PILL BOT

Design Review 1.2 Documentation

MEDICATION DISTRIBUTION ROBOT

ROBO-MEDICS

Joanna Dickinson - ME
Lorena Ferreira - ME
Erin Okuna - EE
Nick Sharp - CPE
Leanna Temple - ME

SEATTLE PACIFIC UNIVERSITY

SENIOR DESIGN
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Executive Summary

The Plan

Ten short weeks ago, the Robo-Medics set out to alleviate several major concerns pertaining to Pill Bot, the autonomous medication delivery robot. One of these risks involved ensuring that the bot had a stable base that could turn corners and accelerate on command. Without a fully functioning, controllable mobilization system, the bot would not be able to maneuver itself about its surroundings. Similarly, the navigation component of the bot must be able to communicate wirelessly via various sensors in order to process its location relative to the environment. Tackling these two critical paths, the Robo-Medics were able to mitigate several high-risk concerns over the course of this quarter and make significant strides towards creating a system that could greatly benefit medical facilities across the globe.

The Process

The base frame assembly was constructed primarily out of aluminum. Two geared DC motors drive the back wheels while the front omni wheels are free to rotate along two axes for increased maneuverability. Several mechanical analyses were completed in order to assure that the ideal products were purchased and that the overall size of the system could be supported by the base frame prototype. Before selecting drive motors, the required torque for the system was calculated and confirmed by several team members to guarantee that the chosen motors could withstand the necessary predicted torque. The team also calculated the anticipated center of mass of the system and completed a rigorous stability analysis to ensure that reasonable speeds and loads would not topple the bot. After selection of the drive motors, the team conducted power capability and power capacity analyses to determine which battery the bot would use. Lastly, the team obtained threshold values for the operable range of the ultrasonic, infrared (IR), and radio frequency identification (RFID) sensors equipped on Pill Bot in completing an attenuation analyses.

Moving Forward

After mitigating the biggest risks involved in this project, the Robo-Medics are excited to continue this momentum and begin planning for next quarter. Over the next month, designs will be drawn and materials will be purchased for the lockbox component of the system as well as the bracing mechanism that will secure the lockbox above the completed base frame. Additionally, mountings and casings will be fashioned to house the electrical components safely. Both software and hardware will be refined: the code on the PSoC 6 will include code for the bot’s autonomous movement, and the team will design the PCB for the final circuitry on the bot.

Risk Reduction Prototypes

Critical Path Diagrams

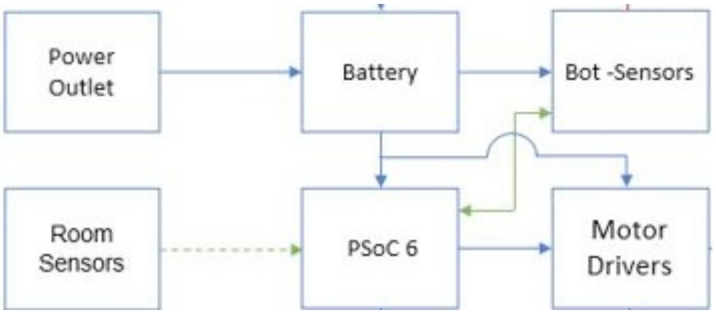


Figure 1: Electrical RRP Critical Path blocks

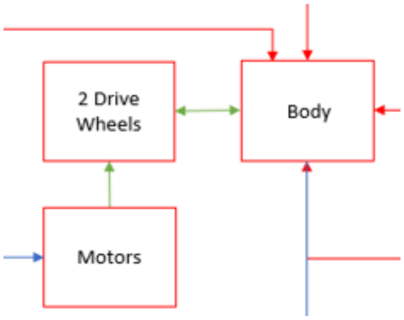


Figure 2: Mechanical RRP Critical Path block

Figures 1 and 2 show the critical mechanical and electrical connection paths. Identified in green, the critical paths in the Pill Bot system are those which were expected to require the highest level of research and skill to successfully design and fabricate. The mechanical critical path involves the base frame, drive motors and wheels of the robot, which combined, provide the system with mobility and stability. This base will support the load of all of the Pill Bot's components and will allow the system to physically move around medical facilities. The electrical critical path focuses on navigation and communication between the Pill Bot's sensors and the PSoC 6 microcontrollers. Wireless navigation is an essential part of Pill Bot system, allowing for autonomous delivery.

Mechanical Risk Reduction Prototype

For the RRP, Robo-Medics proposed to build the frame/wheel structure, as seen in Figures 3-5, which acts as a base for the robot. It is able to turn around corners, travel in a straight line (defined below), and support the system load. Making Pill Bot turn accurately around tight corners was a concern, because if it could not adequately maneuver around a medical facility, the project would not be successful. It was also necessary to ensure that Pill Bot could move at reliable, safe speeds and navigate accurately. The Mechanical RRP is constructed of 0.125” thick aluminum base chosen for its strength, amount of deflection, and price as seen in Appendix 1. Six inch wheels were chosen for their ability to support and allow for enough ground clearance to avoid the base of the bot travelling to close to the floor and getting anything caught underneath. A total of four wheels were selected for stability of the base and overall support. The front wheels are omni wheels to allow for maximum maneuverability of the bot. Two motors drive the rear wheels that are rated at 50 RPM and 50kg*cm torque to easily sustain the full load of the Pill Bot and allow it travel at a safe cruising speed.

Additionally, to aid in the testing of the mechanical RRP, a separate system of radio frequency (RF) sensors pictured in Figure 4 were incorporated into a remote controller set. The NRF24L01 modules provide the appropriate range, allowing the team to successfully test the functionality of the base and the motor drivers of the RRPs wirelessly from a distance.

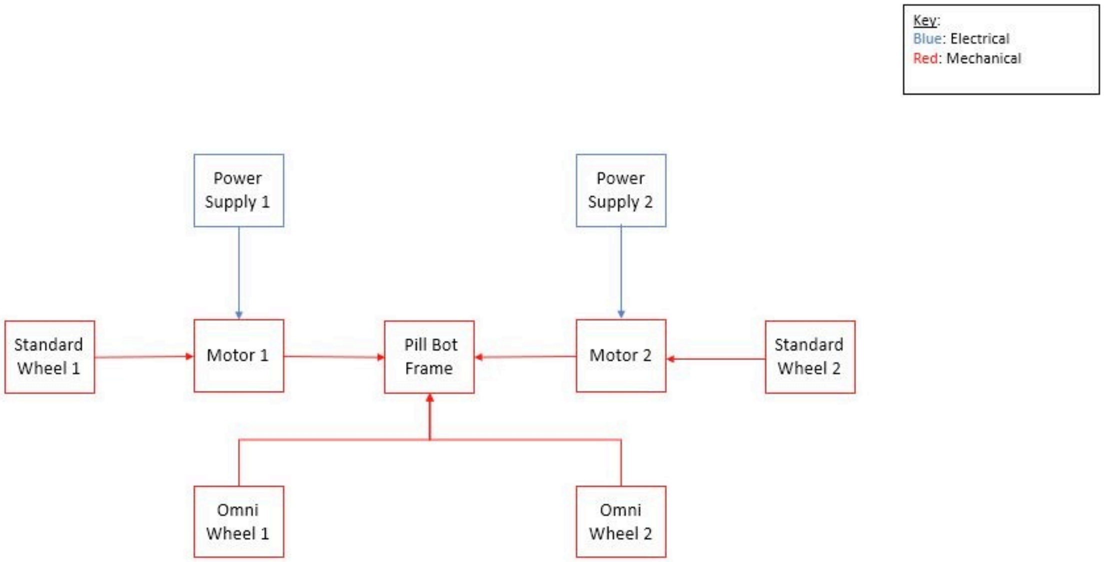


Figure 3: Mechanical RRP Block Diagram

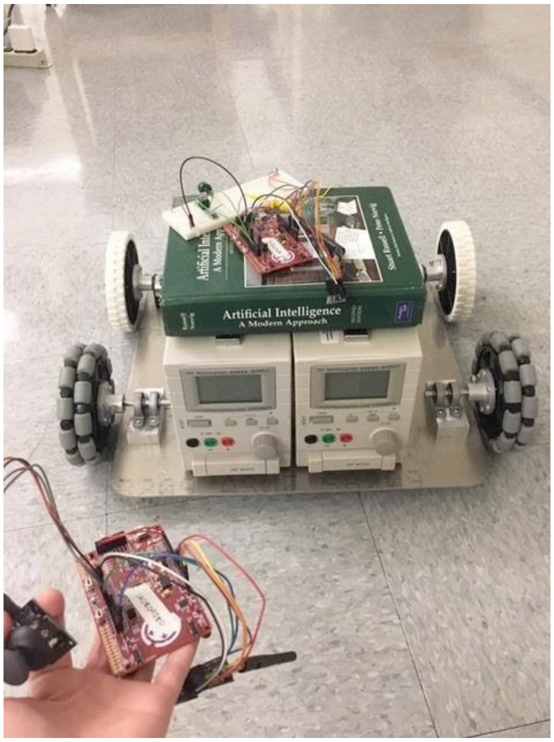


Figure 4: Current Built Mechanical RRP Front

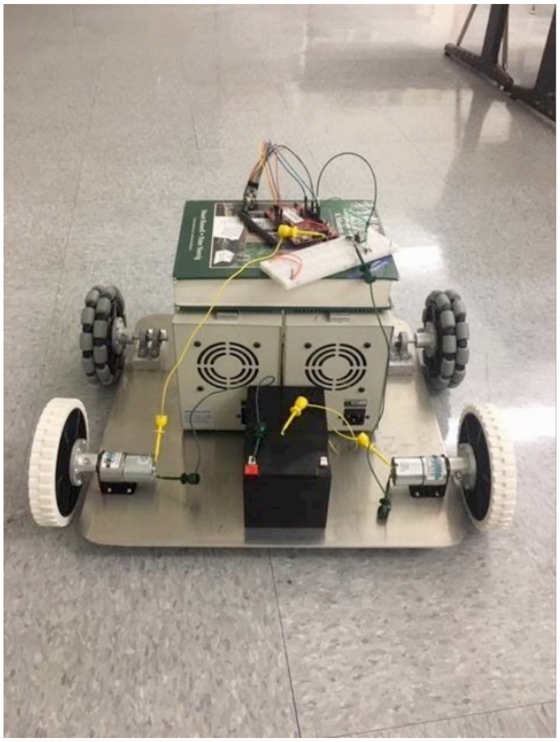


Figure 5: Current Built Mechanical RRP Back

Electrical Risk Reduction Prototype

For the electrical-based RRP, Robo-Medics proposed to build several sensors systems, as seen in Figures 6 and 7. The on-bot sensors system contains ultrasonic sensors for object detection, IR sensors for line counting, and RFID sensors for specialized recognition. Object detection is imperative for the bot to navigate through a medical facility where the bot will encounter an infinite number of unforeseeable obstacles. The HCR-04 ultrasonic sensors were chosen for their range since the robot must detect objects from a long enough distance away to decelerate and move around the obstruction. Line counting will also be necessary for calculating where the robot will travel in the medical facility. The insides of the wheels will be marked with lines, which the bot will count and translate to distance travelled with respect to circumference of the wheels. The OSOYOO IR sensors were chosen for their adjustability and, thus, versatility. The IR sensors sensitivity may be adjusted throughout the entire process of prototyping, refining, and finalizing the bot while still yielding reliable results. Accurately navigating the medical facility and dispensing the correct medication both require specialized recognition for checkpoints, in case the bot gets lost, and protected delivery. The PN532 module was chosen because it offers the best compromise between range, speed, and user-friendliness.

