Smart Autonomous Rollator

BENG 493 - Senior Advanced Design Project 1I

Final Report

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Executive Summary

The smart autonomous rollator or abbreviated as SAR is created in regard to the visually impaired and low mobility population. More than 3 million senior citizens in the United States are visually impaired. Many of them require the use of walkers or rollators due to natural age-related conditions. This is problematic for those who rely on canes to identify obstructions in their simple travels. The increased usage of mobility equipment among the elderly makes navigating their environment challenging for visually impaired cane users. This causes dissatisfaction and results in an inefficient, dangerous, and unreliable procedure. To use their cane, cane users must stop walking and let go of one handle of their walker/rollator. This increases the risk of tipping and other safety related risks. As the elderly population is expected to increase, and more people are projected to have vision impairments, finding a solution to this problem is necessary to help visually impaired elderly people retain their mobility while navigating around obstacles and objects in their daily lives. SAR is meant to ease mobility with its smart autonomous aspect which is a haptic feedback system. The haptics alert the user of the proximity to an obstacle or a curb drop; the closer the user is, the intensity of the vibration increases, and the further away the user is, there is lower vibration intensity. A commercial rollator is the foundation of the device. The mechanism of the haptic feedback system involves HC-SR04 ultrasonic sensors as the input for the detection of depth and distance. This is processed by an Arduino Mega 2500 leading to the output of coin vibration motors. The sensors and microcontroller are placed in a custom-designed 3D-printed box at the bottom center of the rollator. Located at the inward of the right side of the rollator is a custom-designed 3D-printed cane clasp. This is for users to have a location to place their cane while using the rollator. There were three tests conducted with SAR: haptic feedback test, curb detection test, and user experience test. The objective of the first test was to see if the haptic feedback system would detect various objects and obstacles at a series of set distances. This test showed how certain objects had higher fluctuations between the serial monitor compared to actual readings using a tape measurer. The objective of the second test was to see if the ultrasonic sensors could detect curb drops to which the results indicated the curb was detected every trial. The last test includes an obstacle course with two participant populations – students and visually impaired seniors. The participants were followed up with five questions regarding the device for feedback. Overall, the scores of the visually impaired ranked higher than the students.

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Problem Statement

Currently, there are over 3 million visually impaired individuals over the age of 65 in the United States. [1] As people get older and experience injury, surgery, or age-related ailments, many elderly cane users must use walkers or rollators to help with mobility issues. With advancing age in the population in the United States, the use of mobility devices such as walkers/rollators is also increasing. [2] This presents a problem for the blind elderly community who depend on canes to help them detect obstacles in their paths. With the addition of a walker or rollator, cane users are finding it difficult to have both the mobility the rollators provide and the obstacle detection the canes provide simultaneously.

With the current situation of navigating their world with simultaneously both a cane and a walker/rollator, many elderly blind users are left frustrated with the difficulty of getting around in their day-to-day lives. Low mobility cane users are left with a process that is less efficient, unsafe, and unreliable. Dual cane and walker/rollator users must walk a few feet forward, stop, and sweep their canes in front of the walker/rollator to detect obstacles along their paths. This takes more time as they must stop walking to be able to use their cane. This process also requires cane users to have to let go of one handle on their walker/rollator to sweep their cane in front of them, placing more weight on one side of their walker and increasing the risk of tipping. As these elderly blind people already struggle with mobility, this can lead to less safety and efficiency when using the cane and walker/rollator simultaneously.

The elderly population in the United States is expected to reach 22% of the population by 2040. In addition to an aging population, it is projected that 6.6 million people older than 60 years old will have vision impairment or complete blindness by 2050. [3] With both an aging and a visually impaired population, the need for a solution to this problem is compelling and necessary to help blind elderly people retain their mobility while navigating obstacles along the way.

Background/Relevance

There are several stakeholders for this product. These include Dr. Nathalia Peixoto and Dr. Shani Ross, project supervisors in the George Mason University Bioengineering Department, as well as several contacts at the National Federation for the Blind, including Tracy Soforenko, John Halverson, Sandy Halverson, and Nancy Yeager. Other general stakeholders such as doctors may benefit from the outcomes of this project, but perhaps the most important are visually impaired individuals, especially the elderly, that rely on both a rollator or walker and a cane to travel from place to place. These groups would likely require the results of this project the most. Mr. John Halverson is one such elderly gentleman who has previously used both a walker and a cane, and he was interviewed for this project during a meeting with other members of the National Federation for the Blind. Mr. Halverson stated that he relied on having the sensory input that a cane can provide but struggled to use both because he had to remove a hand from the support of the walker when sweeping his cane across the ground in front of him to detect obstacles. He found that the walker caused greater travel-related issues than the cane and would prefer a solution that incorporates cane-like sensory input into a walker. He also supported both the idea of incorporating haptic feedback and incorporating sound-based feedback to inform users of obstacles detected in their path. The team attended the National Federation of the Blind Virginia Convention and had the opportunity to communicate with cane users and rollator users. They mentioned how the design should be as true to the rollator as possible and not draw the attention of nearby people. Audio feedback was not preferred for users as they would have to simultaneously focus on the sounds around them as well as feedback from the device.

As Americans age and develop mobility issues in their day-to-day lives, they rely more heavily on mobility devices. This decrease in mobility can occur from a change in gait, reduced physical strength, and balance difficulties. These mobility issues can increase the number of falls an elderly person has as they try to get around in their environment. [4] With an aging population, there has also been an increase in those who become visually impaired. More than 9.2 million people over the age of 65 have age-related vision loss. [5] The common causes of this vision loss are macular degeneration, cataracts, and glaucoma. The elderly population can also experience vision loss from developing diabetic retinopathy after a diabetes diagnosis. [6]

For elderly people with mobility issues, walkers and rollators can assist in their daily travel. The cost of walkers/rollators isn't excessive for standard models and can help the elderly retain some independence to be active. Currently, standard walkers average a price of $30 - $100, with a standard walker costing about $60. Rollators tend to be a little more expensive, with budget models averaging $70 and more premium models costing upwards of $600. [7] Canes for the visually impaired and blind population are also relatively inexpensive, with the cost of a standard white cane being between $20 and $60. [8]

These solutions are beneficial in helping with mobility and visual impairments but present a challenge for low mobility and blind users. It is difficult for this population to navigate with their walker/rollator while also using their cane to detect obstacles in their paths. There is also a risk of safety when the elderly population must release one hand to use the cane. This can create balance issues, with them placing too much weight on one side of the walker/rollator, increasing their risk of tipping the walker/rollator over. This can present a fall risk for an already vulnerable population.

These challenges to the current solutions create an opportunity to make a smart, autonomous system where the elderly population can have an obstacle detection system integrated into their walker/rollator. Smart canes and walkers exist such as the WeWalk smart cane and WACHAJA smart walker; these are described further below. However, these devices can be too expensive, complex, or heavy for users. Elderly blind patients want a simple, inexpensive, and effective solution to this problem.

There are similar products currently available on the market such as the WeWalk smart cane, and others that are still being researched and prototyped such as the WACHAJA smart walker. The smart cane uses ultrasound to detect above ground obstacles and automatic voice feedback that describes the environment around the user. The handle of the cane vibrates to inform the user of obstacles ahead such as a street sign or a low hanging branch. The device connects via Bluetooth to the WeWalk smartphone app, which allows the user to use the built-in voice assistant for navigation assistance. The market size for this product includes individuals who are visually impaired and have access to a smartphone. [9]

Figure 1. WeWalk smart cane

The WACHAJA is a smart walker for blind users with mobility issues. This device can detect obstacles and provides haptic feedback using a belt that the user wears. The location of the vibrational feedback on the belt corresponds to the direction of the obstacles in relation to the user. The obstacles that can be detected include curbs, staircases and holes in the ground. Obstacles that are closer in proximity result in a faster vibration pulse in the belt. The closer one gets to the obstacles, the quicker the pulse. [10]

Figure 2. WACHAJA smart walker

Our target market for this project will be based on patient characteristics, specifically visually impaired patients of the senior population with mobility issues (65+ years old). According to the National Federation of the Blind, visually impaired patients 65 years and older account for over 3 million people in the United States [11]. Our product costs roughly $150 per finalized rollator. With a target population of ~3 million people in the US, the market cost would be around $450,000,000.

As the aging and visually impaired populations continue to overlap, a new solution for a smart rollator would have a societal impact on the affected population. Our design would create a more comfortable rollator experience for the users who have to rely on rollators for mobility and canes for visual impairment. This device would be an assistive technology that would help improve the quality of life of our users, as it would allow obstacle detection while using the rollator, creating greater ease of use. As our device is affordable and universal, it could be used by people all over the world, having a larger global impact for people outside of the United States as well.

Requirements & Specifications

Current rollators and walkers only have mechanical aspects. The biggest addition to the smart autonomous rollator apparatus is a technological system including sensors, audio, and haptic feedback. The reason for this new addition is to ease the constant switch between the cane and walker/rollator that visually impaired elders deal with. The intention of the new design is not to alter far from the current rollator on the market. Therefore, the smart autonomous rollator will be of similar weight and of slightly elevated price than the rollator on the market. More is elaborated in the "Metrics" section.

Creating a smart, autonomous obstacle detection system to use on either a walker or a rollator will help users successfully navigate while having the mobility the walker/rollator affords. SAR is projected to offer similar technologic aspects at a more affordable price. The size of the target market will not impact the production cost of SAR. The projected production cost of SAR is $120. Standard walkers on the market weigh about 6lbs [4], while rollators have an average weight of 15lbs. [5] The smart, autonomous rollator should be able to support up to 35 kilograms. To keep the rollator within the weight requirement, a lightweight sensor will be fitted to the front of the walker/rollator, adding minimal weight to the setup.

The device will also require audible and haptic feedback. The audible feedback system should be subtle, discreet, and allow the user to blend into a normal environment. The user should be able to be aware of their surroundings while also listening to the audible feedback from the device. The haptic feedback requirement will be incorporated to alert the user of any obstacles in front of them as well as to either side.

The list of requirements is shown in Table 1 below. The list of requirements is broken down into three categories: objectives, constraints, and functions. Constraints are also italicized on the objective tree in Figure 1. The objective tree in Figure 3 organizes the entire list of requirements. It provides a visualization of how the list of requirements is intertwined into subsections.

Priority of the list of requirements can be seen in Table 2. In Table 2, there are three columns: the requirements, the rating, and indication if it is a demand or a want. A higher rating number represents higher importance. Demands of this product include the first subsections of the objective tree along with durability, audible and haptic feedback, weight endurance, and staying within a two-thousand-dollar budget. Demands are absolute items that the smart autonomous rollator must have. Requirements listed as wants are favorable to have but not necessary.

Table 1. Requirements Breakdown

Requirements	Objective	Constraint	Function
Safety	X		
Durable	X		
Weight endurance	X		
Simple technology	X		

Simple design	X		
Minimal change in Rollator/Walker	X		
Marketable	X		
Distinctive Appearance	X		
Long lasting	X		
Perceived as safe	X		
Shock Resistant	X		
Universal solution	X		
Low Production Cost - $120	X		
Easy for seniors to use	X		
Within $2000 budget		X	
No user manipulation		X	
Audible and haptic feedback			X

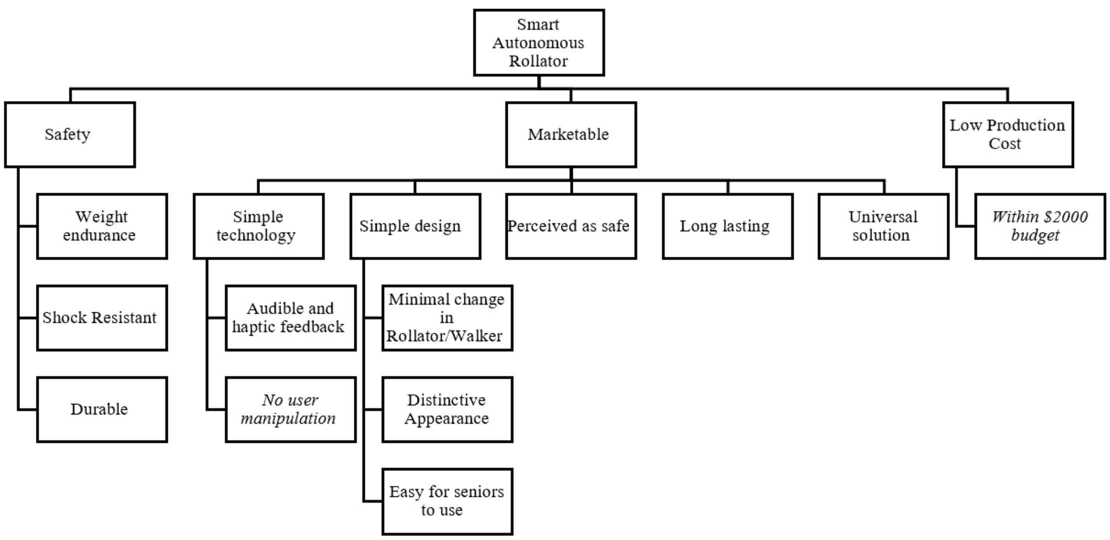

Figure 3. Requirements Objective Tree

Table 2. Importance Rating of Requirements (1 = lowest priority, 10 = highest priority; D = demand, W = wish)

Requirements	Rating	D or W
Safety	10	D
Weight endurance	10	D
Shock resistance	7	W
Durability	10	D
Marketable	10	D
Simple Technology	7	W

Audible and Haptic Feedback	10	D
No user manipulation	8	D
Simple Design	7	W
Minimal change in walker/rollator	7	W
Distinctive appearance	3	W
Easy for senior to use	9	W
Perceived as safe	5	W
Long lasting	8	W
Universal solution	9	W
Within $2k budget	10	D

Metrics

The mandatory requirements for the design include safety, weight endurance, shock resistance, durability, simple technology, simple design, marketability, and an all-in-one, universal solution (see Table 3). Certain requirements will be able to be measured quantitatively, e.g., the weight endurance requirement will be measured by the amount of weight the device is able to support. In this case, it should support at least 35 kilograms. Other requirements will be measured qualitatively, e.g., the simple technology requirement will be measured by whether users are able to use the device without any instructions.

