ELP305: Design and Systems Laboratory

Experiment #3: Add communication sub-systems, protocols between Mule-bots to enhance functionality

Team B

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Authors

	Name	Contact	Responsibility	Entry Number
Lead Coordinator	Shauryasikt Jena	ee1180500@iitd.ac.in	Organizing task distribution	2018EE10500
Activity Coordinator(s) Specifications : electrical	Anubhav Dubey	ee3180529@iitd.ac.in	Elec Specs	2018EE30529
	Shresth Mehta	ee3180564@iitd.ac.in	Elec Specs	2018EE30564
Activity Coordinator(s) Specifications : Mechanical	Sakshi Bhandari	mt6180792@iitd.ac.in	Mech Specs	2018MT60792
	Ayush Srivastava	mt1180747@iitd.ac.in	Mech Specs	2018MT10747
Activity Coordinator Requirements	Ishita Hans	ee3180546@iitd.ac.in	Requirements 1	2018EE30546
	Aditi Rai	mt1180736@iitd.ac.in	Requirements 1	2018MT10736
	Kartikeya Rai	mt6180811@iitd.ac.in	Requirements 1	2018MT60811
Activity Coordinator Design	Siddhaant Priyam	ee3180565@iitd.ac.in	Design 1	2018EE30565
	Adarsh Jain	ee3180525@iitd.ac.in	Design 1	2018EE30525
	Silky Singh	mt1180769@iitd.ac.in	Design 1	2018MT10769
	Kartik Agrawal	ee1180472@iitd.ac.in	Design 1	2018EE10472
	Digvendra Singh Tomar	ee3180539@iitd.ac.in	Design 1	2018EE30539
Activity Coordinator Documentation	Sharut Gupta	mt6170250@iitd.ac.in	Docs 1	2017MT60250
	Hetvi Jethwani	mt1180754@iitd.ac.in	Docs 1	2018MT10754
	Palak Jain	mt1170742@iitd.ac.in	Docs 1	2017MT10742
	Amogh Agrawal	ee1180441@iitd.ac.in	Docs 1	2018EE10441
	Anchit Tandon	mt1170751@iitd.ac.in	Docs 1	2017MT10772

	Name	Contact	Responsibility	Entry Number
Activity Coordinator Design + Doc	Uddharsh Kotahwala	mt1180771@iitd.ac.in	Des + Docs 1	2018MT10771
	Mrinal Thakar	ee3180921@iitd.ac.in	Des + Docs 1	2018EE30921
	Khushi Pathak	mt6180783@iitd.ac.in	Des + Docs 1	2018MT60783
	Aryan Agarwal	mt1180744@iitd.ac.in	Des + Docs 1	2018MT10744
	Ritvik Ajaria	mt1180766@iitd.ac.in	Des + Docs 1	2018MT10766
Activity Coordinator Requirements	Aniket Shetty	ee1180443@iitd.ac.in	Requirements 2	2018EE10443
	Mridul Ahuja	mt1180626@iitd.ac.in	Requirements 2	2018MT10626
	Himanshu Singh Yadav	mt1170731@iitd.ac.in	Requirements 2	2017MT10731
Activity Coordinator Design	Misha Mishra	ee3180624@iitd.ac.in	Design 2	2018EE30624
	Rachit Mittal	mt1180764@iitd.ac.in	Design 2	2018MT10764
	Bhumika Chopra	mt1180748@iitd.ac.in	Design 2	2018MT10748
	Kushagra Singh Saini	ee3180553@iitd.ac.in	Design 2	2018EE30553
	Kushal Gowda	ee1180304@iitd.ac.in	Design 2	2018EE10304
Activity Coordinator Documentation	Shradha Nandkishor Rathod	mt1170751@iitd.ac.in	Docs 2	2017MT10751
	Suhani Jain	ee1180507@iitd.ac.in	Docs 2	2018EE10507
	Ichha Rathod	mt1180755@iitd.ac.in	Docs 2	2018MT10755
	Mihir Kedia	mt1180227@iitd.ac.in	Docs 2	2018MT10227
	Utsav Singhal	mt6170788@iitd.ac.in	Docs 2	2017MT60788
Activity Coordinator Design + Doc	Shivang Seth	ee3180563@iitd.ac.in	Des + Docs 2	2018EE30563

	Name	Contact	Responsibility	Entry Number
	Kartikeya Badola	ee1180221@iitd.ac.in	Des + Docs 2	2018EE10221
	Shaurya Goel	mt6170784@iitd.ac.in	Des + Docs 2	2017MT60784
	Shubh Gupta	mt6170785@iitd.ac.in	Des + Docs 2	2017MT60785
	Tanishq Gupta	ee3180567@iitd.ac.in	Des + Docs 2	2018EE30567

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Contact for Queries	Siddhant Priyam
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Document Statistics

Text Stats

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Readability Indices

Flesch Kincaid Reading Ease	Flesch Kincaid Grade Level	Gunning Fog Score	SMOG Index	Coleman Liau Index	Automated Readability Index
57.2	8.2	9.7	8	11.8	6.4

DISCLAIMER

The incorporation of communication systems among the mule-bots has been merged into the previous document of creating mule-bots. The novel parts of this assignment stand out, though not too flashily, by being colored Navy.

1. Aim

To design a mule bot that can

- Intelligently follow its correspondingly marked customer in a supermarket
- Carry shopping load with unhindered mobility
- *Communicate with other bots for more efficient utilization of resources and streamlined functioning*

2. Requirements

A mule bot (robotic movable platform) has to be designed to help customers carry their shopping load around the mall. Groceries included, the maximum load it should carry is 40 kg.
It should follow the customer around on one floor, staying no closer than 0.5 meter away and no further than 2 meters away from their heels as customers walk around. It needs to be able to move horizontally and only on one floor, it cannot move up/down stairs (the lift can be used to move between floors).
The mule bot should be able to communicate with other fellow bots in the same store to efficiently allocate charging times among themselves, help guide disconnected fellow bots to their customers, aid bots that have exceeded their safe loading capacity. The communication should also enable malfunctioning bots to be swiftly replaced by a functional bot should the case arise.

2.1 Business Model

Considering an Indian target audience, the customers do not prefer to carry their own shopping carts even now. So it is more convenient to offer sell these bots to supermarket stores who can rent them to concerned customers for usage. Looking at how the stores might want these bots:

2.1.1 Cost Estimation

- The total construction is expected to require about **INR 20,000** from the design part, and something around INR 5000 for licensing of various software, GPS system acquiring etc.
- Including all these, the production cost can be estimated at **INR 25,000** and by adding a 10 or 15% margin, the market cost can be tagged as **INR 28500**.
- The initial cost has to be born by the supermarket, but can be eventually be recovered by charging customers for renting this service.
- The cost recovery period will depend on type of store. For eg: In a grocery store, people will tend to rent this more than in an apparel or stationery store. In an optimum model assuming a bot is used for around 4 hrs out of 12 (renting even **INR 60** per hour) is around 4-6 months.

2.1.2 Conception to Sales Time

- Beginning from the very idea of designing such system to being able to sell it, there is a large team having people from diverse background required
- Initial design and prototyping will require 5-6 weeks, focusing on real life obstacles. Then to test it, find a suitable audience for the service, and work upon feedback will take up further few weeks.
- After this, when the bulk production starts, assuming in the initial phase not much automated machinery is available, one bot will require at least 4 weeks to be complete

- Total market supply time becomes around 18-20 weeks or 4-5 months. The production speed can be boosted up if the sales requirement surge.

