Automated Serving Robot

CAPSTONE PROGRESS REPORT L19

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3 PROJECT BRIEFING

This progress report seeks to give a better insight into the process of designing, developing and implanting the Automated Serving Robot proposed by group L19. Looking at the project at a macro level, the project is progressing well and is mostly on schedule. Most of the preliminary design work has been completed and certified by the group and parts to build the robot are under order due to arrive soon. Since there have been minor issues on some of the design work amongst other delays, the group will not meet its ambitious timeline, of having all bronze level millstones completed by the end of December, that was set in the proposal but is still on track and will be ready to do a presentation in January.

4 TECHNICAL APPROACH

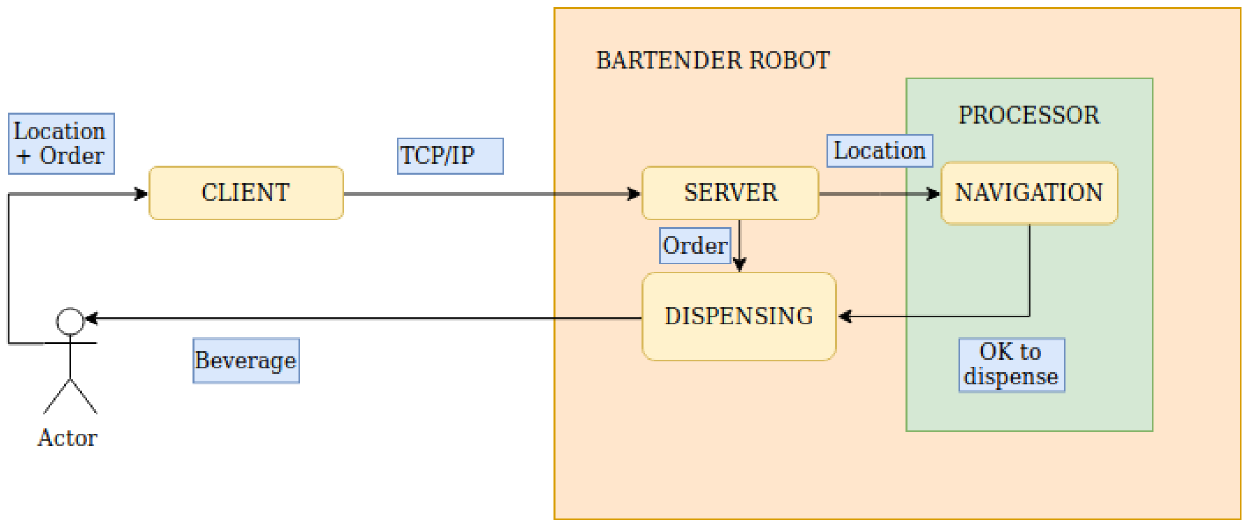

Figure 1: System Block Diagram

4.1 Locomotion

4.1.1 Tractive Motor

The workload for the tractive motor must be determined to select an appropriate part. The starting requirement is the power supply for the motor will be a 12 V battery, thus all motors must be 12 V. This constraint was applied due to part availability. For simplicity, no-loss condition is assumed in the following calculation.

4.1.1.1 Torque Specification Calculator

The goal is to find the torque requirement to select the appropriate electric motor.

$$\tau = F \cdot r$$

Starting first with the required force, *F*, the equation is as follows.

$$F = m \cdot a$$

To determine the mass, *m*, generous estimation is applied based upon initial component. The mass is set to 100 kg, which is more than double the major weight contributor of initial component. The acceleration, *a*, is set to 0.6 to mimic the average human walking acceleration (Teknomo, 2002).

Table 1 - Initial Component Weight

Item	Weight
12 V Battery	30 kg (UPG)
Liquid – three 2L bottles	6 kg

$$\begin{aligned} F &= 100\ kg \cdot 0.6\ \frac{m}{s^2} \\ &= 60\ N \end{aligned}$$

The wheel radius, *r*, is estimated at 100 mm by picking one of the mobility scooter wheel size. Thus, the torque required from the motor, τ, is estimated at 6 Nm:

$$\begin{aligned} \tau &= 60\ kg \cdot \frac{m}{s^2} \cdot 0.1\ m \\ &= 6\ Nm \end{aligned}$$

To conclude, an appropriate tractive motor will operate at 12 V and has a rated torque of 3 Nm . The final number is divided by two as the robot will be driven by two tractive motors.

Table 2 - Torque Conversion Table

Value	Unit
3	Nm
≈ 31	$kg \cdot cm$

4.1.1.2 Speed Specification Calculations

The motor will need to have a speed specification alongside the torque specification. Ideally, the robot will have the average walking speed of a human.

For calculating pedestrian clearance intervals for traffic signals, 0.9 $\frac{m}{s}$ is recommended in a 2006 study (Kay Fitzpatrick, 2006). This recommended speed considers the slower older pedestrians. For the prototype, accuracy has a higher emphasis than speed so the target for speed is set to this recommended number.

