

Mercury Project

Report 4

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Mercury Robotics Executive Summary

- **Summary:** We at Mercury Robotics are an interdisciplinary group of engineers who are utilizing our shared passion and knowledge of robotics to find solutions to pressing societal issues.
- **Problem:** There are approximately 16.9 million Americans with ambulatory disabilities in the United States, and for many of these individuals, simple daily task can prove cumbersome or painful.
- **Solution:** The Mercury project has produced a wireless robotic system meant to assist the millions of Americans living with ambulatory disabilities. The Mercury robot is a directly-controlled device that can be piloted from any computer. It utilizes standard keyboard controls, and can be controlled over any Wi-Fi connection. The robot is capable of moving in all directions, climbing inclines and ramps, and lifting and throwing small objects. It can also use its mounted camera to stream a live video feed to the pilot, accessible to the pilot through any web browser.

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- **Market:** We plan to focus on a beachhead market of disabled veterans as we launch our business.
 - **Size:** There are approximately 1,090,000 American veterans that are afflicted with an ambulatory disability. This provides us with a total addressable market of approximately \$75 million per year over a period of ten years, during which time we will seek to expand our market scope beyond our initial beachhead market.
 - **Customer:** Our customer will be the end users of the product. A typical customer is expected to be a veteran of the United States military with some form of ambulatory disability. They will likely be between the ages of 18 and 65.
- **Business Model:** One-Time Upfront Charge. We will be selling a high-cost, high quality medical device. Additional revenue could be generated through the sale of product warranties, replacement parts, or functionality expansions.
- **Competitive Advantage:** Our main competition will be the more traditional solutions to this problem: wheelchairs and service dogs.
 - **Wheelchairs:** When tested to see which device allowed a user to retrieve a small bag of chips from another room, the wheelchair required the user to physically move to the chair, travel the distance to the next room, and return, a process that took about 4 minutes. The Mercury robot was able to complete this task in two.
 - **Service Dogs:** Service dogs can cost upwards of \$20,000, and require daily sleep, food, water, and activity, limiting their overall usefulness and exponentially increasing their cost across a lifetime of use. A Mercury robot only cost \$2500, and can be operated at any time and without extra cost.
- **Marketing Strategy:** Our device will be sold directly to the customer through either phone or online order, with listings at major online retailers such as Amazon. We will focus our advertising efforts directly to our beachhead market by strategically seeking out advertising opportunities near locations our market individuals are likely to visit, such as Veterans Affairs facilities
- **Status:** Our prototype robot is complete and ready for demo opportunities.

Report 4: Mercury Project

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INTRODUCTION

Problem

There are approximately 16.9 million Americans with ambulatory disabilities in the United States, and for many of these individuals, simple daily task can prove cumbersome or painful.

Need

We need a robotic system that can assist people with ambulatory disabilities to perform task around their home that are too simple to justify the inconvenience and pain of having to use a wheelchair. It should be quicker than the use of a wheelchair at performing these task, and require less movement on the part of the user.

Goal

The goal of this project was to build a robotic system that can be remotely controlled via Wi-Fi to allow the user to complete simple task around their house without having to leave their seat, and generally in a shorter time frame than what would be accomplished through the use of a wheelchair. The robot has an arm that can secure and carry small items for the user, which will let them open doors, flip switches, press buttons, pick up and carry small objects, and many other simple task around the home. The system contains a wireless camera that will stream a live video stream to any web browser, allowing the user to inspect their living space remotely. The robot can be controlled from anywhere in the world, as long as there is Internet access, a function that would be useful in a situation in which someone might want to check up on a disabled relative. The robot will be controlled using a standard keyboard control scheme, and is capable of movement in all two-dimensional directions, as well as climbing ramps.

Deliverables

The robot will ship fully assembled and functional, pre-installed with all necessary software. It will come packaged with a comprehensive user manual included to help the user set up and operate their robot correctly. We will also include chargers for the two on-board batteries, as well as an HDMI cable to allow the user to interface with the robot's on-board computers if necessary.