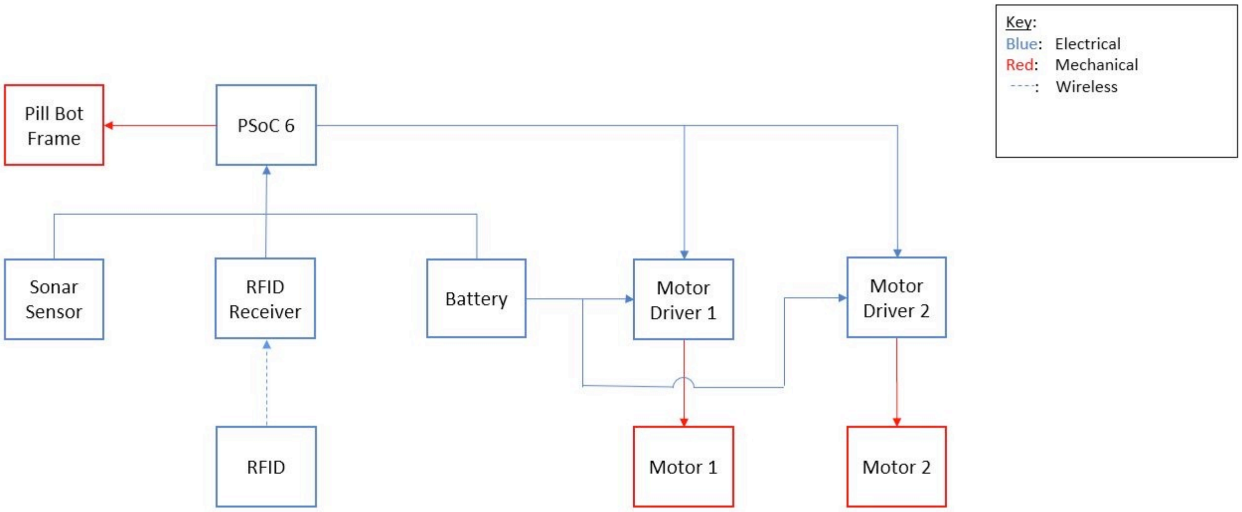


Figure 6: Electrical RRP Block Diagram

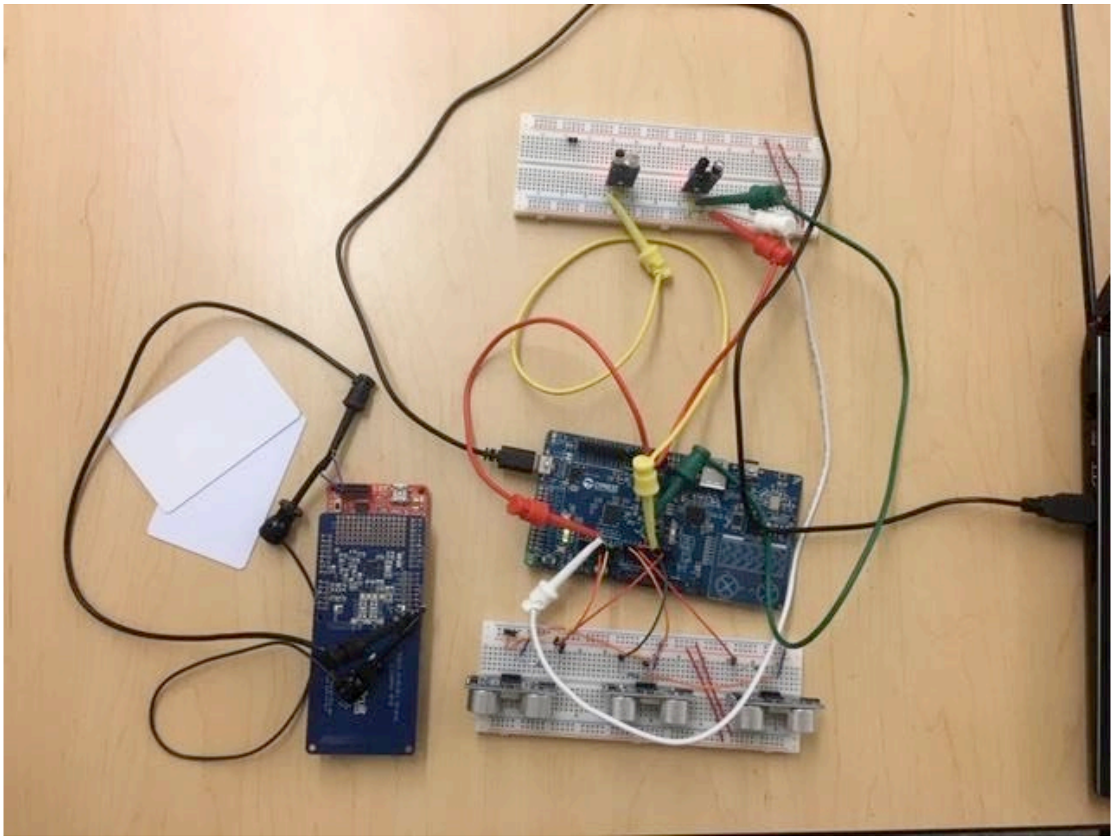


Figure 7: Current Built Electrical RRP

Mechanical Specifications and Validations

M001: Wheel Alignment: **The wheels of the system shall be parallel within 1 degrees of the plate (2 in to the right or the left of designated straight path of 10 ft.). The wheels of the system should be parallel within 0.5 degrees of the plate (1 in to the right or the left designated straight path of 10 ft).** In order for the bot to travel in a straight line, it must be manufactured in such a way that allows the bot to follow a straight line given that the two drive motors are powered identically. The alignment will be determined by measuring the angle between the wheel faces and the assumed flat ground (this is ideally 90 degrees +/- 0.5), as well as the angle between the plate and the edge of the wheel (this is ideally 90 degrees +/- 0.5, +/- 1).

M002: Speed**: The system shall be able to travel at a velocity of at least 1 ft/s. The system should be able to travel at a velocity of at least 2 ft/s.** To prevent running into obstacles, heighten stability of the system, and deliver medications in a timely manner, the robot must be able to travel at a reasonable speed. The reasonable speed of 1 ft/s was determined by experimentally timing travel over a distance of 20 ft and consider that for safety, the bot should travel slower than the average human (4 ft/s). For purposes of the RRP, power source limitations will most likely only allow a travel speed of 1 ft/s, which is sufficient for proving the bot's ability to maneuver around its environment. The system's speed can be verified by measuring the time the robot takes to travel a determined distance once the robot has reached a constant speed.

M003: Turning Radius**: The system shall have a minimum turning radius of 3.5 ft while traveling at approximately 1 ft/s. The system should have a have a minimum turning radius of 1 ft while traveling at approximately 1 ft/s.** The robot will need to turn around corners and into rooms in order to deliver the medications properly. Assuming that an average hallway is 3.5 ft wide, that dimension is the minimum turning radius the robot must be able to satisfy. Ideally, the robot would be able to function with a near zero turning radius, pivoting around a central point. This can be verified by programming the robot to turn as sharply as possible and measuring the radius of the circle it follows and is independent of the stability of the robot.

M004: Stability: **The system, moving and turning at 1 ft/s, shall support a load of at least 45 lbs without tipping. The system, moving and turning at 1 ft/s, should support a load of at least 65 lbs without tipping.** The system will need to hold up and still have the ability to move from room to room to deliver medications. The robot will consist of at least one battery, which is estimated to weigh 10 lbs, and other metal components for security and durability. With the durable materials, the estimated weight of the empty robot is to be 35 lbs. This leaves 10 lbs of space for medications and UI. Before being built, stability can be calculated by finding the center of mass. After construction, weights will be added to the finished system and observed to see whether or not the system can still move.

Table 1: Mechanical Specifications

Spec ID	**Requirement**	**Threshold (Shall)**	**Objective (Should)**	**Validation Method**	**Pass/Fail**	**Notes**
M001	Alignment	Wheels parallel within 2 degrees	Wheels parallel within 1 degree	Use protractor to measure alignment angles and measure deviation from straight path	Partial Pass	Right Wheel: 89 degrees Left Wheel: 88 degrees
M002	Speed	Travel at least 1 ft/s	Travel at least 2 ft/s	Measure speed of robot and verify it meets required speed	Pass	1.28 ft/s
M003	Turning Radius	R < 3.5 ft	R < 1 ft	Measure R of tightest possible circle that the bot can make	Partial Pass	1.75 ft
M004	Stability	Support at least 45 lbs without tipping (at 1 ft/s)	Support at least 65 lbs without tipping (at 1 ft/s)	Load with specific weight and observe movement	Pass	Noticeable deflection under 65 lb load

Specification M001: Alignment

Setup:

1. Obtain a protractor, measuring tape, and masking tape.
2. Measure the angles between the inner surfaces of the drive wheels and the back edges of the metal plate.
3. Measure the angle the wheel makes with the ground, which should be a right angle.
4. To measure deviation from a straight path while at cruising speed, place a 10 ft strip of masking tape on the floor, making sure it is straight by verifying with a level.
5. Align the outer edge of the wheels up with the masking tape
6. Allow Pill Bot to travel the 10 ft without adjustment with the remote control
7. Measure horizontal distance the outer edge of the wheel traveled from the designated straight line.

Validation:

When using a protractor to measure the angle between the edges of the wheels and the metal plate, the left drive wheel produced an angle of 88 degrees, while the right drive wheel produced an angle of 89 degrees. Measuring the angle between the floor and the outer edge of the wheel produced an angle of 89 degrees for the right drive wheel and 90 degrees for the left drive wheel. To verify that the Pill Bot moves in a straight line, the team also measured the Pill Bots deviance from a known straight line over a distance of 10 ft to determine how straight the traveled path was. This deviation length over a 10 ft path was 1in, as seen in Figure 8. Even though the Pill Bot's wheels were misaligned aligned slightly, Pill Bot still only barely deviated from the straight path. Because of this, the Robo-Medics do not see this as a major issue going forward, but the alignment of the wheels can still be improved upon.

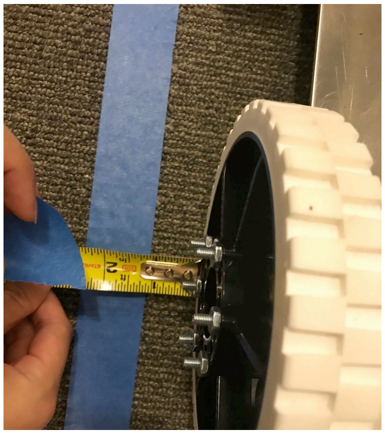


Figure 8: Measured deviation from straight line over 10 ft

Specification M002: Speed

Setup:

1. Obtain a measuring tape and a stop-watch.
2. Mark specific length of 10 ft.
3. Place the bot about 5 ft before the start of measuring tape to allow bot to accelerate to a constant speed from initial start location.
4. Begin timer when front wheels of the bot reach the start of measuring tape.
5. Stop timer when front wheels of the bot reach the 10 ft mark of the measuring tape.