The torque calculation assumes 100 mm for the radius of the wheel. Thus, the speed specification is calculated as follow.

$$\begin{aligned} RPM &= \frac{60 \cdot Speed}{Diameter \cdot\ \pi} \\ &= \frac{60 \cdot \left(0.9 \frac{m}{s}\right)}{(0.2\ m) \cdot\ \pi} \\ &= 85.94\ RPM \end{aligned}$$

To conclude, an appropriate tractive motor will operate at 12 V and be able to provides a minimum rated speed of approximately 86 RPM.

4.1.1.3 Component Selection: Tractive Motor

From previous calculations, the tractive motor must operate at 12 V, provides a load RPM at least 86 RPM and a load torque of at least 3 Nm. Small deviation is acceptable.

Item	Rated Torque (Nm)	Rated Speed	Voltage (VDC)	Current (A)	Price	Store	Link	Comment
PN01007-100	3	100 RPM	12	6 (max)	US$128 /pair US$49 shipping = US$177	**Makermotor** (USA)	Link	USPS. Canada Post strike might affect shipping
JGB37-550	5.1	83 RPM	12	3 (load)	US$52 /pair US$30 shipping = US$82	**AliExpress** - grodd tech Store (China)	Link	Delivery time less than 30 days. 83 RPM is less than calculated 86 RPM.
Same	Same	Same	Same	Same	US$23 /pair US$16 shipping = US$39	**Open Impulse** (Hong Kong)	Link	Storefront looks sketchy
RA-AFSL-30AN-35	≈3.3	≈84	12	6 (load) 62 (max)	US$151 /pair US$35 shipping = US$186	**Surplus Center** (USA)	Link	UPS Ground @ US$35. Will get hit with additional fees.

4.1.2 Motor Driver

The motor driver is an interface between the controller and the motor. The controller operates at low voltage (5 V or less) while the motor, at peak, can go up to 10-20 A. If there is not a motor driver in between to regulate this higher current, then the controller would be burnt out as a result.

4.1.2.1 Component Selection: Motor Driver

Motor driver selection depends on the tractive motor's specification. Based upon our motor selection, a motor driver needs to operate continuously of at least 12 V and 6 A. Additionally, the motor driver should be able to handle a peak current of 20 A of the tractive motor.

For controls, the motor driver will support PWM signal to decrease energy losses and be easy to control. To support steering, the motor driver also needs to be bi-directional to allow tank steering implementation.

Item	Voltage Range (VDC)	Load Current (A)	Max Current (A)	Price	Store	Link	Comment
RB-Cyt-153	5-30	10	30 (10 secs)	CA$31	Robotshop (Canada)	Link	Dual bi-directional
RB-Cyt-218	6-24	10	30 (10 secs)	CA$31	Robotshop (Canada)	Link	Dual bi-directional interfaced to Pi shield. Need to check compatibility and clearance.

4.1.3 Wheels

The wheels of the system will be required to properly support the weight of the robot, while allowing for proper freedom of movement, control, and applicability on multiple types of terrain, such as carpet or tile flooring. Using the load weight of 100kg assumed earlier, and assuming the structural goal of a balanced load (I.e. the center of gravity is in the middle of all 4 wheels) is achieved, the load on each wheel is approximately 25kg each.

4.1.3.1 Rear Driving Wheels

These are the wheels that will connect to the driving motors of the system. The motors for the system were selected using the assumption that the driving wheels they were attached to were 200mm in diameter. To ensure proper motor function, wheels should have diameters near to 200mm. Cost would also ideally be kept to a minimum.

Following these basic parameters, 8" FIRST Rubber Treaded Wheels from Robotshop were selected (Link). Composed of black polycarbonate with rubber treading, these wheels were rated safe for robots up to 120lbs (~54.4 kg) by the 2010 FIRST Robotics Competition (Competition Manual, 2010). Although this is less than the over assumption of 100kg used thus far, considerations were made for the high safety factors in the competition and the real final weight of this system, and the wheels were therefore deemed acceptable for the weight component.

4.1.3.2 Front Idle Wheels

These wheels are the idle wheels connected near the front of the robot. They should be able to rotate freely around their connection point to allow the robot to turn using the rear driving wheels, while still being able to support the weight of the system.

The Shepard Hardware 4-inch Swivel Plate Caster wheel from Amazon (Link) was selected for these specifications. Able to rotate 360 degrees around its connection point and support up to 250lbs (~113.4kg), this caster is ideal for the role.

