Concept Selection

1.6 Concept Selection

This section outlines the concepts chosen for each module of the RTC and why they were chosen. Some designs were modified as the school year proceeded. These design changes are also outlined in this section. The designs are separated by the individual modules, namely a Summary of the RTC Design, Drive System, Frame, Controls, Brakes, and Wheels. The designs were chosen by the team member that was assigned as the lead for the specific module. John Williams was assigned as the lead for the drive system and power system. Oscar Flores was the lead for the control system. Jacob Emerson was assigned as the lead for the brakes and wheels. Bishoy Morkos and Jacob Emerson were co-leads of the frame. The module leads have final say over the module designs chosen, unless a majority of the team agrees with a different design choice.

1.6.1 Summary of the Selection Process

This section outlines the selection process for the concepts that were selected for each module of the Robotic Trash Cart and why they were chosen. Table 1 shows the customer criteria that were considered when deciding upon a design. Senior citizens, the disabled community, and those with limited mobility and strength are the focus for the design of the RTC. Their needs and requirements were outlined through customer interviews. The customers' needs were kept in mind while completing the quality of house chart in Table 1 below. The improvement direction specifies the importance of each characteristic of the RTC. Material durability, battery life, speed of the RTC, and the RTC's price are the top 4 most influential characteristics when designing the RTC to meet the customers' needs and requirements. The RTC needs to be operable for a considerable amount of time considering trash collection generally occurs at least once a week year round. Therefore, the materials used to build the RTC must be able to withstand the weight of the bins and environmental factors. The batteries need to be able to supply enough power to the motors, control system, and emergency lights in order to dispense the waste containers to the curb for pickup on time. The speed that the RTC travels at will affect its stability when transporting the waste containers, the time that it will need to leave the home base in order to get to the pickup location on time, and the drain on the power supply. The cost of the materials and components used to create the RTC will dictate the quality of the product and the price point at which it will be sold at. A quality product will need to be made in order to incentivize the waste management companies to invest in the RTC, but will need to be reasonably priced in order to encourage customers to purchase the RTC and make a profit as well.

Table 1: *Selection Criteria*

Improvement Direction		↑	↓	↓	↓	↑	↑	N/A	↑	N/A	↓
Units		N/A	kg	Dollars	Seconds	Meters	mAh	kg/m^2	cm	m/s	N/A
Customer Requirements	**Importance Weight Factor**	**Material Durability**	**Weight**	**Price**	**Time**	**Transportation distance**	**Battery life**	**Weight Distribution**	**Drive over obstacles**	**Speed**	**Size**
Waterproof/ Weatherproof	4	9		3			3				1
Impact Proof	3	9	1	3			3				1
Easy Access to Waste Containers	4	3			3						
Recharging RTC	3	3		9	9		9				
Perform Consistent Transportation	5	9	1	3	3	9	9	3	3	9	3
Ensure RTC doesn't topple	5		3			3		9	9	9	3
RTC must be able to Traverse Incline	4		3	3		3	3	3	9	3	9
User Friendly	3			9		1	1			1	1
	Raw Score	129	35	102	54	75	108	72	96	105	76
	Relative Weight %	15.14	4.11	11.97	6.34	8.80	12.68	8.45	11.27	12.32	8.92
	Rank Order	1	10	4	9	7	2	8	5	3	6

1.6.2 Drive System

The drive system was selected due to the criteria referred to in the concept generation. A robust 12 V or 24 V drive system is needed to handle the weight, maneuverability, and power requirements for the RTC. In order to simplify the integration of the drive system to the frame of the RTC, the drive system of a used motorized wheelchair was purchased. The Hoveround CIM part #808-075 drive system has the capabilities to consistently carry a 300 pound load and is easily incorporated into our design. This drive system has the motors, gearboxes, and wheels as a single unit when purchased in an aftermarket environment. It is a proven drive system and is used in many of the mobility carts and scooters for the handicapped community and meshes perfectly with the desired conceptual design of the RTC. The drive system is capable of reaching speeds up to 2.24 m/s. This exceeds the target speed of 0.10 m/s, so operating within our target speed will have minimal drain on the power system. This will allow added features to the RTC to have access to the available power system. The drive system specifications are outlined in Tables 2.