Validation:

The team observed that while the bot is loaded with 45lbs and supplied with 100% power, the bot took 7.8 seconds to move 10 ft at max power, as seen in Figure 9. This equates to a speed of **1.28 ft/s** and meets the threshold specification. It is important to note here that these tests were performed with the slower of 2 motor options (Figures 23 and 24). While the original motors were spec'd at 100 RPMs, they were replaced by new motors with a higher torque but only 50 rpms. By reverting back to the original motors or purchasing new motors, the Robo-Medics are confident that speed will not be an issue moving forward.

Figure 9: Speed setup for Mechanical RRP

Specification M003: Turning Radius

Setup:

1. Obtain masking tape and stopwatch
2. Mark with masking tape a 3.5 ft radius
3. Place outer edge of bot's wheel at starting point of the marked radius.
4. Power, start timer, and turn the bot at full turning power.
5. Measure the point the outer edge of the wheel crosses the marked radius line.
6. Stop the stopwatch once the bot has returned to the starting point.

Validation:

The bot was tested for both left and right turning abilities. When turning left, as shown in figure 10, the turning radius was measured to be **1 ft and 9.5 in**. When turning right, the turning radius measured to be **1 ft and 8.5 in**. However, when calculating the speed at which the bot was traveling while turning was about **0.91 ft/s** which is slightly less than the speed of 1 ft/s set in the specification. Since the bot traveled less than 1 ft/s while turning, the threshold specification is marked as yellow.

Figure 10: Turning radius setup for Mechanical RRP

Specification M004: Stability

Setup:

1. Obtain 65lbs. worth of mass as follows:
   a. Battery: 7 lbs
   b. 2 Power Sources: 10 lbs each → Total of 20 lbs
   c. Laptop and electrical hardware: 4 lbs
   d. 4 Textbooks: 6 lbs each → Total of 24 lbs
   e. Base Frame with wheels and mechanical hardware: 10 lbs
2. Place weights on bot.
3. Apply power to bot and verify bot travels at least 1 ft/s and is able to turn corners at minimum turning radius (radius of 3.5 ft) without tipping.
4. If bot does not meet step 3 then remove weight until bot moves as described in step 3.

Validation:

The team observed that while the bot was loaded with 45 lbs, it moved at a cruising speed of 1.28 ft/s and was able to turn around corners at a radius of 2 ft. The team also observed that while the bot was loaded with 65 lbs, it moved at a cruising speed of 1.23 ft/s and was able to move around corners at a radius of 2 ft. Since the bot was able to withstand 65 lbs of weight and travel at least 1 ft/s sec, the objective stability spec was recorded as yellow since when turning around corners the bot moves at speeds slightly below 1 ft/s. The Robo-Medics are not concerned about this low turning speed, because low velocity turns will increase stability and allow for maximum safety in a populated hallway.

Electrical Specifications and Validations

E001: Ultrasonic Object Detection: **The system shall have a minimum obstruction detection distance of twelve inches. The system should have a minimum obstruction detection of twenty-four inches.** The system will need to detect objects in its path, to ensure both that the robot will be able to continue following its route according to its given schedule and that the robot does not injure anyone if the object happens to be a person Twelve inches would provide enough room for the robot to decelerate to a stop before colliding with any blockage and move around it accordingly. An ideal two feet would allow distance and time for an alarm equipped system to decelerate, move accordingly, and alarm bystanders of blockage. Detection radius will be measured by propping up the ultrasonic sensor with nothing in front of it and then moving a hand from far away, closing in towards the sensor and documenting at what distance the hand is detected.

E002: IR Rotation Recording Accuracy: **The system shall count at minimum 90% of the wheels' rotations. The system should count at minimum 99% of the wheels' full rotations.** The system will need to calculate how far it has travelled while running in peak operation mode to process approximately where it is relative to its internal map of the medical facility while making deliveries. The bot will use the number of rotations counted to calculate distance travelled. A minimum 90% accuracy would ensure that the robot, aiming to enter through the middle of a doorway after traversing a hallway, would still enter the correct room. A preferred minimum 99% accuracy would ensure that bot would require performing minimal self-correction calculations. Rotation counting accuracy will be measured by comparing the number of rotations as observed by the IR sensor of a rotating wheel marked with a line (ensuring substantial light contrast for the IR sensor to pick up) and how many times the wheel actually rotates.

E003: RFID Receiver Range: **The system shall have a minimum RFID range of four inches. The system should have a minimum RFID range of eight inches.** The system will need to read RFID tags that indicate which room or checkpoint the bot has entered/passed. A minimum RFID receiver range of four inches would enable the bot to read an RFID tag it has travelled over with substantial clearance off the ground (assuming the RFID receiver attaches to the bottom of the bot and RFID tags are assembled onto the floor). Preferably, eight inches would improve the efficiency of the bot, communicating to the bot its general location and prompting it to act accordingly a lot faster, reducing the time the bot would use to search for the tag. RFID receiver range will be measured by keeping an RFID tag stationary and bringing the RFID receiver from far away, closer to the tag until the receiver picks up the tag's signal, at which point the distance between the two will be documented.

Table 2: Electrical Specifications

Spec ID	Requirement	Threshold (Shall)	Objective (Should)	Validation Method	Pass/Fail	Notes
E001	Ultrasonic Object Detection	D ≥ 12 in.	D ≥ 24 in.	Measure maximum distance at which each ultrasonic sensor will detect an object in front of it.	Pass	0.5 in. ≤ D_{meas} ≤ 69.5 in.
E002	IR Rotation Counting Accuracy	≥ 90% of rotations counted (a wheel will be marked with a single line to document a full rotation)	≥ 99% of rotations counted (a wheel will be marked with a single line to document full rotation)	Document and compare the number of lines counted by the sensor on a wheel rotated in front of it to the number of true rotations.	Pass	99.6% lines counted for 3 sets of 100 lines
E003	RFID Receiver Range	D ≥ 4 in.	D ≥ 8 in.	Measure maximum distance at which RFID receiver would read an RFID tag.	Fail	Spec for module limited by 4 in.; D_{meas} ≤ 3.75 in.

Specification E001: Ultrasonic Object Detection

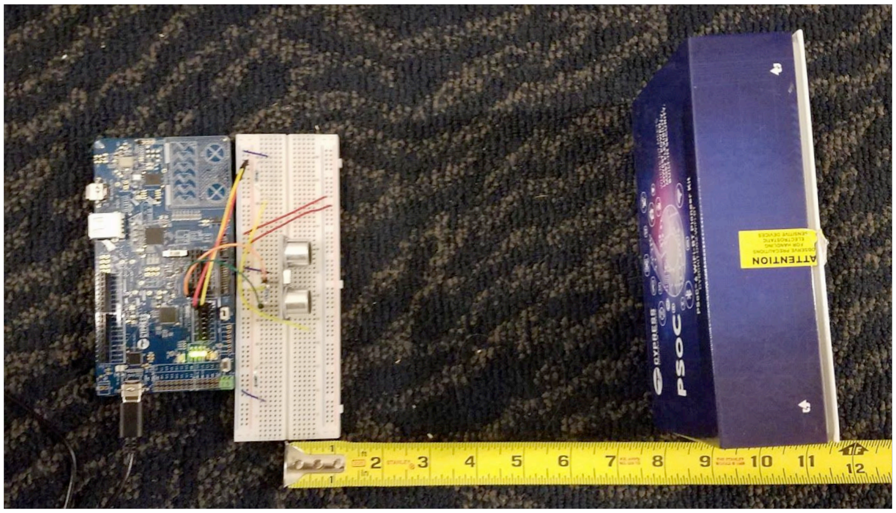


Figure 11: Ultrasonic Sensor Testing Set-Up

Setup:

1. Assemble ultrasonic sensors, ensuring nothing is in front of them, and coordinating PuTTY windows
2. Obtain a yard stick and an object with a broad, flat surface
3. Using the yard stick, measure and mark 12” and 24” from the ultrasonic sensor
4. Place the object at the 12” mark in front of the sensor, flat face perpendicular to it, and observe whether the sensor reacts
5. Place the object at the 24” mark in front of the sensor, flat face perpendicular to it, and observe whether the sensor reacts

Validation:

The team observed that the ultrasonic sensors are able to accurately detect objects within a range from 0.5 in. to 69.5 in. from the front of the ultrasonic sensors. The sensors were programmed so that the values displayed on the PuTTY screen were proportional to the distance between the sensors and the object detected. Within the range of 0.5 in. to 69.5 in. the numbers gradually increase and decrease as the object moves away and moves near, respectively. Holding the object closer to or farther from the sensors yield values that jump from drastically high to drastically low, indicating that the sensors do not process the distance to the object accurately. Because of the great range that the sensors operate in, the team believes that the ultrasonic sensors have met their specification objective.

Specification E002: IR Rotation Counting Accuracy

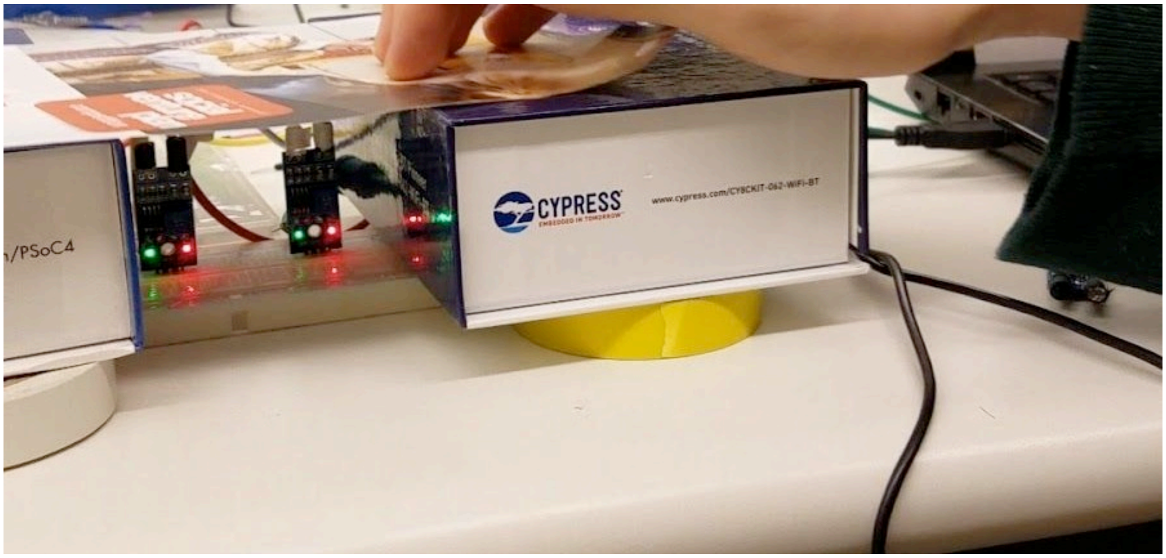


Figure 12: IR Testing

Setup:

1. Assemble IR sensors and coordinating PuTTY windows
2. Assemble two level platforms of equal height on either side of IR sensors, ensuring that the platforms are approximately half an inch to two inches above the tops of the sensors
3. Down the middle of a white paper, draw a broad line with black marker, ensuring that the paper has great enough area to protect the IR sensors from interfering signals
4. Lay the paper across the platforms, line-side down, so that the line extends from one platform to the other
5. When beginning, ensure that the line is NOT over the IR sensors
6. Slide the paper back and forth across the platforms, ensuring that the line completely passes over the IR sensors each time and counting every time that the lines pass over
7. Repeat step 6 until 100 lines have been counted
8. Compare the number of lines counted by the IR sensors displayed on the PuTTY screen

Validation:

The team observed that for the three iterations conducted, the IR sensor counted 99.6% of the possible lines potentially detected, as displayed by the PuTTY window and the lights programmed to blink green every time a line was counted. Because of the high accuracy of the IR sensors' results, the Robo-Medics consider the IR sensor specification objective to have been met.