4.2 Navigation

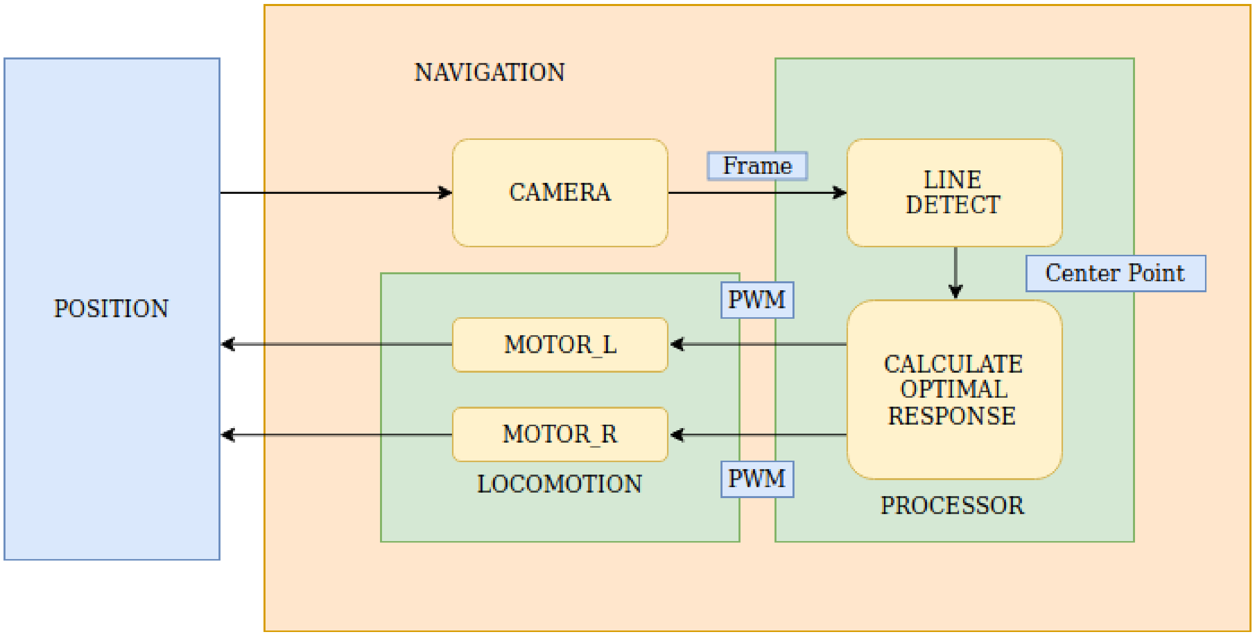

Figure 2: Navigation Block Diagram

4.2.1 Main Controller

The main controller of the system is a Raspberry Pi 3B+. This was chosen due to its powerful ability to work with image processing through the OpenCV library and its immediate availability. Due to the nature of the Raspberry Pi and it's embedded Linux operating system many tasks can be implemented quickly using libraries and a programming language common to all team members: Python. Early in the design process there were concerns about power consumption, however we determined that our power supply would be sufficient to power such a controller. If power becomes an issue it would be possible to port our code to a previous Pi revision and performance should not suffer.

	Zero /mA	Zero W /mA	A+ /mA	A /mA	B+ /mA	B /mA	Pi2B /mA	Pi3B /mA	Pi3B+ /mA
Idling	100	120	100	140	200	360	230	230	400
Loading LXDE	140	160	130	190	230	400	310	310	690
Watch 1080p Video	140	170	140	200	240	420	290	290	510
Shoot 1080p Video	240	230	230	320	330	480	350	350	520

Figure 3: Controller Current Usage based on Different States

4.2.2 Camera Module

The Raspberry Pi Foundation has created an add on camera module that is compatible with our main controller board. This camera can be integrated with OpenCV and will capture the line to follow as well as station related barcodes. This module was chosen because one was already available, and alternatives did not offer any significant advantages.

4.2.3 Navigation Subsystem

The navigation subsystem is encapsulated as a "Bot" object. This object handles connection to the camera, image processing, barcode detection and determination of output. The bot will pull commands from a thread safe command queue and attempt to fulfill the command. The bot contains an internal state machine that determines the course of action to take based on past events and current stimuli.

