Milestone Three – Final Report

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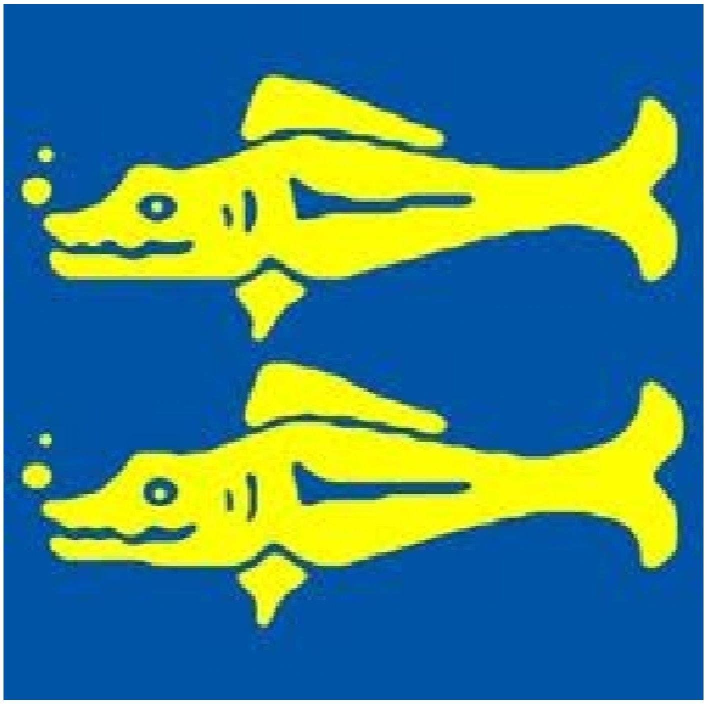

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1 Executive Summary

The robotic platform constitutes the design of an autonomous, mobile robot that is essentially a platform at wheelchair height. It follows patients who are disabled in their homes, acting as an assistant that can have objects placed on top of it. The project involves designing and building a robot with two ultrasonic rangefinders. The rangefinders determine the distance between the robot and the wheelchair. A microcontroller processes this data and uses a pre-loaded program to follow a wheelchair at a set distance. In order for the robot to function properly, both rangefinders are placed on the front of the robot - one for the left side, and one for the right side. Each rangefinder provides feedback to microcontroller, allowing it to decide whether to speed up or slow down a motor. To achieve a solution to the objectives of the problem, the robot was not only built, but considerable research about circuits, electronic components, drive trains, frames and material choice was undertaken prior to construction. Customer needs show that the platform needed to move at a fairly slow speed, be able to hold roughly up to five pounds, and at a manageable cost of roughly $350-$450. All of these customer needs were met by the robotic platform that was designed and constructed over the last six weeks. The robotic platform held up to a tested 150lbs of idle weight, moved at a speed of approximately 0.86 feet per second, and cost approximately $450 to build.

2 Table of Contents

1 Executive Summary 2
2 Table of Contents 3
3 Introduction 4
4 Project Objectives & Scope 4
  4.1 Mission Statement 5
  4.2 Determining Customer Needs 5
  4.3 Defining Product Specifications 7
5 Assessment of Relevant Existing Technologies 7
6 Professional and Societal Considerations 8
7 System Concept Development and Selection 8
8 Subsystem Analysis and Design 13
  8.1 Subsystem 1 – Frame 14
  8.2 Subsystem 2 – Drive Train 14
  8.3 Subsystem 3 – System Configuration 17
  8.4 Subsystem 4 – Power 17
  8.5 Subsystem 5 – Circuitry 18
  8.6 Subsystem 6 – Sensors 20
  8.7 Subsystem 7 – Control 22
9 Results and Discussion 23
  9.1 Results 23
  9.2 Significant Accomplishments 24
10 Conclusions 25
12 References 27
13 Appendix A: Selection of Team Project 28
14 Appendix B: Customer Requirements and Technical Specifications 29
13 Appendix C: Gantt Chart 32
14 Appendix D: Expense Report 33
15 Appendix E: Team Members and Their Contributions 36
  15.1 Team Member 1 – Tinya Cheng 36
  15.2 Team Member 2 – Brian Deignan 36
  15.3 Team Member 3 – Kevin Keating 36
  15.4 Team Member 4 – Michelle Kennedy 36
  15.5 Team Member 5 – Aimee Konet 37
  15.6 Team Member 6 – Ian Marinaccio 37
  15.7 Team Member 7 – Samuel Stouffer 37
16 Appendix F: Statement of Work 38
17 Appendix G: Lessons Learned 39
18 Appendix H: User Manual 40
19 Appendix I: Code 41
20 Appendix J: Circuit Schematics 44

3 Introduction

The design team was presented with four potential problems approximately ten weeks ago and was told to choose one and solve it. After much debate, the design team chose to pursue the creation of a robotic platform that could transport small loads from one location in a room to another. The robotic platform challenge was chosen primarily because of the strengths of the team, which were strong in regards to the programming and electronic skills needed to achieve a solution (see Appendix A for details on the selection of the team project). Detailed customer requirements were complied through surveys, interviews, and research, allowing a more focused project scope to be established. The team chose to create a robotic platform that would follow a person in a wheel chair and act as a moving table to hold items, such as a tray of food or laundry basket. The final list of customer requirements included the following key features: the robotic platform should be able to carry medium sized objects, should be able to follow a person using a wheel chair, should be able to move across an entire room, should be usable by an elderly person with ease, and should be safe and reliable (see Appendix B for detailed customer requirements and specifications). This project was worth solving because there is an unknown need for a product that can perform these functions. People who are wheelchair bound are unable to carry and transport a variety of items without great difficulty, and often have to rely on other people or products to help them. These products are often not meeting the needs of the customer. Although the creation of a moving table is seemingly a complex solution to a simple problem, it has the possibility to improve the quality of life for those who are wheelchair-bound, and thus, is worth pursuing.

This report contains a number of sections addressing the following issues: project objective and scope including mission statement; customer requirements and technical specifications; assessment of relevant existing technologies; professional and societal considerations; system concept development; subsystem analysis and design; results and discussion which includes significant accomplishments; and conclusion. Additionally, there are a number of appendixes which give additional detail and insight on the following: selection of team project, customer requirements and technical specifications, Gantt Chart, expense report, team members and their contributions, statement of work, lessons learned, and user manual.

4 Project Objectives & Scope

- Design, construct, and deliver a robotic platform that can transport small loads to different locations within a room via remote control or autonomously.

- Expand and gain knowledge in electronics and robotics.

- Perform customer analyses to determine the needs of the customer to be included in the robotic platform.

- Perform engineering analyses and tests to guide the design of the robotic platform.

- Research and evaluate advanced solutions involving automation, sensor implementation, and device interfacing.

- Design modular subsystems of the robotic platform that are easy to work on.

4.1 Mission Statement

Table 1 - Mission Statement

Product Description	A robotic platform that can transport small loads to different locations within a room via remote control or autonomously
Benefit Proposition	Able to assist people who are unable to perform everyday tasks by themselves.
Key Business Goals	Create a viable prototype to show a proof of concept.
	Show that the product can be marketed.
Primary Market	Elderly or otherwise disabled people.
Secondary Market	Lazy people.
Assumptions	Relatively easy to build and operate.
	Battery powered.
	Moves - either up and down or on a surface
	Safe to use and operate.
Stakeholders	The customer.
	The design team.
	The IED class/professor.

4.2 Determining Customer Needs

The team decided that it was of importance that the device design should be a product of direct input from potential customers, so it decided that customer needs would be developed based on in-person interviews with potential customers. The basic concept for the project was to design a robot to help the elderly. Accordingly, customer needs were compiled from the elderly and those that provided care for them. Research was conducted at the Eddy Heritage House Nursing and Rehabilitation Center on Tibbits Avenue in Troy, NY.

Data was gathered in the form of three interviews: one with an elderly patient at the center, one with a patient's family member, and the third from a home health care professional that worked at the center. Prior to these interviews, each team member brainstormed potential customer needs questions, a few of which were selected by the group and compiled as a list of interview questions (See Appendix B). Several group members then met with each person and asked the decided questions. The professor was also considered as a customer, since the product will be "purchased" via the reflection of a grade. The professor was not interviewed as his customer needs were made clear beforehand.

After conducting the interviews, the potential customers' answers to our questions were analyzed and interpreted into customer needs. Several of the key customer needs identified were as follows (the full list of customer needs can be found in Appendix B):

- Should be able to carry medium sized objects such as trays of food, laundry baskets, suitcases, grocery bags.
- Should be able to follow a person using a wheelchair.
- Should be able to move across an entire room.
- Elderly patients should be able to use the device with ease.
- Device should be reliable and able to operate for extended periods without maintenance.
- The device should be safe.

For each customer need, the team assigned a metric. This metric was a specific value or property that was measurable and would be necessary for the customer need to be fulfilled. Customer needs with corresponding metrics were as follows (the full list of interpreted metrics can be found in Appendix B):

- Should be able to carry medium sized objects such as trays of food, laundry baskets, suitcases, grocery bags.
    - Should be able to carry at least 10 lbs.
    - Carrying area should be at least 24x24"
- Should be able to follow a person using a wheelchair.
    - Should be able to sense the wheelchair's position.
    - Should turn according to position change.
    - Should travel at least 0.5 m/s.
- Should be able to move across an entire room.
    - Battery operated, no cords.
- Elderly patients should be able to use the device with ease.
    - Simple interface that is understandable to elderly.
        - Buttons should be larger than 1in.
        - Buttons should be clearly labeled with text, not symbols.
        - Input/output requirement should be minimized.
- Device should be reliable and able to operate for extended periods without maintenance.
    - Battery life should be at least one day.
- The device should be safe.
    - Rangefinder sensors to prevent collision.
    - No exposed electrical components.

4.3 Defining Product Specifications

Once the team had received and organized the customer needs, the product specifications were finalized (see Table 2 below). Unfortunately, not all of the customer needs could be satisfied. The specific functionality of the product was decided and the customer needs that pertained to the chosen design were retained (to see corresponding customer needs, see needs metrics matrix in Appendix B).

Table 2 - Specifications

Priority	Specification	Target Value	Min Value	Max Value
4	Dimensions	24”x30”x34”		*24”x36”x36”*
5	Weight	20 lbs		50 lbs
1	Carries weight	20 lbs	10 lbs	
2	speed	1 m/s	0.5 m/s	
5	Power supply	12v		12v
1	Sense wheelchair position			
1	Steer towards wheelchair position			
5	Battery life	5 hours	30min	
3	Rangefinder avoids collision with wheelchair			
3	Simple interface			
1	No exposed circuitry			

5 Assessment of Relevant Existing Technologies

The product was not the first robot designed for use by the disabled. Japan has invested a large sum of money into the development of robotic technologies to support the aging population (MacLeod). Some of these technologies include electromyographically controlled exoskeletons, which rely upon electrical signals sent from the brain to muscles to provide mechanical assistance for motor control. This may eventually lead to robotic devices which attach to the body and provide individuals with the mechanical assistance they require to stand, walk, and carry out activities of daily living. By the year 2020, researchers at Warwick University in England plan to complete the development of a fully-functioning robotic nurse (Walker). However, in the United States, a dearth of products which can provide assistance for simple activities of daily living, such as carrying objects across a room or retrieving targeted objects, already exist.

Other existing technologies are not nearly as complex. One patent the team discovered was an automated medication storage and dispensary device (Michael Handfeld). This device would be of great assistance to patients who lack the mental of physical capacity to open pill bottles or choose from the correct pill containers. Though this product seems highly useful, it does not meet the requirements for assisting patients in moving objects across a room. A very simple device which could help wheelchair-bound patients in transporting objects is the wheelchair tray (Slagerman). This would allow patients to carry small items, such as food or drinks, across the room. It would not be very helpful, however, in transporting medium-size objects, like laundry baskets or grocery bags, across the room. This is similar to the wheelchair storage compartment (Maxwell), where items may be stored in the armrest of the chair. However, only very small objects will fit. This is what sets the wheelchair follower apart. Simple solutions for small tasks already exist. Complex technologies, such as robotic nurses, are being developed for larger tasks. A large area for the development of devices which assist in activities of daily living still remains. In the search for existing technologies, no products which closely matched our customer requirements or target technical specifications could be found.

