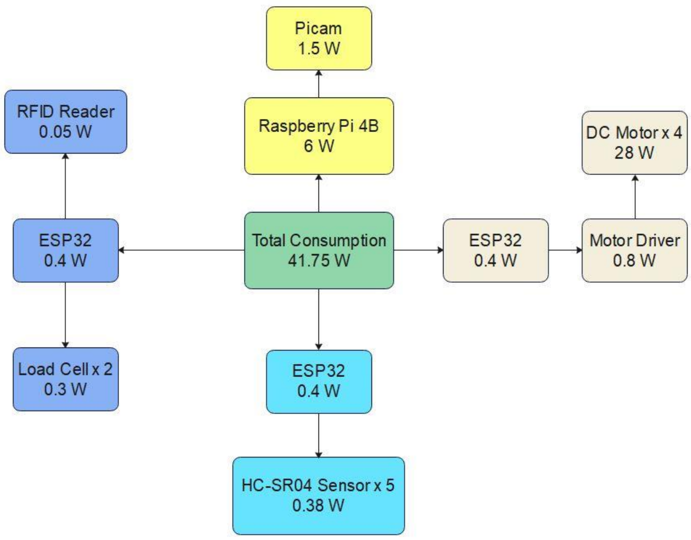


Figure 15: The power distribution diagram for the project

In the light of this power distribution diagram, the weight and power analysis for the components are given in Table 9.

Table 9: Weight and power consumption values of the project components

	Weight (g)	**Power Consumption (W)**
Raspberry Pi 4B	46	4.6
Xiaomi Mi 10000 MAh Power Bank	245	0
HC-SR04 x 5	42.5	0.38
ESP32 x 3	30.9	1.2
Camera	3	1.5
RFID reader	70	0.05
NCR18650b Battery x 5	242.5	0
DC motor x 4	60	28
Basket	150	0
Chassis x 2	200	0
Wheel x 4	36	0
Motor driver x 4	100	3.2
Load Cell x 2	40	0.3
Miscellaneous	100	1
Load	2000	0
Total	**3335**	**41.75**

10. CONCERNS ABOUT SAFETY AND IMPACT ON SOCIETY AND THE ENVIRONMENT

10.1 Safety Measures

The smart shopping cart design is a combination of electrical and mechanical parts working for specific objectives. Then, the main sources of hazards can be categorized into two groups as electrical and mechanical hazards. Electrical hazards pertaining to the smart shopping cart can be listed as

- Getting electrocuted by touching any part of the shopping cart
- Batteries bursting
- Any electrical component bursting with excessive voltage and/or current
- Any cable getting excessive current and catching fire, which may spread

In the design process of the smart shopping cart, these hazards have been in mind and to avoid electrocution all the current-carrying wires are chosen with insulating sheaths, and almost all the electrical components are kept in the bottom chassis to isolate them from the general customer space. The parts left on the basket such as the Raspberry Pi are either used with casings or their open connections are covered with isolating material. In order to solve the rest of the hazards, which are all about excessive current drawn in an arbitrary part, the batteries are isolated from the rest of the cart using DC/DC converters, so no component gets direct power from the batteries. Since DC/DC converters have limited output voltage and current, the rest of the components cannot draw excessive current. The only possible hazard, in this case, is the DC/DC converters failing in which case there would be no bursting due to excessive current.

The possible mechanical hazards in the operation of the smart chopping cart are the cart hitting someone when in motion or the customer getting their fingers pinched by a rotating part. For the first hazard, the weight and impact of the cart at maximum speed are tested and it is seen in the tests that even if the cart crashes into a customer head-on, the impact is mildly hurting the person without any injuries. This is because the cart is only weighing around 4 kg at full load. The second hazard only concerns the wheels, since they are the only rotating parts exposed. Nevertheless, it is abnormal for the customer to stick their finger to the wheel, since a customer only interacts with the cart when the cart is immobile, and when the wheels are turning it is hard to reach the wheels with fingers. Even if such an event occurs, the wheels are turned by small DC motors with a small torque, only enough to thrust the cart. Hence, the wheels stop turning when deliberately stuck by an object, which is also tested.

10.2 Societal Impact

In the case that this smart shopping cart's widespread adoption in shopping centers, some traffic control should be established for large numbers of carts operating together in the aisles so that the carts following their designated customers do not block the way for other customers or other smart shopping carts. Another issue with widespread adoption is that the job description of the cashiers would disappear since the smart shopping cart does their job anyway. With that said, still, there should be a person at the place of payment to check the customers when they rescan their products with the RFID reader so that the abuse prevention system is complemented with human intelligence. As in all the advancements in automation technology, the smart shopping cart rids people of a mundane physical labor, which is unhealthy in a way, since people are already sedentary in the modern world. However, this is a universal problem with a myriad of aspects and it is out of the scope of this product.