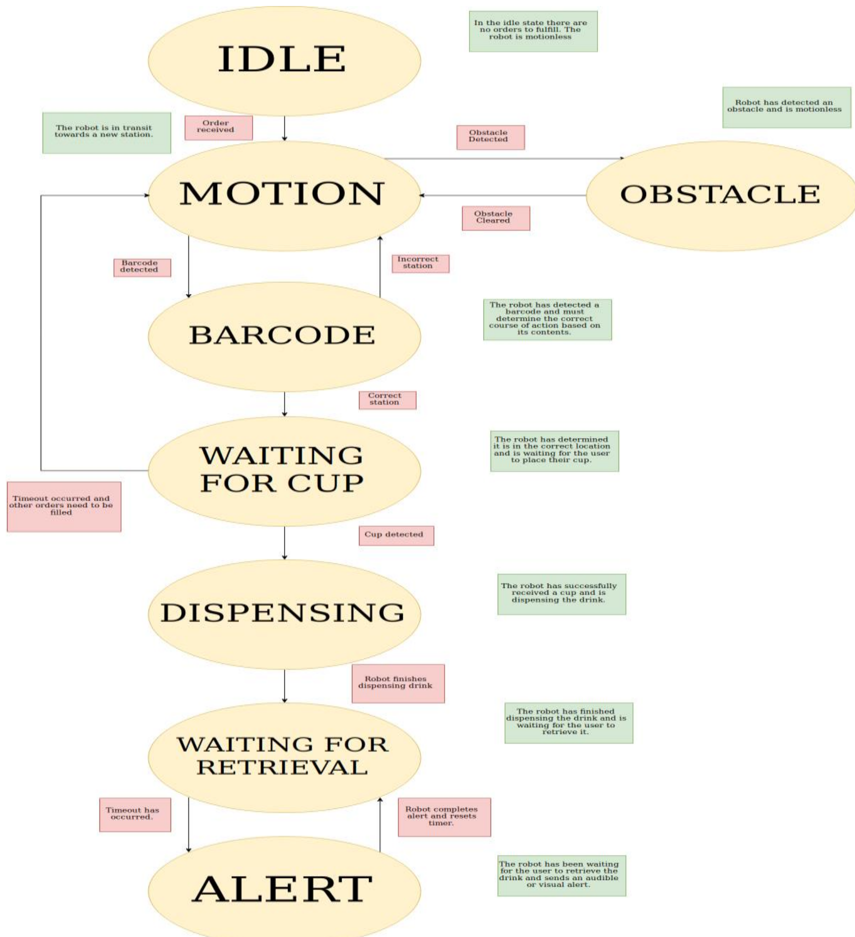

Figure 4: Finite State machine detailing the control flow of the main controller

4.3 Liquid Dispensing

4.3.1 Main Liquid Dispensing System

The liquid dispensing system design process was very much linear in nature. The first step considered was the actual pumping mechanism. There were two schools of thought, either to move the cup to where the desired drink would be or move the drinks to where the cup was. For the first methodology was almost immediately disregarded as it would add more complexity to the system and would take a lot more space and parts and increase the overall weight of the final product which we were trying to minimize. Once it was decided that the drinks would flow to wherever the cup was located, a decision had to be made on how to make the beverage flow. It was decided that peristaltic pumps would be used to facilitate beverage flow.

When sourcing the peristaltic pumps, cost, weight and size were all kept in mind to be minimized. Keeping in mind customer usability, originally, high power pumps were being considered but they lacked the fine control needed for the dispensing system. In the end, a cheaper and slower solution was obtained for practical demonstration purposes which will be used in conjunction with smaller sized cups, so demonstration can be achieved in a reasonable time frame.

Next the control system hardware for the system was designed. To reduce work on circuit development and minimizing the risk of failure a premade 4-channel relay was acquired, which could be controlled with a microcontroller, like the Raspberry Pi 3. It has a 15-20mA driver current, which would not drain the battery too much and can handle up to 10A at 30V DC, which is over-specified for the purposes of the project.

Next taking into consideration the advice of Dr. Li, a "smart" shut-off system was implemented. Using a liquid level sensor that is fed back into the control input of the relay, the risk of overflow was dramatically reduced if not eliminated outright. Another benefit that the sensor provides is that it removed the need to rely on a pre-timed dispensing process, instead making sure all cups are filled to the same level, after which the pumps cannot be activated. Further specification on the system design and software control algorithm can be found in the status section of the report.