Table 3 - Patent Research for Related Technologies

Patent Number	Title / Description	Relation to this project
7735681	Medicament container locking system and method	Automated assistive device for disabled patients
5333929	Wheelchair tray	Wheelchair accessory
5074617	Wheelchair storage compartment	Wheelchair accessory

6 Professional and Societal Considerations

This wheelchair-following robot will contribute to society in a beneficial manner. It will assist the elderly, those who are wheelchair bound, and those that are dependent upon a walker. The robotic platform will make transporting objects easier, with fewer items dropped along the way. If an elderly person is getting their lunch from the fridge, it will be easy for them to transport their food, as the possibility of a drink spilling or food falling is drastically reduced. Those with reduced mobility will feel more independent with this robot. Since the robotic platform does not emit any kind of gas or scent, it is environmentally safe, provided that the individual components are manufactured with minimal impact upon the environment.

However, some safety factors do exist. Weekly wire checks are necessary to make sure the wire insulation remains undamaged. Also, children and pets away should be kept away from the drive chain, as to not get any appendages caught. In the current prototype, the robotic platform is not encased by Plexiglas. Should young children be present, proper procedures should be taken so that no part of the circuitry is touched.

7 System Concept Development and Selection

The initial task in concept generation and selection was to narrow down a focus area for the design topic. After carefully reviewing each of the four proposed design challenge areas, the team met to review what was researched individually, assessed team strengths and interests, and determined a direction for the project. Using the Team Consultation Manual, it was determined that the team’s technical strengths were in electronics, programming, and robotics. The team's weaknesses were in mechanical design and manufacturing. These technical skills and weaknesses heavily influenced project and concept selection.

The main tool used in the selection of the focus area was the decision matrix. The available categories for selection were the robotic platform, renewable energy generation device, Mueller Center retrofit, and biometrics monitoring/logging apparatus. The selection criteria included the team strengths and weaknesses, cost, team interest, project feasibility, ease of breaking the project into modular components, and how well the category complemented each team member's field of study. After each criterion was ranked and the overall scores were tabulated, the team was able to narrow down category selection to either the robotic platform or the biometrics monitoring and logging apparatus. After further consideration and deliberation, there was unanimous agreement that the robotic platform would be the most appropriate design area for the team.

Table 4—Team Project Focus Area Selection Matrix

	Team Project Focus Area			
	Biometrics	**Mueller Center**	**Robotic Platform**	**Sustainable Energy**
Selection Criteria				
Involves programming	1	0	1	-1
Technical manufacturing skills required	0	-1	0	-1
Group interest	1	-1	1	0
Team member experience	0	-1	1	-1
Design complexity	1	0	0	-1
Involves electronics	1	0	1	-1
Estimated cost	-1	0	-1	-1
Ease of concept generation	1	0	1	-1
Related to fields of study	1	0	1	0
Modular components	0	1	1	1
Sum of +1's	6	1	7	1
Sum of 0's	0	0	0	0
Sum of -1's	-1	-3	-1	-7
Net Score	5	-2	6	-6
Rank	2	3	1	4
Continue?	Possible	No	Yes	No

Before developing concepts for the product, the team conducted some market research in an attempt to analyze the needs within the medical industry. Part of the team traveled to a rehabilitation center and interviewed a geriatric patient, a family member and the head of nursing who specialized in home care. From the interviews, it was found that a key area of need, which was not addressed by current products on the market, was the ability for a person in a wheelchair to be able to carry objects around with them. Geriatric patients and patients recovering from other illness often needed help retrieving objects from the floor as well. A different target group of consumers were those who were unable to stand or walk easily and needed assistance in retrieving objects or completing tasks from a chair or bed. After assessing the needs gathered, a number of possible solutions were brainstormed. Preliminary designs and specifications for each product were drafted (see Figures 1, 2, and 3). After careful deliberation, the concepts and criterion were organized into a selection matrix (Table 5). Each criterion was rated with -1, 0, or 1. After final tabulation, a final solution was reached.

Table 5--Robotic Platform Concept Selection Matrix

	Robotic Platform Concepts				
	Wheelchair follower	**Adjustable-height platform**	**Retriever/grabber**	**Urinal/bedpan emptier**	**Food tray retriever**
Selection Criteria					
Complexity (negative)	0	0	-1	-1	-1
Ease of design	1	1	-1	0	1
Feasibility	1	1	0	0	0
Marketability	1	0	1	1	1
Control/programming	1	1	-1	-1	0
Manufacturing/labor	1	0	-1	-1	0
Reduces need for patient mobility	0	0	1	1	1
Appealing to target user	1	0	1	0	1
Appealing to health care professional	0	0	1	1	1
Team interest	1	1	0	0	1
Sum of +1's	7	4	4	3	6
Sum of 0's	0	0	0	0	0
Sum of -1's	0	0	-4	-3	-1
Net Score	7	4	0	0	5
Rank	1	3	4	4	2
Continue?	Yes	No	No	No	No

The wheelchair follower (Figure 1) was determined to be the best solution due to target user appeal, feasibility and manufacturability.

Other designs, which were considered but not selected, were the adjustable-height platform (Figure 2) and the retriever-grabber (Figure 3**Error! Reference source not found.**). The retriever-grabber was deemed to be far too complex for our purposes, and the adjustable-height platform did not seem very appealing to the target markets.

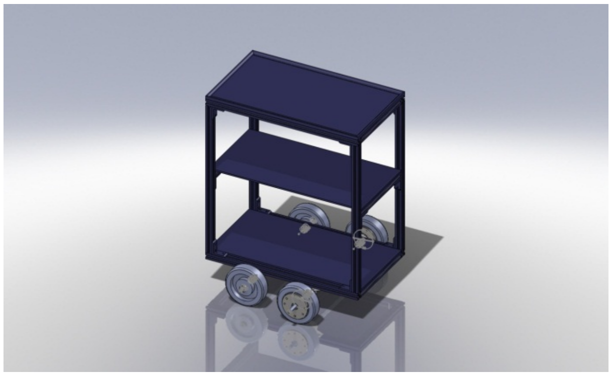

Figure 1 - Wheelchair-Following Robotic Platform

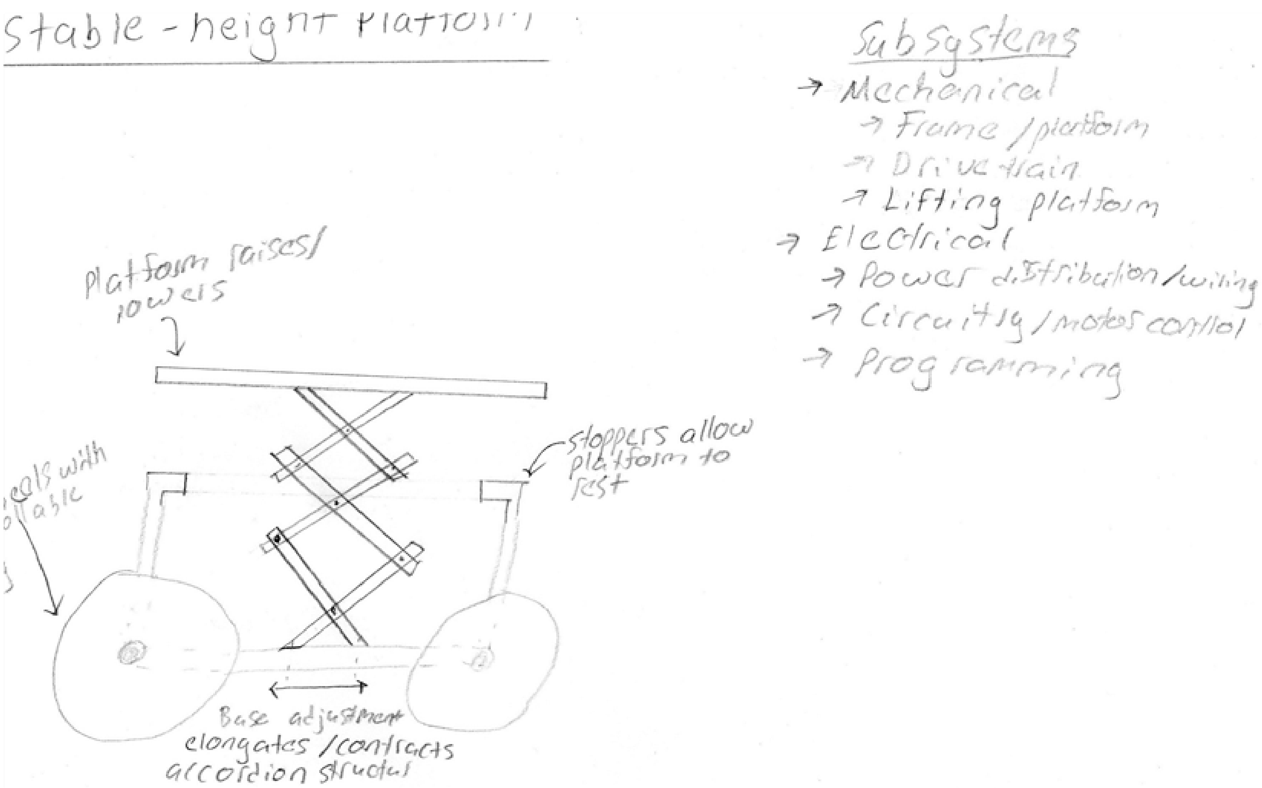

Figure 2 - Adjustable-Height Robotic Platform

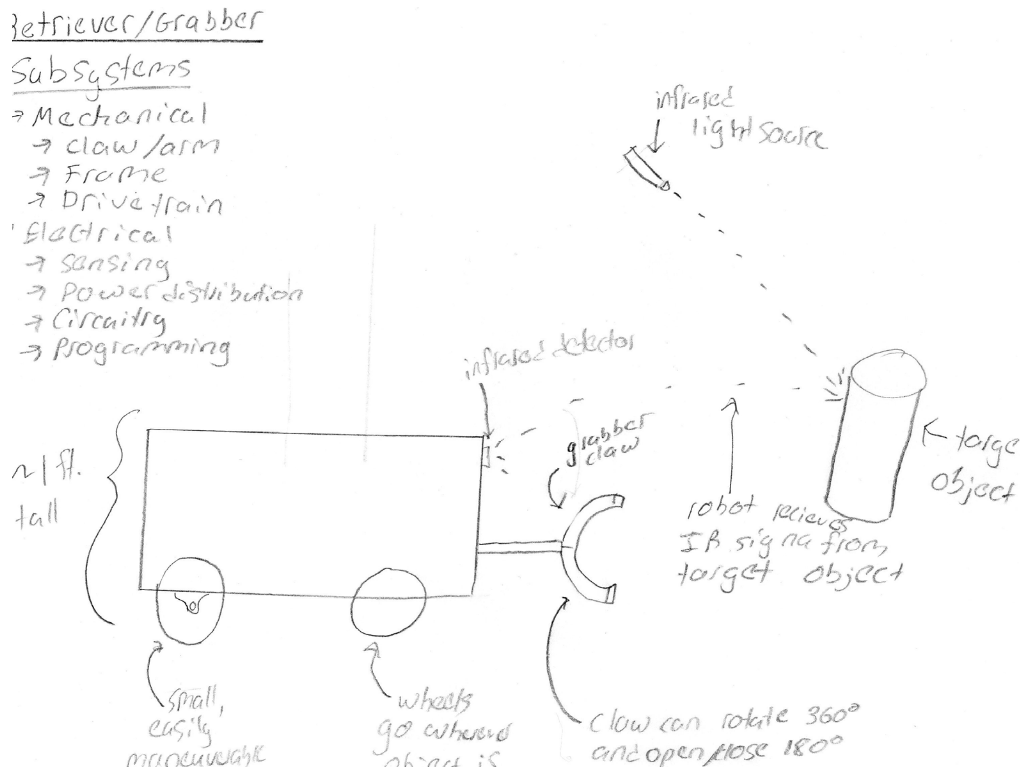

Figure 3 - Retriever/Grabber

Though the variable-height platform did not meet the selection criteria for marketability, the team was still interested in it from a design perspective and looked into the development of the product at the subsystem level (Figure 4). A number of possible solutions for raising and lowering the platform were brainstormed, including pneumatics, hydraulics, accordion jacks and stepper motors.