Table 2: *Drive System Motor Specifications*

Motor with Gearbox	**Cim Number # CM 808-075 with gearbox**
Voltage	24Vdc
Braking	24Vdc
Cost	$149-$299

Gearbox	Pre attached
Speed Capacity	2.24m/s

1.6.3 Power System

To keep manufacturing costs down, the preferred power supply is a Sealed Lead Acid - Absorbed Glass Mat (SLA/AGM) battery. They are the most common types of batteries used with the chosen drive system, because they are both sealed and the casing require little to no maintenance. Lithium ion batteries were also considered, but the cost would make up at least 75% of our $1,000 budget. Our budget has increased to $1,900.00, but even with this increase in funds, purchasing lithium ion batteries would force us to do away with other design aspect. Both SLA/AGM and lithium ion batteries will power the RTC, but using SLA/AGM batteries is more cost-effective. This will make the RTC more marketable to homeowners, as well as waste collection companies. As an added bonus, the SLA/AGM batteries provide more weight allowing us to keep the RTC's center of gravity lower and counteract any top heavy loading problems that may occur. We will use two 12 V SLA/AGM batteries to power the 24 V motors. Table 3 compares the cost of SLA/AGM and lithium ion batteries. Other battery types were considered, but SLA/AGM and lithium ion batteries were considered the best option because of their cost and how readily available they were. If a battery needs to be replace, we can walk into Walmart and purchase an SLA/AGM battery.

Table 3: *Drive System Battery Specifications*

Battery	**Sealed Lead Acid (SLA) rechargeable maintenance free battery**	**Lithium Ion rechargeable maintenance free battery**
DC Voltage (V)	12	12
mAh	3500	3500
Cost for 2	$99-$149	$698-$898

1.6.4 Frame

Aluminum was chosen as the material for the frame of the RTC. A rectangular shape was chosen for the RTC because it will maximize the space to hold both the recycling and garbage bins. The rectangular shape will also minimize the effective size of the RTC. Additionally, the rectangular shape will offer the better stability when comparing to a circular design. The longer sides of the rectangular frame will allow for a large gate and ramp to unload the bins quickly from the RTC with minimal effort. The frame will have four vertical square tubes welded on each corner with two horizontal flat bars welded in between to increase overall stability. Adding siding to the RTC will offer little in terms of structural support. It is added more for aesthetic appeal; therefore, the RTC will not have any siding for the most part. This will lower the overall cost for the RTC. Initially, we were going to use HDPE sheets for the flooring, but we decided to use fiberglass grating instead. It is stronger and more corrosion resistant than the HDPE sheets. The floor of the RTC was chosen to be fiberglass grating for multiple reasons. The first is to allow the rain to seep through the base to avoid any issues with water pooling. The second reason is that the grated fiberglass can also withstand the heat from the sun without warping. Lastly it was chosen due to its high strength to weight ratio that can carry a large weight, such as two full trash cans, for an extended period of time without any structural problems. Using grated fiberglass is more cost-effective compared to aluminum or other metals. This allows for more funds to be allocated to other aspects of the budget, such as the drive system. Table 4 compares the cost between the aluminum and HDPE sheets. These materials are sold in specific proportions. For example, the HDPE sheets are sold in 8’ x 4’ sheets from Grainger. We do have to order through FSU suppliers, which can raise the costs of our materials.

Table 4: *Frame Parameters*

Frame Material	**Aluminum**	**Plastic**
Type	6061-T6	HDPE
Length (ft.)	35.5	8
Width (ft.)	2.5	4
Thickness (in.)	0.375	0.187
Cost	$110.40	$114.00

1.6.5 Control System

Initially, we were considering using a combination of a single board computer (SBC) with microprocessors handling the incoming environmental data and tasks to be completed. The SBC acts as the control center delegating tasks to microprocessors. The stretch goal for the RTC is to make it self-aware. In order to make the RTC autonomous and add object detection capabilities, there will need to be sufficient memory. The increased memory and speeds at which SBCs can operate at makes it the ideal choice; however, for our purposes it is over spec’d. Initially, we chose to use and SBC, specifically the Raspberry Pi 3 Model B+, because it had the greatest amount of open resources and the largest community of users. This would help simplify the programming of the wireless controller. However, SBCs require you to load an operating system on to them and are difficult to debug with. Because of this we chose to go just use a microcontroller, specifically the ESP-32. The ESP-32 has Wi-Fi and BLE capabilities and is Arduino compatible, which helped with programming. It was also supposed to be compatible with the motor controller that came with the used drive system we had purchased; however, the drive system did not come with a motor controller. We tried contacting CIM to purchase a motor controller, but they did not respond to our emails or phone calls. Eventually, they responded when we contacted them through their education/research department, but they would not give us specific information on the motor controller nor allow us to purchase one due to its proprietary nature. We instead purchased a Cytron SmartDriveDuo for our motor controller. It was compatible with the Arduino UNO and MEGA. When we attempted to link it with the ESP-32, we had issues using the PWM. We would have purchased an Arduino MEGA along with an HC-10 BLE module instead of the ESP-32 to simplify the programming, but we had already purchased the ESP-32. The rest of this section outlines why the Raspberry Pi 3 Model B+ and the MSP430 were originally chosen. Table 5 outlines the SBCs we were considering to use.