Specification E003: RFID Receiver Range

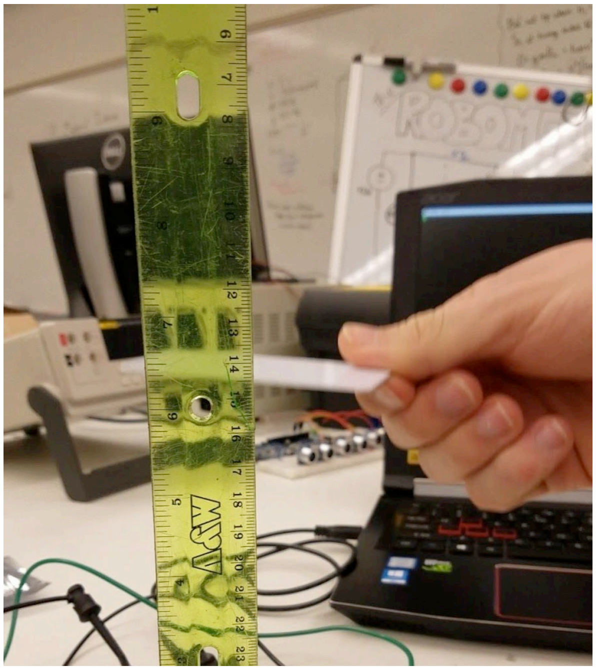


Figure 13: RFID Testing

Setup:

1. Assemble RFID sensor module and coordinating PuTTY window
2. Obtain a plastic ruler and line up the 0 in. mark with RFID module, ascending numbers in the upwards direction, ensuring that the ruler is perpendicular to the face of the module
3. Hold an MFRC522 card 12 in. above the RFID module, face parallel to the module
4. Lower the card slowly until the RFID module reads the presence of the card
5. Document how high the card is above the module using the ruler

Validation:

The team observed that the maximum distance that the RFID module was able to detect the MFRC533 card was at a distance of 3.75 in. The team programmed the RFID module so that the PuTTY window would print the unique identifier (UID) number of the card as soon as the card was detected.

Engineering Analyses

Center of Mass

Planned

Determine the system’s center of mass to determine the stability (likelihood of tipping) when turning and accelerating.

Actual

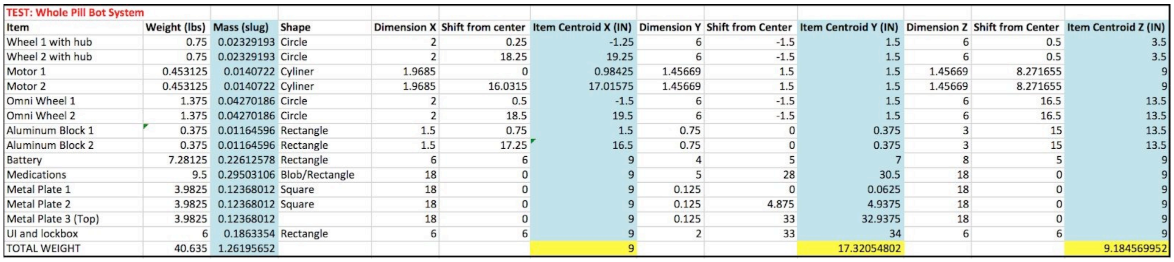
The center of mass was calculated throughout the project through means of an excel sheet so that the accurate masses and locations of items within the Mechanical RRP were identified and accounted for. Center of mass equation was used for each axis, x, y, and z as follows:

$$x_{COM} = \frac{m_1*x_1+m_2*x_2+m_3*x_3+\ldots m_n*x_n}{m_1+m_2+m_3+\ldots m_n}$$

$$y_{COM} = \frac{m_1*y_1+m_2*y_2+m_3*y_3+\ldots m_n*y_n}{m_1+m_2+m_3+\ldots m_n}$$

$$z_{COM} = \frac{m_1*z_1+m_2*z_2+m_3*z_3+\ldots m_n*z_n}{m_1+m_2+m_3+\ldots m_n}$$

The first iteration of the center of mass was made with approximate masses that were based on manufactures provided data. However, as items came in, they were weighed and updated within the excel. The final iteration of center of mass is shown in Figure 14 resulted in a center of mass of (9, 17.3, 9.18) in, the coordinate system is shown in Figure 15 with a basic sketch of the overall Pill Bot system.



TEST: Whole Pill Bot System

Item	Weight (lbs)	Mass (slug)	Shape	Dimension X	Shift from center	Item Centroid X (IN)	Dimension Y	Shift from Center	Item Centroid Y (IN)	Dimension Z	Shift from Center	Item Centroid Z (IN)
Wheel 1 with hub	0.75	0.02329193	Circle	2	0.25	-1.25	6	-1.5	1.5	6	0.5	3.5
Wheel 2 with hub	0.75	0.02329193	Circle	2	18.25	19.25	6	-1.5	1.5	6	0.5	3.5
Motor 1	0.453125	0.0140722	Cyliner	1.9685	0	0.98425	1.45669	1.5	1.5	1.45669	8.271655	9
Motor 2	0.453125	0.0140722	Cyliner	1.9685	16.0315	17.01575	1.45669	1.5	1.5	1.45669	8.271655	9
Omni Wheel 1	1.375	0.04270186	Circle	2	0.5	-1.5	6	-1.5	1.5	6	16.5	13.5
Omni Wheel 2	1.375	0.04270186	Circle	2	18.5	19.5	6	-1.5	1.5	6	16.5	13.5
Aluminum Block 1	0.375	0.01164596	Rectangle	1.5	0.75	1.5	0.75	0	0.375	3	15	13.5
Aluminum Block 2	0.375	0.01164596	Rectangle	1.5	17.25	16.5	0.75	0	0.375	3	15	13.5
Battery	7.28125	0.22612578	Rectangle	6	6	9	4	5	7	8	5	9
Medications	9.5	0.29503106	Blob/Rectangle	18	0	9	5	28	30.5	18	0	9
Metal Plate 1	3.9825	0.12368012	Square	18	0	9	0.125	0	0.0625	18	0	9
Metal Plate 2	3.9825	0.12368012	Square	18	0	9	0.125	4.875	4.9375	18	0	9
Metal Plate 3 (Top)	3.9825	0.12368012		18	0	9	0.125	33	32.9375	18	0	9
UI and lockbox	6	0.1863354	Rectangle	6	6	9	2	33	34	6	6	9
TOTAL WEIGHT	40.635	1.26195652				9			17.32054802			9.184569952

Figure 14: Center of Mass Calculations

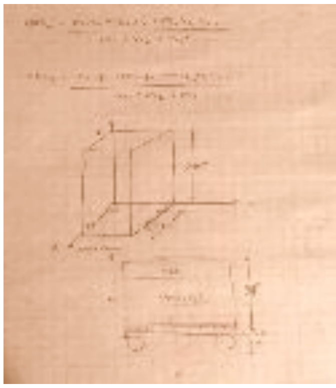


Figure 15: Coordinate System for COM Calculations

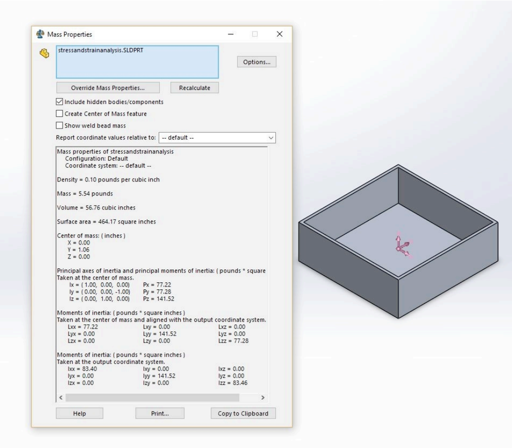
Total Mass

Planned

Determine approximate weight of components in order to build a rough CAD model.

Actual

The total mass of the system was used in the center of mass calculation and used to build a CAD model. The total mass of the Mechanical RRP is accurate based on actual products that were used in the design since they were weighed as they came in and their locations measured and updated in the center of mass sheet as mentioned above. Since the total mass is based on the whole finished system at the end of Winter quarter, some assumptions had to be made. The estimated medication weight takes the weight of the patient's pills, the medicine containers (such as plastic medicine bottles), and the weight of the material for each patient's medications into account. To estimate the total weight of medications, 360 Advil pills weighed in at around 0.5 lbs, individual plastic medicine bottles weighed around 1 ounce each (36 containers to be included at max capacity, total of 2.25 lbs), and building material was estimated to be 6.75 lbs. The building material of the medicine container was assumed to be a 6061-T6 Aluminum 10" X 10" X 3.5" container with 0.25" thick edges and a hollow center as seen in Figure 16 (5.5 lbs) and a 0.125" thick lid as seen in Figure 17 (1.25 lbs). From these calculations, the estimated medicine weight totaled to 9.5 lbs. 6061-T6 Aluminum material was also chosen to make the exterior of Pill Bot and estimated to be 5 lbs as seen in Appendix 2. This 5 lbs was added to the center of mass total mass calculation (40 + 5 lbs) since exterior material did not effect COM calculations and therefore was not included. With these calculations, the total weight of Pill Bot came to be about 45 lbs.