Significance

The Mercury Project produced a robot that can be used as a base model for a product that will be able to help the 16.4 million Americans living with ambulatory disabilities be able to perform simple task around their home with less time-consumption, hassle, and pain.

MARKET RESEARCH

Market Segmentation

Table 1: Market Segmentation Chart.

Market	Entertainment	Military	Ambulatory disabled veterans	Environmental and Geophysical Visualization	Aerospace	Industrial Facilities
End User	<ul style="list-style-type: none"> • Cinematographer 	<ul style="list-style-type: none"> • Explosive Ordinance Disposal (EOD) Specialist 	<ul style="list-style-type: none"> • Ambulatory disabled veteran 	<ul style="list-style-type: none"> • Environmental Specialist • Geophysicist 	<ul style="list-style-type: none"> • Aerospace Engineer 	<ul style="list-style-type: none"> • Manufacturing Engineer and Specialist
Application	<ul style="list-style-type: none"> • Remotely record film in place of a traditional cameraman 	<ul style="list-style-type: none"> • Disposal of hazardous ordinance 	<ul style="list-style-type: none"> • Allow user to perform basic task around the home without 	<ul style="list-style-type: none"> • Inspection • Visualization and analysis of remote and hazardous locations • Drill planning 	<ul style="list-style-type: none"> • Outer space exploration 	<ul style="list-style-type: none"> • Automation and remote production of goods and items
Benefits	<ul style="list-style-type: none"> • Easy to use • Can replace a human worker • Compact size 	<ul style="list-style-type: none"> • Eliminate risk to human EOD tech. 	<ul style="list-style-type: none"> • Perform daily tasks that were difficult or impossible to do before 	<ul style="list-style-type: none"> • Zero human exposure to hazardous waste/materials • Error reduction 	<ul style="list-style-type: none"> • Easy access to remote locations in other planets 	<ul style="list-style-type: none"> • Zero human injuries • Building large items with no stoppage
Market Size	X00,000	X00,000	1,090,000	94,600	X00	230,000
Revenue	\$X00 million	\$27 billion	\$1.635 billion	\$X billion	\$X billion	\$9.2 billion
Competition	<ul style="list-style-type: none"> • Drones and other robots 	<ul style="list-style-type: none"> • MARCbot • PackBot 	<ul style="list-style-type: none"> • Service dog • Wheelchair 	<ul style="list-style-type: none"> • Safety suit • Explorer robot 	<ul style="list-style-type: none"> • Mars Rover • Robonaut 	<ul style="list-style-type: none"> • Industrial robots

With slight modification, the Mercurybot could see use in a variety of industries. It could be used in place of human help in industries like entertainment, allowing film producers to save on the cost of cameramen, and allowing them to film in more hazardous or tough-to-reach places due to the Mercurybot's expendability and small size. It could similarly replace the role of humans in several other industries, such as military applications, space exploration, and industrial manufacturing. The issue with most of these industries is that there are already similar devices to the Mercurybot that would often outperform our product. We therefor decided to focus on the industry with the least direct competition: use as a medical device to help the ambulatory disabled with household task.

Beachhead Market (BHM)

We decided to focus on the disabled veteran market to use as our beachhead. Other potential markets already have well-established competition very similar to the product we would be offering, making them far tougher to gain a foothold in. In contrast, we have no direct competition in the veteran market, as the closest competition would be wheelchairs and service dogs, neither of which is similar enough to be a complete replacement for the Mercurybot, and vice versa. There are approximately 1.09 million ambulatory disabled veterans. We felt that attempting to market the Mercurybot to the full range

of ambulatory disabled Americans – a market of approximately 16.4 million individuals – was simply too broad to properly focus on as a strong beachhead. The full market of ambulatory disabled Americans encompassed individuals of all ages, genders, races, religions, cultural backgrounds, and numerous other factors. Focusing on veterans drastically narrows this down, giving us a more concise culture to focus on, and allowing us to market the bot through locations and publications that would be targeted towards this group in such a way that would be impossible with as broad of a market as all ambulatory disabled Americans. We should also be able to generate a strong word-of-mouth force by focusing on as tight-knit a community as veterans.