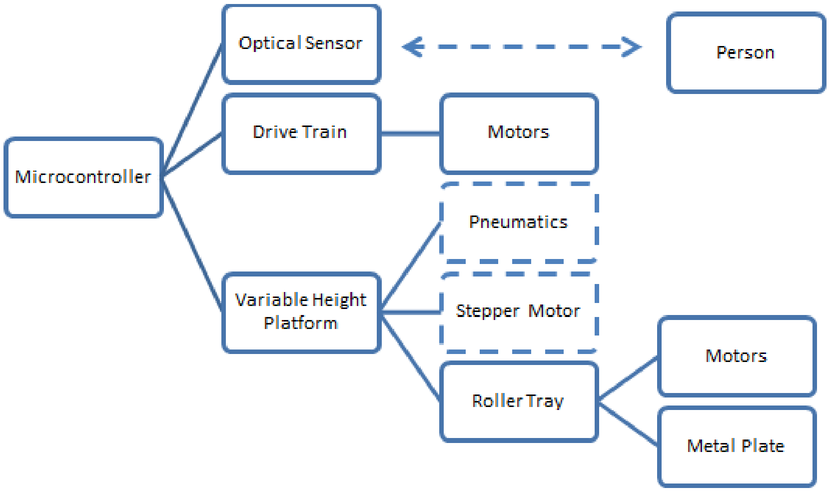

Figure 4 - Adjustable-height Platform Concept

Ultimately, the team did not believe that the variable-height robotic platform would be the best option. For the chosen system, the team began with two separate possibilities for a system concept, seen below in figures 5 and 6.

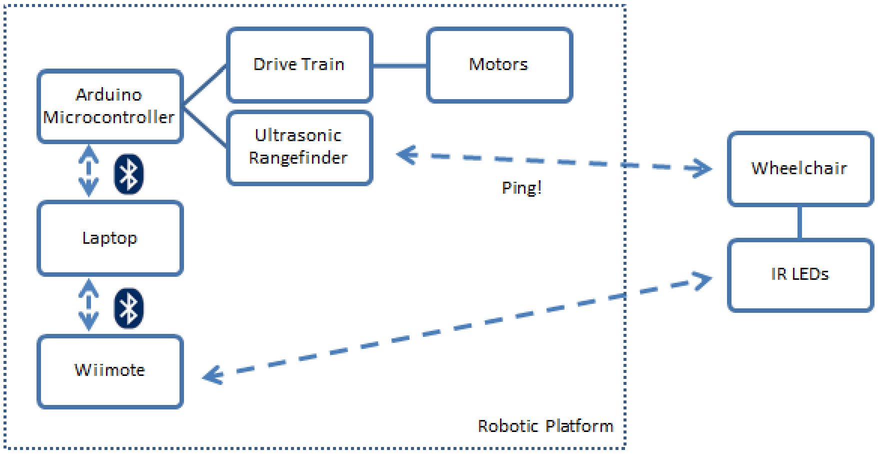

Figure 5 – Wheelchair-Follower Initial Concept

In the first design, the robot would receive sensory input from two sources: an ultrasonic rangefinder and a Wiimote. The Wiimote would pick up on infrared output from IR-LEDs attached to the back of the wheelchair. The Wiimote would be linked via Bluetooth to a laptop, which would then link up to the microcontroller. This design would allow for a lot of flexibility with input, as the Wiimote also had the capability to detect motion and had buttons and a directional pad which could be utilized for controls. The major drawback to this design was its complexity - each subsystem would require a large time investment in research and development.

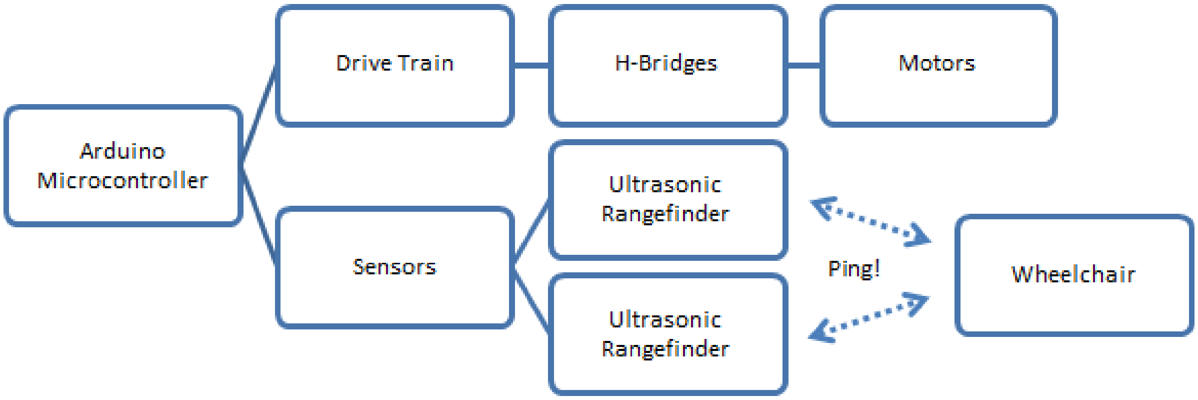

Figure 6- Wheelchair-Follower Final Concept

The second design was far simpler. The sensory inputs were only from the ultrasonic rangefinders mounted to the front. Though this design was simpler, it was found to be sufficient for the team's needs. This design also did not require any modification to the wheelchair itself, which was a considerable benefit. Each subsystem is described in detail later in this report.

8 Subsystem Analysis and Design

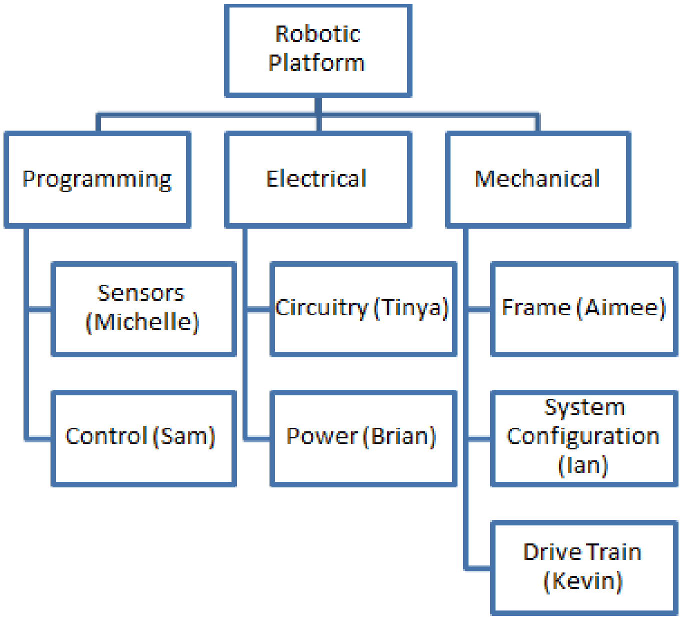

Figure 7 - Subsystem Hierarchy

8.1 Subsystem 1 – Frame

The frame provided structural support for the robot, while also taking into account the size requirements for the other subsystems. Due to the project requirements, the robotic platform needed to fit within a box with dimensions of 24” by 36” by 36”. The robotic platform itself also needed to be structurally stable to make sure tipping did not occur. The base of the robotic platform needed to be wide enough to house the motors and long enough for the battery. In order to maximize safety and minimize component damage, a middle level was installed, dedicated solely for the main circuitry of the robotic platform.

The robotic platform’s frame was created using 80/20 kit pieces. These pieces maintained structural strength and stability while remaining lightweight. In order to meet the specified requirements, the base of the robot was 24” by 36” by 36”. This accounted for the motors, battery, and the stability of the robot. An additional cross sectional support was added to ensure the base could hold the weight of the motors and battery. The superstructure was 24” in height, making the overall height of the robot 30”. It consisted of four 24” pieces which were connected at the top to a mirror image of the base, without the cross-section support. See figure 8 for clarification.

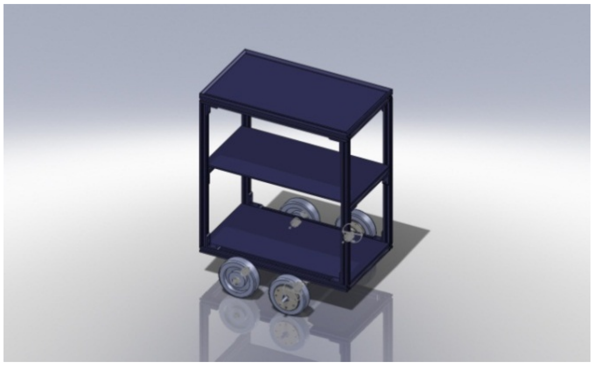

Figure 8 - Frame Design

The second level was located midway between the base and top of the robotic platform. This level increased the safety and stability of the robotic platform. On top of each respective level was a piece of medium density fiber board. All the electronics and added parts were attached to the boards in order to keep them in place. Fiber board was used as opposed to plywood due to its aesthetic quality and adequate structural strength.

8.2 Subsystem 2 – Drive Train

The overall goal for the drive train was to create a reliable system which required low maintenance while delivering high performance. To ensure design robustness, a number of quality components and design features were incorporated. Quality bearings were used to ensure alignment and low friction. A strong axle was used to avoid costly future repairs due to mechanical failure. The power was distributed from the motors in a manner which enhanced control and maneuverability. In a final iteration, the working/moving parts will be housed in a manner which protects them from environmental factors such as water, debris and undesired modification.

The drive train consisted of the wheels, axles, motors, motor-axle connection, motor-chassis connection and axle/wheel to chassis connection. This subsystem shares many components with the frame/chassis subsystem. The major requirements which were considered in the design of the drive train include maximum/minimum speed requirements, maneuverability, ease of integration with electronic control, intended use environment, overall load to be supported by axles, and vehicle shape.

One of the first decisions which had to be made in the drive train design was what type of steering mechanism to use. There are a number of commonly used steering mechanisms, including two-wheel and four-wheel differential drive, rack and pinion, and divided-chassis steering. For ease of programming and assembly, the team decided to use a differential drive mechanism. This is a system in which the wheels on either side of the robot are turned at different speeds, making the robot turn in one direction or the other. The team then had to decide between a two-wheel and a four-wheel differential drive. The major difference between the two configurations would be that, with the four-wheel drive, a sprocket would be attached to each wheel with a chain connecting both wheels on one side to the motor. With the two-wheel drive, only the front wheels would be powered by the motor and the rear wheels would spin freely.

The four-wheel differential drive would distribute the torque generated by the motors evenly to the front and back wheels. However, it would generate a large amount of friction while turning. The two-wheel drive would enable easier turning and be less prone to large frictional effects. In order for the four-wheel drive to work efficiently, both wheels as well as the motor would have to be perfectly aligned, while with two-wheel drive only the front wheels and motors would have to be aligned. Finally, the four-wheel drive system would cost about $30 more, as it would require two more large sprockets and about five more feet of roller chain. Taking these factors into account, the team decided to incorporate the two-wheel differential drive mechanism into the design.

The wheels were attached to a fixed axle mounted below the chassis using pillow blocks with internal bearings. Power was transmitted to the wheels via a chained pulley/gear system. The main components of the gear system were the roller chain, sprockets mounted to the front wheels, and a gear attached to the motor shaft. This configuration allowed power to be transmitted to either side at differential speeds.

Since torque was more important in the design than speed, a large diameter wheel was of interest. However, a large increase in the height of the robot was undesirable, as the stability of the robotic platform decreases. Other considerations taken into account during the decision of a wheel diameter were the protrusion beyond the chassis, the contribution to overall height, and the contribution to the distance between the chassis and the ground. Since the robotic platform will be used in the home and may encounter small objects in its path that it should be able to pass over, a chassis clearance from the ground of at least three inches was desirable. After considering these constraints, the team chose a 6 inch wheel diameter which, when combined to the pillow block used to mount the axle to the chassis, provided the necessary clearance while minimizing the height contribution of the wheels.