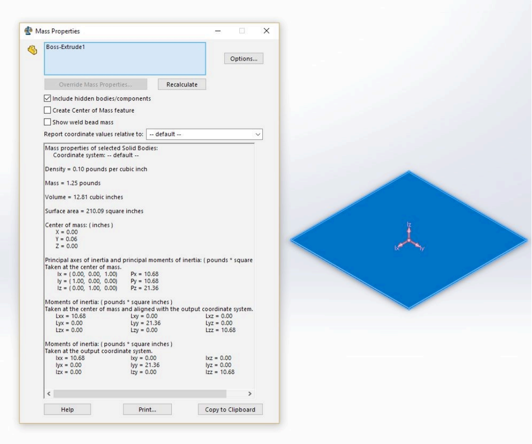
stressandstrainanalysis.SLDPRT

☑ Include hidden bodies/components
☐ Create Center of Mass feature
☐ Show weld bead mass

Report coordinate values relative to: -- default --

```
Mass properties of stressandstrainanalysis
    Configuration: Default
    Coordinate system: -- default --

Density = 0.10 pounds per cubic inch

Mass = 5.54 pounds

Volume = 56.76 cubic inches

Surface area = 464.17 square inches

Center of mass: ( inches )
     X = 0.00
     Y = 1.06
     Z = 0.00

Principal axes of inertia and principal moments of inertia: ( pounds * square
Taken at the center of mass.
      Ix = ( 1.00,  0.00,  0.00)       Px = 77.22
      Iy = ( 0.00,  0.00, -1.00)       Py = 77.28
      Iz = ( 0.00,  1.00,  0.00)       Pz = 141.52

Moments of inertia: ( pounds * square inches )
Taken at the center of mass and aligned with the output coordinate system.
     Lxx = 77.22              Lxy = 0.00              Lxz = 0.00
     Lyx = 0.00               Lyy = 141.52            Lyz = 0.00
     Lzx = 0.00               Lzy = 0.00              Lzz = 77.28

Moments of inertia: ( pounds * square inches )
Taken at the output coordinate system.
     Ixx = 83.40              Ixy = 0.00              Ixz = 0.00
     Iyx = 0.00               Iyy = 141.52            Iyz = 0.00
     Izx = 0.00               Izy = 0.00              Izz = 83.46
```

Figure 16: Medicine Container Base Weight Estimation



Boss-Extrude1

☑ Include hidden bodies/components
☐ Create Center of Mass feature
☐ Show weld bead mass

Report coordinate values relative to: -- default --

```
Mass properties of selected Solid Bodies:
    Coordinate system: -- default --

Density = 0.10 pounds per cubic inch

Mass = 1.25 pounds

Volume = 12.81 cubic inches

Surface area = 210.09 square inches

Center of mass: ( inches )
     X = 0.00
     Y = 0.06
     Z = 0.00

Principal axes of inertia and principal moments of inertia: ( pounds * square
Taken at the center of mass.
      Ix = ( 0.00,  0.00,  1.00)       Px = 10.68
      Iy = ( 1.00,  0.00,  0.00)       Py = 10.68
      Iz = ( 0.00,  1.00,  0.00)       Pz = 21.36

Moments of inertia: ( pounds * square inches )
Taken at the center of mass and aligned with the output coordinate system.
     Lxx = 10.68              Lxy = 0.00              Lxz = 0.00
     Lyx = 0.00               Lyy = 21.36             Lyz = 0.00
     Lzx = 0.00               Lzy = 0.00              Lzz = 10.68

Moments of inertia: ( pounds * square inches )
Taken at the output coordinate system.
     Ixx = 10.68              Ixy = 0.00              Ixz = 0.00
     Iyx = 0.00               Iyy = 21.36             Iyz = 0.00
     Izx = 0.00               Izy = 0.00              Izz = 10.68
```

Figure 17: Medicine Container Lid Weight Estimation

Stability

Planned

Determine what conditions (speed, rotation) would cause the completed system to tip over.

Actual

This analysis used the above center of mass calculation as well as material data and projected velocities. An analysis of forces and system dynamics was completed to determine tipping conditions (Figure 18). The basic assumption used for completing this analysis was that the bot will tip when the normal force against the inside wheels is equal to zero (lifting off the ground). It was determined that in order for the bot to tip while rounding a corner of radius 2 ft, it would have to be traveling at 5.9 ft/s. When turning around a corner with a radius of 2 ft, at 1 ft/s (predicted standard scenario), the bot’s inside wheels would experience a force 21.85 lbf, while the outside wheels would experience a force of 23.25 lbf.

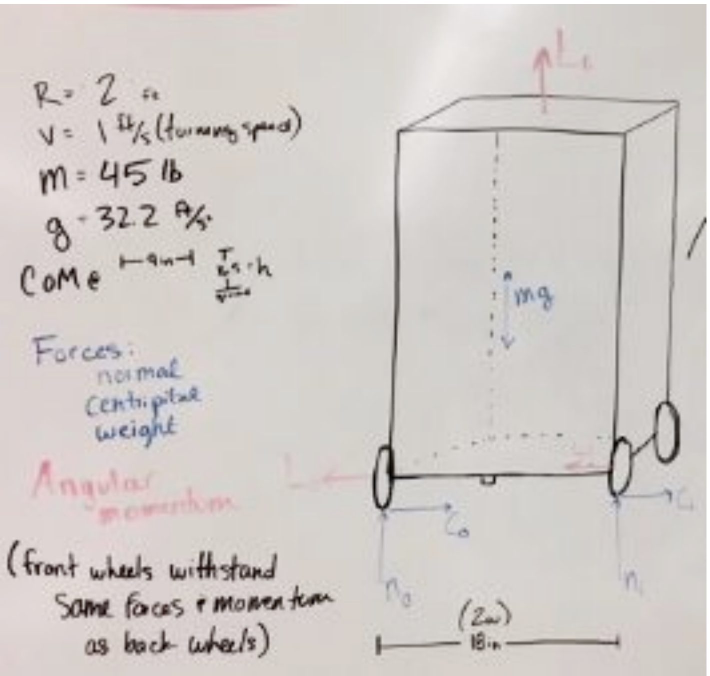


Figure 18: Stability Analysis Diagram

Using Newton’s second law and center of mass concepts:

$$(c_0 - c_i) = m\frac{v^2}{R}$$

$$(n_0 - n_i) = mg$$

Then, torques in the z (out of the board) direction:

$$(n_0 - n_i)w - (c_0 - c_i)h = L\frac{v}{R}$$

where L is the total constant magnitude angular momentum of the wheels:

$L = I\omega$ (x4 wheels)

$I = mr^2$ (mass and radius of wheels)

$\omega = \frac{v}{r}$

Solving for normal forces on the inside and outside wheels:

$$n_0 = \frac{gmRw + hmv^2 + Lv}{2Rw}$$

$$n_i = \frac{gmRw - hmv^2 - Lv}{2Rw}$$

Again, setting $n_i = 0$ (normal force on the wheels on the inside of the curve), we can solve the equation to determine that a speed of approximately 6 ft/s would be required to tip the bot as it turns around a corner of R = 2ft.

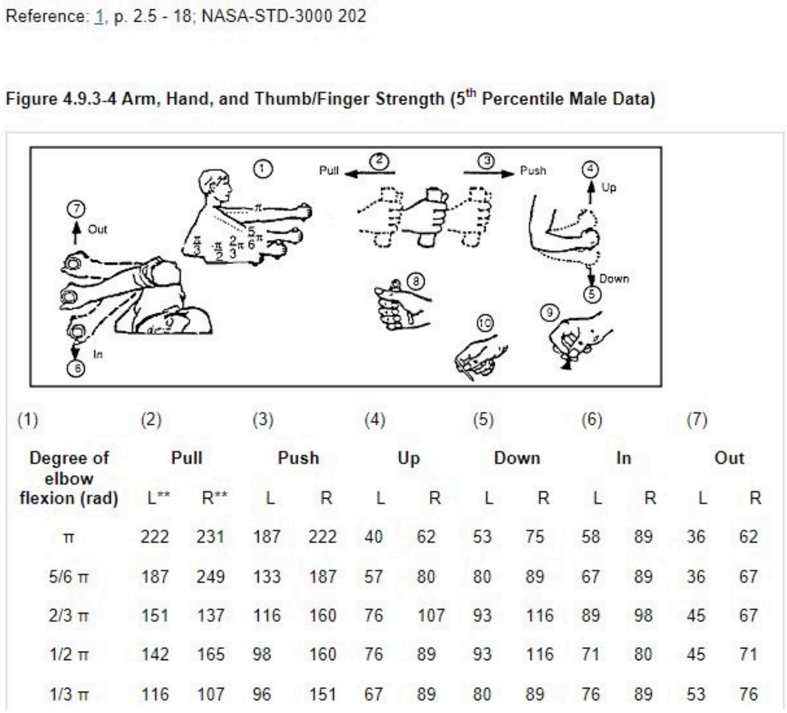
Stress/Strain

Planned

The lockbox is the most important component involved in keeping the medication inside the Pill Bot secure.To ensure that the design can maintain its structural integrity, a rough CAD model with specified material should undergo a SolidWorks FEA analysis.

Actual

A SolidWorks simulation was conducted to certify that a person with a significant amount of strength (modeled as a 5th percentile male) would not be able to break into the medication lockbox using a screwdriver. Data from Nasa's study of human performance capabilities was used to estimate the hand and finger strength that a male could exert. From Figure 19, it was estimated that a 5 percentile male is able to exert a force of 222 N pushing in at an angle of 90 degrees. This force was applied to the lid of the lockbox to determine the deflection it would undergo. Figure 20, 21, 22 are the results obtained from the SolidWorks simulation, and show that the deflection of the lid is very small even when 222 N force is pushing on it.



Reference: 1, p. 2.5 - 18; NASA-STD-3000 202

Figure 4.9.3-4 Arm, Hand, and Thumb/Finger Strength (5th Percentile Male Data)

(1)	(2)		(3)		(4)		(5)		(6)		(7)	
Degree of elbow flexion (rad)	**Pull**		**Push**		**Up**		**Down**		**In**		**Out**	
	L**	R**	L	R	L	R	L	R	L	R	L	R
π	222	231	187	222	40	62	53	75	58	89	36	62
5/6 π	187	249	133	187	57	80	80	89	67	89	36	67
2/3 π	151	137	116	160	76	107	93	116	89	98	45	67
1/2 π	142	165	98	160	76	89	93	116	71	80	45	71
1/3 π	116	107	96	151	67	89	80	89	76	89	53	76