  There are many other practical considerations which will appear when we actually go through design and testing procedure. They can be brought up in later versions of improvement.

- These bots would attract more customers solely on their catchiness
- Each bot's daily charging would not cost more than 8 kWh even on busy days
- Customers will be relieved from pushing around the trolleys as the bots can smartly follow them
- Dynamic shopping data concerning the load weight can be viewed by the customers, to allow them better judgement of how much they can carry back home
- The maintenance costs can be covered by the service taxes levied on goods bought.

To this end, the following requirements are established keeping in mind the most effective and frugal methods to achieve them:

2.2 Mechanical Requirements

A qualitative analysis of functional expectations regarding motion to be realized, with approximations of quantitative analysis wherever required.

2.2.1 Load Bearing

The primary purpose of the bot is to act as a shopping cart. Expected deliverables:

- Working Limit : 40 kg
  Normal load bearing to function without any alerts
- Safety Limit: 60 kg
  Post working limits, text warning on the bot screen about heading towards overload. Motion will not be hindered.
- Maximum Limit: 75 kg *(25% over Safety Limit)*
  Post safety limit, motion will be stopped and alarm sounded to relieve some load.
  Accounting for lax/irresponsible customer practices, allow maximum load bearing capacity to this limit.

Note #1: The display should be able to screen live load weight as in digital balances, for the benefit of real-time judgements of customers.

2.2.2 Volume Analysis

Considering portability and movement from the perspective of customers shopping in narrow aisles, the following parameters can be justified:

- Cart (storage) dimensions: 2ft x 2ft x 2.5ft
- Bot dimensions: 3.5ft x 2ft x 3.5ft
  The extra dimensions are required to fit in all the electronics, and to provide a comfortable height for the customers to put their items in.

Note #2: The bot should have a placeholder to carry the load basket for convenient loading and discharge of shopping goods.
Note #3: By itself, the bot should be lightweight enough to be carried across levels by human effort *(<5 kg ideally)*.

2.2.3 Movement

The bot is required to move on one floor only, with omnidirectional motion capabilities. That can be realized via:

- 2-wheel drive: 2 rear wheels to be attached to high-torque motors.
  The rear wheels are attached to a single motor, which can rotate clockwise or counter-clockwise depending on the situation. This is similar on-road automobiles where the back wheels supply motion power and the front wheels are for providing direction. Here, the size of front and rear wheels is different to reduce the traction torque.

2.2.4 Speed

The bot has to move to match the pace of customers moving in a supermarket. In that range of movement we can work with:

- Normal speed: Variable around 0.5 m/s (1.8 km/h) while customers are strolling
- Maximum speed: 2 m/s to catch up with the customer after overcoming a previously unavoidable obstacle, or when the customer makes a beeline
- Braking: Can be encoded into the Raspberry device that controls the motor
- Turning: High-torque motors will be required, assisted by gears if the needs arise so

2.3 Electrical Requirements

A qualitative analysis of functional expectations regarding working principles to be realized keeping in mind the mechanical deliverables, with approximations of suitable quantitative analysis wherever required.

2.3.1 Navigation

The bot is supposed to closely follow its assigned customer in a confined supermarket environment, not more than 2 m away and trailing around 0.5 m from them. The bot must also avoid bumping into foreign structures and obstacles as much as possible. This can be resolved by:

- High-accuracy GPS + Bluetooth: This tracking system works best in the give range of the problem statement. This method has been executed successfully in popular VR games such as Pokémon Go etc.
- Proximity sensors: These can be attached on all sides to stray away from obstacles as soon as the slightest pressure is detected. Such sensors are important as the supermarket is a dynamic environment in terms of goods getting moved in addition to moving customers/fellow bots.
- RGB-D sensors: These can be installed to maintain a safe distance from their assigned customer due to associated depth sensors, and to have a sense of which direction to go in. These are also preferred over IR only sensors by having better functionality when subjected to sunlight, i.e., external environment. Primarily installed as backup should one of the above 2 methods fail so that the bot does not go out of commission until the required maintenance is delivered.

Furthermore, we are proceeding under the assumption that the bots are available to be rented from the supermarket and hence have affiliations to one particular store. For this:

- Map: The bot should be capable of being fed the layout of one particular environment in which it is to offer services. Also, this map feeding system should be updatable, protected by user PIN, in cases of transfer to another environment.
- Software: Raspberry Pi 4 has 2 GB RAM, capable to have enough memory to work on a preset map, control all the required sensors and the motors. In the worst case, 2 devices

might have to be used simultaneously for division of labor vis-a-vis navigation and motion. Moreover, its compactness makes it suitable for fitting in the final bot.

2.3.2 Security

The bots have to be secured as property of their owners, with temporary shift of ownership to customers who rent them. For this:

- RFID: RFID cards can be employed to unlock the bots from their charging stations in the market. This also facilitates easy transfer of ownership of each unique bot with time-series data collection for usage times.

2.3.3 Power Source

Since the bot is primarily an all-electronics based device, battery-enabled is the most convenient way to go. Battery requirements:

- Battery Capacity: 500 Wh, can last around 10-12 hours of continuous usage considering 9 hours of usage per day (over 24 hours) intermittently.
- Internal Cell Reserve: A 100 Wh capacity battery to function as emergency power for a discharged bot to be docked at the charger. Doubles up as a power bank.
- Battery Specs: Should be rechargeable at charging docks amounting to no more than 8 hours of charging time, with a battery life of 3 years in the worst case.

Note #4: We seek to emulate the battery models employed by Tesla Cars on a smaller scale suited to the problem statement. More details to follow in the design statement, may refer to Reference #5 for current purposes.

Moreover, even during activity the battery usage has to be optimized to conserve power. We can introduce standby mode when all the motors are inactive by turning off some sensors, preferably the tactile sensors as the bot does not face the risk of bumping into obstacles.

2.3.4 Display

An LED Display would be required to fit into one of the walls of the collapsible storage container to give the customer real-time updates on the weight being carried, remaining battery duration, alerts, etc. A complementary audio-based alarm system will also be required for the alerts via connected phone.
Note #5: A digital scale needs to be installed at the storage container base with its output integrated with the display.

2.3.5 Communication

The mule bots will need to communicate with each other, or be facilitated by a central global server, for more efficient allocation of tasks and resources as well as streamlining functioning by replacing sub-optimal performance by fully-functioning available bots at the earliest possible. The following listed causes provide an insight as to why communication is necessary:

- *Replace a fully charged bot in the charging lot by the least charged bot in usage*
- *A bot on the brink of being discharged, say <20% charge left, to be replaced by the bot with greatest battery charge percentage from the charging lot*
- *If a bot reached the load limit of 40kg, an available bot with greatest battery charge percentage can be deployed to aid it*
- *If a bot is facing system failure, say malfunctioning motors, an available bot with greatest battery charge percentage can be deployed to aid it*
- *If a bot gets disconnected via Bluetooth from its customer, it can be guided to the concerned customer via others*

3. Specifications

The following components are required in the current stage of design development. Note that these are subject to change as work progresses in the design statement.