Total Addressable Market (TAM)

The 2014 US census tells us there are 21.8 million veterans of the United States armed forces, and that approximately 5.2% of the American population suffers from an ambulatory disease. We used these numbers to generate a sample size of approximately 1.09 million veterans with an ambulatory disease. At a one-time purchase cost of \$1499, we would need approximately 20,000 sales per year to reach a total addressable market of \$30 million. This number would hopefully be increasing over time as word-of-mouth and advertising made more and more people aware of our product. We believe this market is of adequate size for a beachhead, but more importantly, is focused and tight-knit enough to allow us to make a big splash quickly, and soon expand into the much larger overall market of 16.4 million ambulatory disabled Americans. For future efforts, we will attempt to find more concrete data on the numbers of veterans with ambulatory diseases, as well as which subset of these individuals would actually have a use or desire for the Mercurybot.

End User Profile

Table 2 below demonstrates the end user profile. Our focus is on U.S. military veterans with ambulatory disabilities. They can generally be assumed to have a strong sense of nationalism and pride in their service to their country. They are predominately male, and form a tight-knit community that can easily enable our product to spread over word-of-mouth. They often frequent facilities such as VA hospitals, giving us good locations to focus our initial advertising efforts on. They will generally be the primary economic buyer and the end user of our product.

Table 2: End User Profile.

Veterans with Ambulatory Disability	
Geographic Location	United States
Age Range	21 to 64
Personality	They can generally be assumed to have a strong sense of nationalism and pride in their service to their country. They form a tight-knit community. Generally well-respected by their countrymen for their service.
Reason to Buy	<ul style="list-style-type: none">• Reduces the amount of time spent performing simple task at home• Allows the user to perform simple task without the need to move from their seat.

Full Life Cycle Use Case

Figure 1 below shows the full life cycle use case.



Figure 1: Full Life Cycle Use Case.

High-Level Product Specification

A detailed brochure is provided in Appendix A of this document. Please refer to that section for further details about the High-Level Product Specification.

Quantified Value Proposition

If an ambulatory disabled individual sitting on a couch decides to grab a snack located in another room 20 feet away without any movement assistance, such as a wheelchair, it could take well over 5 minutes for them to move themselves off the couch, into the next room where the snack is located, and back to the couch. On the other hand, if a wheelchair is provided, the process could still take some time, between 4 to 8 minutes—this comprises the transition time from the couch to the wheelchair and the roundtrip travel to and from the object. If the Mercury robot is being utilized, the process would take somewhere between 2 and 2.5 minutes, and require no body movement except controlling the robot a keyboard-equipped computer or similar device. This reduces the amount of time and energy spent in order to acquire an object.

A table of information about the “as-is” state for the customer and the “possible” state with the Mercury robot is created and demonstrated in Table 3.

Table 3: Quantified Value Proposition

Grabbing a Snack 20 Ft. from the Couch

	No Movement Assistance	Wheelchair	Mercury Robot
Movement Time	10 to 12 minutes	4 to 8 minutes	2 to 2.5 minutes
Movement Requirement	Whole body, 20 ft.	Whole body, 2 ft. (18 ft. in wheelchair)	0 ft.

Business Model

The Mercurybot system will allow the end user the ability to survey and interact with their immediate environment without the need to leave their seat. This quicker and more convenient solution to the contemporary wheelchair will generate value for its end user by allowing them to spend less time and energy moving about their home to perform simple task, and allowing them to do so in a method that is less cumbersome and painful than they could previously. Our business model to this end will be a one-time up front charge, as well as selling a high-cost, high-quality medical device that will be expected to work without the need for repair for a long amount of time. The end user will be the first recipient of the value created by this project. There is room for other users to gain value, such as a long-distance relative who might use it to check up on the owner remotely, but in almost all cases it will be the customer and primary end user who receives the value first. The end user is the most likely person to pay for our product. Disabled veterans are paid a monthly sum by the VA due to their disabilities, so the majority of disabled veterans should have no trouble paying for our device. There are other options for monetization of our product, such as a system based off making profit from add-ons like warranties, upgrades, and repairs, but this felt like an unstable and non-viable primary source of profit. In order to test the viability of this business plan, we will offer full product demos to real ambulatory disability patients and gather data from their experiences.