Figure 19: Nasa Human Performance Capability Data

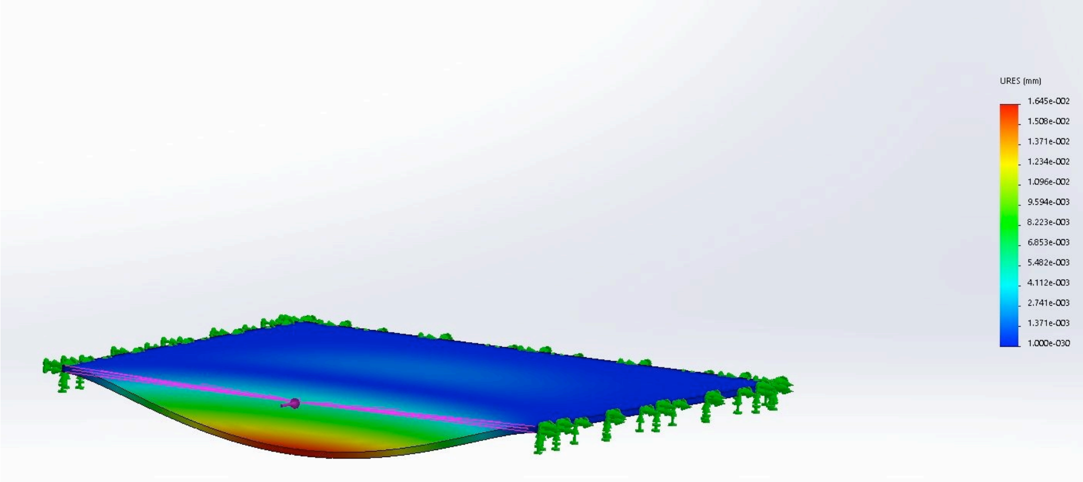


Figure 20: Displacement Analysis

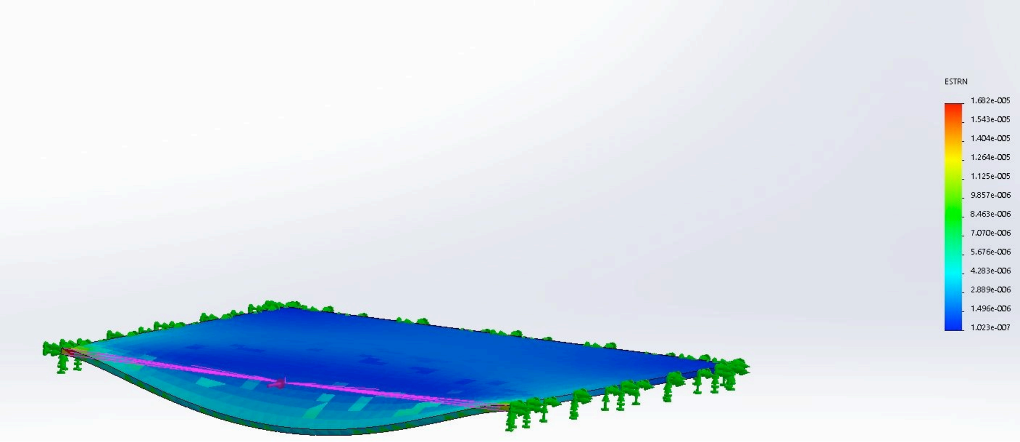


Figure 21: Von Mises Strain Analysis

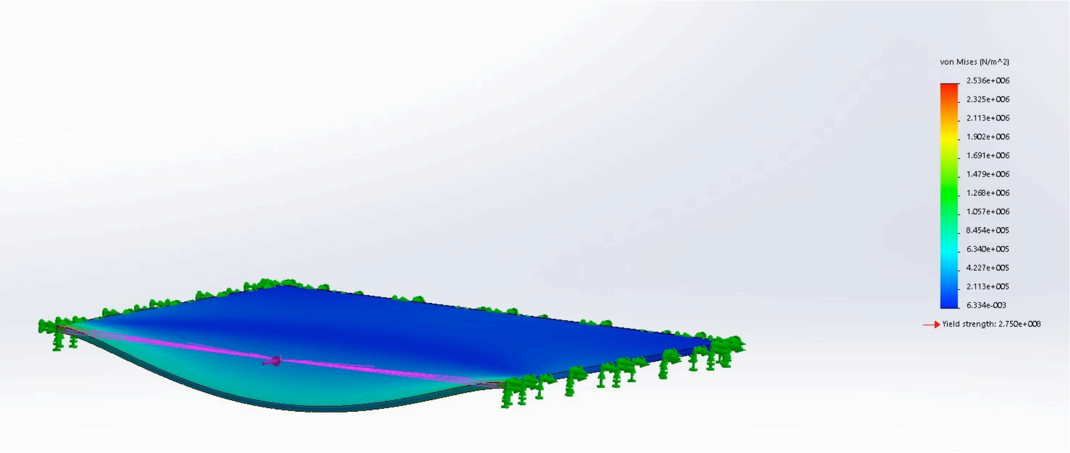


Figure 22 : Von mises Stress Analysis

Torque

Planned

The team planned to choose motors based on a rough calculation of the torque necessary to move the 45 lbs Pill Bot at a velocity of 2 ft/s.

Actual

The following analysis was performed and the selected motors are shown below.

$T = F \cdot r$

$f_r = c \cdot N$

$N = m*g$

At constant speed:

$T = r \cdot c \cdot m \cdot g$

T =((3in/12)(0.35)(50lbs)(32.2 ft/s^2)) x (0.03108 lbf • ft)

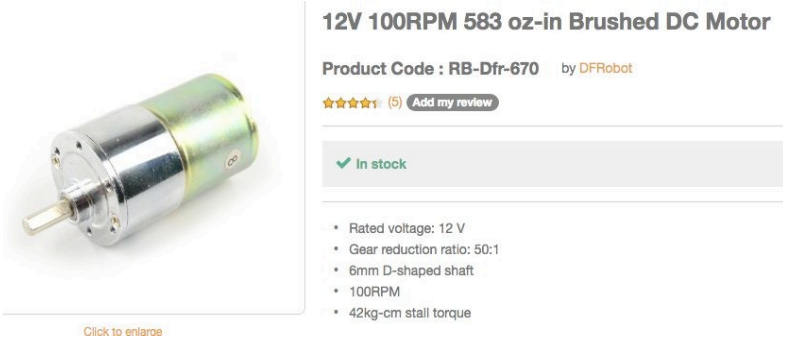
T= 4.4 lbf • ft

During Acceleration:

T = ((3in/12)(0.35)[(50*372)(50 ∗ 1/2

ft/s^2)] T= 4.7 lbf • ft

Figure 23:
100 RPM Motor



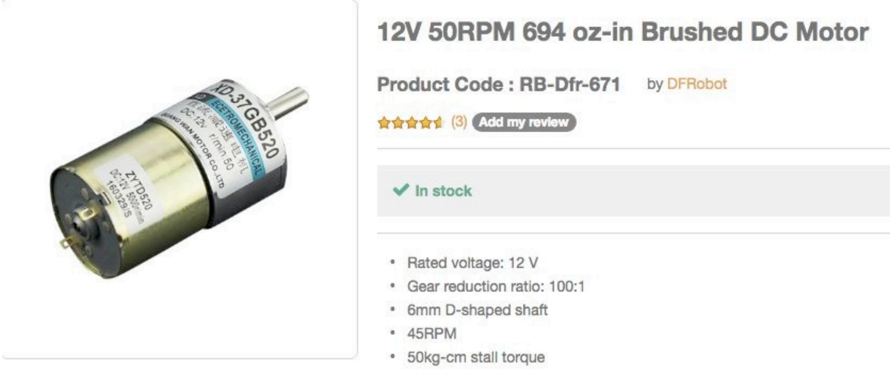
12V 100RPM 583 oz-in Brushed DC Motor

Product Code : RB-Dfr-670 by DFRobot

- Rated voltage: 12 V
- Gear reduction ratio: 50:1
- 6mm D-shaped shaft
- 100RPM
- 42kg-cm stall torque

Figure 24:

50 RPM Motor



12V 50RPM 694 oz-in Brushed DC Motor

Product Code : RB-Dfr-671 by DFRobot

- Rated voltage: 12 V
- Gear reduction ratio: 100:1
- 6mm D-shaped shaft
- 45RPM
- 50kg-cm stall torque

Heat Transfer

Planned

Determine how much all of the electrical components will output in the confined space and calculate heat loss out of the enclosure to the environment to ensure that the medication is properly insulated and not harmed.

Actual

Losses in the motor:

Mechanical Power (Watts) = $P_{out} = \tau \bullet \omega$

P_{out} = ((9kg • cm)(0.0981N • m/1 kg • cm))*((45rpm) x (2π rad/1 rev) x (1 min/60s)) = **4.159 W**

Electrical Power (Watts) = $P_{in} = V \bullet I$

P_{in} = 12V *0.417 A = **5 W**

Motor Efficiency = $\eta = P_{out} / P_{in}$

η = (4.159 W / 5 W)* 100 = **83.2 %**

$P_{in} - P_{out}$ = 4.159 W - 5 W = **-0.841 W (heat loss)**

Losses in the battery:

Heat on discharge:

$P = I_{max}^2 R_{internal}$ = (3.60 A)^2 *(0.0165 Ω) = **0.214 W (heat loss)**

Note : Considering the size of the battery the float charging and recharging heat will be very small, therefore, only the discharge heat dissipation was taken calculated.

Enclosure Temperature Rise:

$Q_{\text{Total dissip within}} = Q_{\text{motor}} + Q_{\text{battery}}$ = 0.841 W + 0.214 W = 1.054 W

Surface area = A = 2[(l x w) + (l x h) + (w x h)]

A = 2[(18 in x 18 in) + (18in x 36 in) + (18in x 36 in)]

A = 3240 in^2 = **22.5 ft^2**

$Q_{\text{Total dissip within}}$ / A = 1.054 W / 22.5 ft^2 = **0.05 W/ft^2**

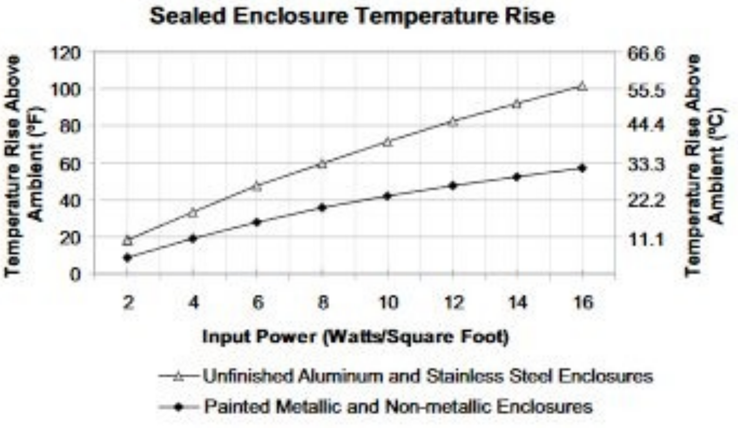


Figure 25: Sealed Enclosure Temperature Rise Chart

ΔT ≈ 5 °F [1.8 °C]

For this heat transfer analysis the battery and motors were considered to dissipate the most heat, while the circuit board and microcontroller would be dissipating a negligible amount of heat. Considering that the temperature increase above room temperature is approximately 5 °F and that medical facilities typically operate at 70 - 75 °F (source below), the heat dissipated by the battery and motor is not sufficient to affect the effectiveness or structure of the pills stored in the lockbox within the Pill-Bot.

Motor Power

Planned

Find out how much power will be required to move the robot at a speed of approximately 1 ft/s when the system is fully loaded, which is estimated to be 45 lbs.

Actual

In order to determine the amount of power (as well as power capability and power capacity in sleep mode) required for the robot to travel at 1 ft/s with a total system load of 45 lbs., the team first measured how much current the motors pulled when the bot is travelling at approximately this desired speed with the specified load. The pulled current was measured to be 0.263 A. Maximum power has been provided by the manufacturer motor specifications.

P_{meas} = 12V * 0.263A = **3.16 W**

P_{max} = **5.00 W**

Power Capability

Planned

Compute how much power each component will draw continuously over a twelve-hour time span in delivery mode and over a nine-hour time span in sleep mode to determine minimum reasonable wattage to be provided by the power source.

Actual

Current drawn during sleep mode is determined solely by current drawn from the PSoC 6, which is approximately 0.022mA. Current drawn during delivery mode is determined by current drawn from the motors and the PSoC 6. The current drawn by the motor is so much greater than that by the microcontroller, that the current by the microcontroller is negligible for this calculation. Current drawn from the motors in delivery mode obtained from calculations for motor power, where current drawn is 0.263 A.