Another consideration for maximizing torque was the gear ratio between the sprockets on the motors and on the wheels. The sprockets on the wheel had to have have more teeth (larger radius) than the sprockets on the motors so that the torque (force X radius) applied to the wheels was greater. For the wheel sprocket, the largest sprocket which would still allow clearance for the chain without getting too close to the floor was chosen (36 teeth). For the motor sprocket, a much smaller number of teeth was chosen (10 teeth). In order to ensure that the gears and chains meshed properly, ANSI #25 standard sized parts were used. ANSI #25 means that the pitch of the gears (spacing between teeth) was one-quarter inch and that it was a bushing chain. This is the smallest standard-sized chain produced, and was appropriate for size and strength requirements.

In order to attach the sprocket to the wheel, hubs had to be machined to specifically match the wheel dimension. A collar was then bored into the hub to facilitate the insertion of the sprocket snugly, allowing the two pieces to be welded together. The final assembly was then bolted through the wheel to a hub on the other side so that when the sprocket was turned the entire wheel would turn without loss of torque.

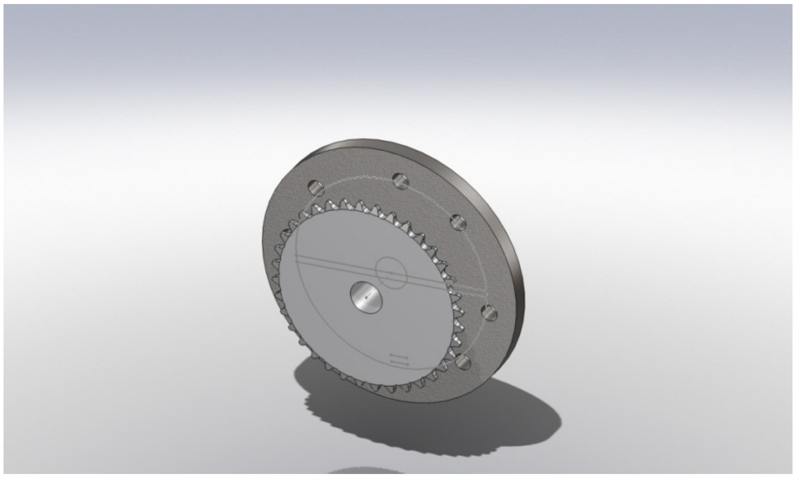

Figure 9 - Sprocket-Hub Assembly

Variables to be considered when choosing the axle material and diameter included maximum cargo load, chassis weight, motor and electrical component weight, and maximum torque to be exerted on the axle by the rotation of the wheels and drive train. A shaft diameter for which bearings could easily be found was chosen, so that the wheels and chassis could be mounted easily. The shear modulus of the material chosen had to be high enough so that it could withstand the load distributed at two regions on each axle. Since any plastic deformation would result in misalignment of the drive train, a high shear modulus is more important than considerations of whether the metal shaft had enough give. In addition, since the robotic platform was to be used indoors on a smooth surface, vibrations due to rough driving conditions and high-velocity tire rotation were assumed to be negligible. With these factors considered, as well as availability and cost, a 1/2” diameter steel (weight = 0.055 lb/inch) for the axle was chosen.

For a motor, the LoCog® DC Gearmotor from Pittman Express™ (the model that comes with the 80/20 aluminum kit) was chosen. The first reason was availability; it came with a kit that the team was already using. The second factor was cost. Provided that it remained intact, use of the motor was free. The motor was robust enough for the small power needs of the robotic platform, and had all of the documentation that was needed for torque and power output calculations.

For testing purposes, the motors were connected to the 12-volt battery to ensure that the wheels would be able to turn and propel the robot forwards. The other components were structural and were not tested except for durability, and were chosen to be intentionally more durable than necessary.

8.3 Subsystem 3 – System Configuration

The frame was able to house all of the subsystems very easily because of the robotic platform's relatively high height. There are three levels in the frame; the bottom base that holds the drivetrain, the middle level that contains the electrical components, and the top that carry the items for transport. Given more time, some form of a tray would be placed on top to more securely hold the item. The prototype was completely open, which allowed for easy access to the circuits and the battery. The finished product could potentially be encased in Plexiglas and the circuits could be placed in some form of a case. Also, the positioning of the ultrasonic range finders was important. Both were placed directly on the chassis frame on the front of the robot, one on each corner. This was the approximate height of an average wheelchair and allowed for the wheelchair to be detected more precisely. Again, in a finished product, these sensors would not simply be attached to the sides, but protected inside.

One problem that occurred with the sensors was their far placement from each other. If the wheelchair was not perfectly centered (such as during a fast, sharp turn), one of the sensors would miss the chair and cause unpredictable motion. Connecting the sensors on the vertical 80/20 beams limited the ability to change the sensors' position.

8.4 Subsystem 4 – Power

Prior to the construction of the robotic platform, two IED 80/20 kits were purchased from the Design Lab in the Johnson Engineering Center. Each kit came with its own standard motor, whose specifications are listed on the Learning Management System website for the class. Each motor has a maximum voltage of 24 volts. This was much more than what was needed in order to complete the project. Tests were done on the motors to determine what battery should be purchased. Tests showed that twelve volts was a sufficient voltage in order to power the motors both while also maintaining a relatively slow speed – a customer need. Both motors were to be wired in parallel since only one battery was purchased. Since the motors were wired in parallel, each would receive the same amount of power as if the battery were wired to just one motor. This helped the robotic platform drive relatively straight and move at a reasonable speed. 22 AWG wires were used during testing, which supplied ample current – sufficient for the prototype and easily available to the team. After testing was completed, a 12 volt, 7.5 amp-hour battery was purchased from Jameco Electronics for $30 with shipping. This battery was chosen since it was the cheapest 12 volt battery. The battery was also much smaller than most 12 volt batteries due to the low number of amp-hours. Despite the low number of amp-hours, the battery proved to last over an hour on a full charge, which was sufficient for demonstrational purposes. The actual stand-by voltage of the battery was approximately 13.5 volts when at a full charge and the cycling voltage, the voltage needed to charge the battery, was approximately 14.7 volts. The robotic platform functioned as if at full power even when the battery dropped to a stand-by voltage of 12.9 volts, which allows for the postulation that the battery could have lasted for 2 hours or more if a full power test was done. The 12 volt battery was mounted on the bottom shelf of the robot in a custom made case which was made of medium density fiber board. The case was three sided and the fourth side remained open to facilitate the insertion and removal of the battery. To prevent the battery from sliding out, a bolt was used to hold the battery in place on the fourth side. An additional nine volt battery was used to power the microcontroller and was mounted on the middle shelf next to the microcontroller. Since we did not have a rechargeable nine volt battery, the disposable nine volt battery was changed periodically to make sure the microcontroller had sufficient voltage.

8.5 Subsystem 5 – Circuitry

There were two parts to the circuitry of the robotic platform – the part with the drive train and the part that provided feedback to the drive train. IED H-Bridge circuit boards (v. 3) coupled the connection between these two parts. For power and signal distribution, a solderless breadboard was used. Toggle switches were also used to facilitate turning each of the two power sources on and off.

The two power sources consisted of a rechargeable 12V battery and a disposable 9V battery. The 12V battery was used solely as a power source for the gearmotors. The 9V battery acted as a power source for the Arduino Uno microcontroller, the ultrasonic rangefinders, and the logic side of the IED H-Bridge circuit boards. A NTE960 positive 5V voltage regulator was put in place between the battery and the microcontroller and sensors, as their maximum input voltage was +5V. The ground of the 9V battery acted as the common/reference ground for the logical side of the H-Bridge circuit boards.

The Arduino Uno microcontroller (Arduino) acted as the “brain” of the robotic platform – it executed actions based upon the loaded program and sensory input. It was powered via the Vin and GND pins by the 9V battery regulated to +5V.

The IED H-Bridge circuit boards (HBCBs) provided a way to control the IED DC gearmotors using pulse width modulation (PWM) signals generated from the Arduino. Since TTL level (+5V) logic signals are used by the microcontroller on the HBCB, the PWM signals, on a scale of 0 to 255, map to an analog voltage scale of 0V to +5V. Using positive logic convention, a PWM signal of 0 maps to 0V, turning the gearmotor fully backward. Similarly, a PWM signal of 255 maps to +5V, turning the gearmotor fully forward. A PWM signal of 127 maps to approximately +2.5V, stopping the gearmotor. Generating PWM signals between any of these reference signals turns the motor at a speed between full stop and full backward/forward. Two HBCBs were used – one to control each side (right/left) of the robotic platform.

On one side of each HBCB, a gearmotor was connected to the VM+ and VM- screw terminals. The right HBCB had the gearmotor connected in reverse polarity to account for the reversed direction of the motor when mounted on the robotic platform. The 12V rechargeable battery was connected to the Vmm and GNDm screw terminals.

On the other side of the HBCB, the 9V disposable battery was connected to the Vin and DGND screw terminals. The left/right HBCB had a wire going from the Brk screw terminal to digital pin 9/8. When an active high signal (+5V) was written to these pins, the respective HBCB implemented a break for the gearmotor by stopping the generation of PWM signals and shorting the gearmotor leads together. The left/right HBCB also had a wire going from the Ain screw terminal to digital pin 5/3. These pins output the PWM signals from the Arduino to the HBCBs.

Initially, raw PWM signals from the Arduino were used as the Ain for each HBCB. However, during testing, a PWM signal approximately in the range of 127 (stop) would cause the drive train to stutter violently. Upon close examination with an oscilloscope, it was found that there was significant noise in the PWM signals. To filter out the noise, a RC low-pass filter was put in place between the PWM pin and the Ain screw terminal for each side of the robotic platform. Since the frequency of the PWM signal was approximately 490 Hz, and we wanted to reduce the frequency by a factor of at least 10, a cut-off frequency of about 40 Hz was desired. Using an arbitrary electrolytic capacitor with a capacitance of 100μF and the equation $f_c = \frac{1}{2\pi RC}$, a resistance of 39.8Ω was desired. A 39Ω resistor was used. While the filter helped to reduce the noise, there was still noticeable noise when the robotic platform was tested. An additional 0.33μF ceramic disk capacitor was placed in parallel with the 100μF capacitor in each filter – this cancelled out any remaining noticeable noise while the robotic platform was running.

Two Parallax PING))) Ultrasonic Sensors were used as the sensory input to the Arduino. Each of these ultrasonic rangefinders had a 3-pin header. Connectors were made using wire, crimp pins and 3-pin female housings. Each rangefinder was connected to the 9V battery regulated to +5V and ground. The left/right rangefinder had a third pin that was connected to digital pin 12/11. These pins were used to listen for pulses from the rangefinders.

The entire circuit of the robotic platform was wired using 22 AWG wire. For future prototypes, lower gauge wire would have to be used, as 22 AWG wire can only handle a maximum of 7A of current. The stall current of each gearmotor alone is nearly 10A, and defective HBCBs have produced currents in excess of 20A before. While the 22 AWG wire handled testing short periods of time, a continuous testing period of approximately two hours sourced enough current to melt the insulation of the wires and fuse them together – creating a situation in which dangerous shorts could happen. A wire gauge of at least 16 AWG would be recommended, as it can handle a maximum of 22A, 2A above the 20A fuse the HBCBs use.

During the testing of the robotic platform, it was found that many of the HBCBs were defective. One notable example was a defective HBCB that contained a short – it shorted the gearmotor, in effect breaking it and making it magnitudes harder to turn the gearmotor. As a result, when the gearmotor tried to turn, stall currents in excess of 20A were created, thus routinely blowing out the 20A fuse installed on the HBCB to protect it. For future prototypes, a better designed speed controller less liable to defects and damage would be recommended.

Finally, as stated before, a solderless breadboard was used for power and signal distribution. For future prototypes, using a power distribution (DIN) rail and a printed circuit board (PCB) would be recommended. Using a solderless breadboard allows for shorts that cannot be easily found (as they are hidden underneath the plastic) and insecure connections that can become easily disconnected from the vibrations of the robot traveling over terrain.

The circuit schematics can be found in Appendix J.