Pricing Framework

The Mercurybot will be available for purchase through a one-time cost of \$1499, with an optional annual extension of \$100 for full warranty. This price is significantly higher than what you would pay for a wheelchair, which can be found online for slightly over \$100, but are significantly cheaper than our most directly comparable functional replacement, a service dog, which often carry an initial cost of \$20,000, not considering the continuing cost of food and medical care. The price of \$1499 allows us to make a significant profit on each unit sold without pricing ourselves too high as to forcing a majority of customers to write off our product as unreasonably expensive. We hope to back up this data through the further use of our market viability testing, and then adjust our price based around that feedback.

Define the Minimum Viable Business Product (MVBP)

Our Minimum Viable Business Product would need to include the fully assembled and functional robot and a comprehensive user manual. All current functionality will be required to meet the customer's needs, and the user manual will be required for the customer to properly set up, maintain, and operate their Mercurybot. We would also need customer service available to help with any issues that might arise, such as defective products or customers that need more help beyond what the user manual can provide. This will be implemented through 24/7 phone help lines, online FAQs, and email help. Finally, we would need a system to collect anonymous error data, so that we can diagnose and remedy any persistent bugs and errors that arise. The customer will receive their desired value from the robot's base functionality. In order to receive this value, they will have to pay up front. Our data collection will allow us to receive information on our robot's shortcomings and existing issues, allowing us to perform updates and repairs, as well as diagnose problems that will need to be dealt with in future products.

Show That "The Dogs Will Eat the Dog Food"

To test the validity of our market and pricing structure, we plan to offer full product demos to ambulatory disability patients. Subjects will be asked to answer a few short questions following their demo, such as what degree do they think the Mercurybot would help them in their daily life, what price range would they expect to have to pay to own a Mercurybot, and what additional features would make them more likely to purchase a Mercurybot.

METHODS

Design Overview

The purpose of the Mercury project is to design a robotic system to help the ambulatory disabled individual do basic daily tasks, such as picking an item off the floor, grabbing an object from a table, opening a door, and flipping a switch. In order to do the aforementioned tasks, the robot needs to have an arm that can grab and secure items, as well as motors and wheels so that it can move around. The motors must be strong enough to climb a 30-degree incline, and the wheels must be wide and made of rubber so that it can have better grip on slippery floors. Motor drivers will be needed to drive the motors both for the wheels and the arm. Furthermore, a type of minicomputer with wireless capability is essential to be able to communicate with the robot in order to control it. A microcontroller will also be needed to act as the main control system for all the motors. A camera is also needed so that the operator can see what is in front of the robot. The robot chassis must be sturdy enough to withstand simple environmental hazards and accidental abuse, but light enough to be easily transported by someone with an ambulatory disability. The size of the entire robot must be small enough to be able to go through narrow hallways. The battery used needs to be able to last for up to 3 days.

Figure 2 on the next page shows the overview diagram for the Mercury robot design. The user uses a laptop to connect to the Raspberry Pi (Model B+) minicomputer via Internet using an attached Wi-Fi dongle. The Pi connects to the wireless network via Wi-Fi. The Pi sends a live camera stream to the pilot, as well as relaying the commands it is receiving from the user to the Arduino Mega microcontroller. The Mega translates the commands into electrical signals that are sent to the appropriate motor drivers to control the wheels and arm. (Please turn to the Equipment section of this document to read a more detailed description of each component used to build the robot.)