Table 3. Design Requirements, Specifications and Metrics

Requirement	Specifications	Metric
Safety	None	Number of ways device could cause bodily harm
Marketability	Target audience should perceive device as safe	Percentage of target audience that can afford the product and perceives device as safe
Shock Resistant	none	How much sudden applied force the walker/rollator can withstand
Durable	none	How many times the walker/rollator can be knocked over without breaking
Low Production Cost	Within $2000 budget	Cost of product
Simple technology	No user manipulation; should include audible and haptic feedback	Whether or not the user can use the device without any instruction

Weight Endurance	Should support at least 35 kg.	Amount of weight the walker/rollator can support without collapsing
Simple technology	No user manipulation; should include audible and haptic feedback	Whether or not user can use the device without any instructions
Long Lasting	None	Amount of time the device lasts
Simple Design	Easy for seniors to use; minimal change in walker/rollator	How many seniors can use the device without any instructions
Universal Solution	All in one system	Percentage of walkers/rollators that the device is able to attach to and function properly

Standards

There are several ISO standards and additional codes that limit the possibilities of this design. Two such standards are ISO 13485 and ISO 14971. ISO 13485 specifically states that a risk management plan must be in place for any medical device that is developed, and ISO 14971 outlines how to apply these risk management practices. While these standards generally apply to any medical device, there are a few additional ISO standards that apply to the specific product being developed for this project. These include ISO 11199 and ISO 23599. ISO 11199 primarily pertains to walkers, rollators, and other walking assistive devices that require two hands to use, with a focus on devices used by people weighing more than 35 kg. Part 1 of this ISO states that users must be able to place their full body weight on the walker and details several dimensional requirements and test conditions [6]. Part 2 provides the same information for rollators, and additionally mentions that they can have a seat, backrest, or other method of support for the user [7]. Since this product will be modifying an existing walker or rollator with a small, lightweight sensor, dimensional constraints should automatically be met. This ISO limits potential stakeholders to those that weigh over 35 kg.

ISO 23599 describes standards for canes and other tactile walking surface indicators (TWSIs) that visually impaired individuals can use to travel from place to place. It states that initial use of these devices must be done on a smooth surface, and that they should not glare, as those with residual vision must be able to see them clearly. It also describes the difference between attention pattern TWSIs, which mainly indicate hazards, and guiding pattern TWSIs, which are used for general motion. This ISO limits the product to something that should be visually obvious to other pedestrians as a TWSI and ensures that only materials without glare can be used to create the device. Additionally, the differences between attention pattern and guidance pattern as provided by this ISO can be referenced when determining what the best method may be to alert users of this product when they face a potential obstacle or hazard [8].

Lastly, ISO 9921 describes standards for appropriate volume when it comes to devices that output sound messages, especially to alert people of potential hazards or transmit information [9]. This ISO, in combination with ISO 7731 (which details parameters for auditory danger signals in louder environments) can be used to determine appropriate methods of communicating obstacles in the path of visually impaired users of this research product [10]. This includes determining the ideal communication system and conducting the appropriate tests in each environment where this device may be used. While this does not constrain the product, it can be used as guidance regarding how to best develop it.

Outside of ISO, an HCPCS code may be applied to this product to enable its insurance via Medicare. This code, such as E0141 (rigid wheeled walker), will categorize the assistive device being developed. As a result, the dimensions and functions of the product are constrained to whichever HCPCS code is determined as the best fit description [9]. Additionally, the World Health Organization's document on Assistive Product Specification for Procurement will be referenced in order to ensure that any potential rollators being used meet durability and assistive requirements, as this document provides several classifications and requirements for this equipment [11].

Final Design

The design for the Smart Autonomous Rollator (SAR) incorporates an additive smart system and a cane attachment to a standard rollator. The aim of this design is to ease traveling for those who are both visually impaired and dependent upon assistive mobility devices. The design enables them to receive obstacle detection feedback while traveling, reducing the need for a cane, while also providing the user with the opportunity to use a cane when they need to. The main components of SAR are a commercially available rollator, a haptic feedback system to notify users of objects and obstacles, an attachment to mount the cane directly onto the rollator, ultrasonic sensors to visualize the user's path and identify if a potential obstacle is present, and a box attachment to hold the microcontroller and breadboard. The cane mount is seen in Figure 4 along with the dimensions of the rollator. It will be made from polylactide (PLA) and clips to the rollator's vertical bars. The clip has a c-shaped design, allowing users to easily attach and detach their cane when necessary. The rollator itself weighs roughly 14 lbs and has 6-inch wheels. The handle is 30-35 inches off the ground and approximately 24 inches wide, and the seat height is 20 inches. These are the dimensions of a generic rollator [12].

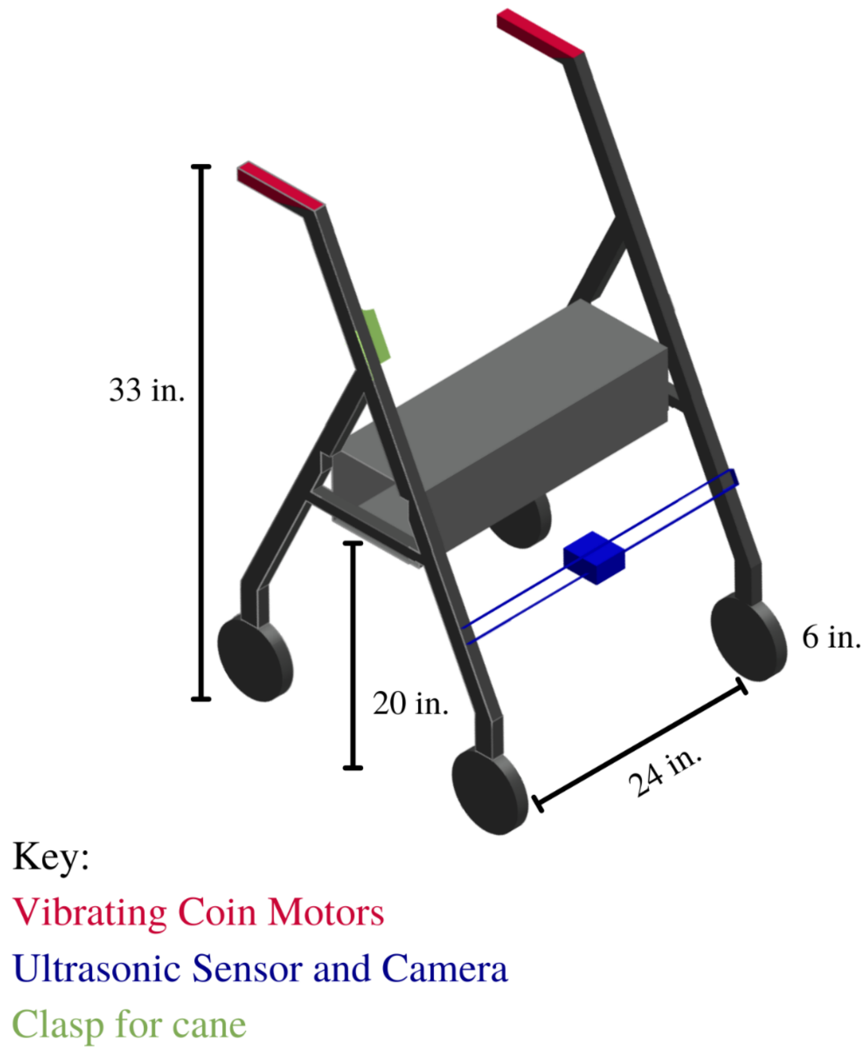

Figure 4. CAD Drawing of prototype schematic

A haptic feedback system was chosen based on client feedback received at the Virginia Convention for the National Federation of the Blind. We spoke with visually impaired Virginia residents who used canes, and they recommended haptic feedback over other methods such as audible feedback because it could be less overwhelming to the user and draw less attention from passersby. Our system includes coin vibration motors taped inside adjustable rollator handle grips that are Velcro-attached to the rollator handles. Ultrasonic sensors were selected over other sensor types because they can be used at various light levels, since it uses sound waves to detect obstacles in the user's path. Specifically, ultrasonic sensors work by emitting high frequency sound waves via a transducer and using their echo to understand foreign object proximity and possibly size. The ultrasonic sensor used in this prototype is the HC-SR04 sensor which is an ultrasonic distance sensor compatible with Arduino. The HC-SR04 has a detection range of 2 centimeters to 4 meters [13], a frequency of 40 kHz [14], and a measuring angle of 15 degrees [13]. These sensors have a range from 20 cm to about 10-15 m, depending on sensor quality, and can be used in the dark [15]. When using an ultrasonic sensor, the distance between the sensor and any object it detects can be calculated using the following equation [16]

$$distance = \frac{time\ delay}{2} \times (speed\ of\ sound)$$

Equation 1

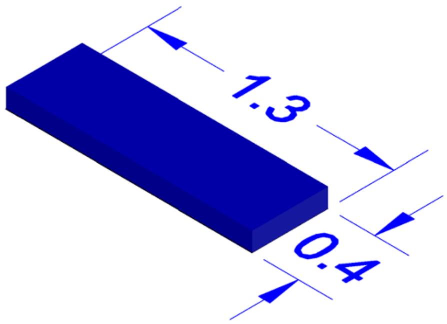

Figure 5. Dimensions of the Ultrasonic sensor and camera box. Not imaged: the height of the box is 0.1 in.

Haptic feedback was chosen because the vibration of rollator handles can be used to communicate the presence of obstacles to the user as they travel with a rollator. The connecting link between the haptic feedback system and ultrasonic sensors is an Arduino microcontroller, and wires connect all three aspects. The Arduino connects to the vibration coin motors that provide haptic feedback using circuitry. The vibrating coin motors have a vibrating speed of 10k RPM and a motor voltage of 3 V [17]. The sensors will be placed in a 3-D printed plastic casing of approximately 8 x 2 x 5 in, and this casing will also weigh less than 1 lb. This compartment is intended to protect the sensor system from elemental hazards such as rain, snow, or wind, and will also protect the system from obstacles in the user's path. It is to be placed at the center of the rollator as seen in blue in Figure 7.

Haptic feedback response will be placed at the handles of the rollator. Vibration coin motors will be embedded in handle grips which will then cover the handles on the rollator. Users will feel vibrations in accordance with the response of their surroundings. Vibrations also occur depending on the orientation of the user to provide clearance of placements in their environment. If an object is detected on the user's left side, the left handle will vibrate. If the object is detected on the user's right side, the right handle will vibrate. If an object is in front of the user, not specifically on the left or right, both handles will vibrate. The closer the object in detection is, the higher the intensity of the vibrations, as more motors will vibrate with increased proximity (each handle will contain 3 motors).

The Arduino will be connected to both the ultrasonic sensor, microcontroller, and coin vibration motors using the circuitry shown in Figure 7 below. Figure 6 shows the circuit diagram of curb detection. One sensor is angled at 15 degrees and another is angled at 30 degrees. The distances detected by both sensors are calculated to provide indication of a drop or elevation. Vibrations will indicate the presence of obstacles and provide depth perception to the user [19]. Depth perception will be indicated by the number of motors that vibrate. As of now, the Arduino circuit is powered by a 12V battery pack that holds 8 AA batteries. It has a battery life of 9 hours when used consistently or up to a week when used intermittently (by manually unplugging the battery when not in use or incorporating code that puts the Arduino to sleep when inactive). The circuit can also gain power from a laptop when plugged in, as long as the laptop itself has charge. Future options for a longer-lasting power source include rechargeable batteries or powering with a larger battery pack than 12V. Users will be alerted by a dying battery if the haptic feedback noticeably decreases in intensity even when all coin vibration motors are activated.