8.6 Subsystem 6 – Sensors

The first design for the sensor subsystem involved the use of an infrared sensor with the use of two ultrasonic rangefinders. These sensors were chosen due to the ease they could be integrated into a coherent sensing system, cost, ease of programming, and level of necessity. This initial design would first have an infrared sensor that would include a Wiimote attached to the front of the wheelchair. This would sense the position of the wheelchair in front of it by collecting and processing the infrared signals sent out by the Wii sensor bar attached to the back of the wheelchair. In addition to this, there would be two ultrasonic rangefinders – one on the front of the robotic platform and one on the back – which could sense if the robotic platform is about to hit an object.

However, during the initial stages of building, this design was altered due to problems with device interfacing and the complexity of the system as a whole. Therefore, in order to simplify the design, the infrared sensor was replaced with two ultrasonic rangefinders. This no longer required the use of LabVIEW to interface the various components and thus allowed the robotic platform to be run using just a microcontroller. Additionally, the ultrasonic rangefinder at the back of the robotic platform was deemed unnecessary. Therefore the final design consisted of two ultrasonic rangefinders at the front of the robot – one on the left side and one on the right. Each one of these rangefinders sends out an ultrasonic 'ping' and then keeps track of the amount of time before that ping bounces off a surface and is detected again by the sensor. In the program, code (Figure 10) was written to translate the time needed for the ping to return into the distance between the sensor and the detected object. This code was part of the documentation included with the rangefinders. Thus, by using two sensors, the robotic platform can sense when the wheelchair is moving forward (the distance detected increases), moving backwards (the distance is decreasing), or turning (the distance detected by one rangefinder is greater than that detected by the other).

```
int getRange(int pingpin)
{
  // establish variables for duration of the ping,
  // and the distance result in inches and centimeters:

 int duration, inches;

  // The PING is triggered by a HIGH pulse of 2 or more microseconds.
  // a short LOW pulse is given beforehand to ensure a clean HIGH pulse:

  pinMode(pingpin, OUTPUT);
  digitalWrite(pingpin, LOW);
  delayMicroseconds(2);
  digitalWrite(pingpin, HIGH);
  delayMicroseconds(5);
  digitalWrite(pingpin, LOW);

  // The same pin is used to read the signal from the PING: a HIGH
  // pulse whose duration is the time (in microseconds) from the sending
  // of the ping to the reception of its echo off of an object.

  pinMode(pingpin, INPUT);
  duration = pulseIn(pingpin, HIGH);

  // convert the time into a distance

  inches = duration/74/2;

  return inches;
}
```

Figure 10 - Sensor Code Segment

The requirements and specifications for this subsystem were relatively simple – the sensors had to be able to sense the wheelchair position. Therefore, as long as the sensors were working properly, then all specifications were met. This was tested during the final stages of the overall design testing and was proven to work when the robotic platform responded to change in wheelchair position.

The testing done to verify the subsystem prior to integration consisted of two stages. First, each rangefinder was wired temporarily to the microcontroller and test programs were ran to ensure that each functioned properly. Second, both rangefinders were wired together and test programs were ran to ensure that they functioned properly as one unit. During this stage all problems with the programming was worked out. Additionally, during this stage, both the depth and width that each rangefinder could detect an object was observed, and it was ensured that these values were within the range needed to detect the wheelchair and that the ping ranges would not overlap.

8.7 *Subsystem 7 – Control*

The control subsystem consists of the code that is loaded onto the microcontroller. It is responsible for sending the right PWM signals to the H-bridges to make the motors move at the correct speed. The code is written in a slightly modified version of C used for Arduino microcontrollers. A full version of the code can be found in Appendix I.

The control method used was Proportional-Integral-Derivative (PID) control. PID control is a closed loop feedback system, in which the control function takes into account external feedback. In the PID control algorithm, the three terms, proportional, integral, and derivative, are calculated based on periodic checking of the system's error. The proportional term is simply the error, the integral term is the integral of the error from the start to present time, and the derivative term is the derivative of the error in respect to time. Each term is multiplied by a gain and then added together resulting in the algorithm's output.

$$\mathrm{u}(\mathrm{t}) = \mathrm{MV}(\mathrm{t}) = K_p e(t) + K_i \int_0^t e(\tau)\, d\tau + K_d \frac{d}{dt} e(t)$$

The proportional term causes the system to move towards the desired value, thus reducing error. The proportional term functions fairly well on its own with the exception that it will often overshoot the goal, causing the system to oscillate. The derivative term can effectively predict future error because it is the error's rate of change. This is used to dampen the oscillation caused by the proportional term. Finally, the integral term tracks the accumulation of past errors and will accelerate the system towards the set point when a great deal of error accumulates.

Written in a programming language, the algorithm looks somewhat like the following pseudocode found on Wikipedia:

```
previous_error = 0
integral = 0
start:
  error = setpoint - actual_position
  integral = integral + (error*dt)
  derivative = (error - previous_error)/dt
  output = (Kp*error) + (Ki*integral) + (Kd*derivative)
  previous_error = error
  wait(dt)
  goto start
```

The algorithm will, for the most part, look like this for every application. The reason for this is that there is an enormous amount of variation that can result from changing the gains for each of the three terms. A good implementation of PID is a product of extensive experimentation with gains. Proper balancing of the three terms can result in a system that reaches its target quickly, with damped oscillation and minimal overshoot. Improper balance will produce the exact opposite.

The motor control consists of two instances of the PID algorithm, one to ensure an optimal distance between the follower and wheelchair and another to keep the follower aligned with the back of the chair (steering.) The error for both functions was obtained and derived from the two rangefinder sensors described in an earlier section.

The steering function used the difference of the ranges collected by the rangefinders to measure its error. The function implements the PID algorithm to output a steering offset. This offset is passed to the motor control function. The motor control function receives the steering offset in addition to its assigned error, which is the smaller of the two collected ranges. Once the motor control PID has been calculated, it is used in two different terms, one for each motor. Both motor terms contain the motor control PID output added to the motor's specific PWM value for zero. The left term adds the steering offset to itself while the right term subtracts the offset from itself. The two terms are then adjusted so that they fit within the acceptable range of PWM values. After adjustment the program sets the output of each motor pin to the signal designated by its respective PWM value.

Due to recurring problems in the team's electrical subsystem, the team did not have a sufficient amount of time to test the gains for the PID functions. Because of this, the steering function was omitted from the product demonstration. In the demonstration, system was able to follow a wheelchair linearly, but it did not do so in an optimal manner. If more time to experiment was available, the derivative term would probably be reduced because the system already had a great deal of natural damping.

9 Results and Discussion

9.1 Results

Overall the design met the initial specifications and objectives. The robotic platform met the set dimensions and weight, and was able to carry much more than the necessary weight. The speed of the robot was slightly lower than what was necessary to follow a wheelchair, but that would be fixed with the use of a 24 volt battery. Battery life met the minimal requirement. The sensors worked correctly and enabled the robot to sense the wheelchair position, to steer towards it, and to avoid collision with the wheelchair. The interface was simple with only two switches to operate. While the circuitry was exposed on the prototype, it would be covered in the final product. The only specification that was not met by the end of the project is the robot platform's ability to follow the wheelchair as it turned. The program was written to allow this to be done - however, due to various issues in the final days of the project, the testing for this section of the project was not completed. Therefore, the success of this part of the project is unknown, but given adequate testing time, final touches could be made to the program to allow for the robot to turn correctly.

As for the objectives, a robotic platform was created and it was able to transport items across a room by following a person in a wheelchair. Each team member gained knowledge in either electronics or robotics, and most members gained knowledge in both. Research was done on various solutions to the problem and these solutions were implemented in the final design. The separate subsystems that were created were modular and easy to work on separately and as a whole system. Finally, engineering analyses was conducted to test the robotic platform both during and after the building phase.

Tests were done in individual subsections including the following: tests to find the zero position of the motors; tests to determine the battery power needed to move the motors; tests on the effect of the PWM on the motor speed; and tests on individual components before they were integrated into the system as a whole. As for the final testing done on the system, it was simply a matter of making sure that the robot would follow behind a wheelchair. Multiple attempts were needed to work out the final bugs in the programming as well as the wiring. Testing for this project as a whole was primarily dependent on whether certain parts worked correctly separately and as a whole - therefore hard data was not obtained. Instead, results were qualitative in nature, and the success of the project was dependent on whether it preformed its final function correctly.

After completing the robot, a few enhancements would be made for future references. The robot as a whole was quite heavy and in order to decrease the weight, lighter wheels and hub caps should be used. This will decrease the overall weight, increasing the efficiency of the motors. In this particular robotic platform, some of the components used were not in standard sizes, resulting in a custom made hub cap that was welded to another component. In the future, using a bigger drive chain would work more effectively. Another modification would be to use new H-bridges as the IED supplied H-Bridges that we used in the prototype had been discarded by another team, causing us to doubt their state of repair. Thicker wires would also be used to ensure that the insulation does not melt, resulting in an overall increase in safety. Also, the robotic platform would be encased with Plexiglas to increase its safety and to enhance its overall appearance. There is a great deal of tuning that can be done with the control system. First, the gains for distance PID function would be tested and optimized. Next, the steering PID function would be implemented and have its gains tuned as well.

9.2 Significant Accomplishments

The most significant accomplishment for the design team was working with or around parts that would not function properly. The trouble began shortly after the first microcontroller was purchased. This microcontroller was Bluetooth enabled - a key element of the original design. However, the Bluetooth would not connect properly with a laptop in order to upload a program onto the microcontroller, thus rendering the microcontroller practically useless and resulting in a large amount of time lost and a major design change to the project. Being able to recognize that the team could no longer continue with the original design and choosing to simplify it without wasting too much time to complete the project or losing all hope in the design, was a huge accomplishment on the part of the team. However, during the final days of the project, there was additional trouble with electrical components. Due to circumstances that were not the fault of the team, the H-Bridge fuse was blown during the final testing of the project. This resulted in the need to find another H-Bridge; however, none were left that could be guaranteed to be fully functional. This problem resulted in the search for a working H-Bridge which was never fully successful. The design team did manage to find an H-Bridge that would not blow a fuse for long enough to demonstrate the project worked. However, there were still problems with the wiring and the H-bridge which resulted in a melting of a few wires not 20 minutes before the presentation was to be given. Keeping level heads during stressful times, these last minute fixes were another significant accomplishment for individuals and the team as a whole. A third technical difficulty was encountered during the drive train development. It was much harder to set up a drive train system than originally thought, as components needed could not be purchased. A hub was needed to connect the sprocket to the wheel, but there was no standard hub in the size needed. Instead a custom hub needed to be machined, modified to attach to the wheel, and then welded to the sprocket – three things the team had wanted to avoid. However, the team overcame this challenge and was able to successfully design the part to be machined and then weld it.

As for non-technical accomplishments, the main accomplishment was the fact that the design team worked together without any major disagreements. The layout of the team and the division of labor amongst the various sub-systems and team members led to a design team that could work efficiently as individual subgroups and as a whole. Additionally, though good communication, these subgroups were always aware of the progress the other groups had made and of what needed to be done. The design team was able to overcome various other challenges – such as time constraints, busy schedules for most team members, and numerous technical setbacks – because the team worked so well together.

10 Conclusions

Over the last six weeks, many hours of work in the design lab ensued which led to the completion of the robotic platform. Using the objectives and guidelines outlined in prior sections of this proposal, the team fulfilled the customer needs that were gathered from potential customers at the Eddy Heritage House Nursing and Rehabilitation Center in Troy, NY. Despite the fact that all customer needs were met, improvements can still be made. Programming still needs to be fine tuned on the robot in order to allow the robotic platform to turn properly. Additionally, the robotic platform seemed to follow at somewhat of a far distance which could also be fixed in the programming. Some future improvements to the robot which could be made would be adding something around the edges of the top of the robot to allow it to hold rounded objects which would otherwise roll off during transport. Edges of approximately 4 inches in height could be added to the top of the robot to allow sufficient transport of rounded objects. These edges could be constructed using the medium density fiber board which was used for the shelves on the robotic platform. Another option would be to have a pole extend up at each corner at a predetermined height (6 inches or so would be sufficient) and then use these poles to wrap a net around the top edges of the robot which would keep rounded objects on top of the robotic platform. The robot can use several improvements aesthetically as well. One of the lesser customer requirements that was not achieved was to make sure that the robotic platform was not too scary for children to be around. To achieve this, the robotic platform could possibly be painted and maybe have the LEDs unexposed since children may find the blinking lights scary. Plexiglas could also be incorporated to seal in the components and prevent any damage from occurring. An improvement that could be made to the electronics would be the use of a printed circuit board rather than a protoboard. A printed circuit board allows all of the connections to be soldered which helps prevent shorts from occurring in the circuit. During testing, there was a short and one of the wires melted, but luckily, was easily replaced without any problems. One suggestion that the team received from a fellow classmate was to move all of the electronic components to the bottom shelf which would allow two shelves to be used for transporting materials, which would greatly improve the functionality of the robotic platform. One last improvement that could be made would be a sturdier case for the battery. The case that was made for the battery did not hold up very well since the edges of the case were hot glued together. There are several improvements that could be made to the robot but overall it performed well during the demonstration.