Overview Diagram

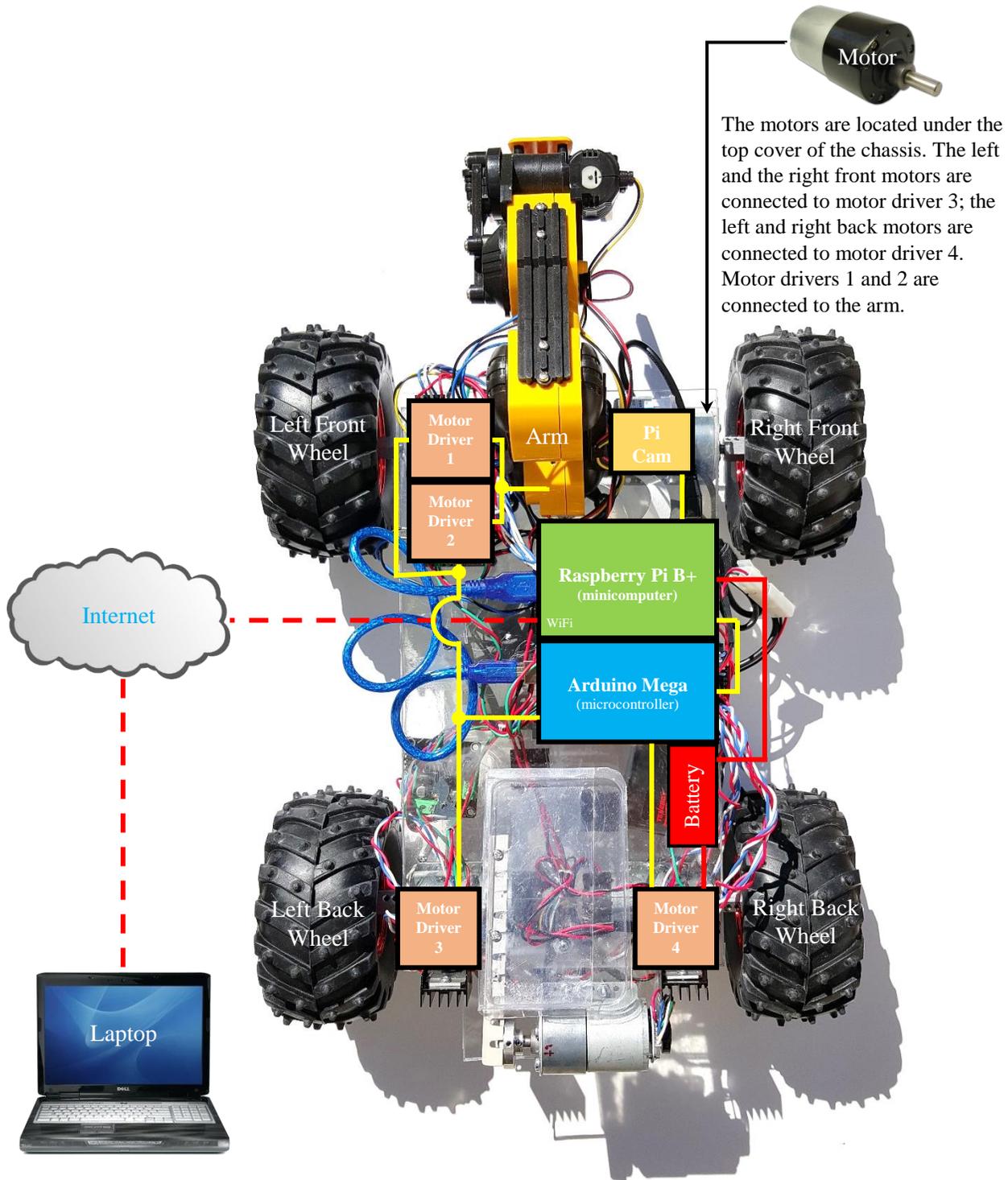


Figure 2 : The overview diagram for the Mercury project

Equipment

The Raspberry Pi B+ and the Arduino Mega were used as the minicomputer and microcontroller for the Mercury robot, respectively. The purpose of the Pi is to handle the wireless communication between the robot and the network, as well as the serial communication between the Pi and the Mega. The Pi was chosen because it is a full-fledged computer; it has its own OS that functions similar to that of Microsoft Windows operating systems. Thus, setting up a Wi-Fi connection or an SSH connection is simple, because there is no need to code this ourselves. The only thing one must do is to click on the network icon and select the desired network from the provided list of available connections. When the communication between the Pi and the network are disconnected, the Pi will automatically reconnect to that same network when the connection is restored. For the microcontroller, while there are many I/O boards under development for the Pi, the Arduino is well established. It has plenty of analog and digital I/O pins to control all the motors needed for the project.