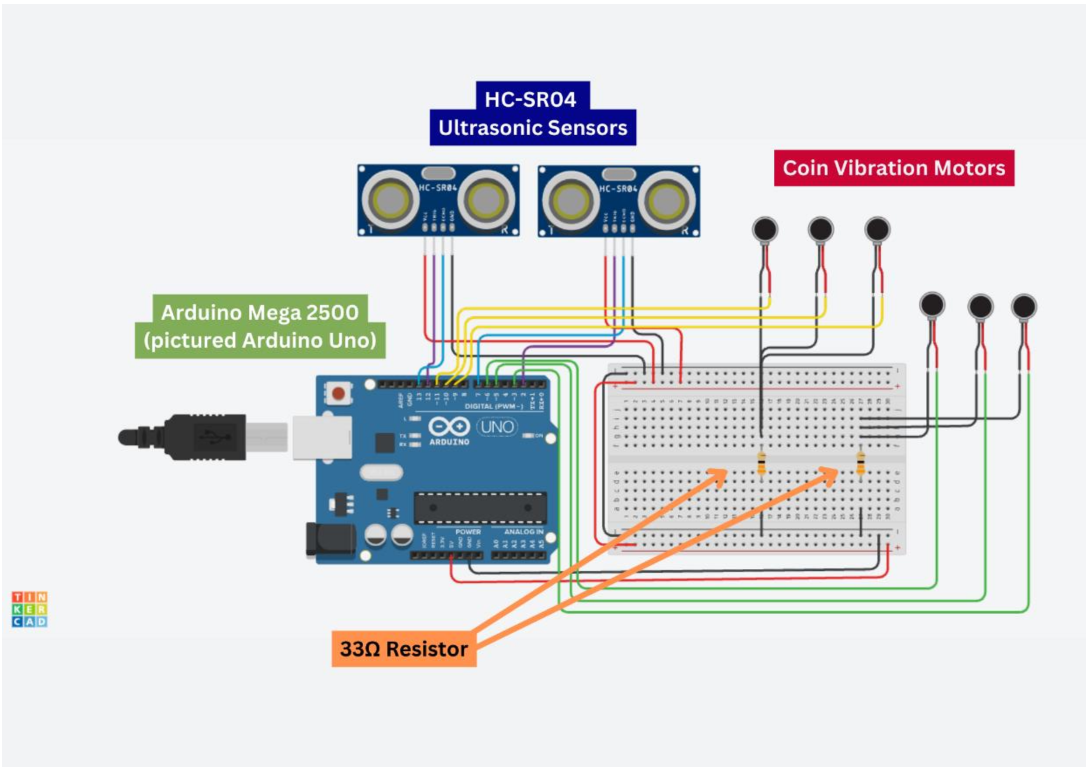

Figure 6. SAR Circuit Diagram of Curb Detection

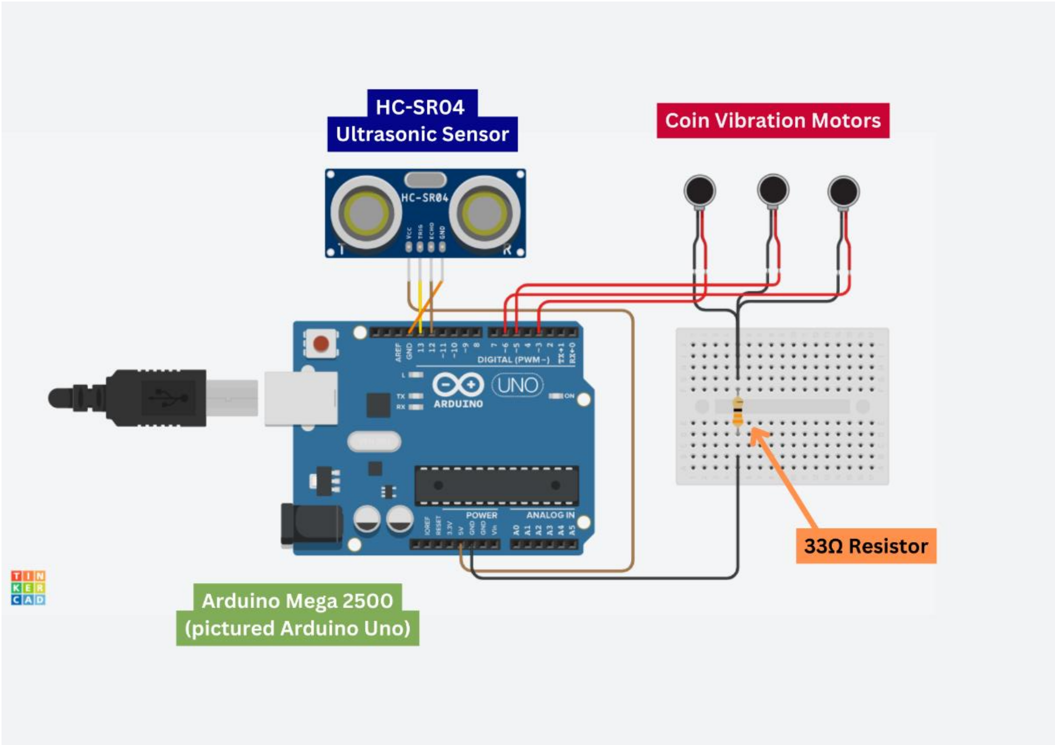

Figure 7. SAR Circuit Diagram simple

The flowchart in Figure 10 below depicts the general principles of the code that will be used to connect the ultrasonic sensor and camera to the microcontroller that can then trigger haptic feedback. Figure 9, Figure 10, and Figure 11 depict our final design as it stands thus far. Figure 12 shows the 3D printed cane mount made of PLA. Figure 13 shows how a commercial retractable cane fits in the made cane clasp on the rollator.

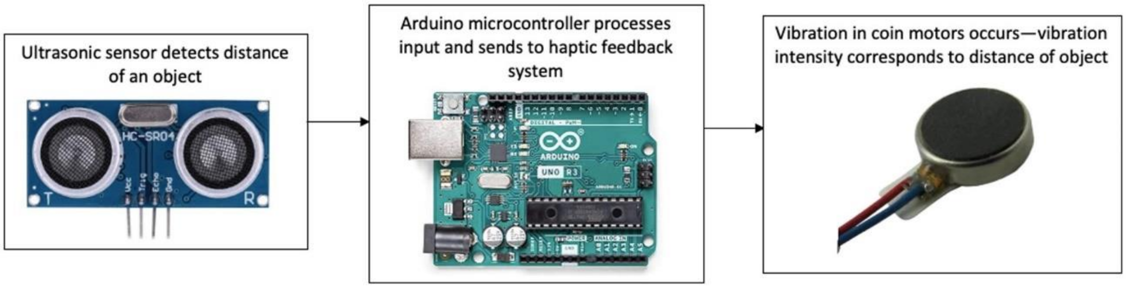

Figure 8. Flowchart of Haptic Feedback System

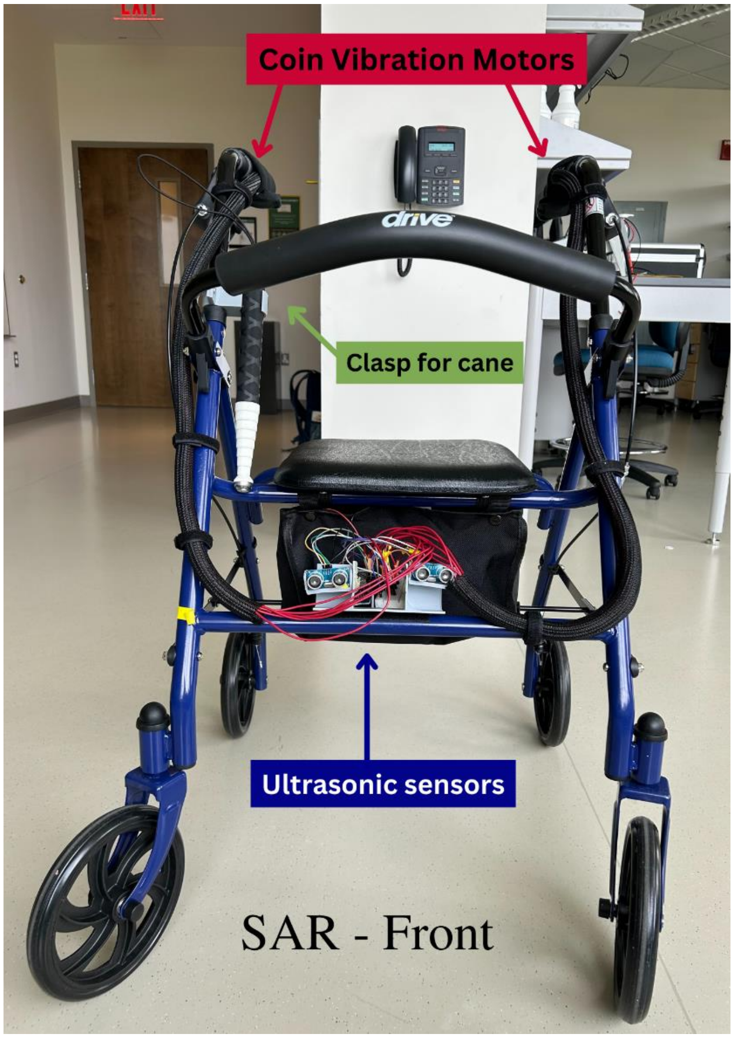

Figure 9. Smart Autonomous Rollator (SAR) - Front

Figure 10. Smart Autonomous Rollator (SAR) - Right Side

Figure 11. Smart Autonomous Rollator (SAR) - Back

Figure 12. Smart Autonomous Rollator (SAR) - Cane Clasp

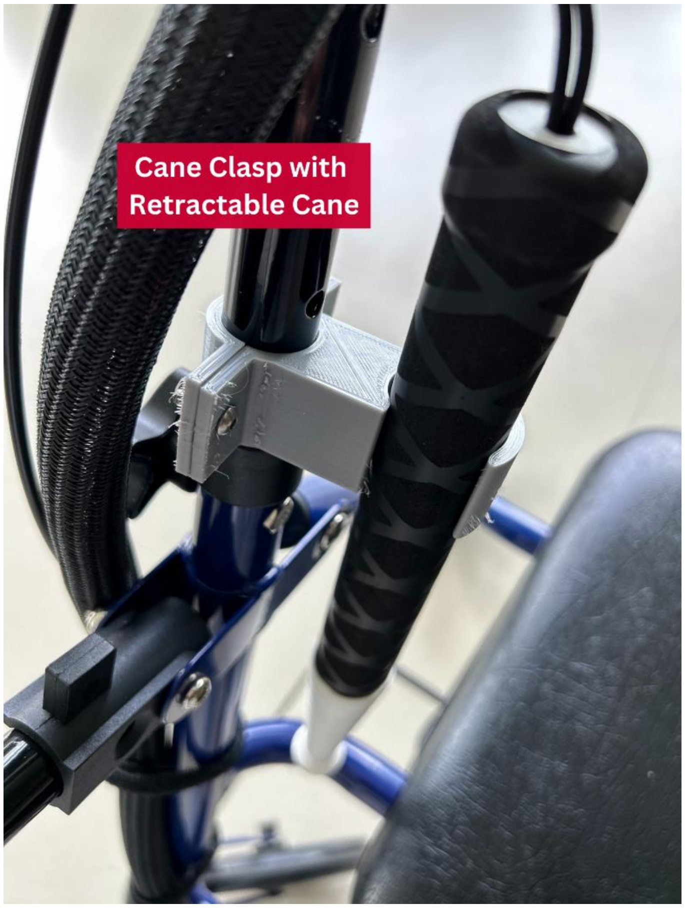

Figure 13. Smart Autonomous Rollator (SAR) - Cane Clasp with retractable cane

Verification and Validation of Design

Test 1: Ultrasonic sensor haptic feedback accuracy test

Description

The ultrasonic sensor haptic feedback test was conducted to test whether haptic feedback responded appropriately when the ultrasonic sensor detected various objects and obstacles at three distances: 50cm, 100cm, and 250cm away from the sensor system. Two distances between each of the 0 – 50cm range, and 50 – 100cm range were tested for accuracy within those ranges. Four additional distances were tested after the initial three distances: 25cm, 40cm, 65cm, and 80cm. Additionally, this test was conducted to determine the maximum distance that the objects and obstacles could be from the sensor system before it was unable to detect them. The objects that were used to test the sensor included a person, chair, and small cardboard box, and the obstacles were a wall, pillar and door. Our data included whether the object or obstacle detected caused the coin vibration motors to vibrate, the distance measured on the serial monitor, and the distance measured using a tape measure.