E_{sleep} = 5V * 0.022mA * 9 = **0.99 mWh**

$E_{delivery}$ = 12V * 0.263A * 12 = **37.82 Wh**

Power Capacity

Planned

Compute the amperage to be provided by the power source for the time spans indicated under power capability so that components work at their desired performance to determine minimum reasonable battery capacity.

Actual

Currents drawn during sleep mode and delivery mode were previously calculated under analyses for motor power and power capability.

I_{sleep} = 0.022mA * 9 = **0.20 mAh**

$I_{delivery}$ = 0.263A * 12 = **3.26 Ah**

Attenuation

Planned

Determine the decrements of wireless communication attenuation over range for each ultrasonic, IR, and RFID sensor to determine physical thresholds for mounting to the bot.

Actual

After successfully programming and assembling the sensors, the attenuation range of the bots were tested. The team observed at what minimum and maximum distances each sensor receiver would respond to the corresponding sensor transceiver.

ultrasonic $_{min}$: **0.5 in.**

ultrasonic$_{max}$: **69.5 in.**

RFID$_{min}$: **0 in.**

RFID$_{max}$: **3.75 in.**

Risks Reduced and Remaining

Mechanical: Base-Frame Mobility RRP

Building the base frame, the Robo-Medics determined that it is entirely possible to move a 45 lb load at speeds that are safe for travel within a medical facility. Seeing that the structure could easily be maneuvered about its environment using a remote control system, the mobility risk has been reduced.

Electrical: Sensor System RRP

Integrating a system of sensors including Ultrasonic for distance detection, IR sensors for speed detection, and RFID for location has reduced the overall electrical risk of this project. One of the key elements the Pill Bot has is the ability to travel autonomously through a medical facility. The system of sensors will collect data from its surroundings to then constantly update its current location in relation to the floor layout. All of the sensors work and most of them are well within the defined specifications. This means that navigation risks were successfully reduced.

Remaining Risks

After testing specifications and completing analyses, there are not many looming risks involved with the completion of this project. Mechanically, the biggest remaining concern is increasing the cruising speed of the bot. This should be a relatively simple fix with a new motor selection that is capable of achieving higher rpm values while keeping torque high. Electrically, the RFID sensors do not communicate with as extensive of a range as was predicted. This is mildly concerning, as the ultrasonic object detection sensors and RFID location sensors will need to work in harmony to navigate the bot. This data will also now need to be processed in some way to actually determine the bots current location.

Updated Project

System Diagram

Since the Robo-Medics' overall project of the Pill Bot does not include major changes, the system diagram remains unchanged as seen in Figure 26 below.

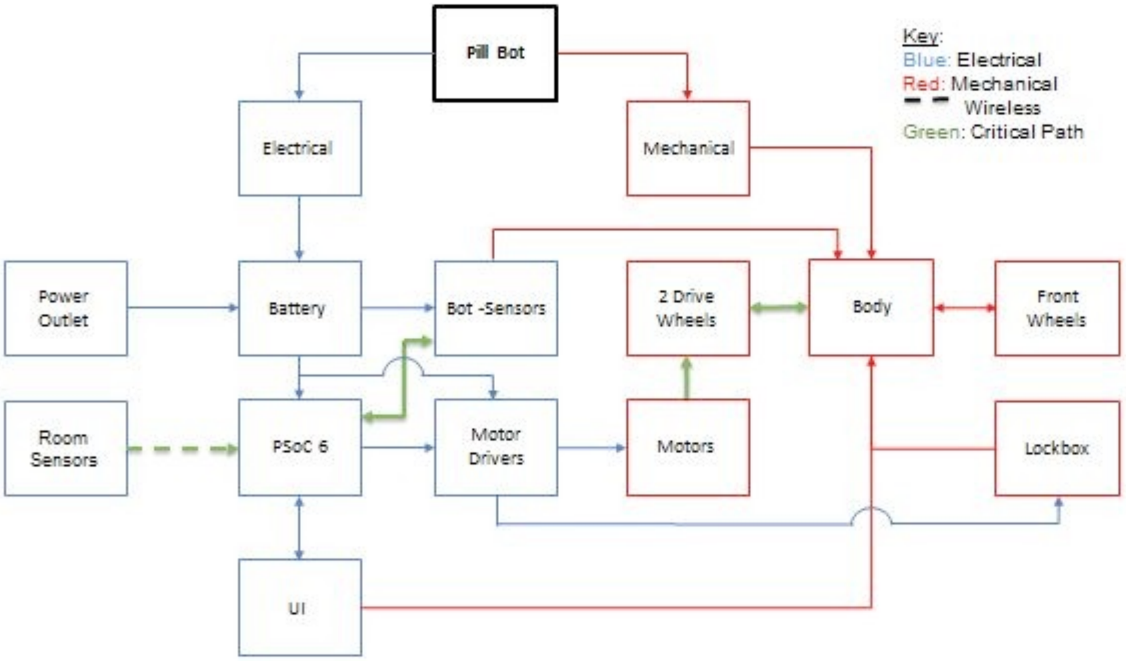


Figure 26: Pill Bot Block Diagram

Explanation of Changes

There were not any major mechanical design changes made to the Base-Frame RRP, though a significant electrical component was added to this RRP. While originally, the team had planned to power the base-frame using variable voltage independent power sources, it was instead decided to use a wireless remote controller. This decision made it possible to control the base without hazardously long cables and wires. As for electrical changes, the only one was the module being used for the RFID detection. The previous RFID module was a third party chip that only had support for Arduino kits. This was later changed to an Adafruit module that had support for Arduino and PSoC. The new module also had the added benefit of a larger detection distance which was one of the specification for the RRP.

Upcoming Design Choices

Several upcoming design choices will need to be made before winter quarter fabrication can commence. The lockbox material and locking mechanism will need to be determined. There is a general plan for these aspects of the project, but they have yet to be finalized. Similarly, the team will need to determine how exactly the lockbox will be supported above the base. This attachment will need to be secure and strong enough to support the load of the box and medications. The outside material that covers the robot’s internal components will most likely be formed from a pliable plastic, but the exact material has yet to be selected.

The upcoming electrical design choices that will need to be made for winter quarter are the memory device used, whether H-bridges will be utilized, and sensor mounting location. The memory device will hold information such as the hospital layout, patient room number, and medication. As of now the Pill Bot can only travel in one direction, the use of an H-bridge would let the bot move forward or backward for more movability. A decision will have to be made for where the sensors will be mounted to get the most accurate readings.

Winter Break and First Week Schedule

To research over Winter Break

- New motors (higher torque and rpms)
- Internal bracing structure to support lockbox
- Locking mechanism
- Nurse Access/ID verification: input pin code vs. RFID card
  - Outer protective material (pliable plastic, sheet metal)

To order over Winter Break:

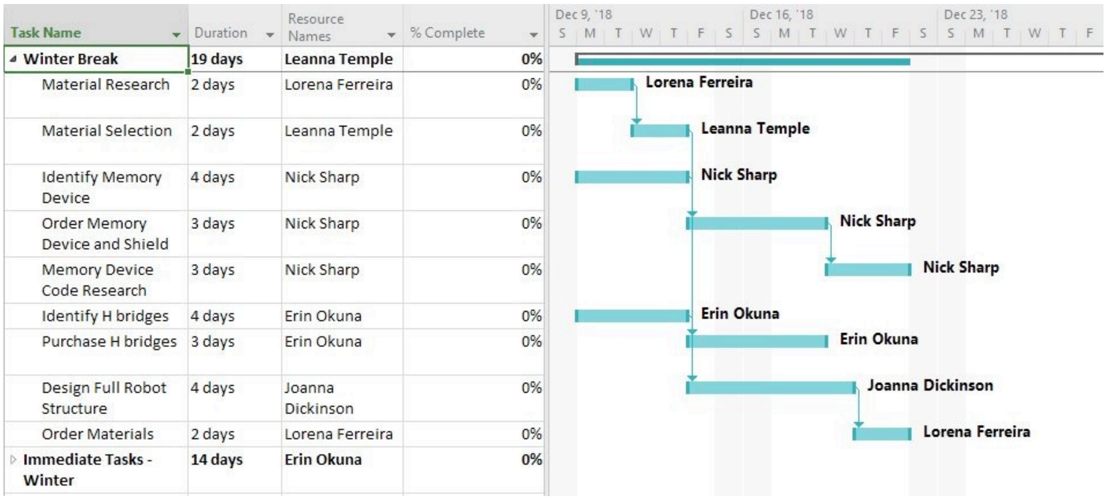
- New motors (higher torque and rpms)
- Internal bracing structure to support lockbox
- Custom made lockbox or sheet metal to build lockbox

First Week Schedule:

- Fabricate buffer between electrical components and metal base plate
- Identify possible alternative motor mounting to reduce bending load on shafts
- Update Bill of Materials
- Update CAD drawings with design decisions from Winter Break
- Create fabrication plan for the remainder of the quarter