The Pololu branded 70:1 Metal Gearmotors (37Dx54L mm) and Dagu Wild Thumper Wheels (120x60 mm) were used for the robot motors and wheels. The motors have a thick 6-mm diameter D-shaped output shaft, which is more sturdy and better at handling hard bumps without breaking than motors with only 4-mm diameter shafts. The Dagu wheels were chosen over the Mecanum wheels because the robot needs to be able to climb a 30-degree incline. The Mecanum wheels gave the robot a unique ability to do strafe and diagonal movements in addition to the ordinary left-right-forward-backward movements, but when it comes to climbing the incline, the Mecanum wheels fail to gain enough traction to propel the robot upwards. For the motor drivers, the SEPP branded motor drivers were chosen over the other motor drivers because they are Arduino compatible, which means less time doing research on how to make it compatible with Arduino.

For the battery, a BLUESUN Solar 12-V 54000 mAh was chosen. A LiPo type was not selected because it could cause heat issues, as well as sustain permanent if I dropped below a certain voltage.

Data Collection

Most of the robot's functionality was handled through a simple eye test that determined rather it could perform the desired task, such as its basic movements (forward, backwards, turning, climbing the incline), streaming a live camera feed, receiving commands from a pilot over the internet, etc.

Robot Speed Test

The robot's speed was determined by running the robot from 0 ft. to 20 ft. with a stopwatch in hand. The stopwatch started the moment the robot started moving forward, and stopped when the robot reached 20 ft. This was repeated five times, and the results gathered were averaged.

Arm Speed Test

The arm was tested on how fast it could grab and secure an item. The robot will try to grab a beanbag and secure it. The moment the arm starts to move to grab the beanbag, the stopwatch will be started. Once the beanbag is secured, the stopwatch is stopped. This will be done five times, and the results will be averaged.

Command Reaction Speed Test

The time the robot is able to react from a command via wireless network will be determined by using the ping command on Tera Term. Ping is often used to measure the latency between two devices on a network. Ten packets will be transmitted and the results will be averaged.

Data Analysis

For the robot speed test, once the average time (in seconds) has been acquired, it will be input into the following formula in order to obtain the final result in miles per hour:

$$\text{Robot Speed (mph)} = \left(\frac{20 \text{ ft}}{\text{avg. time (s)}} \right) \left(\frac{60 \text{ s}}{1 \text{ min}} \right) \left(\frac{60 \text{ min}}{1 \text{ hr}} \right) \left(\frac{189.394 \times 10^{-6} \text{ mi}}{1 \text{ ft}} \right) \quad (1)$$

If the result in eq. (1) is close to 1 mph, the test is considered successful. Otherwise, motor speed will need to be adjusted. A percent error formula will be used to determine whether the result is indeed close to 1 mph or not. A result that produces a percent error of less than 5% will be regarded as close to 1 mph.

$$\text{Percent Error} = \frac{|\text{result} - 1 \text{ mph}|}{1 \text{ mph}} \times 100\% \quad (2)$$

For the arm test, the average time will be checked if it is below 40 s. If not, arm speed will require some adjustments.

For the ping test, the average time will be checked if it is within the range of what is considered very low latency—that is, anything below 20 ms

Results

Table 4 shows the results from the robot speed test. The average time acquired from the test is 14.2622 s. Using eq. (1) from above, the determined result is 0.956118 mph and the percent error is 4.3882%. Since the percent error is less than 5%, the result is valid and the test is considered a pass.