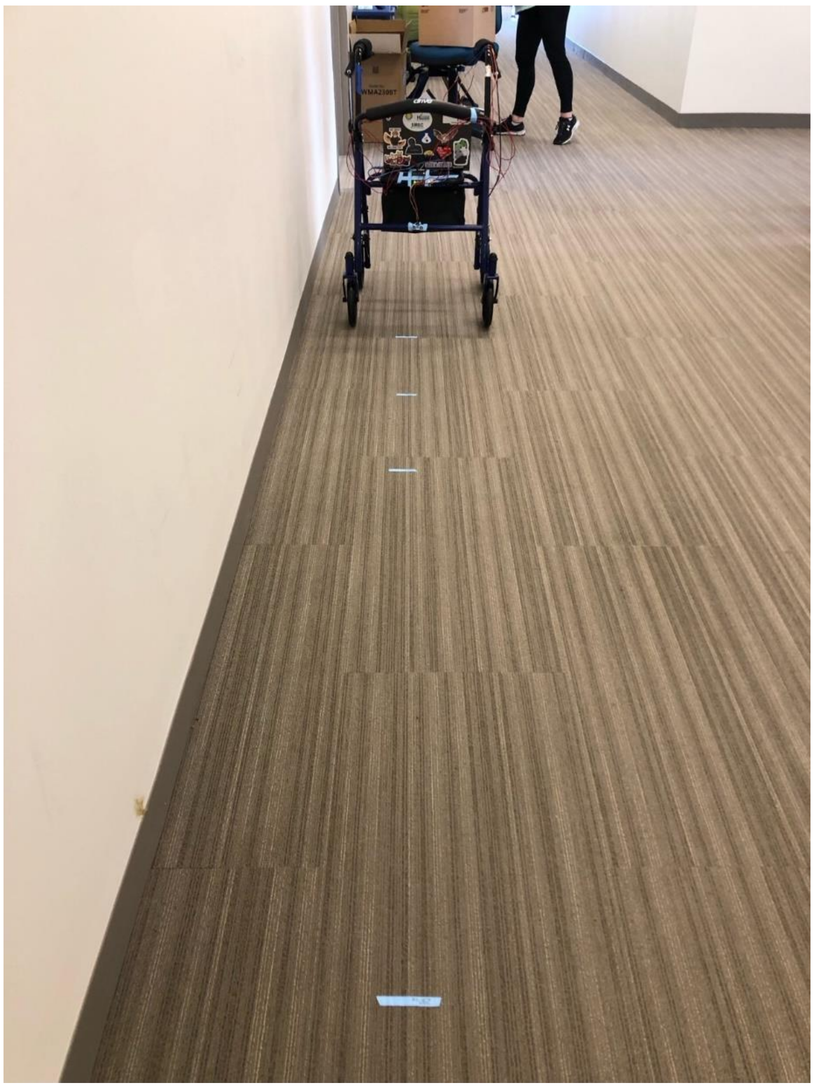

Figure 14. Ultrasonic sensor haptic feedback test set-up

Figure 15. Pillar used for obstacle detection

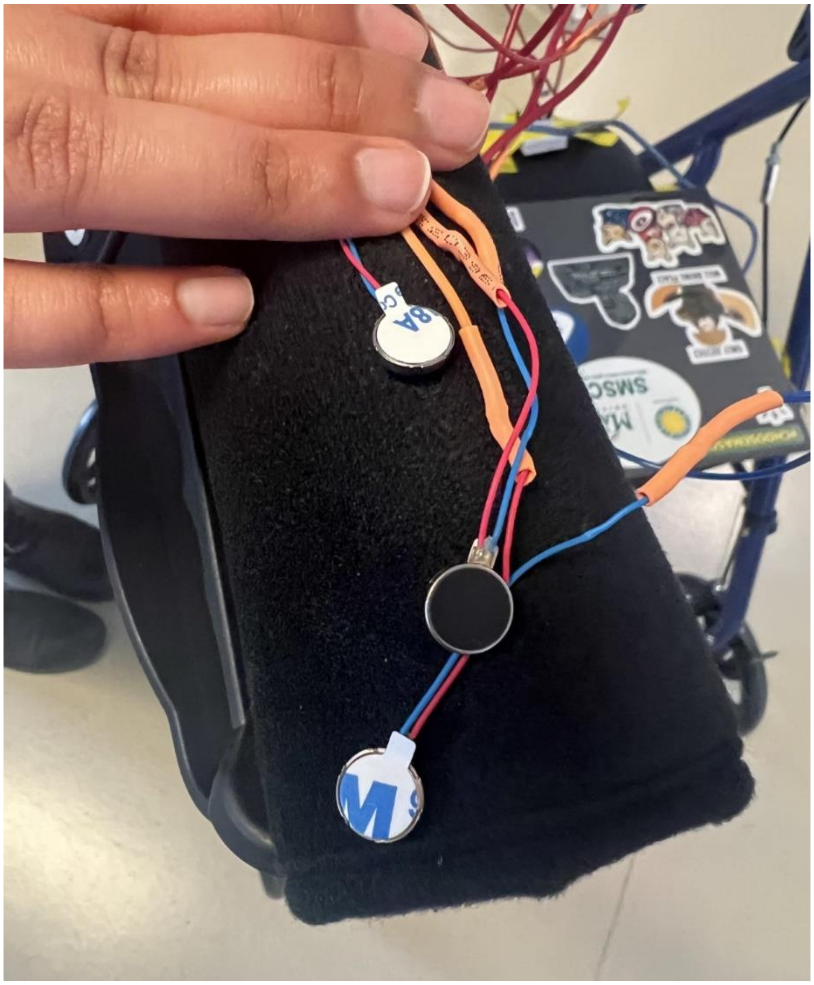

Figure 16. Coin vibration motors/handlebar cover set-up

Figure 17. Chair object detection at 100cm

The photographs above demonstrate various aspects of the test that was conducted. Specifically, Figure 14 depicts the experimental setup for testing the rollator system's ability to detect objects, and Figure 16 demonstrates where the motors were placed on the rollator. In order to conduct testing, we first taped the ultrasonic sensor to the center of the bottom bar on the front of the rollator, at an angle where its line of "vision" was parallel to the ground. We kept a laptop on the seat of the rollator to view the Serial Monitor while conducting testing, and this monitor was connected to an Arduino Uno (also on the rollator seat) that powered the ultrasonic sensor. The final item located on the seat was a breadboard to which three coin vibration motors were connected, and these vibration motors were placed on top of one of the rollator handles so that they could be held and checked for vibrations during the testing process (Figure 16). These motors will be placed inside the handle grips in the final design and we previously determined that their vibrations can be felt through the grips, but we kept them outside for this test so we could observe them visually as well.

For the initial three distances, once the rollator was set up, we placed four labeled blue pieces of tape on the ground at distances of 0cm, 50cm, 100cm, and 250cm from the rollator. Then, we put each object in front of the rollator and placed it at the 50cm mark, before moving it back to the 100cm mark (as seen with the chair in Figure 17) and then the 250cm mark. At each of these distances, we recorded the distance value detected by the Serial Monitor as well as noting the tape measure value on the ground. These three distances were tested three times for each object. Then, we conducted three trials for each object where we moved the object as far away from the rollator as possible, until it was no longer detected by the ultrasonic sensor. We recorded the largest value measured by the Serial Monitor and also recorded the distance via tape measure to determine the accuracy of the sensor in detecting objects at further distances. After completing these trials with the objects, we moved to each obstacle (such as the pillar in Figure 15), re-measured and placed the tape markings at the appropriate distances on the ground, and conducted three trials for each of the seven distances at each obstacle. For these trials, since the obstacles were fixed, we moved the rollator back to each marking on the ground. We also repeated the process of measuring and recording the maximum distance for each obstacle. The same procedure was done for the latter four distances of 25 cm, 40 cm, 65 cm, and 80 cm.

During this process, it was expected that the coin vibration motors would react differently at each of the pre-determined distances, and that the rollator would detect all of the objects and obstacles at 250cm or closer. When the ultrasonic sensor detected an object/obstacle between 0-50 centimeters away, all three-coin vibration motors vibrated. When it detected something between 50-100 cm away, two motors should have vibrated (although all three continued to during the actual trials). When the ultrasonic sensor detected the object/obstacle between 100 and 250 centimeters away, only one motor vibrated, and when it was more than 250cm away, none of the coin vibration motors vibrated. These vibrations were also considered and tracked during data collection to determine whether they worked as expected.

Results

The distances indicated by the Serial Monitor in the Arduino IDE of three objects – a person, a chair, and a small cardboard box – and three obstacles – a wall, a pillar, and a door – were measured at seven specified distances via the tape measurer – 50cm, 100cm, 250cm, and 25cm, 40cm, 65cm, 80cm. There were three trials performed at each distance.

The distance from the serial monitor, whether or not the motor vibrated, the distance using a tape measure, and the number of motors that vibrated were recorded for each distance and are shown in Table 4 and Table 5 below. From the obtained results, as seen in Table 4 and in Table 5, the coin vibration motors vibrated when the ultrasonic sensor detected any distance less than 250 cm. If the distance went over 250 cm according to the ultrasonic sensor, the coin vibration motors would not vibrate. This can be seen in Trial 3 for the chair at 100 cm, as the Serial Monitor recorded 253 cm which resulted in no vibrations. The asterisk attached to any Yes in Table 4 indicates less vibration due to further distance detected from the object or obstacle.

Table 4. Raw data of recorded distances and vibrations for each object and obstacle tested at distances 50cm, 100cm, 250cm, and the maximum distance.

		50cm				100cm				250cm				Maximum (cm)			
	Trial #	Did it vibrate?	Tape Measure	Serial Monitor	Number of Vibration Motors	Did it vibrate?	Tape Measure	Serial Monitor	Number of Vibration Motors	Did it vibrate?	Tape Measure	Serial Monitor	Number of Vibration Motors	Did it vibrate?	Tape Measure	Serial Monitor	Number of Vibration Motors
Person	1	Yes	50	67	3	Yes	100	117	3	Yes*	250	188	1	No	224.6	252	0
	2	Yes	50	70	3	Yes	100	113	3	Yes*	250	220	1	No	239.84	249	0
	3	Yes	50	66	3	Yes	100	111	3	Yes*	250	220	1	No	255.08	263	0
Chair	1	Yes	50	58	3	Yes	100	107	3	Yes*	250	241	1	No	356.68	364	0
	2	Yes	50	60	3	Yes	100	132	3	Yes*	250	243	1	No	349.06	356	0
	3	Yes	50	52	3	Yes	100	108	3	No	250	253	1	No	356.68	362	0
Small Cardboard Box	1	Yes	50	46	3	Yes	100	94	3	Yes*	250	244	1	No	801.18	686	0
	2	Yes	50	46	3	Yes	100	95	3	Yes*	250	242	1	No	620.84	610	0
	3	Yes	50	46	3	Yes	100	95	3	Yes*	250	245	1	No	529.4	522	0
Wall	1	Yes	50	53	3	Yes	100	100	3	Yes*	250	245	1	No	706.12	445	0
	2	Yes	50	51	3	Yes	100	99	3	Yes*	250	246	1	No	689.41	676	0
	3	Yes	50	54	3	Yes	100	101	3	Yes*	250	247	1	No	681.8	689	0
Pillar	1	Yes	50	51	3	Yes	100	97	3	Yes*	250	249	1	No	340.36	337	0
	2	Yes	50	55	3	Yes	100	100	3	Yes*	250	249	1	No	332.74	343	0
	3	Yes	50	50	3	Yes	100	99	3	Yes*	250	249	1	No	337.82	341	0
Door	1	Yes	50	51	3	Yes	100	96	3	Yes*	250	243	1	No	773.24	759	0
	2	Yes	50	50	3	Yes	100	98	3	Yes*	250	246	1	No	773.24	759	0
	3	Yes	50	50	3	Yes	100	98	3	Yes*	250	245	1	No	719.89	724	0

*Only one vibration motor was functioning for less vibration with respect to further distances. Three coin vibration motors vibrated otherwise.

Table 5. Raw data of recorded distances and vibrations for each object and obstacle tested at distances 25 cm, 40 cm, 60 cm, and 80 cm

		25cm				40cm				65cm				80cm			
	Trial #	Did it vibrate?	Tape Measure	Serial Monitor	Number of Vibration Motors	Did it vibrate?	Tape Measure	Serial Monitor	Number of Vibration Motors	Did it vibrate?	Tape Measure	Serial Monitor	Number of Vibration Motors	Did it vibrate?	Tape Measure	Serial Monitor	Number of Vibration Motors
Person	1	Yes	25	24	3	Yes	40	37	3	Yes	65	61	3	Yes	80	78	3
	2	Yes	25	27	3	Yes	40	39	3	Yes	65	62	3	Yes	80	77	3
	3	Yes	25	25	3	Yes	40	38	3	Yes	65	60	3	Yes	80	80	3
Chair	1	Yes	25	27	3	Yes	40	38	3	Yes	65	62	3	Yes	80	77	3
	2	Yes	25	28	3	Yes	40	39	3	Yes	65	63	3	Yes	80	77	3
	3	Yes	25	27	3	Yes	40	38	3	Yes	65	62	3	Yes	80	76	3
Small Cardboard Box	1	Yes	25	23	3	Yes	40	37	3	Yes	65	62	3	Yes	80	76	3
	2	Yes	25	22	3	Yes	40	37	3	Yes	65	61	3	Yes	80	76	3
	3	Yes	25	22	3	Yes	40	37	3	Yes	65	62	3	Yes	80	77	3
Wall	1	Yes	25	25	3	Yes	40	39	3	Yes	65	64	3	Yes	80	78	3
	2	Yes	25	25	3	Yes	40	39	3	Yes	65	64	3	Yes	80	78	3
	3	Yes	25	25	3	Yes	40	39	3	Yes	65	64	3	Yes	80	78	3
Pillar	1	Yes	25	24	3	Yes	40	40	3	Yes	65	64	3	Yes	80	80	3
	2	Yes	25	25	3	Yes	40	40	3	Yes	65	65	3	Yes	80	79	3
	3	Yes	25	25	3	Yes	40	41	3	Yes	65	65	3	Yes	80	80	3
Door	1	Yes	25	25	3	Yes	40	40	3	Yes	65	65	3	Yes	80	78	3
	2	Yes	25	24	3	Yes	40	41	3	Yes	65	65	3	Yes	80	79	3
	3	Yes	25	25	3	Yes	40	40	3	Yes	65	65	3	Yes	80	78	3

Statistical analysis was performed for the set of data obtained which is shown in Table 6 and in Table 7. Percent error for each object and obstacle was calculated by using the average of the distance recorded in the Serial Monitor per distance (ie. 25cm, 40 cm, 50 cm, 65 cm, 80 cm, 100 cm, 250 cm) as the experimental value. The total percentage error for all of the objects and obstacles was also calculated. These values were less than 10% for objects/obstacles at 50 cm and less than 5% for objects/obstacles at 40cm, 65cm, 80cm,100cm and 250cm. The total percent error was less than 1% for objects/obstacles at 25cm. The highest percent error calculated is 35.3% with a person at 50 cm. The lowest percentage is 0% with a wall at 100 cm. There is a significant difference between these two values.

Average distances per trial recorded by the Serial Monitor were calculated. The visual representations of the average distances per object/obstacle can be seen in Figured 18 - 24. Additionally, the standard deviations of the total recorded distances at each set distance and the standard deviations of each object and obstacle at different distances were calculated to compare the overall set of recorded distances in relation to the average is. The lowest standard deviation value at 50 cm was 0.500 with the door and the highest standard deviation value was 8.995 with the person. The lowest standard deviation value at a distance of 100 cm was 0.816 with the wall and the highest standard deviation value was 13.961 with the chair. The lowest standard deviation value at 250 cm was 0.500 with the pillar and the highest standard deviation value was 25.318 with the person. The lowest standard deviation value at 25 cm was 0 with the wall and the highest standard deviation value was 1.414 with the small cardboard box. The lowest standard deviation value at 40 cm was 0.500 with all three obstacles and the highest standard deviation value was 1.500 with the small cardboard box. The lowest standard deviation value at 65 cm was 0 with the door and the highest standard deviation value was 2.160 with the person. The lowest standard deviation value at 80 cm was 0.500 with the pillar and the highest standard deviation value was 1.893 with the small cardboard box. Generally, the obstacles had lower standard deviations between the tape measurer readings and the serial monitor readings. The obstacle with the lowest standard deviation value was 0 with the wall at 25 cm and with the door at 65 cm; the object with the highest standard deviation value was 25.318 with a person at 250 cm.