12 References

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13 Appendix A: Selection of Team Project

The decision process on concept combinations was done mostly on a subsystem basis and in accordance with the decision matrices developed during Milestone 1. From these matrices the frame was decided to be made out of the 80/20 kit, the power distribution was set to use a din rail and power blocks, and the circuit-device interfacing was set to be controlled using the Arduino microcontroller. The final decisions (drive train, and sensors) which could not be decided based off of the decision matrices alone were chosen based off of a concept combination chart (also from the first milestone). From considering various combinations of drive train and sensor configurations the team chose to use a 2 wheel differential in the drive train since it would make the most sense in the overall design (specifically the power distribution) and to have two different sensor types – infrared and ultrasonic – since both have their advantages and can be used well in coordination with each other.

However, once the project was underway, this coordination did not prove easy. The Bluetooth Arduino we initially used was unreliable and would only successfully connect to the laptop a tiny percent of the time. Also, having LabView communicate to the microcontroller proved even more difficult. It is possible to have the Wii-mote and the ultrasonic rangefinder work together, but given the time constraint it was decided to switch to two ultrasonic range finders that would be programmed by a wired Arduino only. This also changed the power distribution, since the Arduino is wired through a breadboard and thus negating the possibility of using a din rail. These changes made our robotic platform more feasible and greatly simplified the system as a whole.

14 Appendix B: Customer Requirements and Technical Specifications

Table 6 - Customer Requirements Charts

Customer: Family Member of Geriatric Patient		
Question / Prompt	**Customer Statement**	**Interpreted Need / Metric**
Typical Uses	Able to carry cans, mail, tea/coffee, etc.	Related need Related metric for this need
	Able to transport laundry baskets, large platters of food, vacuum cleaner, suitcases, grocery bags	Weight capacity about 20 lb Carrying tray at least 24”X24”
	Helping to get them across room to bathroom, make breakfast, etc.	Handgrips/supports
	Able to transport across a room	Typical distance 12-15 ft.
Likes	Not many buttons, big buttons	Inches
Dislikes	Need technical skills to operate	Universal design
	Threatening appearance/motion	Smooth movements/edges
Suggested Improvements	Graduated scale on needs basis, use cost-sharing model with Medicare	
	Japanese already have geriatric robots, look at them for model	
Customer: Professor		
Question / Prompt	**Customer Statement**	**Interpreted Need / Metric**
Typical Uses	robotic material delivery system	A robot with the ability to transport items
	device that can transport small items from one location in a room to another	A robot with the ability to transport items
	for individuals with various physical challenges and those with limited mobility, including the elderly	Can be focused on a variety of people in need of such a device
	home or business applications	Can be versatile in place of use
	device’s packaging will be important for achieving the intended functionality	Packaging reflects function
Likes	safe	Safe product
	divided into subsystems	Seven subsystems
	transportable	Low weight and size
	weight less than 20lbs	Weighs less than 20lbs
	fit in a 24”x36”x36” box	fit in a 24”x36”x36” box

Dislikes	non-working products	Working product
	welded connection	Minimize welds
	use of large amounts of liquids	Minimize liquid use
	altered radio waves emitters	Don’t alter radio waves
	unapproved motors/materials	Use approved/suggested parts
Suggested Improvements	automated	Self-controlled
	preprogrammed route	Pre-programmed
	stowing area	Storage compartment
	end effector	Device to pick up objects
	voice/sound/sight activated	Takes input from environment
	Wheeled/track/hovercraft	Able to move
	battery powered or 110VAC	Runs on a source of power
	navigate around objects	Able to correct its path
Customer: Geriatric Patient (Wheelchair)		
Question / Prompt	**Customer Statement**	**Interpreted Need / Metric**
Typical Uses	Picking up things that have been dropped	Must be able to grasp objects
	Objects dropped are telephone, newspaper, remote control, pills	Small objects, less than 6” diameter
	Carry small objects	5 lb capacity, 20 foot distance
	Following/moving ahead of a walker or wheelchair	Position sensing ability
Likes	Reliability	Long term use, and many times during the day
	Ability to retrieve objects that are out of reach	Long arm/maneuverability
Dislikes	Memorizing symbols/color codes	Universal design consideration
	Ugly/scary looking design	Aesthetically pleasing appearance
Suggested Improvements	Use words to make things more obvious than symbols	Universal design consideration
	Come in different colors	Color selection
Customer: Home Health Care Professional		
Question / Prompt	**Customer Statement**	**Interpreted Need / Metric**
Typical Uses	Retrieving lunch/food from fridge	Platform must be able to grip and carry objects—carrying capacity 5 lb

	Carry/empty urinal or bedpan	Ability to flex and rotate robotic arm
	Stroke patients need to move around	
Likes	Big numbers/symbols, color coded	
	Reliability	Must be able to be used multiple times without being reset
	Ease of use	Follow autonomous path
	Multiple functions	Multiple targets/paths depending on input signal
Dislikes	High cost	
Suggested Improvements	Get it covered by Medicare or set up a monthly payment plan to make it more appealing	
	More features that will replace need for home health aides will make the product more feasible	

Table 7 - Needs-Metrics Matrix

	Abides by design restrictions	Dimensions	Weight	Carried weight	speed	Power Supply	Wheelchair sensor	Course Correction	Battery Life	Rangefinder collision prevention	simple interface	no exposed circuitry
Can be used in a competition	X	X	X			X						X
Is easy for a senior to use											X	
Carry medium sized objects		X		X								
Follow wheelchair					X		X	X				
Move across a room									X			
Reliable									X			
Extended use									X			
Safety										X		X

13 Appendix C: Gantt Chart

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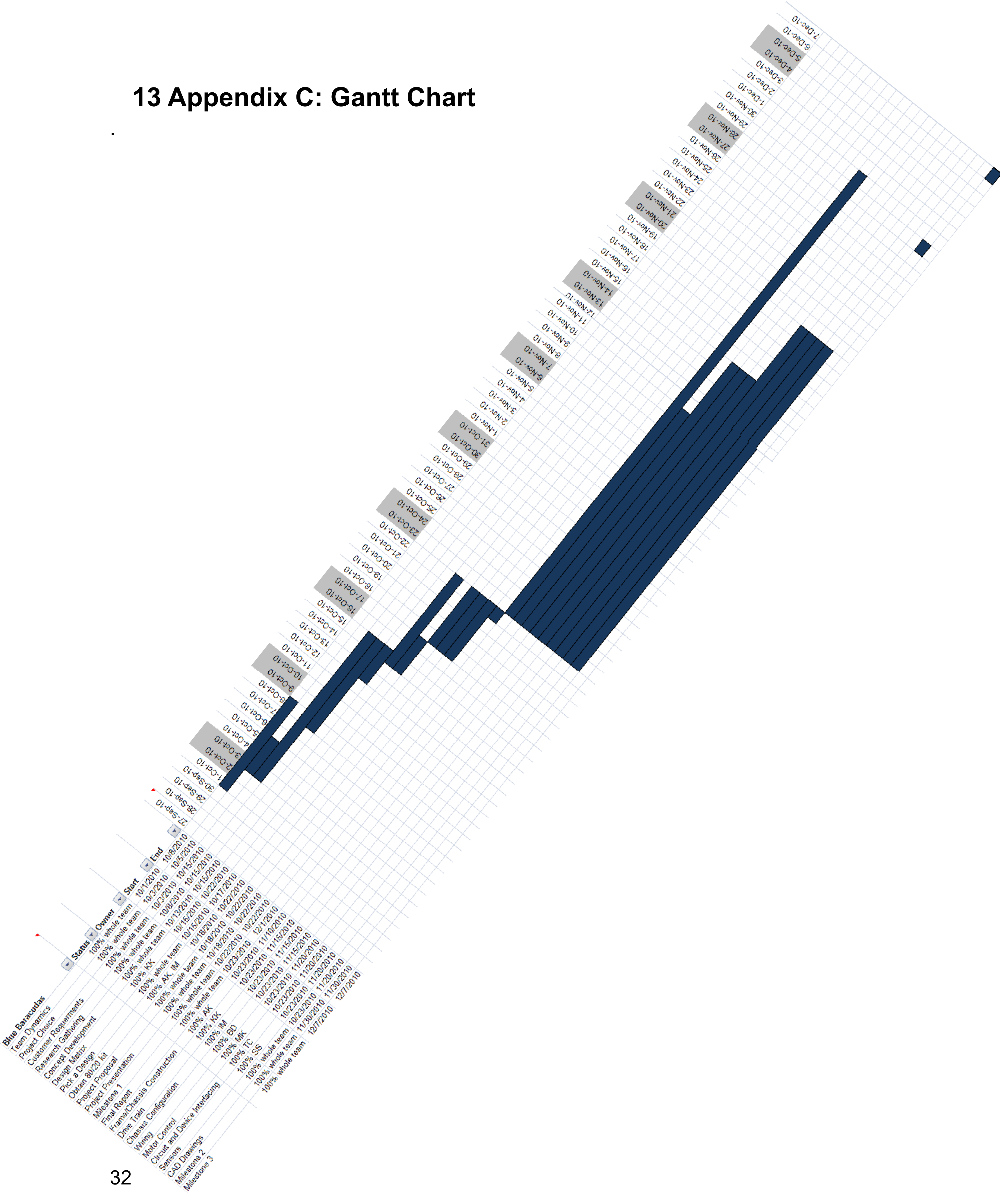


Blue Baracudas

- Team Dynamics
- Project Choice
- Customer Requerments
- Research Gathering
- Concept Development
- Design Matrix
- Pick a Design
- Obtain 80/20 kit
- Project Proposal
- Project Presentation
- Milestone 1
- Final Report
- Frame/Chassis Construction
- Drive Train
- Chassis Configuration
- Wiring
- Motor Control
- Circuit and Device Interfacing
- Sensors
- CAD Drawings
- Milestone 2
- Milestone 3

Status	Owner	Start	End
100%	whole team	10/1/2010	10/8/2010
100%	whole team	10/3/2010	10/5/2010
100%	whole team	10/3/2010	10/15/2010
100%	whole team	10/8/2010	10/15/2010
100%	KK	10/13/2010	10/15/2010
100%	whole team	10/15/2010	10/22/2010
100%	AK, IM	10/15/2010	10/17/2010
100%	whole team	10/18/2010	10/22/2010
100%	whole team	10/18/2010	10/22/2010
100%	whole team	10/22/2010	10/22/2010
100%	AK	10/23/2010	12/1/2010
100%	KK	10/23/2010	11/10/2010
100%	IM	10/23/2010	11/15/2010
100%	BD	10/23/2010	11/15/2010
100%	MK	10/23/2010	11/20/2010
100%	TC	10/23/2010	11/20/2010
100%	SS	10/23/2010	11/20/2010
100%	whole team	10/23/2010	11/20/2010
100%	whole team	11/30/2010	11/30/2010
100%	whole team	12/7/2010	12/7/2010

14 Appendix D: Expense Report

Our original budget goal was 350 dollars, but we actually spent 455.81 dollars. However, we expected to go over this estimate but did not want the project to cost more than 70 dollars per person. We were able to keep the amount per person under this limit at 65.12 dollars each. With a higher budget, several improvements could have been made. A suspension system could be added to the drivetrain to make the platform move smoother. A 24 volt battery instead of the 12 would provide much great power and allow the robot to move faster. Finally, thicker gauge wire would have alleviated several problems during testing.