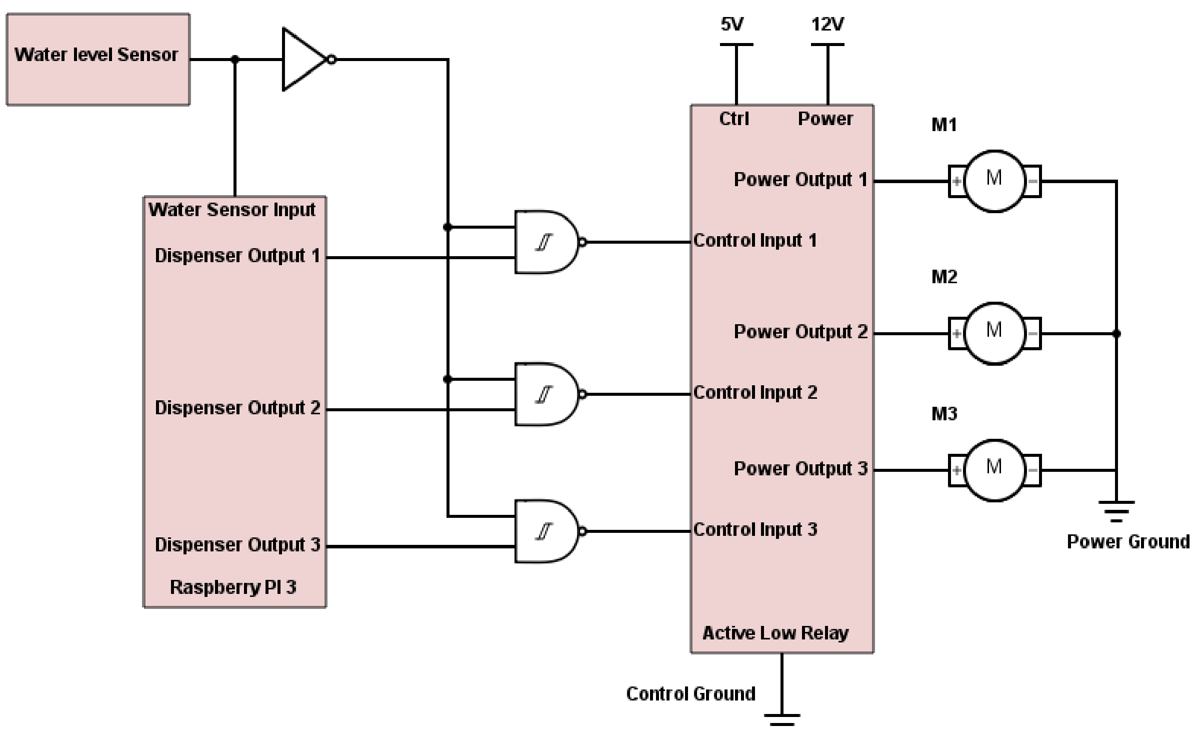

Figure 5: Dispenser System Schematic

4.3.2 Drink Elevator

A sub-system involved in serving drinks is the so-called drink elevator, which will be used to bring the drinks from the serving platform on top of the robot down into the robot interior, where the liquid dispensing will occur. The system is straight forward in nature, involving a reticulating ball screw connected to a repurposed drill motor. Both these components have been used in applications requiring over a hundred pounds of force and are therefore deemed adequate for the purpose intended here. The elevator will be structurally connected to outer shell of the robot and will be powered from a separate 18V drill battery, rated for 27Wh and controlled using a motor driver connected to the main CPU of the robot. The approximate travel time for the elevator will be less than 3 seconds, based on a motor speed of 1300rpm and a screw pitch of 4mm.

4.4 Structural Design

4.4.1 Structural Overview & Design Philosophy

The structural design of the robot focused on blending aesthetics with function. The goal was to create a robot that looked sleek and simple while also showing off its mechanical functions in a presentable manner. This will be achieved using a large steel garbage can cut open to demonstrate the interior mechanisms of the robot. This will also act as a support structure for parts of the dispensing system and the drink elevator. Below is a model of the assembled major mechanical parts, completed in Autodesk Inventor 2015/2017.

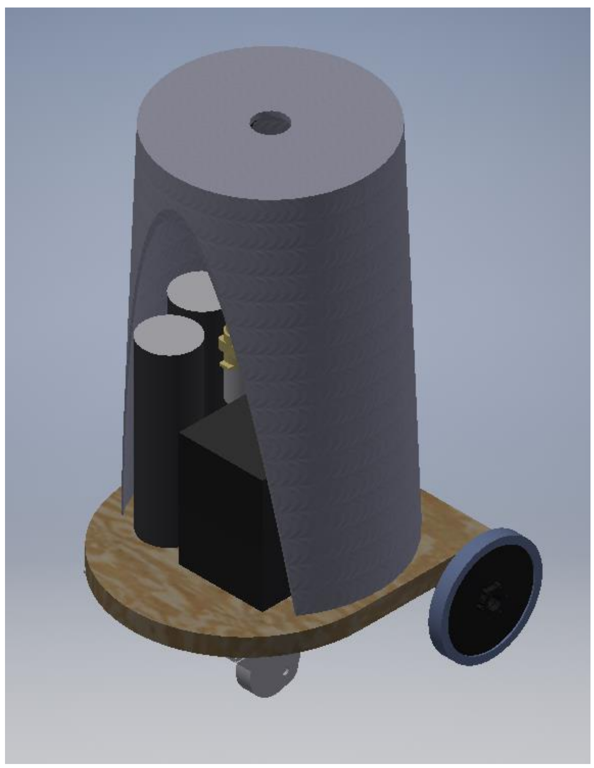

Figure 6: Visualization for the Final Robot (Subject to Change)

4.4.2 Integration with Propulsion System

A primary challenge to overcome involving the propulsion system was the physical mounting of the system as well as auxiliary points of contact with the ground. The propulsion system was chosen to be placed on the rear of the robot to allow for simple reverse and forward commands to each motor to determine the direction and speed of the system. Motor mounts were designed with the intent to bear >30% of the total robot weight with minimal deflection as a safety measure.

The material used for these mounts is 20-gauge galvanized sheet steel, chosen for its strength as well as its ready availability in the JHE machine shop. After considering the points of connection and torque enforced by the wheel being beside rather than underneath the robot, the final force used to ensure safety was 600N. The following simulation result demonstrates a deflection at the furthest end of the motor to be approximately 1mm, with actual deflection in the mount itself to be less than 1/10th of a millimeter.