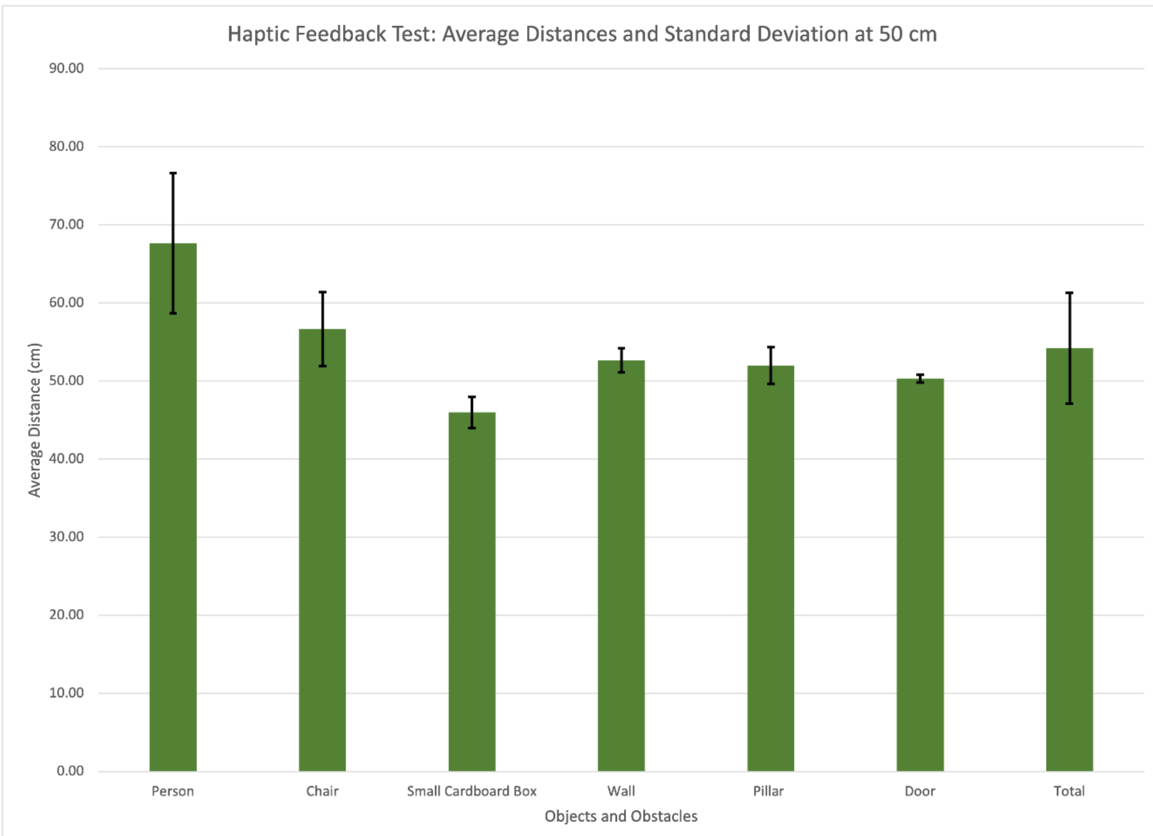

Figure 18. Haptic Feedback Test: Average Distances and Standard Deviation at 50 cm

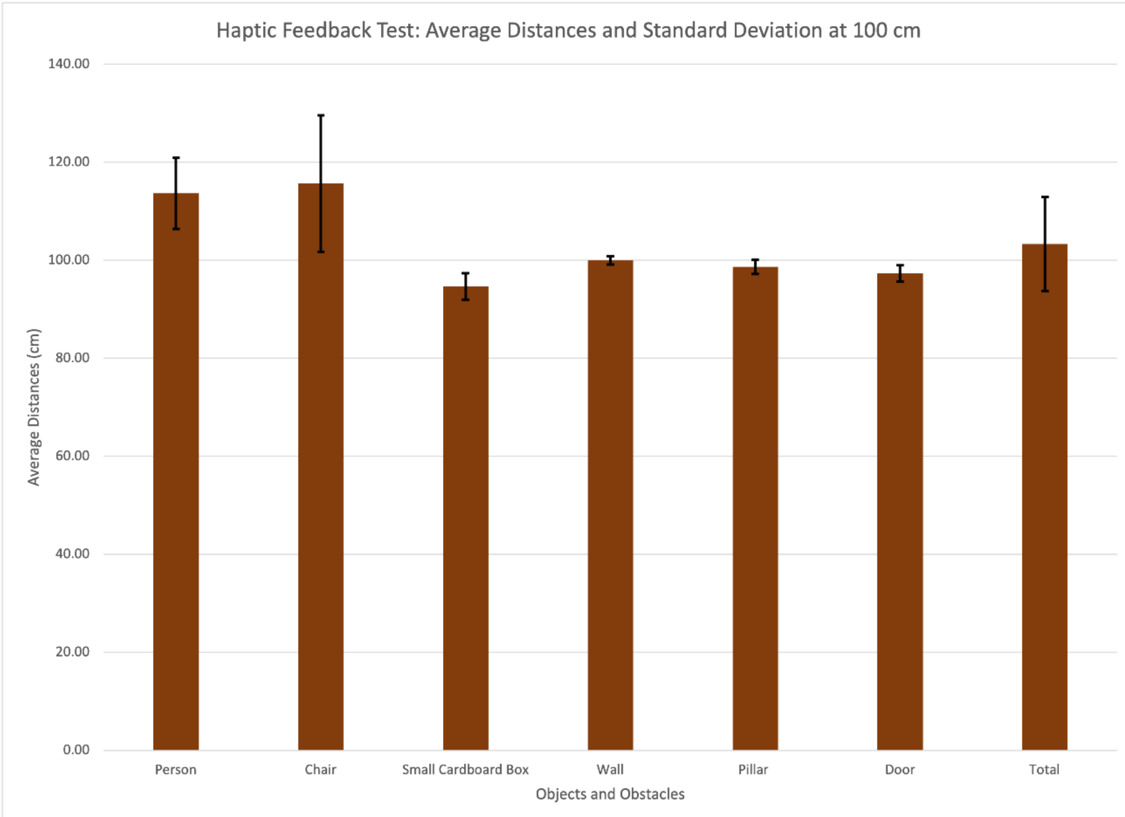

Figure 19. Haptic Feedback Test: Average Distances and Standard Deviation at 100 cm

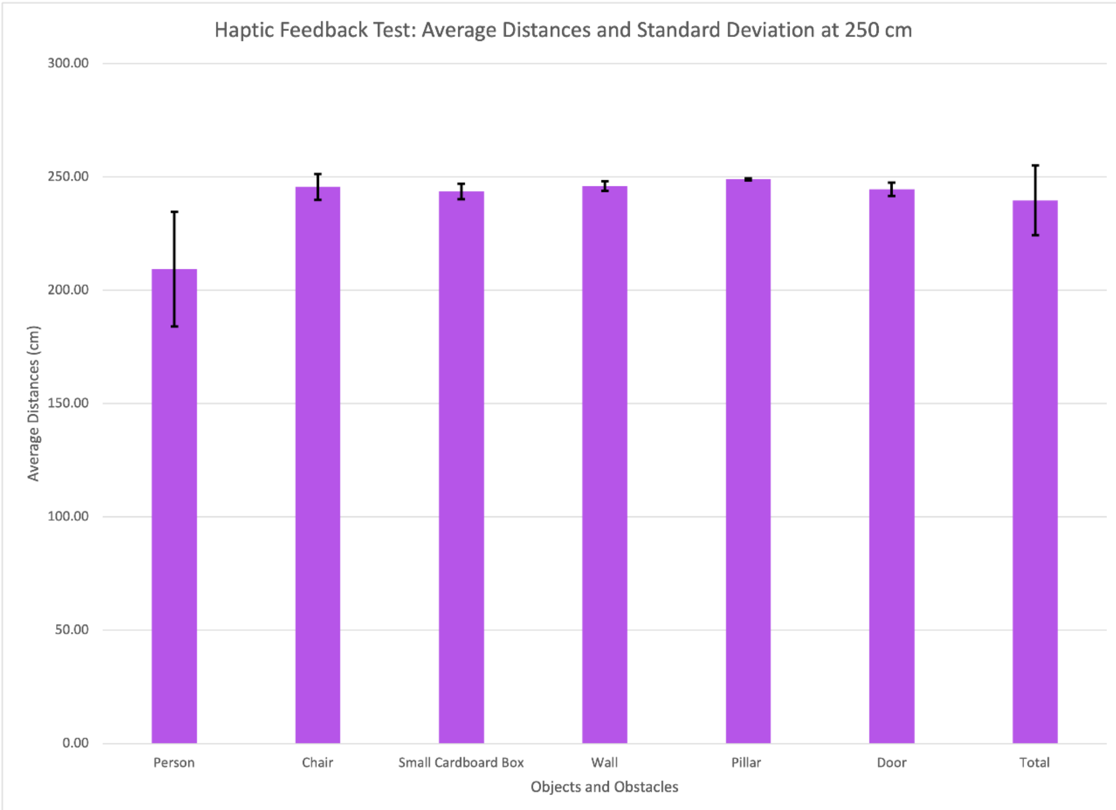

Figure 20. Haptic Feedback Test: Average Distances and Standard Deviation at 250 cm

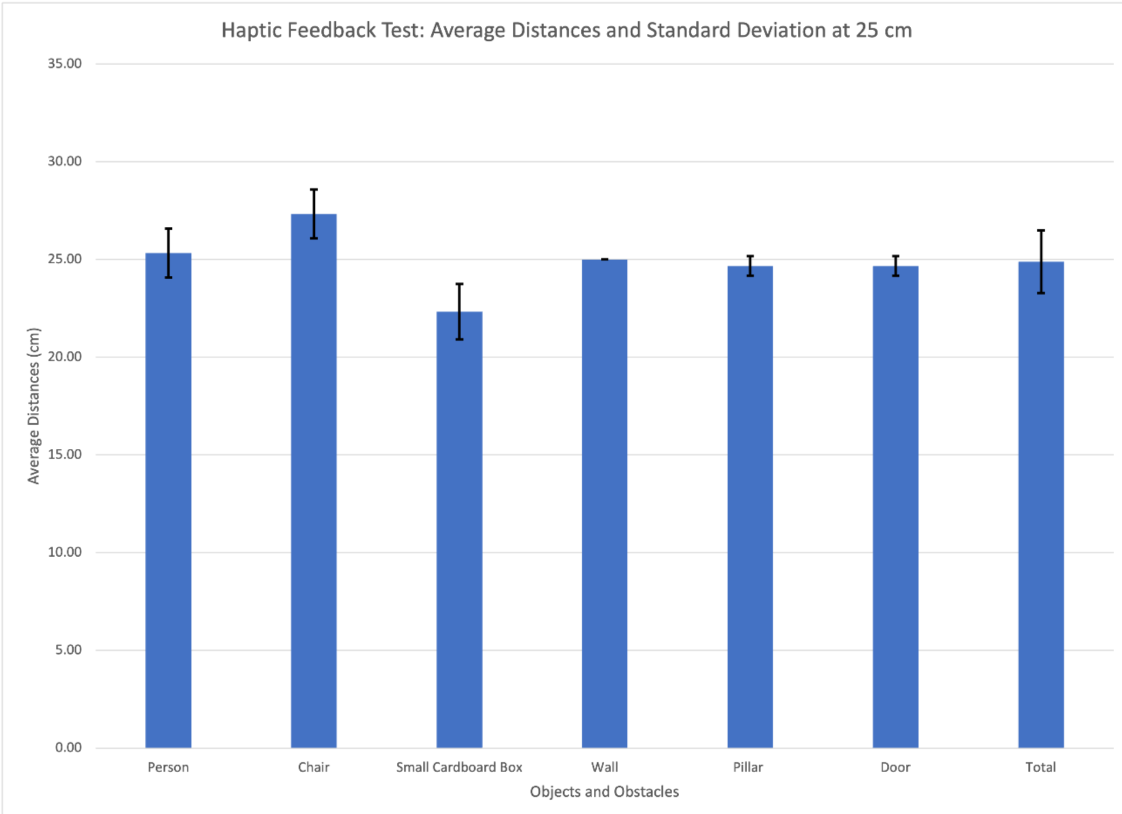

Figure 21. Haptic Feedback Test: Average Distances and Standard Deviation at 25 cm