3.1 Mechanical Specifications

Component	Description/Details	Quantity
Load Basket	HDPE Shopping Basket 100L (Detachable)	1
Platform	Medium Density Fiber (MDF) Board ~1/4"	3
Motor	24V, 144 RPM, 90W	1
Rear Wheels	Swivel Cast 4"	2
Front Wheels	Swivel Cast 2"	2

3.2 Electrical Specifications

Device/Component	Model/Rating/Value	Quantity
High Accuracy GPS	Parallax PAM-7Q GPS Module	1
Bluetooth	HC-05 Bluetooth Module	1
Motor Controller	L298N Module	1
Proximity sensors	LJ12A3-4-Z/BX Inductive Proximity Sensor	4
RGB-D Sensors	OV2640 Binocular Camera	1
Software Controller	Raspberry Pi 4 Model-B	1
RFID Reader	RC522 Module	1
Battery	12V 20800mAh Li ion (Rechargeable)	2
Reserve Cell	7.4V 6600mAh Li ion (Rechargeable)	2
Charging Dock	12V Lithium-Ion Battery Charger	1
Display	HD44780 Displays	1
Weight Sensor	HX711 weight sensor	1
Weight Reader	RPi Load Cell (60 kg capacity)	1
Microcontroller Wi-Fi Modules	**Raspberry Pi Wi-Fi Wireless Adapter/Dongle 802.11 n/g/b**	**1**

4. Mockup

The following diagrams are the isometric view and left-hand side view of the designed mule bot. *Kindly note that this is subject to change with the inception of design.*

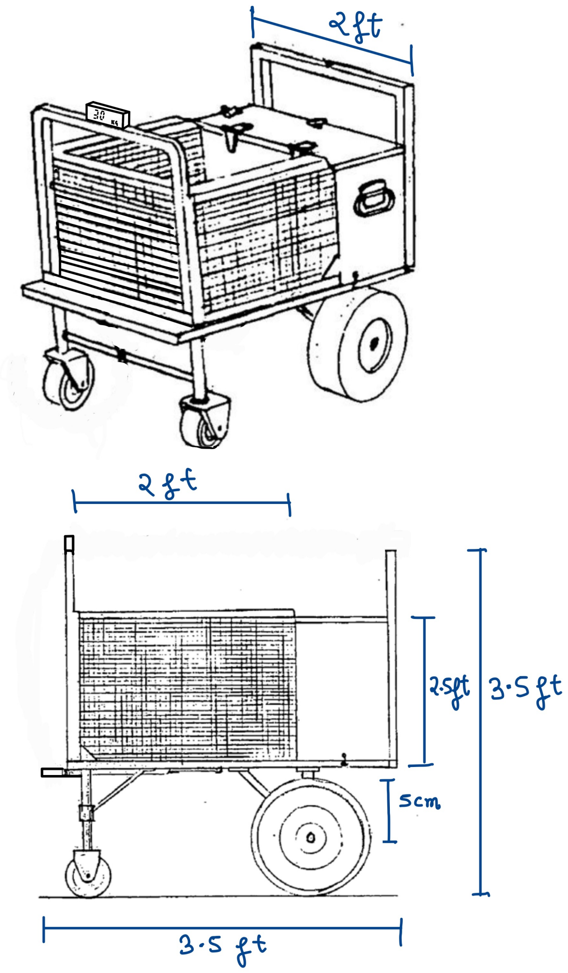


Fig 4.1: Isometric View and Left View (top to bottom)

5. Design

5.1 CAD/Assembly

The following image is the 3-D diagram of the designed mule bot.

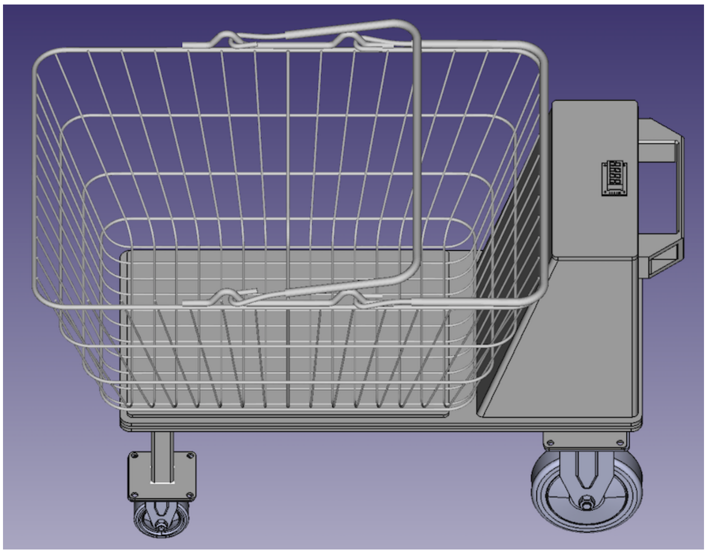


Fig 5.1.1: Layered Top View

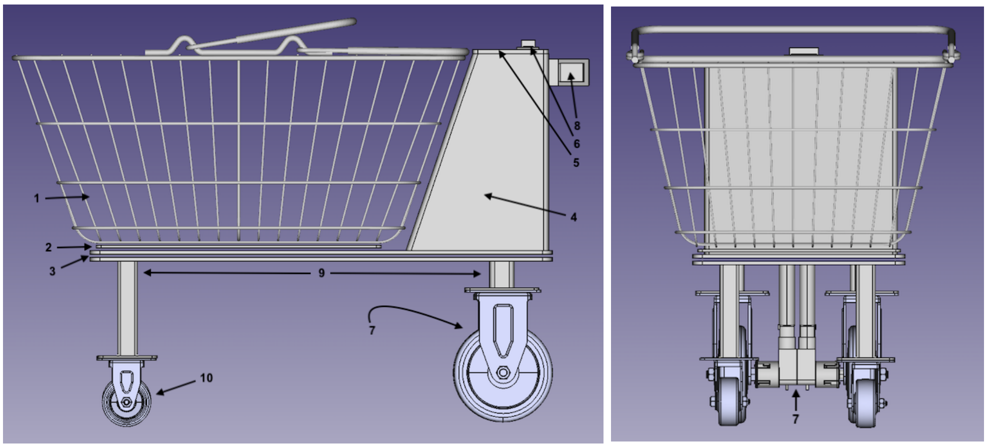


Fig 5.1.2: Side View and Front View (L to R)

The components of the mule bot are detailed as follows:

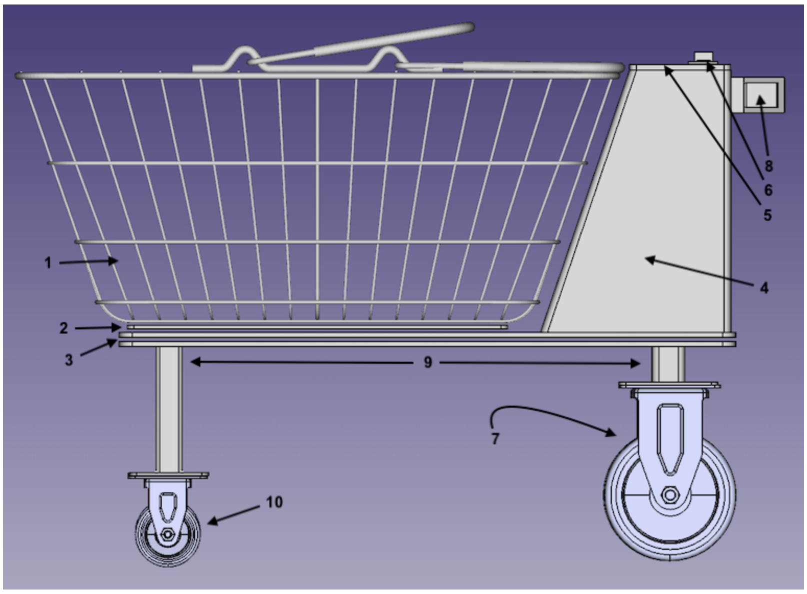


Fig 5.1.3: Component Labels

Label 1 - Basket and its handles
The shopping baskets already existing in the mart can be loaded onto the bot, avoiding redundancy by building new load carriers for the bots. The basket can be docked onto the weighing plate following which the customer may begin shopping.