Table 5: *SBC Comparisons*

Board	**BeagleBone Blue**	**SanCloud BeagleBone Enhanced**	**LattePanda**	**Raspberry Pi 3 Model B+**
Processor	ARM3358 ARM Cortex - A8	ARM3358 ARM Cortex - A8	Intel Cherry Trail Z8350 Quad Core	Broadcom BCM2837B0 Quad core
Max. Processor Speed	1 GHz	1 GHz	1.8 GHz	1.4 GHz
Analog Pins	4 Pins at 1.8V	7 Pins - 1.8 V	6 Pins	None: needs add on
Digital Pins	24 Pins - 3.3 V	65 Pins - 3.3 V	6 Pins	40 pins
RAM	512 MB DDR3	1 GB DDR3	2 GB DDR3L	1 GB LPDDR2
Memory on-Board	4GB (eMMC)	4GB (eMMC)	32 GB (eMMC)	None: Micro SD port
USB	1x micro USB 2.0 1x USB 2.0	1x mini USB 2.0 4x USB 2.0	1x USB 3.0 2x USB 2.0	4x USB 2.0
Video	1x SPI Displays	1x micro HDMI	1x HDMI 1x MIPI-DSI	1x HDMI 4x Pole Stereo Output and composite video
Audio	Bluetooth	micro HDMI	Audio jack	Included in Video
Interface	4x UART 1x 2-cell LiPo 2x SPI 1x I2C	4x UART 12x PWM/Timers 1x LCD	1x 100 Mbps Ethernet WiFi Bluetooth 4.0	WiFi Bluetooth 4.2 Bluetooth Low Energy (BLE)

	4x A/D converter 1x CAN bus 8 6V servo motor 4x DC motor 4x quadrature encoder	1x GPMC 1x MMC1 2x SPI 2x I2C 1x A/D Converter 2x CAN Bus	6x Touch Panel Overlay Connectors	1x 300 Mbps Ethernet
Cost	$79.00	$69.00	$89 without Windows 10	$35.00
Notes	1x Micro SD port Small amount of open source resources and community forums, projects and support.	1x Micro SD port Small amount of open source resources and community forums, projects and support.	Option to install Windows 10 on the board. Power: 5V/2A There is an option for 4G RAM and 64G eMMC	Power: 5V/2.5A Has a micro SD port for memory. 1x CSI camera port 1x DSI display port

Trade Offs:

The LattePanda tends to get hot, so a cooling system may need to be added. It has connections already integrated for an Arduino Leonardo, which is a microcontroller that sells for $19.80. It is a cheaper version of the Arduino UNO, and has 20 GPIO pins. The LattePanda is slightly larger than the other SBCs; however, the SBCs and microprocessors are small and light enough that their size and weights are negligible. The LattePanda has only been around since 2015; therefore, it has the least amount of open source resources and the least amount of assistance from global users. It is also the most expensive of the four options. There is a version with Windows 10 already installed on the board for $119.00, but Windows 10 is not needed for this project. The LattePanda has the largest amount of memory at 32 GB and the fastest processing speed at 1.8 GHz. This ensures enough resources for other features to be enabled, such as object detection and autonomous capabilities. However, 32 GB is excessive for this project. The LattePanda has the most features that can be used for a broad range of applications, but is also the most costly. The Raspberry Pi 3 B+ and BeagleBone boards have much larger open source resources and community forums, projects, and support than the LattePanda. These are the primary reasons why it was not used.

The BeagleBone boards have the most communication protocols. The SanCloud BeagleBone Enhanced would be preferred to the BeagleBone Blue due to the larger number of analog and digital pins. This will allow for more features and applications to be enabled. It is $20.00 cheaper than the LattePanda, but the community assistance is not as extensive as the Raspberry Pi SBCs.