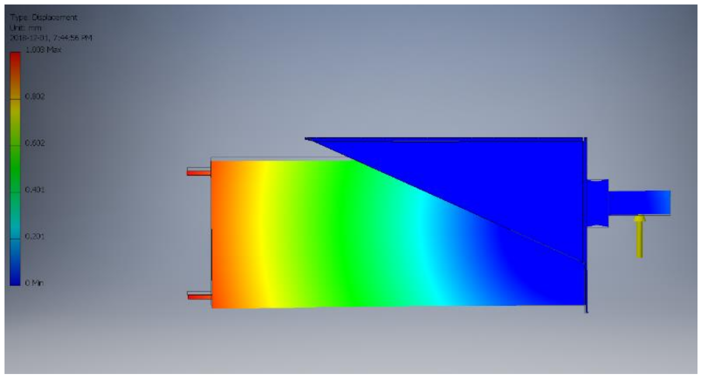

Figure 7: Deflection Simulation of the motor mounts

A final consideration was the center of mass of the robot and the possibility of tipping due to improper wheel placement. With a relatively small wheel base and large weight, tipping had to be considered a possibility. The center of mass was calculated by adding all relevant weights (barring smaller ones that could be ignored for practical purposes) and the following position was found:

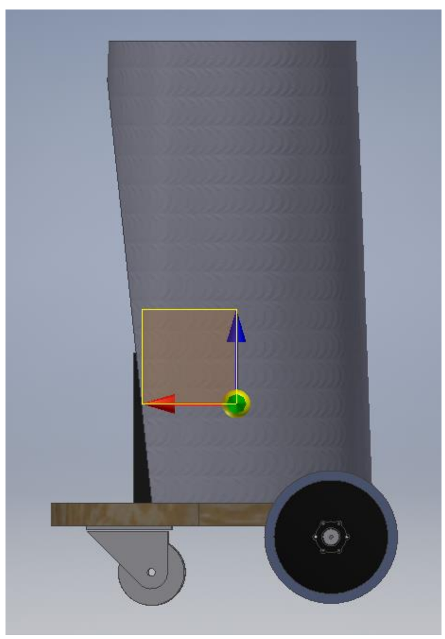

Figure 8: Side Visualization for the Final Robot (Subject to Change)

The relative position from the front wheels was 259.5mm above and 129.02mm behind them. Using the following free body diagram, the effect of stopping within 0.5s (aka 1.8m/s^2) was determined. Note that only the front stopping case is analyzed since the rear wheels are further from the CoM and their linear acceleration is much less than the case being considered.

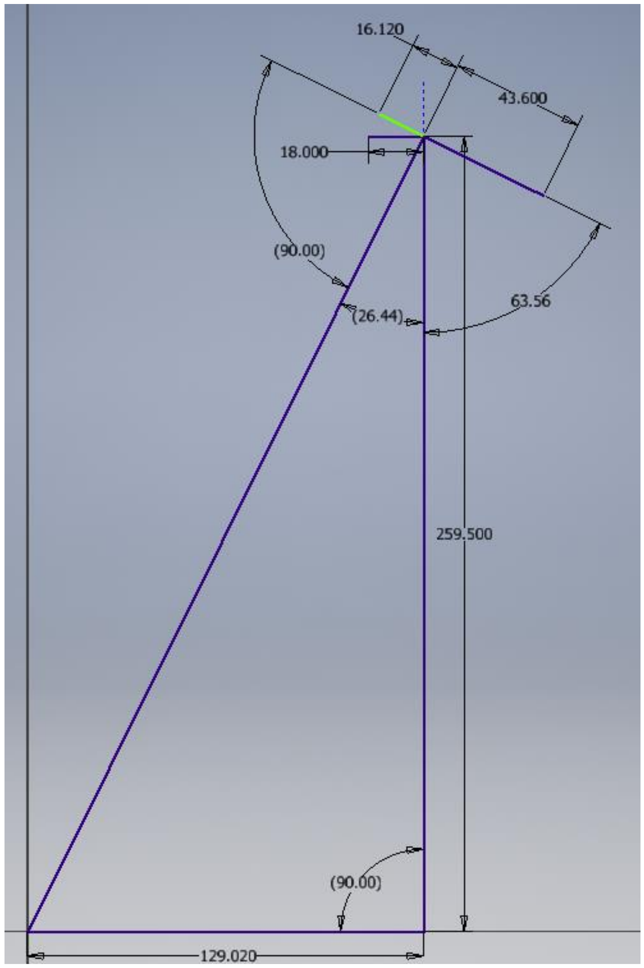

Figure 9: CoM Positioning

The main triangle represents the position of the CoM relative to the front axles in mm. The smaller lines radiating from the top of the triangle represent the accelerations acting on the CoM when stopping at a rate of 1.8m/s^2 (these values were multiplied by 10 to more clearly show their scale). As the diagram shows, the relative torque acceleration presented by linear acceleration of 1.8m/s^2 is much less than the 4.36m/s^2 presented by gravity. This leads to the conclusion that if the stopping speed is approximately 0.5s, the robot will not tip forward over its front wheels.