Label 2 - Weighing Plate
The plate just below the basket is the weighing plate which will weigh the contents of the basket and display it on the weight display (Label 6). Weighing plate is kept as a separate layer to avoid any unnecessary weight on the PCB.

Label 3 - The 2 Base Plates
These are metal plates between which the PCB will be placed, protected by springs from the weighing plate to smoothen the rate of loading on sensitive circuitry. The proximity sensors are attached on all sensors for keeping track of surroundings and the RGB-D sensor is attached in the front edge-center to gauge the distance from the customer and decide the course of motion accordingly via the RPi logic controlling the motors.

Label 4 - Instrument Box
The Instrument Box houses the modules for GPS, Bluetooth and Motor Controller as well as the Raspberry Pi 4 Model-B for processing. It also houses the battery, with connections for charging via a port and cable. The battery is connected from the charger PCB, and is connected to the PCB that directs logic flow to the RPi which simultaneously takes input from the Bluetooth and GPS modules. The RPi, then in turn, commands the motor controller module to execute the necessary motor functions.

Label 5 - Instrument Box Lid
It's the top covering of the instrument box over which is placed the weight display (Label 6).

Label 6 - 4-Digit 7-Segment Weight Display in Green and Red
It will display the weight measured by the weighing plate.

Label 7 - Rear Castor Wheels (diameter-100 mm) and the Motor Assembly
We need the functionality of varying speeds between the rear wheels so as to change direction. Thus, the motor assembly comprised of a pair of motors to allow different speeds, motor shafts and motor support pipes through which the wires travel down from the instrument box to the motors. The wheels are fit by a swivel cast to allow 360^{o} motion for changing direction.

Label 8 - Push Handle
Although the mule bot is automated, we attached a small push handle which might come handy to maneuver the bot manually in case of unforeseen limitations on functioning.

Label 9 - Wheel Support Pipes
They connect the front wheels and rear wheel assemblies to rest of the bot/cart.

Label 10 - Front Castor Wheels (diameter-50 mm)
The front wheels of the mule bot. These will not have motors attached to them.

Following images are the images of the mule bot from other viewing angles.

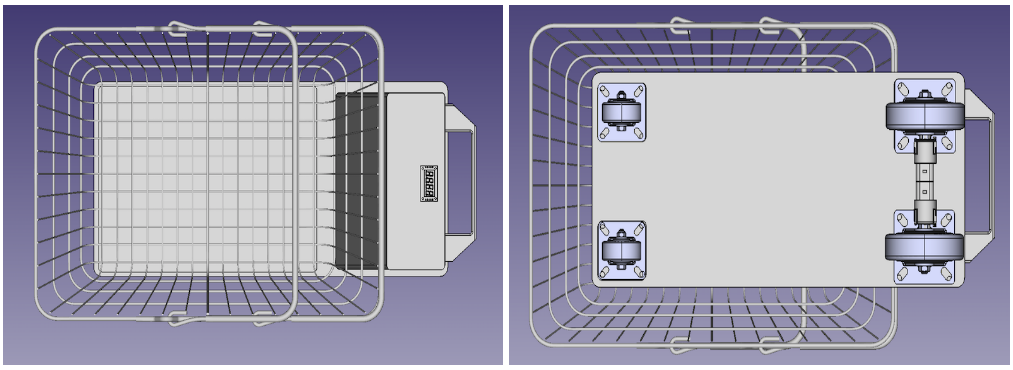


Fig 5.1.4: Top View and Bottom View (L to R)

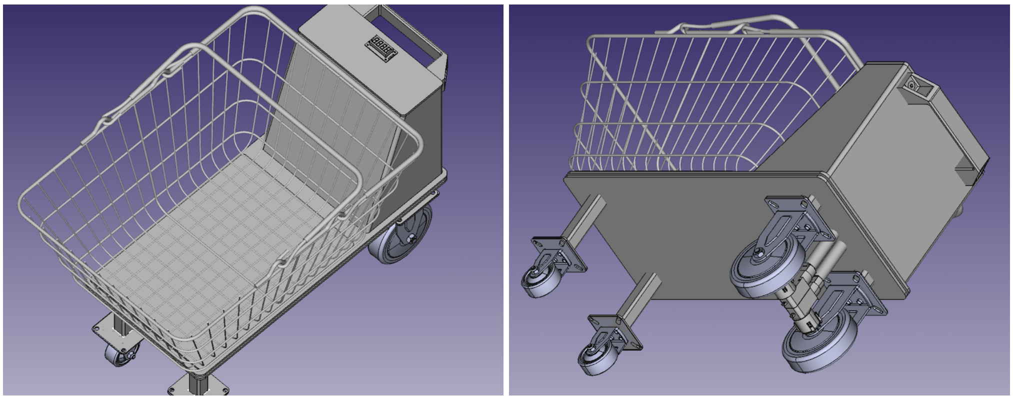


Fig 5.1.5: Isometric Views of the Mule Bot

5.2 PCB

The next step in realizing our design is etching it on a printed circuit board (PCB). We prefer PCBs over other methods to drive and support the circuit because of the ease in scalability and building.

We use KiCAD to do the PCB design. For each component of the schematic we define a footprint, i.e., the dimensions of the corresponding "real-life" variant of the component, along with the placement of pads to allow for soldering of component to PCB. Once these are set according to market-availability of the corresponding parts, we arrange these blocks on the PCB.

The Bluetooth and HX711 sensors are mounted on the PCB through pins, while the Raspberry Pi is mounted separately and connected through a 2x20 cable. The LM298 (voltage regulator) is also mounted separately connected through power and data cable headers from the PCB. The camera port is present on the Raspberry Pi itself and hence is not placed on the PCB.

Overvoltage protection is done through a crowbar circuit, which operates by putting a short circuit (low resistance) path across the 12 V and the 7.2 V voltage output. We have also used a fuse for over current protection. The PCB also contains the surface mount LED, which lights up when the battery is discharged.