The Raspberry Pi 3 B+ is the cheapest of the SBCs at $35.00, but does not have any on board memory. A Micro SD can be added, but will add $15.00 to the cost. Even with this add on, it is still the cheapest option. It does not have any analog pins either, but this isn't a problem, because we plan to use microprocessors to interface with the sensors and motors. The Raspberry Pi will primarily be used to add autonomous functionality and object detection capabilities. Having to use a Micro SD, increases the chances of having a fault or error due to loose or damaged connections. It is compatible with various programming languages, such as Python, C, C++, and JAVA. The Raspberry Pi 3 B+ was chosen because of the easy user interface, price, and simple integration with microprocessors. Table 6 outlines the microprocessors and microcontrollers we considered using

Table 6: *Microprocessor and Microcontroller Concept Selection*

Boards	**MSP430F5529LP (Reference)**	**Arduino UNO Rev3**	**Arduino Leonardo with Headers**	**ESP-32**
Operating Voltage	5V and 3.3V	S	S	5V and 3.3V
Number of Pins	40	-2	-1	0
RAM	8 KB	-1	-1	0
Flash Memory	128 KB	-2	-2	+2
Clock Speed	25 MHz	-1	-1	+1
Cost	$12.99	-1	-1	-1
Programming Ease	0	+2	+2	+2
Score	0	-5	-4	+4

The MSP430F5529LP outscored both Arduino microcontrollers in every category except for the Operating Voltage and Programming Ease. The ESP-32, however, outscored the MSP430. Its compatibility with the Arduino IDE simplified the coding. The coding syntax used for Arduino is much easier than the TI boards, which use Assembly and C programming language. However, this limits the capabilities of Arduinos and ESP-32. For a cheaper price, the MSP430F5529LP has more memory, faster clock speed, more pins, and has greater capabilities than Arduino boards. The MSP430F5529LP is also the best option, because of our familiarity with the coding platform. We ended up using the ESP-32 because it was compatible with the CIM motor controller. We had to purchase a separate motor controller, which was compatible with Arduino microcontrollers. We ended up not using a PlayStation controller like we originally had planned. We spoke to gaming shops in the Tallahassee area and found that many times refurbished controllers many times have several alterations to their components and may not use BLE as its communication protocol. To avoid any surprises, we decided to use a free smartphone app call BLE JoyStick. This app is free and compatible on iOS and Android. This way anyone can download the app and you do not have to keep track of a controller.

1.6.6 Brakes

The best types of brakes for the Robotic Trash Cart are either electronic brakes. The electronic brakes can be integrated into the drive system. This wouldn't require any additional components other than manipulating the motor to become the brake for the cart. The size and cost of these brakes would also be nothing due to it already being built in the motor. However, one downside of the electronic brakes is that it would draw a small amount of energy over time. Table 8 shows a Pugh chart we made when consider different types of brakes. Fortunately, the drive system we purchased came with brakes already integrated into the motors; therefore, we no longer used brakes as a module for the RTC from this point forward.

Table 8: *Brakes Concept Selection*

		Electric Braking	Hydraulic Braking	Air Brakes	Drum Brakes	Disc Brakes	Parking Brakes
Price	0.2	6	1	2	3	4	5
Size/Compactability	0.25	6	1	2	4	3	5
Ease of Integrating	0.15	6	1	2	4	3	5
Doesn't Require Additional Componets	0.15	6	1	2	3	4	5
Effectiveness	0.25	1	6	5	2	3	4
Raw Score		4.75	2.25	2.75	3.15	3.35	4.75
Relative Weight %		22.6	10.7	13.1	15	16	22.6

1.6.7 Wheels

The wheels that were selected for the motorized wheels of the RTC are the rubber air filled wheels because of multiple factors shown in the Table 7 below. The rubber air filled wheels scored the highest on the Analytical Hierarchy Process with plastic wheels coming in a close second. One reason why the rubber air filled wheels beat the plastic wheels is due to their high availability with rubber wheels being the most common type of wheel. Another reason why plastic wheels aren't the best option is due to their durability and toughness of how quickly they wear out when rolling over rough surfaces that aren't completely flat. Lastly, rubber air filled wheels will be the best option for the motor wheels due to the ease with which they roll. Senior citizens and the disabled persons have difficulty pushing and pulling heavy objects. If the RTC malfunctions and needs to be brought back to the home base, then it needs to be easily retrieved. Rubber air filled wheels additionally provides the best rolling properties while providing some damping. The caster wheels were chosen to be a hard rubber due to its high reliability and toughness. These caster wheels will take most of the brute force of any bump so toughness is a key factor.

The drive system we purchased came with partially foam filled and air filled tires. They are used tires from a wheelchair drive system. The caster wheels we chose to use are an industrial hard rubber with heavy tread to ensure good traction.

Table 7: *Wheels Concept Selection*

		Rubber Foam Filled	Rubber Air Filled	Hard Rubber	Plastic	Steel
Price	0.3	6	8	4	10	2
Reliability	0.1	2	4	10	8	6
Availability	0.2	8	10	4	6	2
Toughness	0.25	2	4	8	6	10
Ease of Rolling	0.15	8	10	6	4	2
Raw Score		5.3	7.3	5.9	7.1	4.4
Relative Weight %		17.66	24.33	18.66	23.66	14.66