10.3 Environmental Impact

The modern world has many solutions to the problems of humanity, but this process has gravely affected the environment, where most of the damage is somewhat irreversible. Hence, any new product should be designed as environmentally friendly as possible with minimum energy dissipation. The smart shopping cart is designed in a minimalistic spirit to limit energy consumption, and it is possible to recycle all its components when their life cycle ends since they are electronic carts, plastic, acrylic, and wood. The cart only uses electric power and it has no byproducts in its operation. Hence, if a good habit of recycling is prevalent in the society where the cart is used, the cart would have a negligible carbon footprint.

11. CONCLUSION

In eight months, an ambiguous idea of a smart shopping cart has become a tangible reality. This smart shopping cart can follow its customer among all other people, it can identify and list the products to be bought and give the total price on its display, it can avoid collisions and detect theft attempts. It performs all of these in four systems, separated physically but working together and intertwined. All these functionalities are possible thanks to the advancements in electrical and electronics engineering since all the work is done by electrical power and electronic components.

The customer detection phase is made possible with a train custom image detection model running on a Raspberry Pi armed with a Picam for live capturing, where the model recognizes the logo of the company on the back of the customer and follows the logo. This system obtains the coordinates of the customer in the video frames and sends them to the ESP32 that controls the motors through Bluetooth.

The product identification and abuse prevention system uses RFID technology, which is purely an electrical and electronics engineering application in the field, where the products are identified by the sticky RFID tags on them. The abuse prevention system is implemented with two load cells, which are nothing but a Wheatstone-connected resistor bank that changes the output current with the applied weight.

For avoiding collisions, the system uses HC-SR04 ultrasonic sensors for checking the closest obstacles around it. This technology uses sound waves to measure distances, where it uses the speed of the sound for converting the time difference to a length measure. Five such sensors are placed around the cart to avoid blind spots and have good coverage of the surrounding objects. The measured distances are sent to the cart control system using a UART connection.

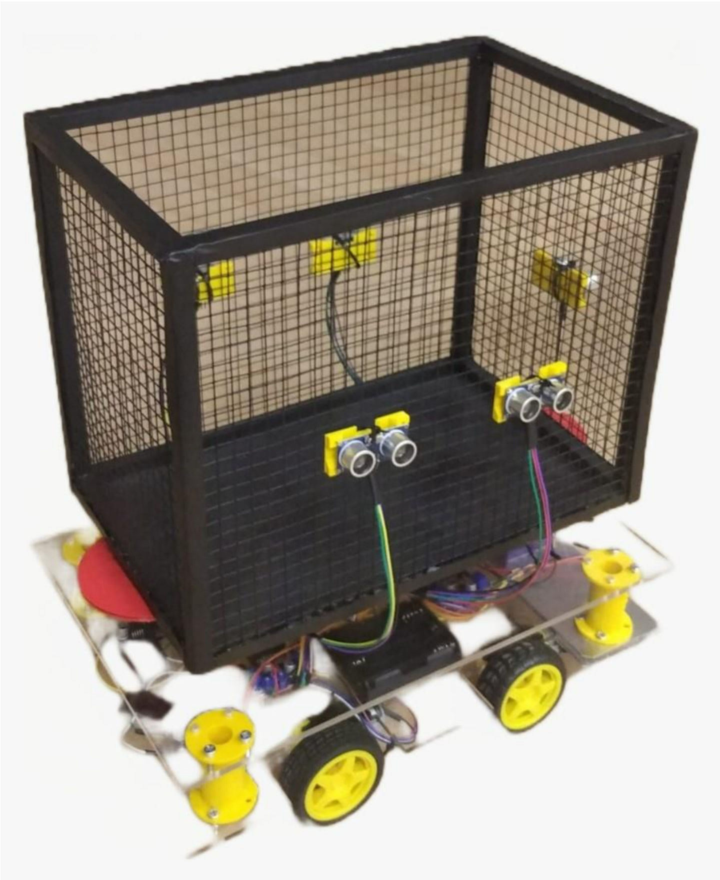
Finally, the cart control system is implemented with four L298N motor drivers and four DC motors. This system is the brain of the cart where the control algorithm is embedded in the ESP32 corresponding to this system. It takes all the necessary inputs from other systems and decides on a speed and direction for the cart. This system is heavily based on electrical engineering with motor drivers and mounted DC/DC converters, brushed DC motors, and communication channels in both wired and wireless scenarios.

This smart shopping cart is in essence a concept vehicle to elicit attention to this possible field and to attract investment in our company to make a realistically sized version of this cart to be actually used in shopping centers. It saves both time and money for the shop owners who buy and deploy it in their shops.

APPENDIX

The list of deliverables is showcased here for the shop owners who are thinking about a smart shopping cart purchase.