Table 8 - Project Expenses

Item	Unit Price	Quantity	Subtotal	Shipping	Cost
Aluminum axle	$6.61	1	$6.61	$0.00	$6.61
Screws	$4.97	1	$4.97	$0.00	$4.97
8/32 nuts	$3.77	1	$3.77	$0.00	$3.77
Tube Clip	$0.54	2	$1.08	$0.00	$1.08
Screws	$0.98	1	$0.98	$0.00	$0.98
9V battery	$7.12	1	$7.12	$0.00	$7.12
Battery	$22.50	1	$22.50	$6	$28.50
Wii Sensorbar	$8.50	1	$8.50	$5.00	$13.50
Roller chain sprocket, 10 teeth	$4.24	2	$8.48	$10.29	$18.77
Connecting link	$0.83	3	$2.49	$0.00	$2.49
Shaft collar	$0.79	16	$12.64	$0.00	$12.64
Pillow block	$10.95	4	$43.80	$0.00	$43.80
Wheel	$13.86	4	$55.44	$0.00	$55.44
Roller chain	$13.60	1	$13.60	$0.00	$13.60
Steel rod (axle)	$6.24	2	$12.48	$0.00	$12.48
Fiber board	$5.65	1	$5.65	$0.00	$5.65
Large sprockets	$10.33	2	$20.66	$4.62	$25.28
Rubber strip	$4.63	1	$4.63	$0.00	$4.63
Large copper brackets	$0.70	2	$1.40	$0.00	$1.40
Small copper brackets	$0.70	2	$1.40	$0.00	$1.40
1/4 - 20 Bolts 3" (3 pack)	$0.98	6	$5.88	$0.00	$5.88
Hex nuts	$5.77	1	$5.77	$0.00	$5.77
Washers	$4.37	1	$4.37	$0.00	$4.37
#8-32 Machine Screw	$4.37	1	$4.37	$0.00	$4.37
Chain links	$0.83	2	$1.66	$4.39	$6.05
Shipping of Boebot/Vex Pieces	$0.00	1	$0.00	$32.00	$32.00
Ranger	$29.95	1	$29.95	$6.00	$35.95
Ranger	$29.95	1	$29.95	$5.02	$34.97
9V Holder	$0.69	2	$1.38	$0.00	$1.38

9V battery	$1.95	4	$7.80	$0.00	$7.80
35064 switch	$1.67	1	$1.67	$0.00	$1.67
35180 switch	$3.85	1	$3.85	$0.00	$3.85
9V leads	$0.49	2	$0.98	$0.00	$0.98
Shipping for Arduino	$0.00	0	$0.00	$23.24	$23.24
Breadboard	$9.71	1	$9.71	$0.00	$9.71
3-socket	$0.98	2	$1.96	$0.00	$1.96
2-socket	$0.96	2	$1.92	$0.00	$1.92
O ring	$0.53	4	$2.12	$0.00	$2.12
Screws	$7.71	1	$7.71	$0.00	$7.71
				Total	$455.81
				Total per Person	$65.12

The production of this robotic platform would not use a rented 8020 kit or IED motors so the manufacturing cost will be much higher than that of our prototype. The materials and their cost come from a variety of distributers and represent an average.

Table 9 - Manufacturing Costs

Category	Description	Qty	Cost Each	Total Cost
Drivetrain	Roller chain sprocket, 10 teeth	2	$4.24	$8.48
Drivetrain	Connecting link	3	$0.83	$2.49
Drivetrain	Shaft collar	3	$4.00	$12.00
Drivetrain	Pillow block	4	$5.00	$20.00
Drivetrain	Wheel	16	$0.79	$12.64
Drivetrain	Roller chain	4	$10.95	$43.80
Drivetrain	Steel rod (axle)	4	$13.86	$55.44
Drivetrain	Large sprockets	2	$10.33	$20.66
Drivetrain	Rubber strip	1	$4.63	$4.63
Drivetrain	Large copper brackets	2	$0.70	$1.40
Drivetrain	Small copper brackets	2	$0.70	$1.40
Drivetrain	Motor 24 V	2	$35.00	$70.00
Electrical	Breadboard	1	$9.71	$9.71
Electrical	22 gauge wire	1	$3.75	$3.75
Electrical	Toggle switch	2	$1.67	$3.34
Frame	Aluminum rod 1.5''X1.5''x14''	7	$3.92	$27.44
Frame	Aluminum rod 1.5''x1.5''x24''	8	$7.53	$60.24
Frame	Corner clamp	12	$3.69	$44.28
Frame	Small corner clamp	12	$3.29	$39.48
Frame	Bolt/Screw	90	$0.69	$62.10
Frame	Aluminum sheet 12'x24'x1/32'	3	$10.61	$31.83
Frame	Plexiglas 24''x24''	3	$10.00	$30.00
Microprocessor	Arduino	1	$30.00	$30.00

Power	12 V battery	1	$22.50	$22.50
Power	9 V battery	1	$1.95	$1.95
Sensors	Ultra-sonic range finder	2	$29.95	$59.90
Components Total				$679.46
		Hours		
Assembly	Frame	1	$13.00	$13.00
Assembly	Chassis	2	$13.00	$26.00
Assembly	Programming	1	$13.00	$13.00
Assembly	Wiring	2	$13.00	$26.00
Assembly Total				$78.00
Grand Total				$757.46

15 Appendix E: Team Members and Their Contributions

15.1 Team Member 1 – Tinya Cheng

As one of team members with experience in electronics and robotics, Tinya was in charge of circuitry and provided general knowledge of other subsystems. The main electrical components used in the circuitry were researched, chosen, and ordered by her. She wired majority of the circuitry, and fabricated any connectors needed for the robotic platform. She also acted as the team's primary organizer by keeping track of schedules, documents, and meetings by introducing tools such as Tungle and DropBox. Additionally, with experience in writing and presenting research papers, Tinya put together the first presentation and acted as the final editor for both presentations and reports.

15.2 Team Member 2 – Brian Deignan

Brian purchased and maintained the battery of the robot as well as provided help to many of the other subsystems. He made sure that the battery was charged whenever he was in the lab and constructed the case for the battery. He also played a big part in the assembly of the robot. He drilled most if not all of the holes during the construction of the robot and cut most of the medium density fiber board used for the robot as well. He also helped with the construction of the drive train by cutting the axles for the robot and adjusting the chains to the proper length.

15.3 Team Member 3 – Kevin Keating

Kevin was in charge of the drive train subsystem. This involved choosing, designing and/or purchasing the axles, wheels, sprockets, chain and other components of the drive train. Since no standard parts were available to attach the sprocket to the wheel, he also had to design a hub system, create CAD documentation for the hub, and have it machined. He and Aimee modified the hub so that it could be welded to the sprocket. Kevin did a lot of the CAD assemblies for the product, which involved taking multiple part files and assembling them into a representation of the entire system. He also did a lot of driving (i.e. to Home Depot, Radio Shack, Trojan Electronics, etc). Kevin worked together with Aimee and Brian to assemble the drive train and attach it to the frame. During the initial stages, he coordinated the trip to Eddy Heritage House to gather customer requirements.

15.4 Team Member 4 – Michelle Kennedy

Michelle's role in the team was mostly managerial. Michelle helped to prepare the various presentation and papers as well as insure that the team stayed on track during all stages of the project. Additionally, as one of the people most familiar with both the electrical/programming and the mechanical parts of the project Michelle helped to integrate both parts into a coherent whole. During the concept development and selection phase Michelle contributed various ideas and ultimately helped to shape the final design. In regards to Michelle's subsystem (sensing) she worked with Tinya and Sam on the wiring and initial testing of the two range finder sensors as well as their mounting and placement on the robot. Finally, Michelle wrote a series of programs involved in the initial testing of the motors.

15.5 Team Member 5 – Aimee Konet

Aimee was in charge of constructing the frame of the robot. This however did not take long and her attention was then directed to building and attaching the drive train and wheels to the frame. Despite numerous trips to Home Depot and endless problems, she assisted Kevin in the assembly of his subsystem. She also helped in writing her designated sections of the report and aided in the creation of the PowerPoint presentation. While in the project brainstorming stage she visited the Eddy Heritage House Nursing and Rehabilitation Center with other team members to interview potential customers.

15.6 Team Member 6 – Ian Marinaccio

Ian was in charge of the budget. He collected receipts and documented each purchase so that team members who spent more during the project could get reimbursed by others. His subsystem was System Configuration and was responsible for the location for each component. Also, he assisted during the construction process and the final testing.

15.7 Team Member 7 – Samuel Stouffer

Sam was assigned to the Control subsystem. Being the most experienced programmer on the team, he was responsible for writing the majority of the code that was used in the project. Sam was also involved in the wiring and design of the electrical subsystems. He played a major role in the final testing and debugging of the project.

16 Appendix F: Statement of Work

Semester Objectives:

1. Design, construct, and deliver the robotic platform that can transport small loads to different locations within a room via remote control or autonomously.
2. Expansion and gaining of knowledge in electronics and robotics.
3. Perform customer analyses to determine the needs of the customer to be included in the robotic platform.
4. Perform engineering analyses and tests to guide design of robotic platform.
5. Research and evaluate advanced solutions involving automation, sensor implementation, and device interfacing.
6. Design modular subsystems of the robotic platform that are easy to work on.

Approach:

Research customer needs and specifications and develop a modular system for the robotic platform that will meet those customer needs and specifications. Test and observe the device in use to develop a general device that can meet the needs of a broad spectrum of customers.

Deliverables and Dates:

1. Variety of design plans of several subsystems that will potentially appeal to customer needs and specifications. (10/8)
2. Meet potential customers to survey customer needs and specifications. (10/12)
3. Use results from surveyed data to concretely decide robotic platform concept and which subsystems to include. (10/13)
4. Milestone I – Formal presentation and written proposal for selected design area and concepts proposed to address the needs presented by potential customers. (10/22)
5. Milestone 2 – Prototype demonstration. (11/30)
6. Milestone 3 – Design Review and Documentation (12/7)

17 Appendix G: Lessons Learned

There were plenty of lessons learned from this project as well as lessons learned from the mini-project which we tried to incorporate into this project. Some things that worked well and we would use again was our conflict management skills. All conflicts within the group were managed effectively and had no hindrance on the completion of our project. Our group was very task oriented and we were able to stay on task when working in the lab. Some problems that arose were blown fuses on one of the H-Bridges. During the last week of testing we blew 11 fuses total which is an absurd amount. This was due to the fact that we had a faulty H-Bridge. We found out that there was an H-Bridge tester in the Design Lab after blowing 11 fuses which came in handy in fixing the problem and should be noted for future projects involving H-Bridges. Another problem was not following the Gantt chart. We thought we had learned this lesson from the mini-projects but we ended up not being able to follow the Gantt chart once again. Things to try for the future would be strictly following the Gantt chart to allow for a sufficient amount of time to test our project. Another thing would include making CAD drawings during the preliminary stages to help make sure that our design is feasible as far as having enough clearance for each part being utilized in the project. A third thing that we can try for the future would be to show our design to a professional. A professional could critique our design and reveal to us any flaws as well as give suggestions for improvement. These lessons will be very useful in our future endeavors.

18 Appendix H: User Manual

The operation of our product is exceedingly simple.