Table 4: Robot speed test results.

Avg. time (20 ft.)	14.2622 s
Speed	0.956118 mph
Percent error	4.3882%

The only data needed for the arm speed test is the average time it took the arm to grab and secure an item. The acquired result is 32 s, which is less than 40 s. Thus, the test passed.

Before moving on to the next test results, it is important to mention that the data results from both the arm and robot speed tests can be used to prove what is mentioned in the Quantified Value Proposition section, that the robot can travel 20 ft. to grab a snack and return within 2.5 minutes or less. Observe that from the knowledge we have of the average time in Table 4, we know that it will take 28.5244 s for the robot to travel 20 ft. and back. In addition to this, it takes 32 s for the robot to grab a snack. Adding 28.5244 s and 32 s together results in 60.5244 s (or approximately 1.01 min). This leaves us over a minute to spare for possible difficulties in getting the robot to run at an ideal speed.

Figure 3 displays the ping test results. The average time of 2.836 ms, which is framed in red, is way below 20 ms. Therefore, the test was passed.

```
pi@raspberrypi:~$ ping -c 10 99.102.86.209
PING 99.102.86.209 (99.102.86.209) 56(84) bytes of data.
64 bytes from 99.102.86.209: icmp_seq=1 ttl=255 time=2.01 ms
64 bytes from 99.102.86.209: icmp_seq=2 ttl=255 time=2.69 ms
64 bytes from 99.102.86.209: icmp_seq=3 ttl=255 time=7.75 ms
64 bytes from 99.102.86.209: icmp_seq=4 ttl=255 time=4.64 ms
64 bytes from 99.102.86.209: icmp_seq=5 ttl=255 time=1.82 ms
64 bytes from 99.102.86.209: icmp_seq=6 ttl=255 time=1.90 ms
64 bytes from 99.102.86.209: icmp_seq=7 ttl=255 time=1.91 ms
64 bytes from 99.102.86.209: icmp_seq=8 ttl=255 time=2.03 ms
64 bytes from 99.102.86.209: icmp_seq=9 ttl=255 time=1.75 ms
64 bytes from 99.102.86.209: icmp_seq=10 ttl=255 time=1.84 ms

--- 99.102.86.209 ping statistics ---
10 packets transmitted, 10 received, 0% packet loss, time 901ms
rtt min/avg/max/mdev = 1.756/2.836/7.750/1.835 ms
pi@raspberrypi:~$
```

Figure 3: Ping results when ten packets were transmitted.

The results from these tests reveal that the robot has indeed satisfied the requirements for the speed of the robot, the grab-and-secure item speed, and the command reaction speed. It was also able to perform all desired functionality previously stated, as well as others, including climbing a 30% incline and surviving a teeter-totter effect fall afterward without sustaining any noticeable damage, being able to use the mounted LED lights to navigate a dark tunnel, and throw its payload at least three feet. However, more tests can still be performed. Network latency test can be performed under multiple network situations, varying distance and bandwidth, to see what effect they have on the results. Various performance test can also be conducted in order to determine how the robot acts at various levels of battery charge, and when the ideal time for a battery charge would be.

Conclusion

The Mercury Project was a personal and overall success for everyone involved. The Mercurybot was able to overcome all obstacles and operate within the defined parameters of the OSU Mercury Robotics Competition, and provides a base model for a feasible product to assist the ambulatory disabled in the future.

APPENDIX A

**Access to your entire
home without having to
leave the couch**



**Any small object in your home is
right at your fingertips! Control
Mercurybot from any smart
phone, tablet, or computer**

**With Mercurybot, you can
perform task that would take
several minutes with a
wheelchair in a fraction of the
time**

**Never have to painfully haul
yourself into a wheelchair for
household task again!**



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Robotic Arm



Pick up snacks, clothes, the TV remote, and more!



Video and Pictures



Stream live video to any web browser, and take still pictures at the click of a button

24-Hour Customer Support



We're here for whatever you need, whenever you need us