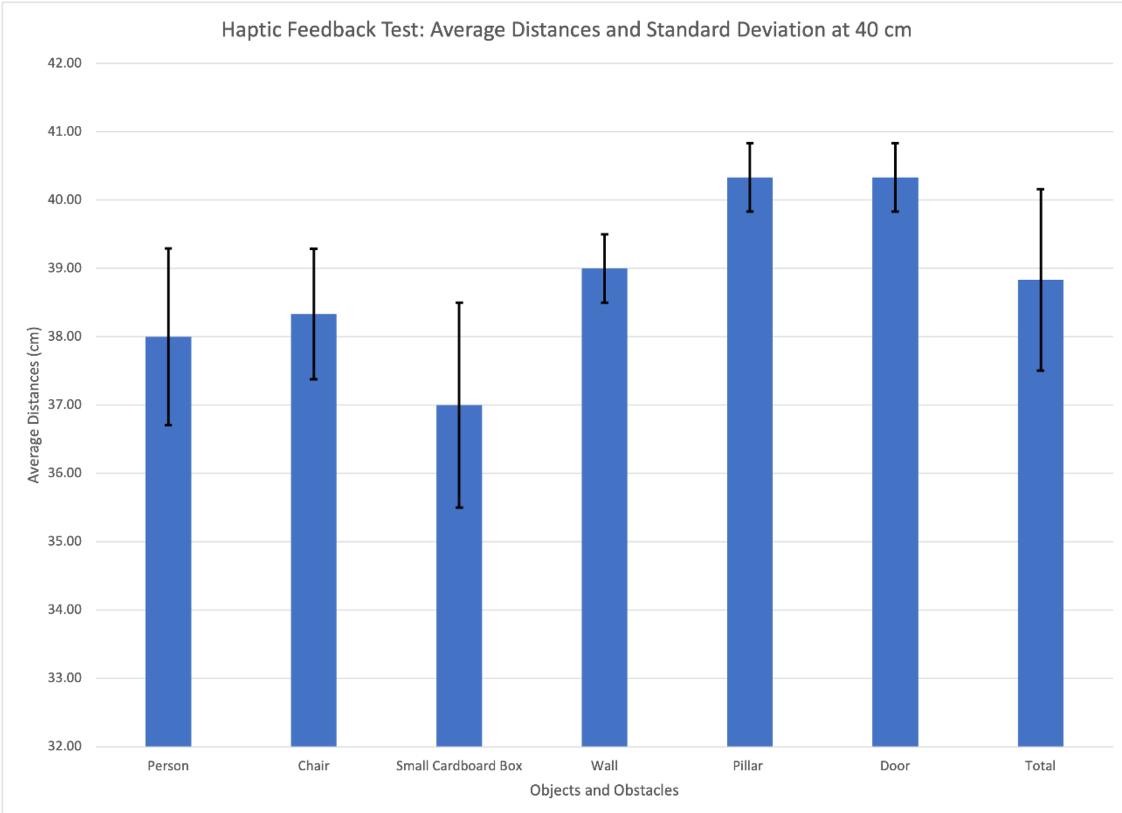

Figure 22. Haptic Feedback Test: Average Distances and Standard Deviation at 40 cm

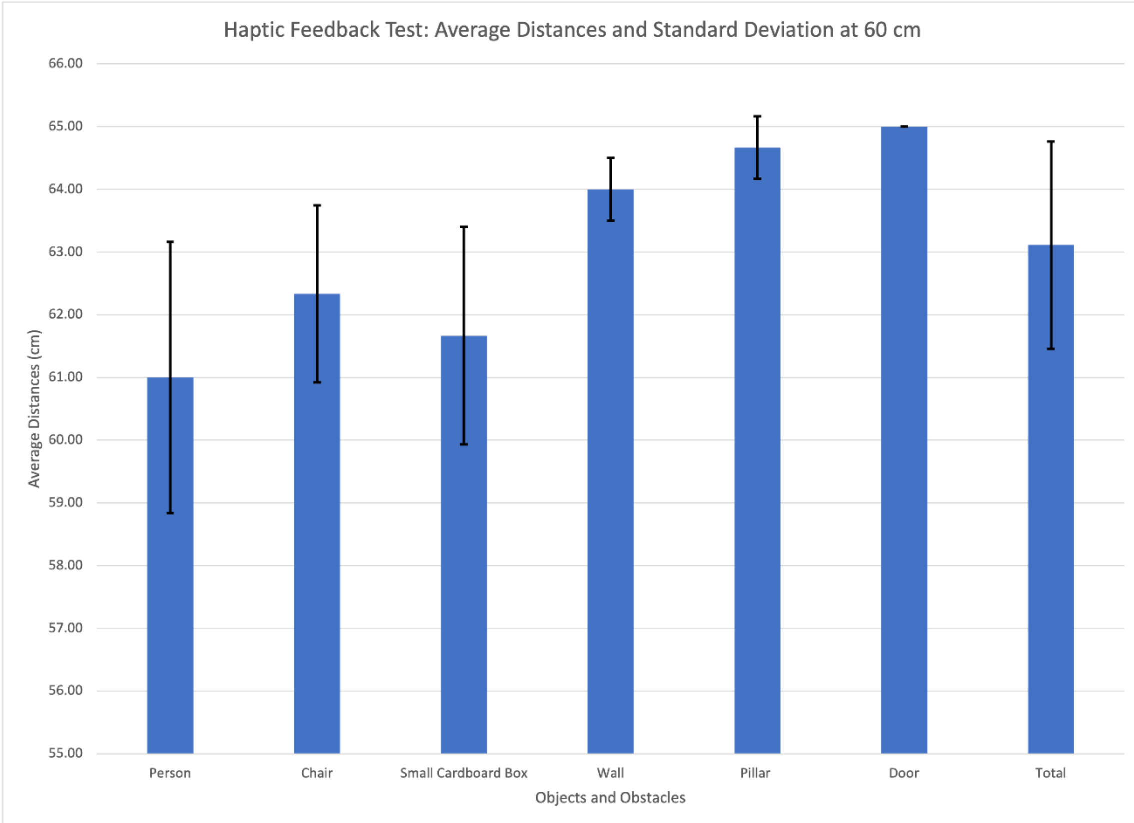

Figure 23. Haptic Feedback Test: Average Distances and Standard Deviation at 60 cm

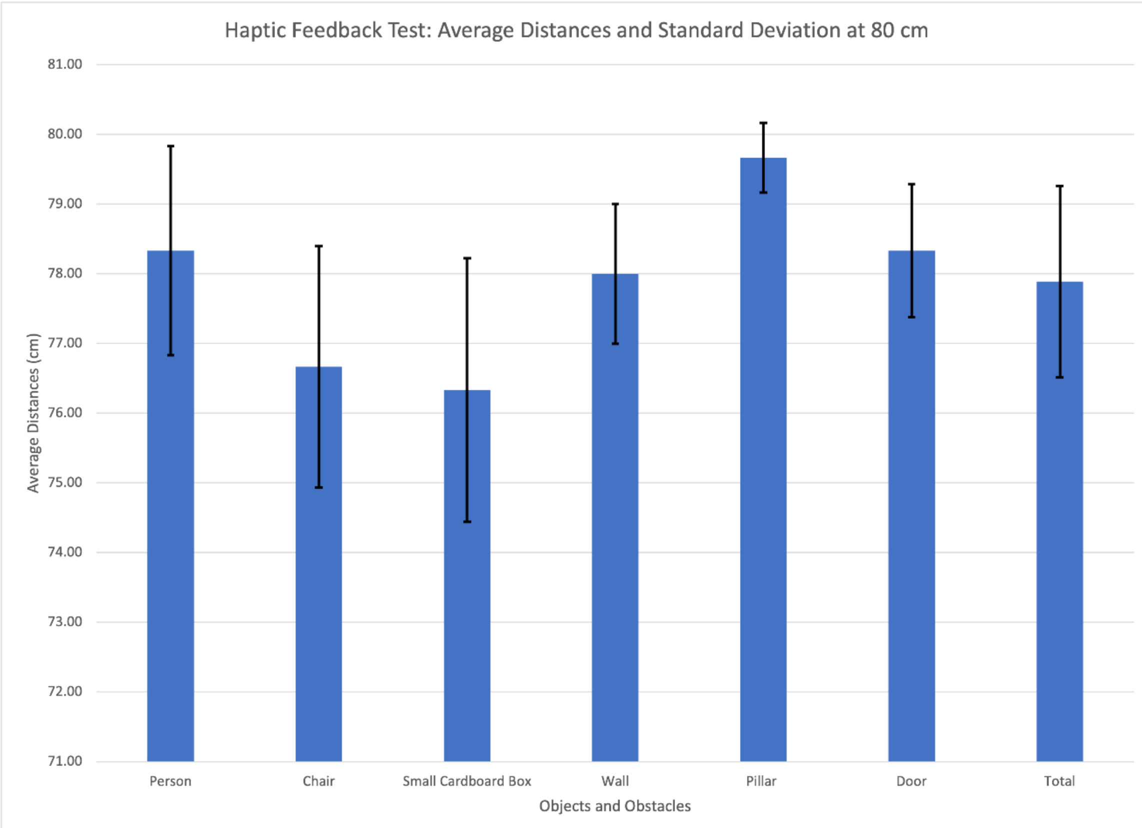

Figure 24. Haptic Feedback Test: Average Distances and Standard Deviation at 80 cm

A t-test was conducted as well; a p-value under 0.05 means the data is significant. For this test, the p-value for the trials recorded at 100cm was 0.1678 and at 25cm, it was 0.774. The p-value for the trials at distances of 40cm, 50cm, 65cm, 80cm, 100cm, and 250cm were less than 0.05 indicating significance. The reason for the p-values at 25cm and 100cm being insignificant is because there is more under and overdispersion amongst the data from these trials compared to the other trials.

Table 6. Percent errors for the data presented in Table 1.

Percent Error (%)	(|experimental-actual|/actual)*100						
Measurement (cm)	25	40	50	65	80	100	250
Person	1.333	5.000	35.333	6.154	2.083	13.667	16.267
Chair	5.333	4.167	13.333	5.641	2.500	15.667	1.733
Small Cardboard Box	6.667	4.167	8.000	5.128	2.500	5.333	2.533
Wall	9.333	4.167	5.333	4.103	4.167	0.000	1.600
Pillar	4.000	5.000	4.000	4.103	4.583	1.333	0.400
Door	4.000	6.667	0.667	5.128	5.000	2.667	2.133
Total Mean Percent Error	0.444	2.917	8.444	2.906	2.639	3.333	4.111
T-Test | p-value	0.7774	0.0018	0.0243	0.0001	0.0000	0.1678	0.0125

Table 7. Statistical analysis for the data presented in Table 1. The average/standard deviation column pairs and the percent error columns at the top respectively correspond to the three distances tested.

	50		100		250			
	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation		
Person	67.667	8.995	113.667	7.274	209.333	25.318		
Chair	56.667	4.761	115.667	13.961	245.667	5.679		
Small Cardboard Box	46.000	2.000	94.667	2.708	243.667	3.403		
Wall	52.667	1.528	100.000	0.816	246.000	2.160		
Pillar	52.000	2.380	98.667	1.414	249.000	0.500		
Door	50.333	0.500	97.333	1.633	244.667	2.944		
Total	54.222	7.110	103.333	9.570	239.722	15.365		
	25		40		65		80	
	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation
Person	25.333	1.258	38.000	1.291	61.000	2.160	78.333	1.500
Chair	27.333	1.258	38.333	0.957	62.333	1.414	76.667	1.732
Small Cardboard Box	22.333	1.414	37.000	1.500	61.667	1.732	76.333	1.893
Wall	25.000	0.000	39.000	0.500	64.000	0.500	78.000	1.000
Pillar	24.667	0.500	40.333	0.500	64.667	0.500	79.667	0.500
Door	24.667	0.500	40.333	0.500	65.000	0.000	78.333	0.957
Total	24.889	1.595	38.833	1.329	63.111	1.653	77.889	1.374

The maximum distance the ultrasonic sensor was able to detect an object or obstacle was measured in accordance with the Serial Monitor and the tape measurer. Likewise, with the previous trials, there were three trials for each object and obstacle. Results from these trials are seen in Table 4 and in Table 5. The same statistical analysis for these results as done for the other trials was performed. The result for the statistical analysis is shown in Table 8, which shows that the only set of trials with a statistically significant difference between Serial Monitor and tape measure values was for the chair which was 0.09. The lowest percent error for this test was 1% with the pillar. The highest percent error for the test was 12.87% with the wall. Figure 25 provides a visual representation of the average distances per object and obstacle along with error bars of the respective standard deviation.

Table 8. Statistical analysis for the maximum distance data comparing the accuracy of the ultrasonic sensor to the values determined by the tape measure used. TM = Tape Measurer, SM = Serial Monitor.