4.4.3 Integration with Navigation, Dispensing, & Control

Most components involved in control, dispensing, and navigation are lightweight and small enough to be placed wherever there is room on the robot. The motors involved in liquid dispensing will be placed along the shell of the robot and the drink containers themselves will be placed beside the battery on the base of the robot. Several navigation sensors such as the camera and ultrasonic sensors can be placed with little restriction around the robot to allow for optimal range and detection.

4.5 HMI

4.5.1 Client

The client program will connect to the raspberry pi server. Currently the ip and port parameters are saved to a text file and must be known in advance before using the program. Once connected the client will wait for the user to input a command. If a command is not recognized the program will prompt the user with a mention of the “help” command. There are currently 4 commands available to the client.

1. “Quit” will terminate the connection and exit the program
2. “Order <args>" will take the order the user inputs and pass it to the server. If no args are input the client program will prompt the user.
3. “Base” will have the robot return to the base station and ignore all orders.
4. “Help” will display a message listing these options.

4.5.2 Server

The server program begins once the controller boots up. The server will listen for connections and will currently only accept one at a time. If the server receives a valid “Order” or “Base” command, it will format it and place it on to the message queue, so the bot may process it. If it receives the quit command, it will terminate the connection. All interactions with client programs are saved to a logfile, “Server.log” along with timing information and error details if necessary.

5 LIST OF TASKS

5.1 LIQUID DISPENSING

For the liquid dispensing sub-system, the software to control the pumps needs to be written for the Raspberry Pi 3.

5.2 HUMAN MACHINE INTERFACE (HMI) SYSTEM

A final decision needs to be made on how the end user will interact with the bartending robot, either through a webserver or an Android/iPhone application. After that the software for that system needs to be written.

5.3 NAVIGATION

PID parameters need to be tuned for the final physical system. The main controller system needs to be connected to the locomotion subsystem. Silver and Gold milestones need to be researched and implemented.

5.4 STRUCTURAL

The large components of the system such as the baseplate and outer shell need to be manufactured and assembled. The smaller components must be prepped for mounting once the larger ones are done.

6 CURRENT STATUS

6.1 STRUCTURAL

The structural side of the system is almost entirely designed and only requires a few smaller mounting parts such as those for the Pi and the motor controllers. Most of the components required for the basic assembly (no outer shell or elevator) are ready for assembly or awaiting final manufacturing steps. Connective parts such as bolts and screws will be acquired over the winter holidays to ensure the basic assembly is ready for the mid-January demonstration.

6.2 LIQUID DISPENSING

Currently most of the parts for the liquid dispensing system have arrived. The only missing parts are easy to source and should be here within a week. The system has been fully designed as shown in the figure below and will be ready to be implemented into the housing soon. The code for controlling the system still needs to be written but a general algorithm has been planned and will be ready to implement after consulting with our microcontroller expert.

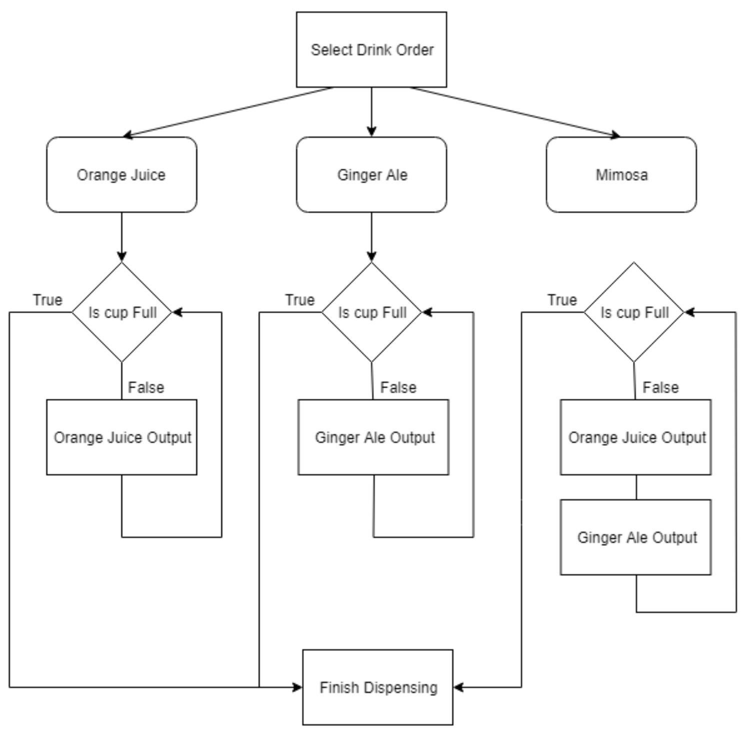

Figure 10: Basic Dispensing Algorithm

6.3 HUMAN MACHINE INTERFACE (HMI) SYSTEM

As of right now the bronze milestone has been met using a terminal-based client-server socket application. A user with the client-side application can communicate with the raspberry pi board and facilitate commands. Currently orders do not map to any physical GPIO output, this will be determined later. In the future this interaction will be orchestrated through a webpage or as a mobile application. The team will decide based on our technical strengths and the ease of use for the end user.