Layered view of all PCB layers

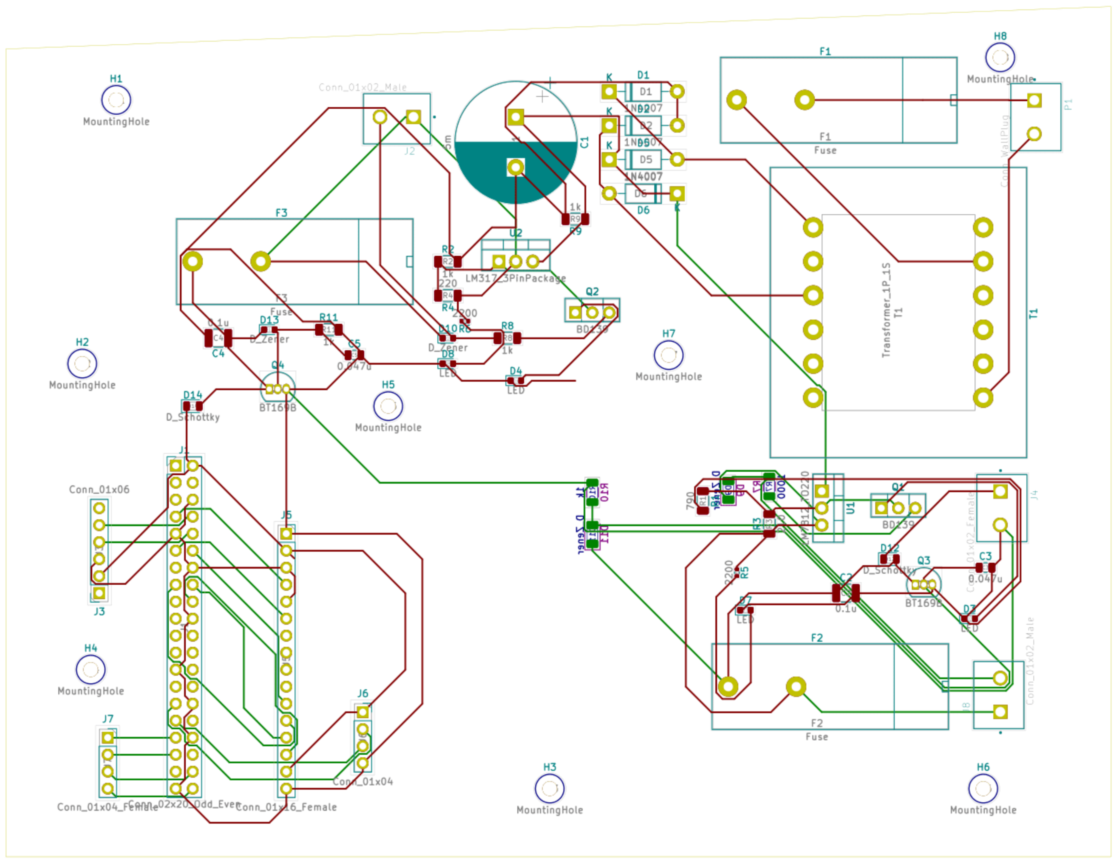


Fig 5.2: PCB Layers

5.3 Charger

There are 2 charger circuits designed for the 2 different batteries used in the mule bot. Both take input power from the AC mains, and convert it to required DC voltage.

5.3.1 Requirements:

- **Input**: 230V AC mains (10% tolerance)
- **Output**: 12V DC supply and 7.4 V DC supply to the batteries (within 5% voltage tolerance) & (no change in operation for temperature ranging 10^{O}C to 80^{O}C)
- Same box of adapter can home the 2 circuits, having different output lines, with indication
- Standard Size, size of the range 2 in x 2 in x 4 in with LED indicator
- A 3-pin standard plug, connected to adapter, connecting to the charging jack
- The power will be transferred through the battery caps connected to the adapter via jack

5.3.2 Working:

- **Step Down Transformer:** Coupled inductor transformer is used to bring down the voltage to circuit elements limit. 2200uF to 4.7uF inductors are employed for the purpose. It has approximately 250 turns on the enameled copper wire on the primary and 6 turns of the same on the secondary. SWG of the primary coil ranges between 36-40 while that of the secondary range between 26 and 28.
- **Ripple Filtration:** We have used the 4 diode bridge rectifier, in parallel with filtering capacitors, in order to convert it to almost DC of amplitude 14V.
- **Voltage Regulation: LM317 IC** is used for 7.4V generation. It operates for a wide input range, and provides 5V-30V output based on resistor-based potentiometer attached. **LM7812 IC** provides the constant 12V DC output. The provided output current is 1.5-2A which is sufficient to charge the battery.
- **Other Features:** There are then 2 LED's attached to indicate charging or battery full in green and orange colors respectively. This is jointly controlled by a BD139 transistor and a Zener diode, not allowing backflow from the battery.

The settling time for the power is around 5 ms, after which a reliable DC output is obtained.

5.4 Movement code

There are 2 parts in understanding the movement code algorithm. First we divide the 360 degree region around the bot into regions numbered from 0 to 3 (see figure) which are stored in the variable GPS.

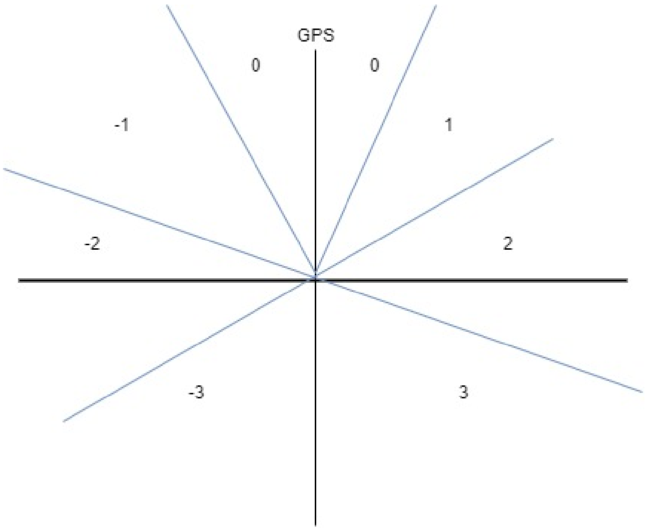


Fig 5.4.1: GPS Logic

Next, there are function indicator variables which output whether proximity sensors detect anything in those specified regions. The movement code utilizes the GPS and function variables to decide movement at each time step, as is explained in the next subsection. The RPM(Rotations per minute) of each wheel is assumed to be discrete in the range {0,1,2,3}, and the movement code either increases or decreases the RPM of each wheel separately at each step. Note that absolute values of RPM have an impact on transverse movement of the bot, while the difference in RPM decides the angle of the turn.

A list of all the variables and their meaning is as follows:

- GPS : A discrete value indicating the direction of displacement from the mule-bot to the cart
- dist : Distance from the user

There are 3 outputs from the movement code to the hardware :

- enforce(i,j) : This increases (or decreases if the value of i or j is negative) the RPM of the left wheel by j and the right wheel by i
- enforce(i, max = MAX) : This makes sure that the difference between the RPM of the left wheel and the right wheel is equal to i, while the maximum RPM allowed for either of the wheels is MAX.
- STOP (or enforce (-3,-3)) : This decreases the RPM of both wheels to 0. This situation is only encountered when there is no possible way for the bot to move without facing obstructions. The user is indicated through a buzzer that they must relocate the bot manually.

An exhaustive list of the function indicator variables are:

- left-front
- left-back
- right-front
- right-back
- front

5.4.1 Pseudo code

The sequential logic behind the pseudo code is as follows :

1. Slow down the bot if it is near the user
2. If the cart is in front of the bot, and there is no obstacle in the way, keep the bot moving as is or speed up the bot if it is far from the cart
3. If the cart is in front of the bot, but there is an obstacle in the way, slow down the bot and call the algorithm to avoid obstacles (by moving along the tangents)
4. If the cart is on the right side of the box, utilize the move right table to decide on the output. If the move table output is to STOP, then call the algorithm to avoid obstacles.
5. If the cart is on the left side of the box, utilize the move left table to decide on the output. If the move table output is to STOP, then call the algorithm to avoid obstacles.