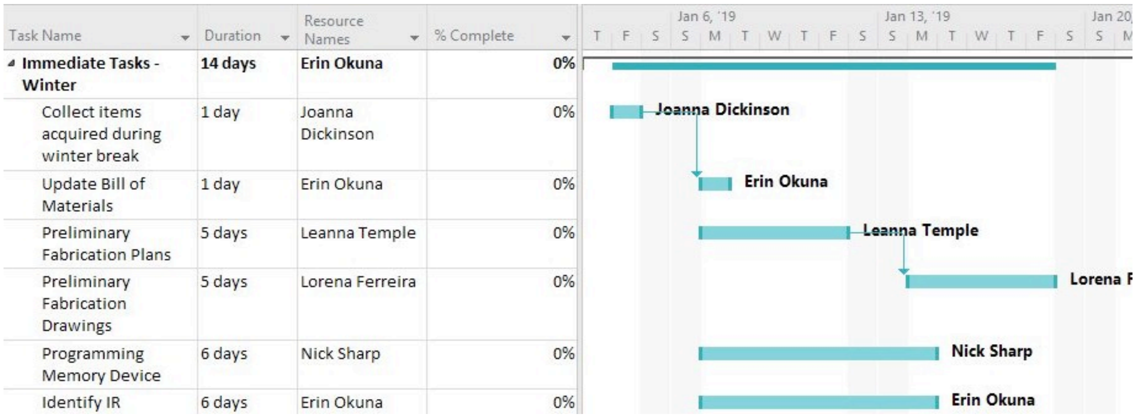
Preliminary Full Year Schedule

Gantt Chart



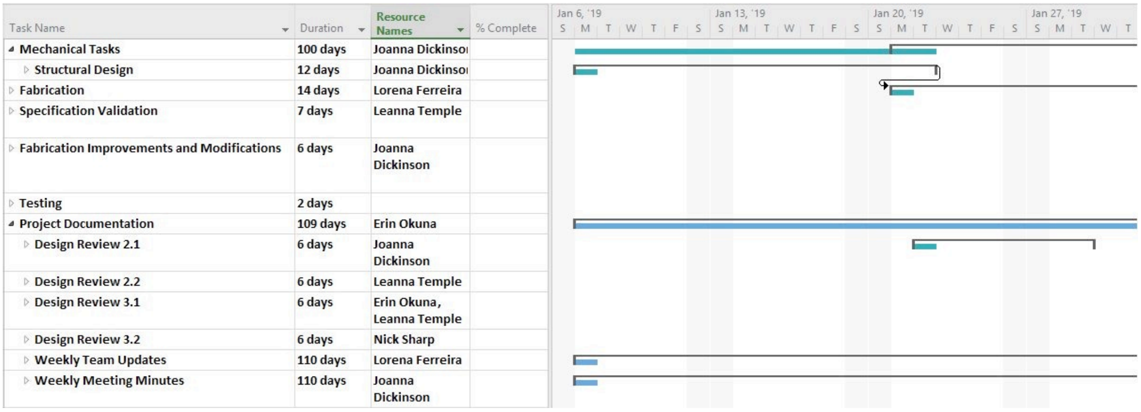
Task Name	Duration	Resource Names	% Complete
Winter Break	**19 days**	**Leanna Temple**	**0%**
Material Research	2 days	Lorena Ferreira	0%
Material Selection	2 days	Leanna Temple	0%
Identify Memory Device	4 days	Nick Sharp	0%
Order Memory Device and Shield	3 days	Nick Sharp	0%
Memory Device Code Research	3 days	Nick Sharp	0%
Identify H bridges	4 days	Erin Okuna	0%
Purchase H bridges	3 days	Erin Okuna	0%
Design Full Robot Structure	4 days	Joanna Dickinson	0%
Order Materials	2 days	Lorena Ferreira	0%
Immediate Tasks - Winter	**14 days**	**Erin Okuna**	**0%**

Figure 27: Gantt Chart Part 1



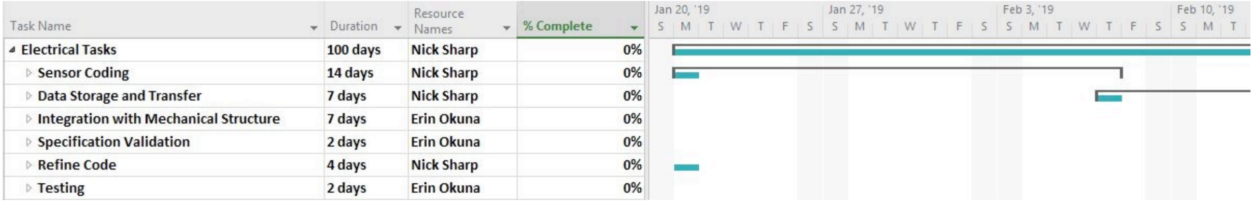
Task Name	Duration	Resource Names	% Complete
Immediate Tasks - Winter	**14 days**	**Erin Okuna**	**0%**
Collect items acquired during winter break	1 day	Joanna Dickinson	0%
Update Bill of Materials	1 day	Erin Okuna	0%
Preliminary Fabrication Plans	5 days	Leanna Temple	0%
Preliminary Fabrication Drawings	5 days	Lorena Ferreira	0%
Programming Memory Device	6 days	Nick Sharp	0%
Identify IR	6 days	Erin Okuna	0%

Figure 28: Gantt Chart Part 2



Task Name	Duration	Resource Names	% Complete
Mechanical Tasks	**100 days**	**Joanna Dickinso**	
Structural Design	**12 days**	**Joanna Dickinso**	
Fabrication	**14 days**	**Lorena Ferreira**	
Specification Validation	**7 days**	**Leanna Temple**	
Fabrication Improvements and Modifications	**6 days**	**Joanna Dickinson**	
Testing	**2 days**		
Project Documentation	**109 days**	**Erin Okuna**	
Design Review 2.1	**6 days**	**Joanna Dickinson**	
Design Review 2.2	**6 days**	**Leanna Temple**	
Design Review 3.1	**6 days**	**Erin Okuna, Leanna Temple**	
Design Review 3.2	**6 days**	**Nick Sharp**	
Weekly Team Updates	**110 days**	**Lorena Ferreira**	
Weekly Meeting Minutes	**110 days**	**Joanna Dickinson**	

Figure 29: Gantt Chart Part 3



Task Name	Duration	Resource Names	% Complete
Electrical Tasks	100 days	Nick Sharp	0%
Sensor Coding	14 days	Nick Sharp	0%
Data Storage and Transfer	7 days	Nick Sharp	0%
Integration with Mechanical Structure	7 days	Erin Okuna	0%
Specification Validation	2 days	Erin Okuna	0%
Refine Code	4 days	Nick Sharp	0%
Testing	2 days	Erin Okuna	0%

Figure 30: Gantt Chart Part 4

Explanation of Schedule

As seen in Figure 27, Winter break tasked have been outlined to include identification of materials and preliminary designs for Pill Bot before starting Winter quarter. As seen in Figure 28, Winter quarter starts off quickly with the immediate tasks that need to be completed before the fabrication and integration process can begin which is estimated to take the vast majority of Winter quarter. Figure 29 then shows the design, mechanical fabrication, and testing that will be completed during the quarter. Figure 30 shows the individual electrical code development and the integration with the mechanical components to complete the full Pill Bot before performing final overall testing.

Major Concerns

Mechanical concerns:

From completing the mechanical analyses and specifications, it has become clear to the team that the major concern remains to be speed of the robot. With the current motors, a maximum speed of 1.28 ft/s was achieved at maximum power when the Mechanical RRP was loaded with 45 lbs. While this met the threshold specification for speed, this would not meet expectations for the Pill Bot's final design. While a significant amount of time was taken to search for suitable motors, the team will take time over Winter break to search for motors that provide enough torque similar to the second set of motors purchased for the Mechanical RRP while still achieving the high RPM similar to the first set of motors purchased. If not motors can be found at a suitable price point, a trade off between torque and speed will be evaluated before moving forward in Winter quarter. Lastly, a major concern is that when the RRP was loaded with 65 lbs of weight, a deflection was noticed. If the Pill Bot would need to carry such a load in Winter quarter then a thicker base plate that could handle more load with less deflection would be needed.

Electrical concerns:

The first major electrical concern, is that when the motor is connected directly to a power source and the motor is then stalled, it will pull 2.5 amps but this is not true when connected to the motor driver. When connected to the motor driver, the motor stall current is 1.87 amps which is lower than when directly connected to a power source. Considering that the motor is being pushed to its limits, it will need all the power it can pull to accelerate the robot forward. The second major concern, is that the Ultrasonic sensor is accurate but will on occasion jump a few thousand counts. When the whole system is controlled by these sensors and they jump, even if it is rare, it will move the robot accordingly. This can cause issues because the bot movement is directly tied to the sensor.

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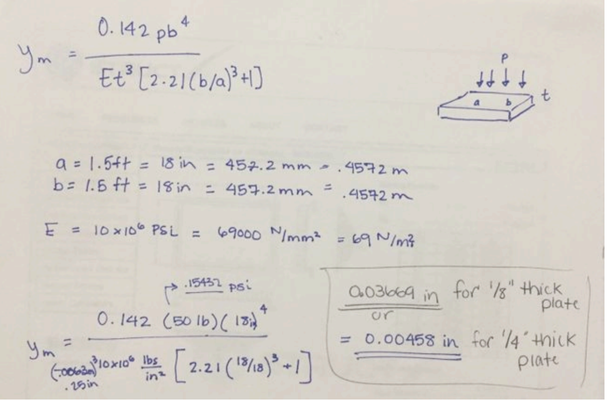
Appendix

1: Aluminum Plate Selection for Mechanical RRP Base

0.125 aluminum was the final selection.



$$y_m = \frac{0.142\,pb^4}{Et^3\left[2.21(b/a)^3+1\right]}$$

a = 1.5ft = 18 in = 457.2 mm = .4572 m
b= 1.5 ft = 18in = 457.2mm = .4572 m

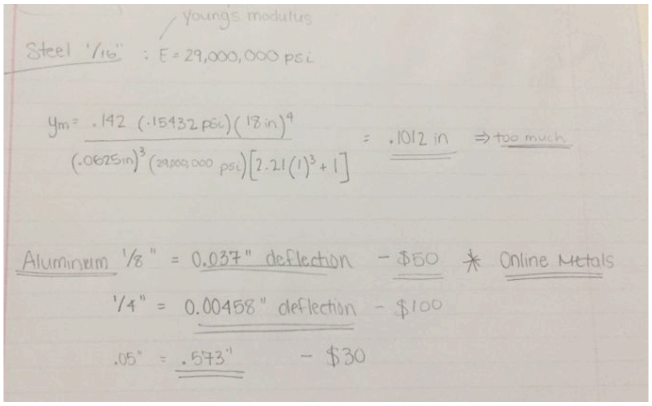
E = 10×10⁶ PSI = 69000 N/mm² = 69 N/m²

.15432 psi

$$y_m = \frac{0.142\,(50\text{ lb})(18\text{in})^4}{(.0063m)^3\,10\times10^6\,\frac{\text{lbs}}{\text{in}^2}\left[2.21(18/18)^3+1\right]}$$

.25in

0.03669 in for 1/8" thick plate
or
= 0.00458 in for 1/4" thick plate



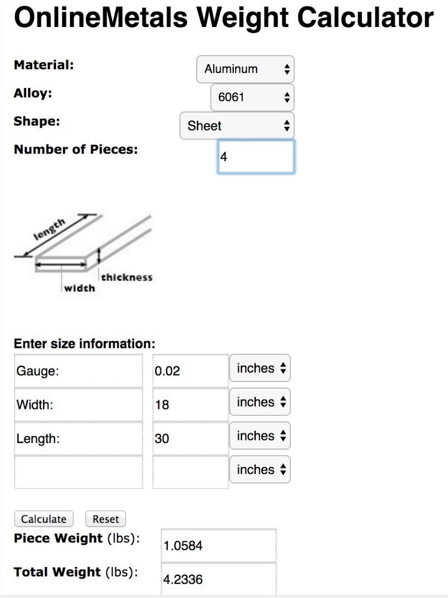
Young's modulus

Steel 1/16" : E = 29,000,000 psi

$$y_m = \frac{.142\,(.15432\text{ psi})(18\text{ in})^4}{(.0625\text{in})^3(29{,}000{,}000\text{ psi})\left[2.21(1)^3+1\right]} = .1012\text{ in} \Rightarrow \text{too much}$$

Aluminum 1/8" = 0.037" deflection - $50 * Online Metals
1/4" = 0.00458" deflection - $100
.05" = .573" - $30

2: Exterior Material Weight Estimation



OnlineMetals Weight Calculator

Material: Aluminum
Alloy: 6061
Shape: Sheet
Number of Pieces: 4

Enter size information:

Gauge:	0.02	inches
Width:	18	inches
Length:	30	inches
		inches

Piece Weight (lbs): 1.0584
Total Weight (lbs): 4.2336

Weight of exterior material (Aluminum 6061- T6) for 4 sides of Pill Bot was rounded to be 5 lbs. The remaining two sides (top and bottom) were accounted for in the plate measurements as seen in the COM calculations.