1. Position the device behind the customer’s wheelchair
2. Turn on the Black plastic switch to start the control circuitry
3. Turn on the Metal switch for the device to begin following
4. To deactivate the device turn off the Metal switch and then turn off the Black plastic switch

- Charge the battery when the device is not in use
    - The battery for the current prototype can only be charged with a DC power supply. Future prototypes would include AC adaptor
- If the light on the microcontroller is not lit when the Black switch is turned on replace the 9V battery

19 Appendix I: Code

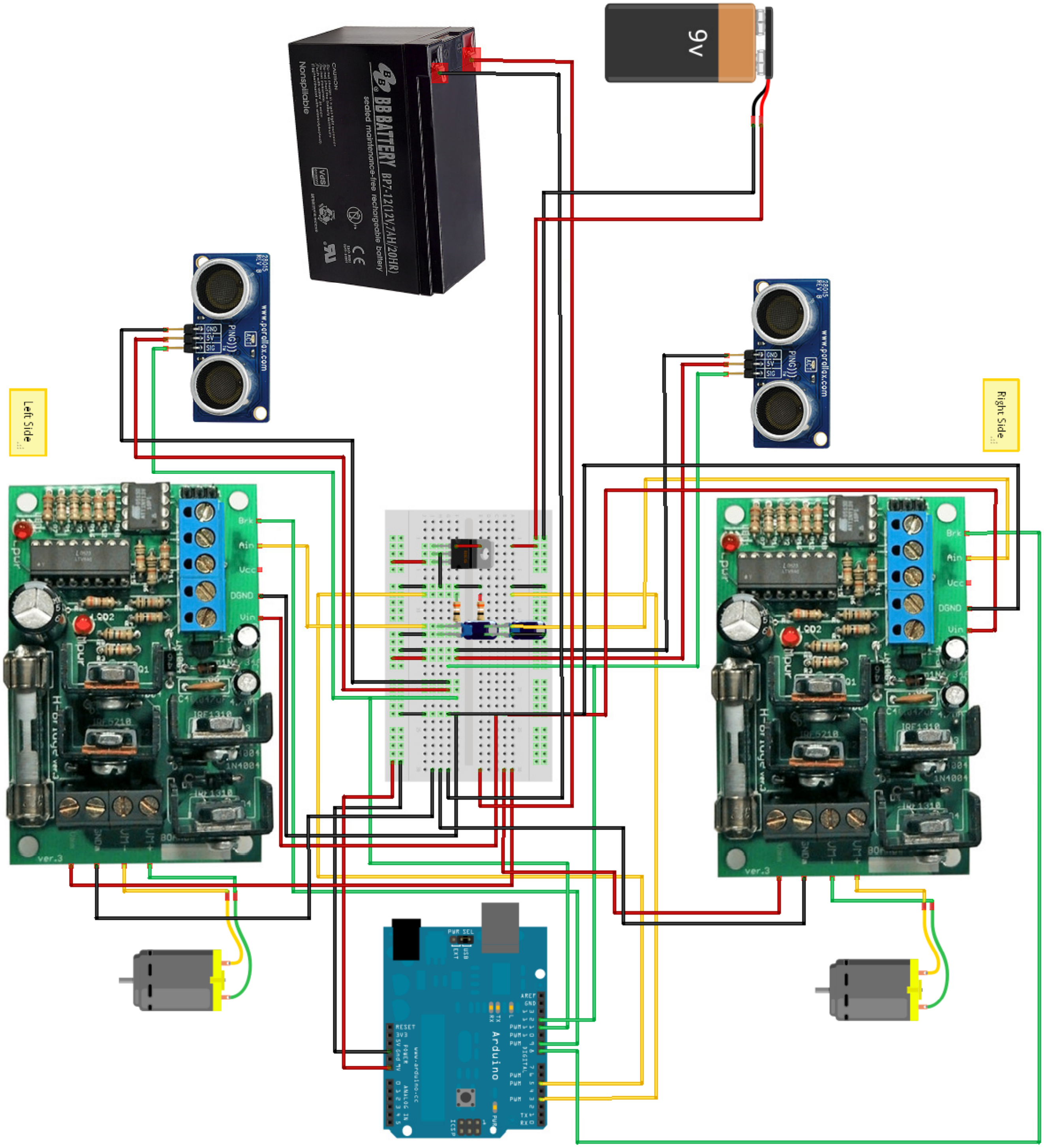
```
//////////////////////////////////////////////////////////////////////////////////////////////////////
//  Motor Control Code  \\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\
//////////////////////////////////////////////////////////////////////////////////////////////////////
//  Blue Barracudas \\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\
//////////////////////////////////////////////////////////////////////////////////////////////////////

//  Definitions///////////////////////////////////////////////////////////////////////////////////////
//----------------------------------------------------------------------------------------------------
#define LMOTOR 5        //The left motor is assigned to pin 5
#define RMOTOR 3        //The right motor is assigned to pin 3
#define LPING  11       //The left range finder is assigned to pin 11
#define RPING  12       //The right range finder is assigned to pin 12

#define SKp    1        //Steering proportional gain
#define SKd    1        //Steering derivative gain
#define SKi    1        //Steering integral gain
#define MKp    1        //motor proportional gain
#define MKd    2        //motor derivative gain
#define MKi    0.5      //motor integral gain

#define SK     1        //Steering Gain
#define dt     0.5      //The amount of time in between each motor control iteration

#define maxcount 100    //used for debugging purposes

//The pwm values accepted by the left and right H-bridges that cause them to output 0V
#define lpwmzero 77
#define rpwmzero 127

#define Desired_Position 24    //The ideal distance between the wheelchair and the follower

double steering_preverror;     //The steering error value from the previous steering control iteration
double steering_integral;      //The integral value for the steering control function

double motor_preverror;        //The position error value from the previous motor control iteration
double motor_integral;         //The integral value for the motor control function

int count;   //Used for debugging purposes
//---------------------------------------------------------------------------------------------------

/////////////////////////////////////////////////////////////////////////////////////////////////////
//  adjustforpwm  ///////////////////////////////////////////////////////////////////////////////////
/////////////////////////////////////////////////////////////////////////////////////////////////////
//Receives a double value, changes it to the maximum or minimum accepted pwm value if it is above or
//below the accepted range respectively, and returns the value converted to an int
//---------------------------------------------------------------------------------------------------
int adjustforpwm(double value)
{
  if(value > 255)
    value = 255;
  else if(value < 0)
    value = 0;
  return (int)value;
}
//---------------------------------------------------------------------------------------------------

/////////////////////////////////////////////////////////////////////////////////////////////////////
//  steering_control  ///////////////////////////////////////////////////////////////////////////////
/////////////////////////////////////////////////////////////////////////////////////////////////////
//Recieves the steering error, and then calculates and returns a steering offset value that is used in
//the motor control function
//---------------------------------------------------------------------------------------------------
double steering_control(double steering_error)
{
  //The integral term is updated with the latest steering error
  steering_integral += steering_error * dt;

  //The derivative term is equal to the current error minus the previous error all divided by the change
  //in time in between data collection
  double derivative = (steering_error-steering_preverror)/dt;
  //The previous error value is set to the current error
  steering_preverror = steering_error;

  //The three terms are multiplied by their respective gains and then added to get a steering offset
  double value = SK * (steering_error*SKp + steering_integral*SKi + derivative*SKd);

  if(count > maxcount) //For debugging purposes
  {
    Serial.print("Steering Offset: ");
    Serial.println(value);
  }

  return value;
}
//---------------------------------------------------------------------------------------------------
```

```
//////////////////////////////////////////////////////////////////////////////////////////////////////
//  motor_control  ///////////////////////////////////////////////////////////////////////////////////
//////////////////////////////////////////////////////////////////////////////////////////////////////
//  The motor control function recieves a steering offset and the position error as an input.
//The function determines a value representing the necessary motor setting to minimize position error.
//The value is modified for each motor by adding or subtracting the steering offset.  Each modified
//Value is adjusted to be a proper pwm value and is set as the output signal to its respective H-bridge
//----------------------------------------------------------------------------------------------------
void motor_control(double steering_offset, int position_error)
{
  //The integral term is updated with the latest position error
  motor_integral += position_error * dt;

  //The derivative term is equal to the current error minus the previous error all divided by the change
  //in time in between data collection
  double derivative = (position_error-motor_preverror)/dt;
  //The previous error value is set to the current error
  motor_preverror = position_error;

  //The three terms are multiplied by their respective gains and then added to get an output value
  double output = position_error*SKp + motor_integral*SKi + derivative*SKd;

  //The left motor value is set to the left pwm zero plus the output value plus the steering offset
  double lspeed = lpwmzero + output + steering_offset;
  //The right motor value is set to the right pwm zero plus the output value minus the steering offset
  double rspeed = rpwmzero + output - steering_offset;

  //Both motor values are adjusted for use as pwm values
  lspeed = adjustforpwm(lspeed);
  rspeed = adjustforpwm(rspeed);

  //Outputs the values for debugging purposes
  Serial.print("Left Motor: ");
  Serial.print(lspeed);
  Serial.print("\tRight Motor: ");
  Serial.println(rspeed);

  //The left and right motor pins are set to output their respective values
  analogWrite(LMOTOR, lspeed);
  analogWrite(RMOTOR, rspeed);
}
//----------------------------------------------------------------------------------------------------


//////////////////////////////////////////////////////////////////////////////////////////////////////
//  getRange  ////////////////////////////////////////////////////////////////////////////////////////
//////////////////////////////////////////////////////////////////////////////////////////////////////
//  The getRange function retrieves and returns a distance value from an ultrasonic rangefinder
//that is connected to the specified pin
//----------------------------------------------------------------------------------------------------
int getRange(int pingpin)
{
  // establish variables for duration of the ping,
  // and the distance result in inches and centimeters:
  int duration, inches;

  // The PING is triggered by a HIGH pulse of 2 or more microseconds.
  // a short LOW pulse is given beforehand to ensure a clean HIGH pulse:
  pinMode(pingpin, OUTPUT);
  digitalWrite(pingpin, LOW);
  delayMicroseconds(2);
  digitalWrite(pingpin, HIGH);
  delayMicroseconds(5);
  digitalWrite(pingpin, LOW);

  // The same pin is used to read the signal from the PING: a HIGH
  // pulse whose duration is the time (in microseconds) from the sending
  // of the ping to the reception of its echo off of an object.
  pinMode(pingpin, INPUT);
  duration = pulseIn(pingpin, HIGH);

  // convert the time into a distance
  inches = duration/74/2;

  return inches;
}
//----------------------------------------------------------------------------------------------------
```

```
//////////////////////////////////////////////////////////////////////////////////////////////////////
//  setup  ///////////////////////////////////////////////////////////////////////////////////////////
//////////////////////////////////////////////////////////////////////////////////////////////////////
//  Setup is a function that always runs before everything else in an arduino program.  Our setup
//function initializes integral and previous error values such that the all derivative terms start at
//zero and all integral terms are equal to the proportional term
//----------------------------------------------------------------------------------------------------
void setup()
{
  Serial.begin(9600);
  int Lrange, Rrange;
  Lrange = getRange(LPING);
  Rrange = getRange(RPING);
  count = 0;
  steering_preverror = Lrange - Rrange;
  steering_integral = 0;
  motor_preverror = min(Lrange, Rrange) - Desired_Position;
  motor_integral = 0;
}
//----------------------------------------------------------------------------------------------------


//////////////////////////////////////////////////////////////////////////////////////////////////////
//  loop  ////////////////////////////////////////////////////////////////////////////////////////////
//////////////////////////////////////////////////////////////////////////////////////////////////////
//  Loop is an arduino required function that will execute the contained code and repeat ad infinitum.
//This is where we call the main control functions
//----------------------------------------------------------------------------------------------------
void loop()
{
  int Lrange;
  int Rrange;

  //The left and right ranges are obtained by calling the getRange function on their respective pins
  Lrange = getRange(LPING);
  Rrange = getRange(RPING);

  //Outputs the ranges for debugging purposes
  /*if(count>maxcount)
  {
    Serial.print("Left Range:");
    Serial.print(Lrange);
    Serial.print("\tRight Range: ");
    Serial.println(Rrange);
  }*/

  //The position and steering errors are calculated from the ranges
  double position_error = min(Lrange, Rrange) - Desired_Position;
  double steering_error = Lrange - Rrange;

  //The motor control function is called
  //For our prototype we commented out the steering control function and replaced it with zero
  //so that there is no steering offset
  motor_control(0/*steering_control(steering_error)*/, position_error);

  //The function waits dt milliseconds before it repeats
  delay(dt);

  //For debugging purposes
  /*if(count > maxcount)
  {
    count = 0;
  }
  else
  {
    count++;
  }*/
}
//----------------------------------------------------------------------------------------------------
```

20 Appendix J: Circuit Schematics

Developed using Fritzing.



Developed using ExpressSCH.