The move right table is given as follows:

GPS	right-front	right-back	front	Output
1	1	1	1	STOP or enforce(-3,-3)
1	1	1	0	STOP or enforce(-3,-3)
1	1	0	1	STOP or enforce(-3,-3)
1	1	0	0	STOP or enforce(-3,-3)
1	0	1	1	enforce(1,max = 2)
1	0	1	0	enforce(1,max = 3)
1	0	0	1	enforce(1,max = 2)
1	0	0	0	enforce(1,max = 3)
2	1	1	1	STOP or enforce(-3,-3)
2	1	1	0	STOP or enforce(-3,-3)
2	1	0	1	STOP or enforce(-3,-3)
2	1	0	0	STOP or enforce(-3,-3)
2	0	1	1	enforce(2,max = 2)
2	0	1	0	enforce(2,max = 3)
2	0	1	1	enforce(2,max = 2)
2	0	0	0	enforce(2,max = 3)
3	1	1	1	STOP or enforce(-3,-3)
3	1	1	0	STOP or enforce(-3,-3)
3	1	0	1	STOP or enforce(-3,-3)
3	1	0	0	STOP or enforce(-3,-3)
3	0	1	1	enforce(2,max = 2)
3	0	1	0	enforce(2,max = 3)
3	0	1	1	enforce(3,max = 2)
3	0	0	0	enforce(3,max = 3)

The move left table is given as follows:

GPS	left-front	left-back	front	Output
-1	1	1	1	STOP or enforce(-3,-3)
-1	1	1	0	STOP or enforce(-3,-3)
-1	1	0	1	STOP or enforce(-3,-3)
-1	1	0	0	STOP or enforce(-3,-3)
-1	0	1	1	enforce(-1,max = 2)
-1	0	1	0	enforce(-1,max = 3)
-1	0	0	1	enforce(-1,max = 2)
-1	0	0	0	enforce(-1,max = 3)
-2	1	1	1	STOP or enforce(-3,-3)
-2	1	1	0	STOP or enforce(-3,-3)
-2	1	0	1	STOP or enforce(-3,-3)
-2	1	0	0	STOP or enforce(-3,-3)
-2	0	1	1	enforce(-2,max = 2)
-2	0	1	0	enforce(-2,max = 3)
-2	0	1	1	enforce(-2,max = 2)
-2	0	0	0	enforce(-2,max = 3)
-3	1	1	1	STOP or enforce(-3,-3)
-3	1	1	0	STOP or enforce(-3,-3)
-3	1	0	1	STOP or enforce(-3,-3)
-3	1	0	0	STOP or enforce(-3,-3)
-3	0	1	1	enforce(-2,max = 2)
-3	0	1	0	enforce(-2,max = 3)
-3	0	1	1	enforce(-3,max = 2)
-3	0	0	0	enforce(-3,max = 3)

5.4.2 Obstacle Avoidance Algorithm

In this section, we will use diagrams to explain the obstacle avoidance algorithm.

Key for the diagrams

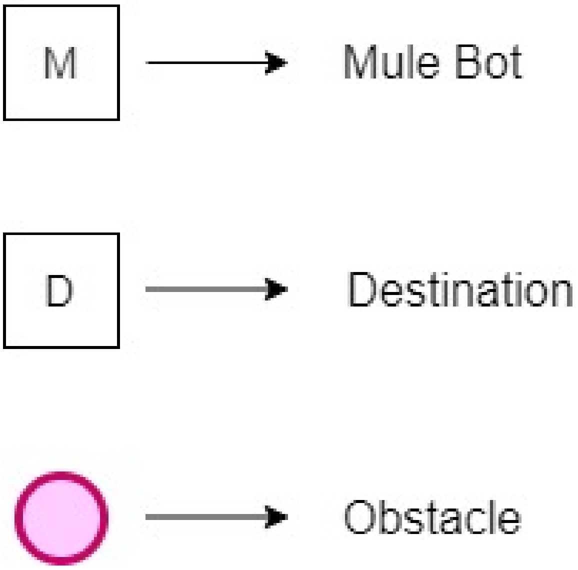


Fig 5.4.2: Key

The circle of free movement for the mule bot

The area covered by the green circle represents the area of free movement of the bot. The circumference of this circle is the locus of the point from which the perpendicular drawn to the axis of rotation is of maximum length.

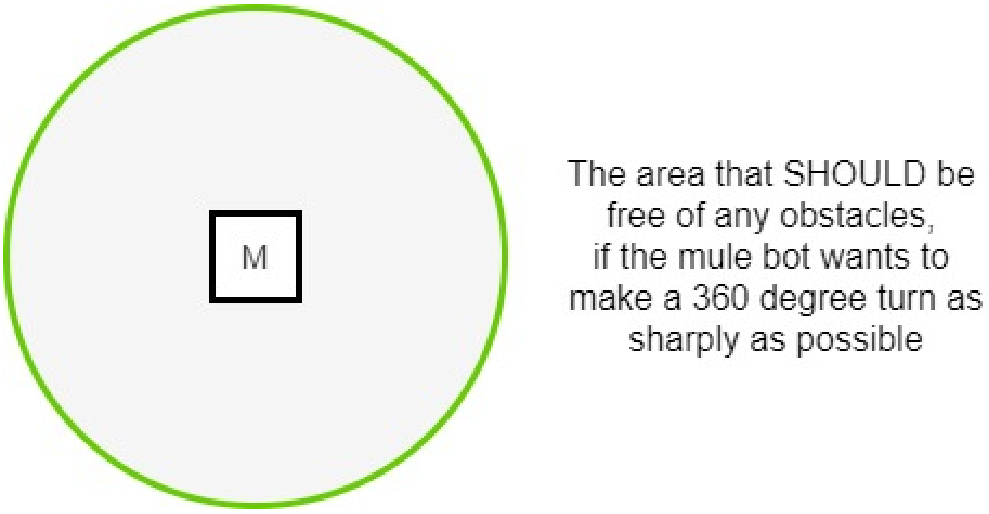

M
The area that SHOULD be free of any obstacles, if the mule bot wants to make a 360 degree turn as sharply as possible

Fig 5.4.3: Radius of free movement illustrated

Considering the bot of length of approximately 1m and a clearance distance of 25%, the radius of free movement would be approximately 62.5 cm as the bot is equipped with freely rotating swivel casts for attaching wheels.

Obstacle Avoidance scenario

Assume the following scenario where the obstacle lies on the straight line path from the bot to its destination.

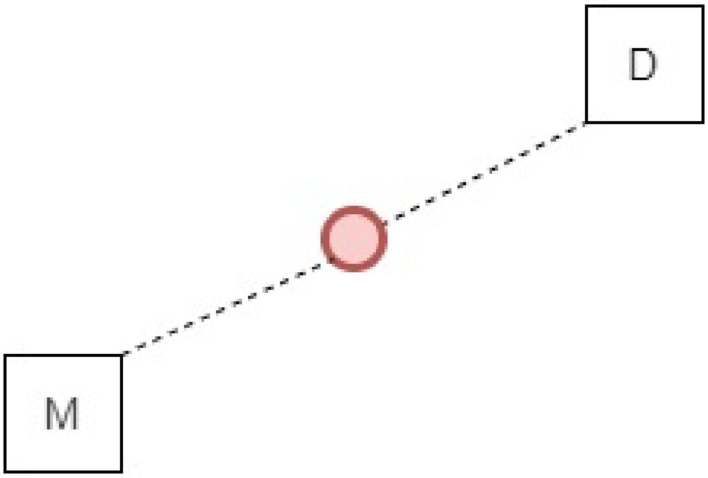


Fig 5.4.4: Mule bot(M), Obstacle, and Destination(D) in a line

Detection of the obstacle

As the bot senses an obstacle in its path, it switches its movement to a tangent from the point of contact of the obstacle and periphery of the circle of free movement of the mule bot.