	Average TM	Average SM	Percent error	SD TM	SD SM	T-test
Person	239.840	254.667	6.18	15.240	7.371	0.143
Chair	354.140	360.667	1.84	4.399	4.163	0.009
Small Cardboard Box	650.473	606.000	6.84	138.292	82.073	0.336
Wall	692.443	603.333	12.87	12.441	137.275	0.410
Pillar	336.973	340.333	1.00	3.880	3.055	0.483
Door	755.457	747.333	1.08	30.802	20.207	0.315

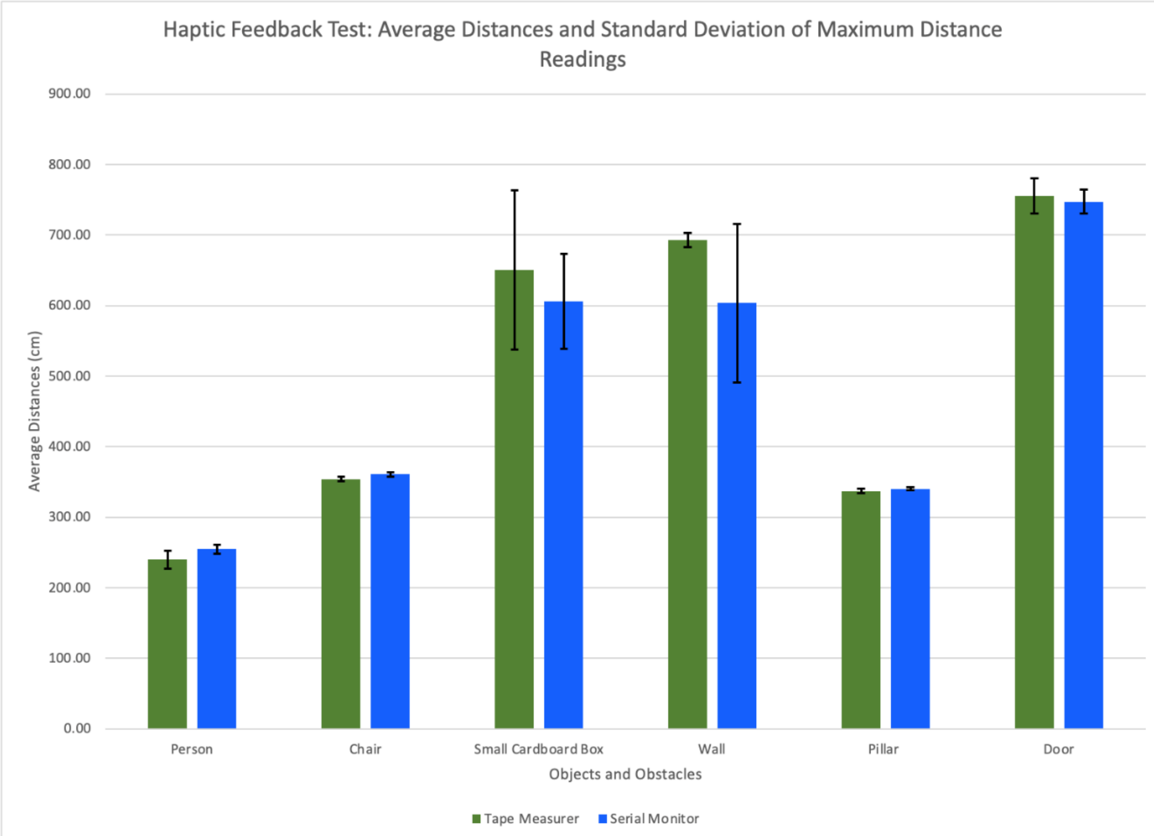

Figure 25. Haptic Feedback Test: Average Distances and Standard Deviation at Maximum Distance Readings using the Tape Measurer and the Serial Monitor

Discussion and Next Steps

The sensor was successful in detecting a chair, small cardboard box, wall, door, and pillar at each pre-determined distance, and successfully detected a person up to 220cm. The detection for the obstacles was also very precise, due to the low precision errors and standard deviation values. However, the sensor was unable to detect the correct distance for some of the objects, i.e., the person and chair, and the percentage error/standard deviation values varied much more for these objects. Because of the different depths for the chair, i.e., the seat of the chair and the supporting pole of the chair, the ultrasonic sensor picked up different distances from the actual chair placement and was less accurate. This suggests that our sensor setup is ideal for flat surfaces and larger objects/obstacles compared to non-uniform ones within 250cm. Regarding the maximum distance values, the chair, pillar and wall demonstrated errors below 2% between Serial Monitor and tape measure values. Additionally, some objects and obstacles were easier to detect at further distances compared to others. For instance, a person was only detected to a range of 240-260in yet a door could be detected at a distance from 719 –773in. Overall, if we assume a null hypothesis that there is no statistically significant difference between tape measure and Serial Monitor values across all objects and obstacles, only the chair rejects this hypothesis – supporting the conclusion that it is harder for the sensor to accurately detect non-uniform shapes.

The acceptance criteria were whether the sensor could detect objects and obstacles at 0-50cm, 50-100cm, and 100-250cm away, and communicate their presence via haptic feedback with a 90% success rate for each distance. This was mostly successful, as all of the objects/obstacles were detected at the three determining distances along with the rest of the distances. Additionally, three vibration motors vibrated when the sensor detected an object/obstacle 0-50cm away as expected, one vibration motor worked when the sensor detected an object/obstacle 100-250cm away, and none of them vibrated when the object/obstacle was more than 250cm away. However, only one vibration motor worked detecting an object/obstacle at 50-100cm away. We are not sure why this error occurred – it worked at all the other distances, so we know there is no issue with the code, wires, or motors themselves. However, we re-loaded the circuit for the user experience test and observed that the motors had functioned correctly during this test. The acceptance criteria for 50-100cm was for two vibration motors to vibrate, so this aspect of the test was not successful. The vibration coin motors vibrated for each of the ten trials conducted. The recorded distances of when the vibrations started are shown in Table 4 and in Table 5. The distances measured with the tape measurer and the distances recorded in the Serial Monitor from the Arduino IDE were recorded. Statistical analysis was calculated for these trials. The average distance measured with the tape measurer was 71.80 in and the average distance measured with the Serial Monitor was 121.850. The percentage error of these values was 69.708%. This indicates the difference between the two sources of measurement when the rollator was at the same location. The standard deviation for the values recorded from the tape measurer was 26.70 whereas the standard deviation for the values from the Serial Monitor was 184.433. This shows the data obtained from Serial Monitor is more dispersed from the average at least seven times than from the tape measurer. The p-value of the entire trial was 0.408 indicating the data is not significant.

The results obtained show that we have met our requirements of detecting an object and sending haptic feedback to the coin vibration motors. However, there is still some room for improvement. We have also incorporated ultrasonic sensors on the sides of the device and have determined that they are able to communicate with the Arduino. Only the left handlebar vibrates for an obstacle on the left side of the user, and only the right handlebar vibrates for an obstacle on their right. When an obstacle is in front of the user, both handles vibrate. While we have been able to demonstrate this communication, we have not yet conducted a formal test, so this would be our immediate next step. We could also incorporate additional methods of obstacle detection (ex. camera with image detection algorithm) and feedback (ex. audible via Bluetooth module and SHOKZ headphones).

Test 2: Curb detection test

Description

The purpose of this test was to ensure that the rollator could detect a curb and to ensure that the user is made aware of the curb prior to their arriving at that point, to reduce their risk of tripping and falling. A HC-SR04 ultrasonic sensor was placed in the center of the lower horizontal pole of the rollator and attached via masking tape. This type of sensor has a range of 0.02m-4m and a measuring angle of 15 degrees. The sensor was placed at a 30-degree angle on the rollator relative to the horizontal pole, so that it could point towards the ground in order to detect a change in elevation between flat ground and curb. It was connected to an Arduino Uno that in turn was connected to a laptop, which acted as both a power source and an outlet for viewing data provided by the Serial Monitor. The other major connection to the Arduino Uno was a breadboard that contained wires for three-coin vibration motors, which were held on top of one of the rollator handles.

To measure curb detection, we tested the ultrasonic sensor to determine if the curb was able to be detected within 10 feet. The rollator with the affixed ultrasonic sensor was first placed 20 feet away from the curb pictured in Figure 27 and Figure 28, and this distance was measured using a tape measure. Then, the rollator gradually moved closer to the curb until there was consistent vibration from the vibration coin motors. When this occurred, the distance value on the Serial Monitor was recorded to determine what the ultrasonic sensor observed, and the distance from the rollator to the curb was recorded after being measured via tape measure. This process was done 10 times to test if the sensor was accurate and consistent in its detection, and the primary acceptance criterion was that the ultrasonic sensor would detect the curb (causing the coin vibration motors to vibrate) at least 90% of the time. The test assumed that the ultrasonic sensor system was secured onto the rollator, and that the equipment did not negatively affect the basic functions of the assistive walking device.

Figure 27. Curb detection

Figure 28. Curb detection 8.5’ from the curb

A second curb detection test was conducted using two HC-SR04 ultrasonic sensors placed at the front of the rollator. One sensor was placed at 30 degrees and the other was placed at 45 degrees relative to the horizontal pole. The sensors were connected to an Arduino Mega 2500 that was connected to a laptop, which acted as both a power source and a way to ensure that the circuit was functioning. The rollator was placed three feet away from the curb at the start of each trial, as the senior volunteers who tested the initial design requested curb detection to only occur close to the curb. The distance at which the rollator was able to detect the curb, i.e., when the coin vibration motors started to vibrate, was recorded for each trial. Data collected included whether the device was able to detect a curb and the distance that it detected from the curb. The acceptance criterion for this test was successful curb detection within 3 feet 90% of the time.

Results

Table 9. Recorded distances of curb detection

Trial	Did it detect?	Tape Measure Distance (in)	Serial Monitor (in)
1	Yes	43	34.646
2	Yes	130	25.983
3	Yes	103	471.654
4	Yes	57	471.654
5	Yes	55	38.583
6	Yes	84	43.307
7	Yes	67	30.315
8	Yes	67	34.252
9	Yes	52	29.134
10	Yes	60	38.976

Table 10. Statistical Analysis of the data in Table 9

Average	71.80	121.850
Percent Error		69.708
Standard Deviation	26.70	184.433
T-test		0.408

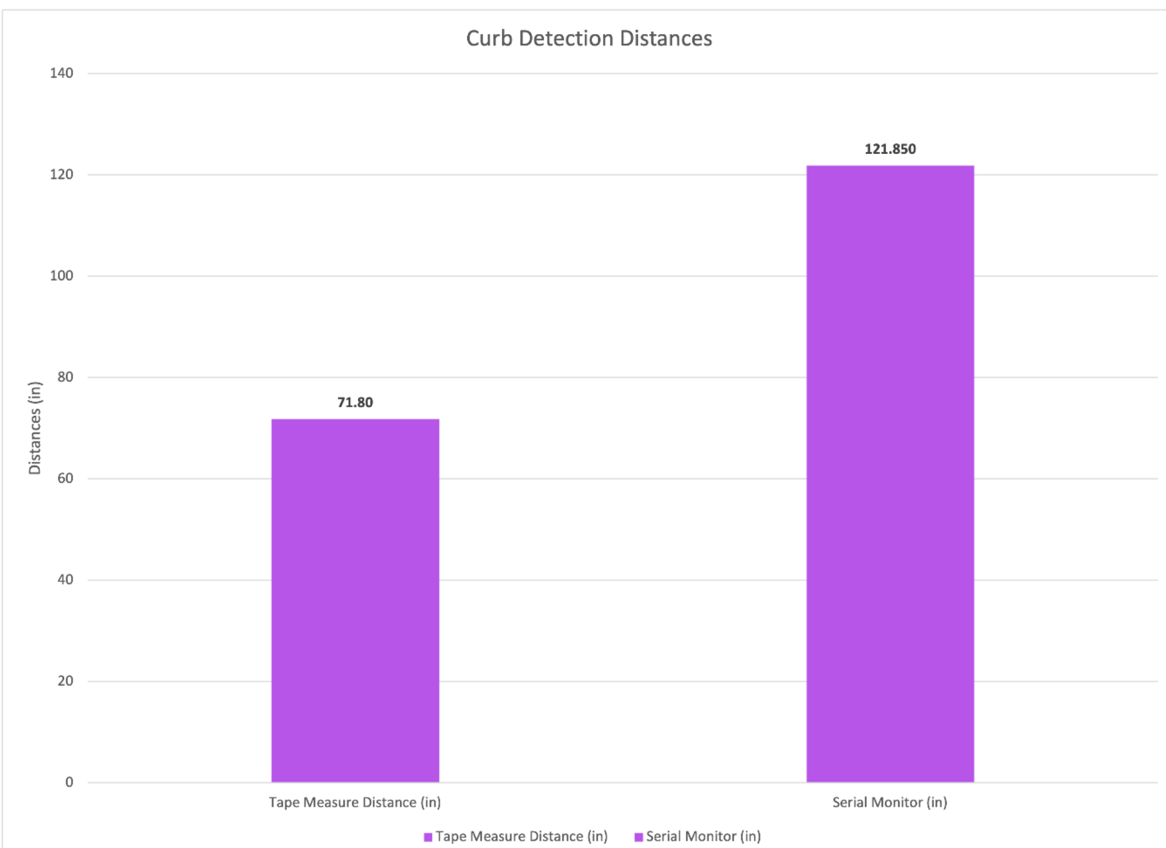

Figure 29. Curb Detection averages of tape measurer and serial monitor

The vibration coin motors vibrated for each of the ten trials conducted in the first test. The recorded distances of when the vibrations started are shown in Table 9. The distances measured with the tape measurer and the distances recorded in the Serial Monitor from the Arduino IDE were recorded. Recorded measurements between the tape measurer and the Serial Monitor varied and differed a lot. Statistical analysis was calculated for these trials. The average distance measured with the tape measurer was 71.80 in and the average distance measured with the Serial Monitor was 121.850. Figure 29 shows a visual representation of the average detection distance. The percentage error of these values was 69.708%. This indicates the difference between the two sources of measurement when the rollator was at the same location. The standard deviation for the values recorded from the tape measurer was 26.70 whereas the standard deviation for the values from the Serial Monitor was 184.433. This shows the data obtained from Serial Monitor is more dispersed from the average at least seven times than from the tape measurer. The p-value of the entire trial was 0.408 indicating the data is not significant.