6.4 Navigation

The navigation system is currently in the early proof of concept stages. As there is currently no system built it is impossible to determine that the control software will function as designed. The software currently does not take any input or output from GPIO, the I/O is determined programmatically. The main programming logic is sound but will need to be debugged on a physical system.

6.5 Locomotion

The locomotion parts, motors and motor drivers, has been ordered. Vendor's poor communication and Canada Post strike had delayed the arrival of the parts.

7 PROBLEMS ENCOUNTERED

Few problems other than busy workloads and overestimating our timeline have been encountered. Some minor problems surrounding manufacturing of the motor mounts was encountered but assistance from the JHE machine shop quickly rectified the issue. In the future a more consistent application of time management skills will be used to properly prepare the timeline for delays and allow time for testing different subsystems.

8 PROBLEMS YET TO BE SOLVED

8.1 Liquid Dispensing

Due to a weight and complexity constraint on the final product the Gold level milestone, of adding in a mechanism for ice cube dispensing, has not been achieved yet. The group believes it to be a complex problem that is out of the scope of the final product as of right now, and after the minimum of bronze milestones are achieved for the rest of the sub-systems, we will look at it again to determine viability.

8.2 Locomotion

The control algorithm for the motors has not been coded. The datasheet is limited and does not gives enough information to create a reliable simulation for algorithm development. As such, the algorithm will not be developed until the parts arrives.

8.3 Navigation

Our proposal promises that for the silver and gold milestones there will be an intelligent queueing system that will minimize distances. I have yet to determine a way to allow for the robot to turn around and maintain visual contact with the guidance line while determining the correct direction to travel. As of right now the robot will travel in a loop in one direction. There may need to be additional data stored in the barcode system.

9 SELF-EVALUATION

9.1 MAHARSHI PATEL

I was responsible for the design and testing of the dispensing system. After the group meeting where we split responsibilities, I was chosen to do the dispensing system as I had done the most background research on it. By the week of the technical presentation a black box design was completed for the system and all the power specs were ready for the power systems that will need to be designed. The design was specified to reach the silver level of our milestones for the dispenser and the gold level, of adding in dispensing mechanism for ice cubes is a technical challenge that we have decided to put lower on the priority list for now. As for future steps I will be working with Joe, our microcontroller expert and developing code to test and control the peristaltic motors. After the dispensing system is ready to be implanted in the final product, I will move on to HMI systems and help there and act as general support for anyone else that needs it.

9.2 PAUL NGUYEN

I am the primary author on background research for the project. After the proposal was completed, I lead the design of the locomotion system. Once the parts arrive, I will be developing the control algorithm. All my assigned tasks were submitted fully. Updates were made frequently to apprise the group of the progress. When possible, I identified the need of the group and made sure it is filled. Overall, I will give myself full marks in my contribution to the group.

9.3 MALCOLM MACEACHERN

I was entrusted with the overall mechanical design of the robot, including assessment of structural component weaknesses and viability, designs for mounting components from all other subsystems, and manufacturing of all required structural and mechanical parts not easily purchased. I was also given the task of designing and implementing the drink elevator. I also was heavily involved in the sourcing and purchasing of parts, contacting suppliers and purchasing many components involved in my assigned systems and others. Our group luckily has a wide range of complimenting skills related to engineering, which is why I was assigned these roles mostly due to my background in electromechanical projects and their manufacturing. The structural design of the system was done in Autodesk Inventor CAD program due to my experience in its use. I have started manufacturing most of the parts needed but not easily purchased, such as the motor mounts and the baseplate. I am continuing with the final structurally relevant designs and will be making most of them in the early weeks of next semester in both Hatch and the JHE machine shop. In the future I will be interacting with the rest of the team to determine where their parts must be or can be placed, as well as designing and making components that may not currently be required yet and determining overall quality in the assembly of structural and mechanical parts.

9.4 Joe Perri

I took the lead on the navigation module of our project. Determining how our robot would navigate was a challenge. Eventually it was determined that for the Bronze level the robot would use computer vision to follow a line. This responsibility was given to me because I own a Raspberry Pi with a camera module and that I have experience extensive experience using the Pi and have been using the OpenCV library for personal projects. Each member of any group has their own strengths and areas of expertise. In the case of our group I fall towards the embedded software side and will be working extensively in this area and assisting other team members when necessary. In the future I will be fine tuning the navigation system to effectively control the position of the robot and perhaps have it been able to navigate without following a line.

Additionally, I have implemented the bronze level of the HMI module using the Python sockets API. In the future I feel that a simple webapp for order processing would be simple to implement given I have worked on some web development related side projects.

10 REFERENCES

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