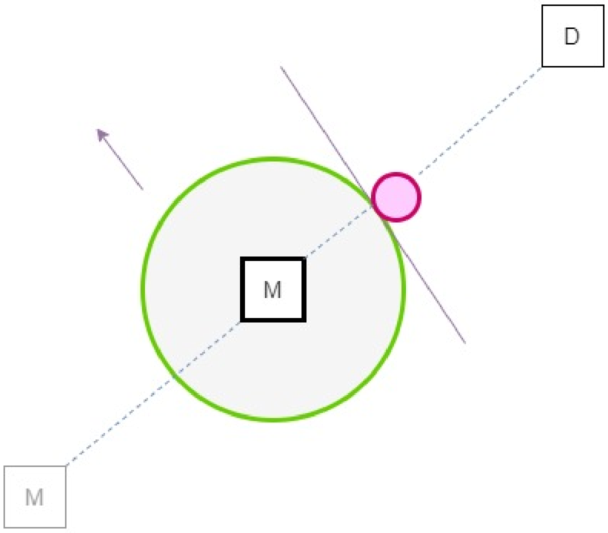


Fig 5.4.5: Planning a tangent

Adjusting velocity of the bot

The velocity of the mule bot is maintained such that it is parallel to the tangent at point of contact of the circle of free movement of the mule bot and the obstacle as shown in the following diagrams.

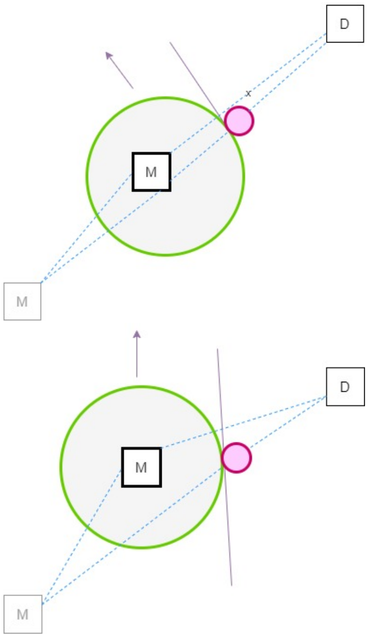


Fig 5.4.6

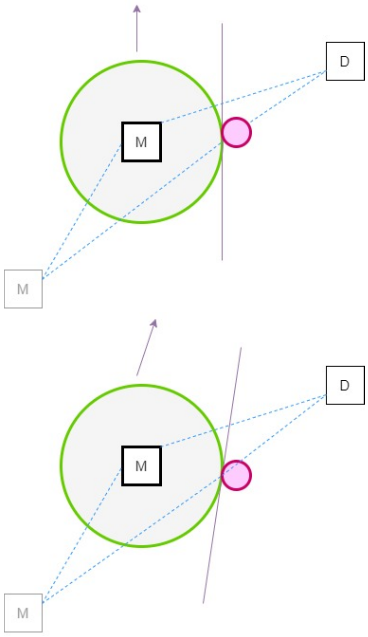


Fig 5.4.7

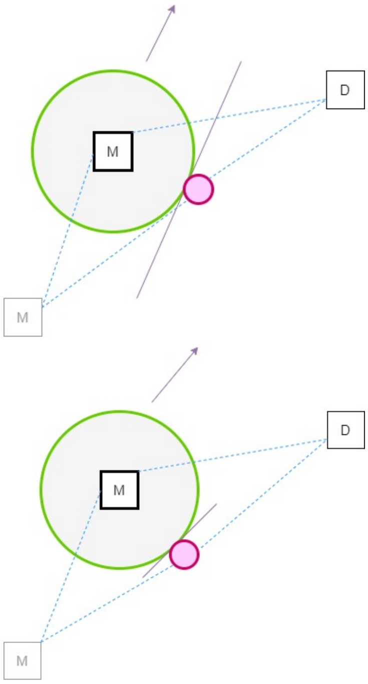


Fig 5.4.8

This way the mule bot is able to avoid the obstacle and create a new path to the destination.

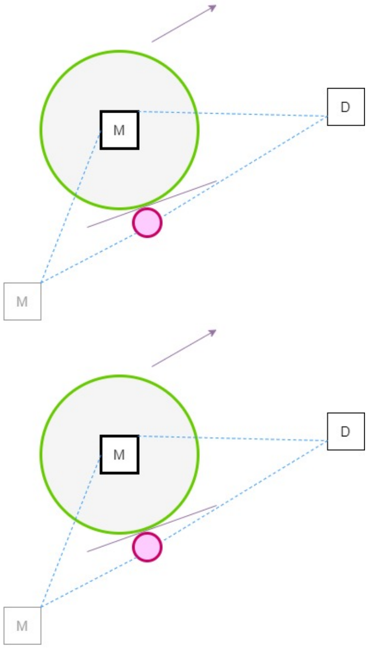


Fig 5.4.9: On the new path

Termination of the Obstacle Avoidance Algorithm

When the velocity of the bot is towards the destination, then the bot continues with the same velocity.

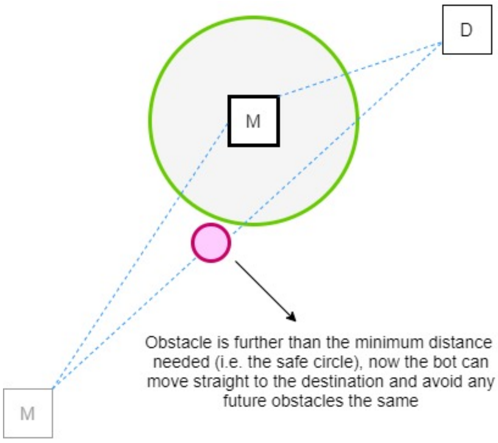

D
M
Obstacle is further than the minimum distance needed (i.e. the safe circle), now the bot can move straight to the destination and avoid any future obstacles the same
M

Fig 5.4.10: Straight to Destination(D)

Exception - The case of two obstacles.