The Smart Shopping Cart



5 18650 Batteries

18650 Battery Charger

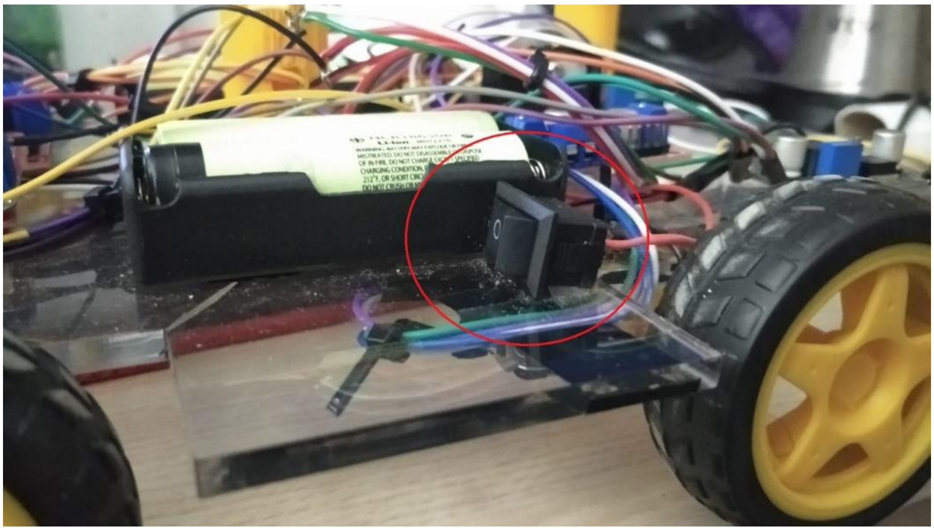
Sticky RFID Tags for the Products

User Manual

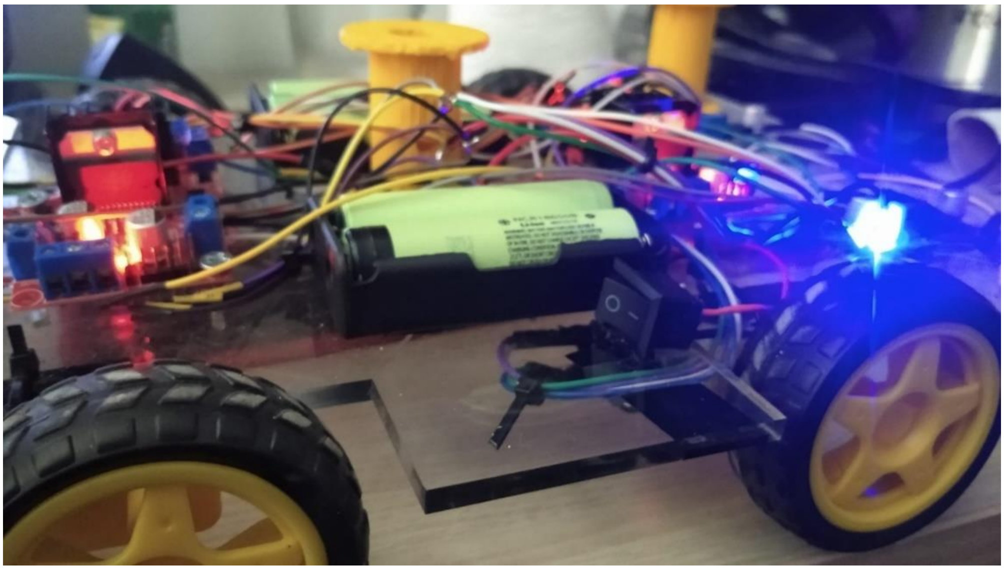
Booting up the cart:

1) First, press the button seen in the figure below to power the Raspberry Pi

2) Wait 1 minute so that the device can boot up its operating system
3) Now locate the switch seen in the figure below and turn it on



4) Now, the lights of the ESP-32 and DC/DC voltage converters should be on like the figure below



Caution: If the lights are not on, then first check the connections of the batteries. Make sure that they are mounted correctly and there is no disconnection between batteries and battery mount. If the lights are still not on, then charge up the batteries and try again.

5) If the lights are on, the Raspberry Pi will automatically connect to the ESP-32 via Bluetooth. Congratulations, smart shopping cart is now ready to operate.

Operation:

To properly operate the cart, tie up the belt with the symbol around the customer. After that, the smart shopping cart will follow the customer inside the market. For best operation, try not to move too abruptly.

Shopping:

During shopping, please make sure that you hold the items near the RFID sensor so that the products can be recognized. If the product is put inside without being identified by the system first, then misuse or abuse has happened and the system will give a loud alarm to notify the shop authorities. If the customer wants to cancel a registered product from the cart so that it does not turn on the alarm, they can scan it again to the RFID reader, this cancels the purchase. When the shopping experience is finished, hold the items you bought into the RFID sensor again so that system can recognize all the items again. If an item is taken out without the RFID sensor recognizing it first, then the system will give a loud alarm since abuse is detected.