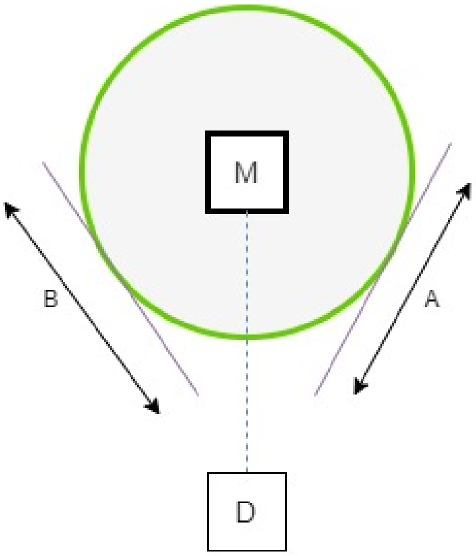


Fig 5.4.11: The Case of Exception-two obstacles

In this case, the current obstacle avoidance algorithm will result in the following 4 possibilities:

1. Towards the destination: If the tangential velocities computed using both the obstacles have a larger component towards the destination, the net result is that the mule gets stuck between both the obstacles as a result of both obstacles entering its circle of free movement.
2. Away from the destination: If the tangential velocities computed using both the obstacles have a larger component away from the destination, the net result is that the mule bot recedes along the path that it came from.
3. A enters the circle of free movement: If the tangential velocities at point A has the larger component away from the destination and the tangential velocity at point B has the larger component towards the destination, then the resultant velocity is towards A and A enters the circle of free movement of the bot.

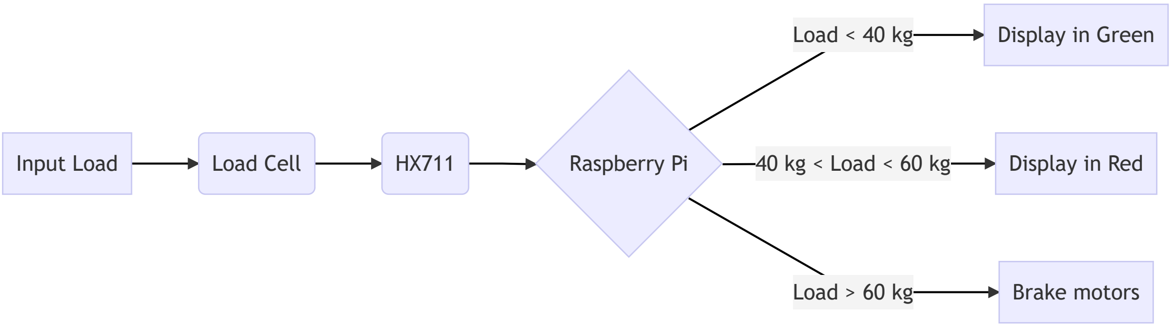
4. B enters the circle of free movement: Similar to 3, if B has the larger component away and A has it towards the destination, then the resultant velocity is towards B and B enters the circle of free movement of the bot.

The work-around suggested in this regard is to hard code the bot to not move along the paths calculated by the obstacle avoidance algorithm in either of the four cases mentioned above.

If there is no possible path to reach the destination, the bot signals the user that it is stuck.

5.5 Weight Sensing Mechanism

The weight reading process can be better understood by the following logic sequence:

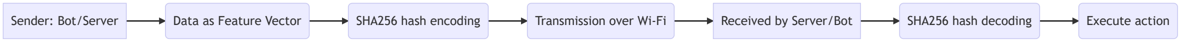


- The load cell reads the weight from the weighing plate as a low power signal, and sends the signal to HX711 for strengthening the signal into a high power signal.
- HX711 sends the high power signal into the RPi for weight computation.
- The RPi displays the weight read on the LCD as per the different conditions as shown in the flowchart.

5.6 Communication Systems

The communication is established via a central server, preferably a proper computer such as a desktop. The server is set up with a local Wi-Fi adapter for the Raspberry Pi's incorporated in each bot. In turn, the respective Wi-Fi Dongle(s) 802.11 n/g/b is set up with each bot's USB Type-A port in the Raspberry Pi so that all the bots are present as clients on the central server's WLAN.

Now all communication is via signal transmission over the Wi-Fi set up. The logic flow can be perceived better by the following flowchart:



As can be observed, we are employing SHA256 Hashing to compress data packets to smaller sizes for faster transmission over Wi-Fi. The feature vectors that are precursor to the hashing are elucidated in the following sections.

5.6.1 Bot Class

We employ a feature vector to convey information and send requests (Decimal system of integers 0-9 for each bit) from the bot to the server. The server is set up to receive information according to the following data format:

1. Bot Id (3 digit)

2. Timestamp of last data packet update with server (2400 hrs. Format with xx seconds => 6 digit)

3. Current working status (1-digit: Yes => 1, No => 0)

4. Bluetooth Connection Status (1-digit: Yes => 1, No => 0)

5. System Malfunction (1-digit: Yes => 1, No => 0)

6. GPS ID (5-digit N-S coordinate, 5-digit E-W coordinate; prefix 0=>North, East; prefix 1=> South, West) in metres from store center: XX.YY

7. Battery Charge Percentage (3-digit: 000-100)

8. Charging Status (1-digit: Yes => 1, No => 0)

9. Load weight (5-digit: XX.YYY in kilograms)

Note #6: The GPS is suitably calibrated for the concerned store so that the store-centre reads 00.00N, 00.00E, which is used as the origin for all subsequent GPS ID's of mule bots.

Eg: 07214365511014250020500930021530

- 072: Bot ID
- **143655: Time in 24 Hrs Format**
- 1: Working
- 1: Bluetooth connected
- 0: No system malfunction
- 14250: 42.50m south
- 02050: 20.50m east
- 093: 93% charge
- 0: not charging
- 21530: 21.530 kg load

5.6.2 Server Class

Simlar to the bot class of signals, we employ a feature vector to convey information and send requests (Decimal system of integers 0-9 for each bit) from the server to the concerned bot. The bots are set up so as to receive information according to the following data format:

- Timestamp (6-digit)
- Modifier (1 digit: 0=> carry on without change; 1=> accept following commands)
- Target bot ID (3-digit)
- Security code of store Wi-Fi (8- digit PIN passcode)
- Command code (2-digit)

01 --> Fully charged bot to replace least charged functional bot with given ID at GPS ID (3+10=13-digit)

02 --> Functional bot with <20% Charge to replace the most charged bot with given ID at charging slot (3-digit, following 10 digits are 0)

03 --> In case of overload, most charged available bot deployed to help bot with ID at GPS ID (3+10=13-digit)

04 --> Most charged available bot to replace malfunctioning bot with given ID at GPS ID (3+10=13-digit)

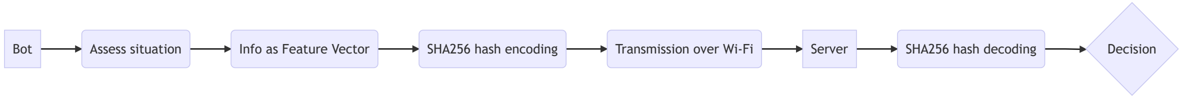
05 --> Reach location at given GPS ID (10-digit)

Given command codes cover, and cater to, all possible urgencies that may necessitate communication for the concerned issues as mentioned in the requirements.

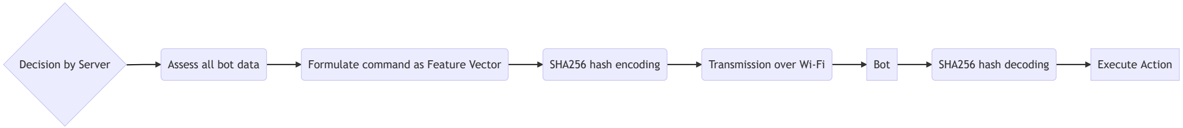
5.7 Comunication System Logic

The logic flows can be classified into 2 broad categories: bot-to-server signal, and server-to-bot signal. Their logic flows can be understood as follows:

1. Bot-to-Server Signal:



2. Server-to-Bot Signal:



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