Table 11. Curb Detection Test – Part B Data

Trial	Did it vibrate within 3 feet?	Distance via tape measure that it vibrated (in)
1	YES	24
2	YES	36
3	YES	14
4	YES	31
5	YES	23
6	YES	34
7	YES	33
8	YES	35
9	YES	32
10	YES	30
	Average distance	29.2
	Standard deviation	6.876691711

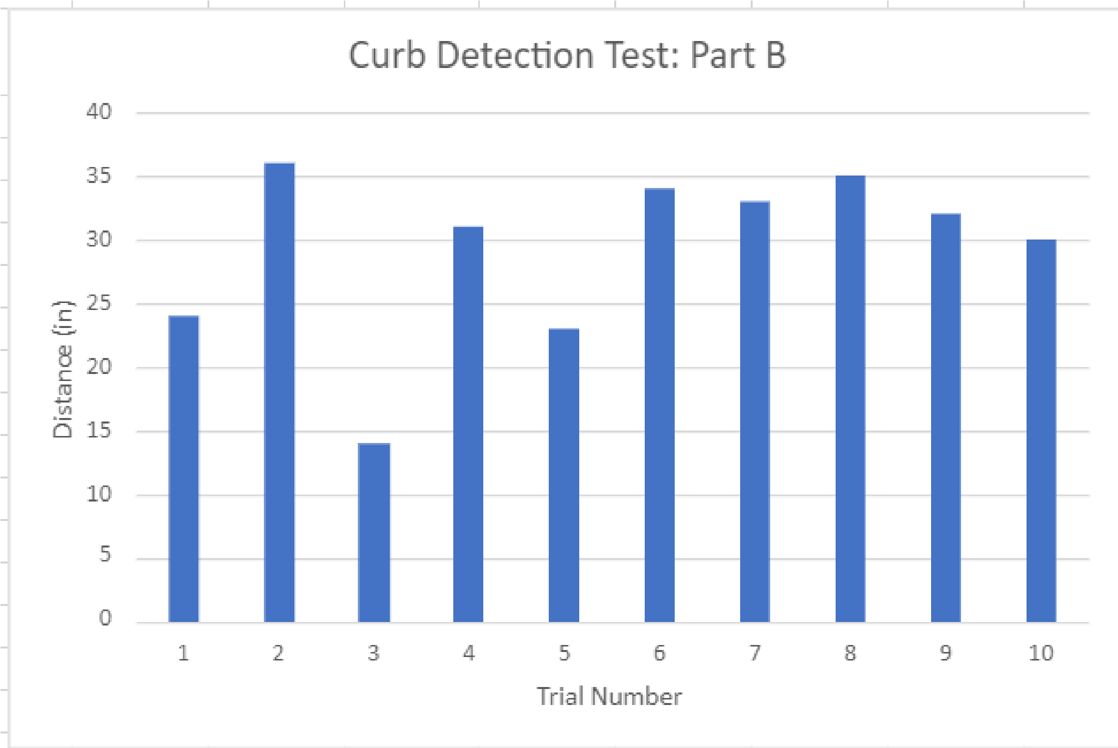

Figure 30. Curb detection distances of tape measure.

The results of the second test are shown in Table 11. The table includes the results of each trial, which consisted of whether the device vibrated within three feet of the curb and the distance from the curb that it vibrated at. The average distance that it vibrated was 29.2 inches and the standard deviation was 6.87 inches. Figure 30 is a visual representation of the distance in inches of which the curb was detected by SAR.

Discussion and Next Steps

The results of the first test indicate that the sensor was able to detect the curb 100% of the time, and the curb was detected within 10 feet 90% of the time, meeting the acceptance criteria. The Serial Monitor measurements did not reflect the measurements of the tape measure. It would have made sense for the Serial Monitor values to be slightly higher than the tape measure values since it was measuring the ground at an angle rather than horizontally, but many of the values did not correspond at all. We hypothesize that this is the case because the ultrasonic sensor is detecting inconsistencies in the surface such as grass, divots in the curb, and debris on the ground, none of which would affect the tape measurement of the actual distance. We attempted to address this in our second test by incorporating two sensors and modifying the code to detect a larger difference in elevation. Some design requirements were also met for this test as the sensor setup did not interfere with the rollator's function as an assistive walking device and the coin vibration motors did work properly in communicating with the ultrasonic sensor. However, the performance of the ultrasonic sensor was unsatisfactory due to its inconsistency and sensitivity. The ultrasonic sensor detected changes in elevation besides just the curb itself, which caused unwanted haptic feedback. For instance, part of the 20-foot distance was on grass, and the motors sometimes vibrated due to the uneven ground – suggesting that our current setup is only effective on flatter terrains. The sensor also may have detected divots in the concrete of the sidewalk, which could have contributed to unwanted haptic feedback. For the second test, the results indicate that the curb was detected 100% of the time, within 3 feet each time. This indicates that the acceptance criterion for this particular test was met. This portion of the test addressed some of the concerns from the previous test, as divots in the sidewalk were no longer detected by the sensors and no longer induced vibrations. However, the high standard deviation indicates that the exact point of curb detection was still inconsistent, possibly because the angles need to be adjusted for more accurate detection. The next steps for this test would be to adjust the angles and determine what combination results in the most accurate curb detection. We could also use a camera instead of, or in addition to, an ultrasonic sensor for the purpose of detecting a curb. We may consider implementing an image detection algorithm using machine learning. We also may modify the type(s) of feedback that the user will receive to be notified of a curb. We are considering the use of SHOKZ bone conduction headphones to provide the user with audio feedback in addition to haptic feedback when a curb is detected.

Test 3: User experience assessments
Description

Part A: Students

The purpose of this test was to obtain user feedback on our design from young, healthy individuals. Our goal was to determine the comfort and ease of use of our smart autonomous rollator and understand what modifications we need to make before we test a more advanced prototype with our clients at the National Federation of the Blind. In order to do this, we recruited four student volunteers from the BENG 493 course at GMU as well as one additional senior who resided on-campus. We started each person's test by explaining how to use the rollator and discussed the expectation that the haptic feedback would activate within 250 cm of the device. Then, we conducted a device testing portion, where we supervised each volunteer as they attempted to navigate an obstacle course (as shown in Figure 30 and in Figure 31 below). We gave volunteers the option to be blindfolded if they wanted to, and verbally communicated potential obstacles in case the device didn't pick up on them. The obstacle course was set up indoors, with volunteers first moving towards the wall and then turning into a path that contained a chair, a small cardboard box, and a person walking back and forth before ending in front of a door. Each volunteer conducted one trial, and we counted how many objects/obstacles were detected successfully each time.

Once testing was completed, we held a feedback session with our volunteers. During the feedback session, we asked each volunteer to rate various aspects of their experience on a scale of 1-10. Specifically, we asked: 1) how easy was the rollator to use, 2) how successful was the device in communicating obstacles, 3) how confident the users were while trying it, 4) how likely they think someone who would need this product would use it, and 5) how much they enjoyed the overall experience. We also wrote down any additional thoughts and criticisms that the volunteers shared outside of these ratings. Our acceptance criteria were that at least 80% of all the ratings we obtained would be 6 or higher, and that we would receive additional constructive feedback to improve our design.

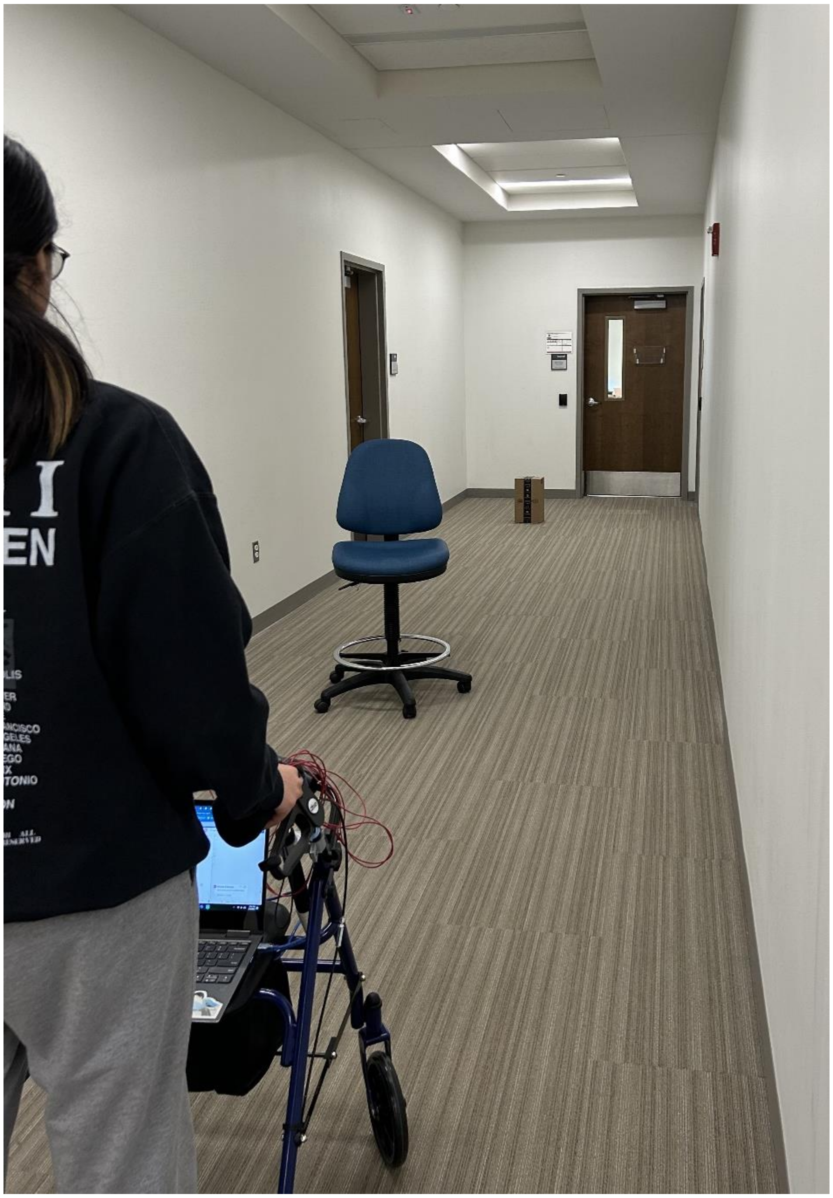

Figure 30. Obstacle course from Participant’s view

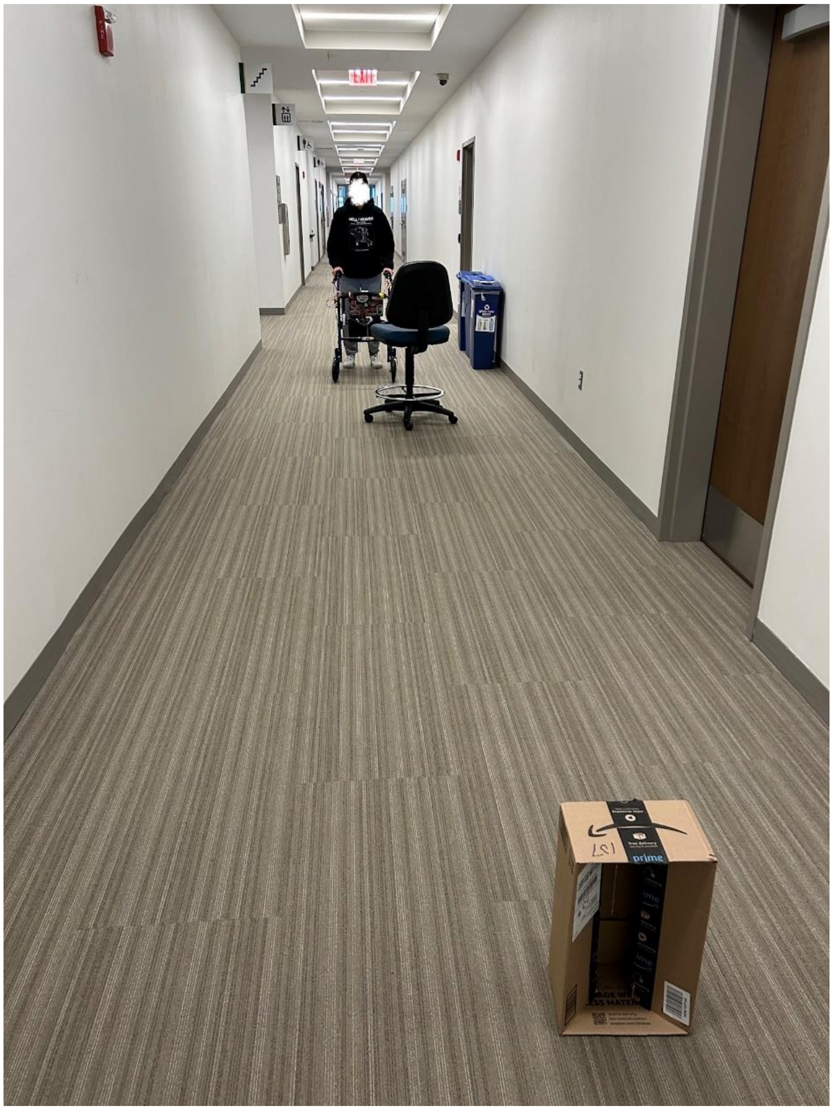

Figure 31. Obstacle course

Part B: Seniors

The second round of user experience testing was conducted at a senior residence in Fort Belvoir, VA, where seven senior volunteers with varying degrees of vision and mobility tested our smart autonomous rollator on a very similar obstacle course containing the same types of objects, except that the chair came before the wall in the path they completed. This test received IRB approval and was conducted with a student researcher accompanying each senior on their trial. The purpose of this test was to obtain feedback on our design from the target population, to make sure the design could actually be used by the target population, and to ensure that their needs and preferences are met as much as possible. We asked our senior volunteers the same survey questions as the students after their respective tests. Our goal was to receive client-specific feedback that would allow us to appropriately modify our design further, and our acceptance criteria was the same as for the student portion of the test.

Results

Part A:

Table 11. Recorded ratings of Student Participants with Average Responses for each question

Participant	# detected	How easy?	How successful?	How confident?	How likely?	Enjoyment?
A	5	6	8	4	6.5	10
B	5	8	9	8	9	10
C	5	8	8	9	6	10
D	5	6	9	4	8	8
E	5	10	10	10	10	10
Average	**5**	**7.6**	**8.8**	**7**	**7.9**	**9.6**
Standard Deviation	**0.000**	**1.673**	**0.837**	**2.828**	**1.673**	**0.894**

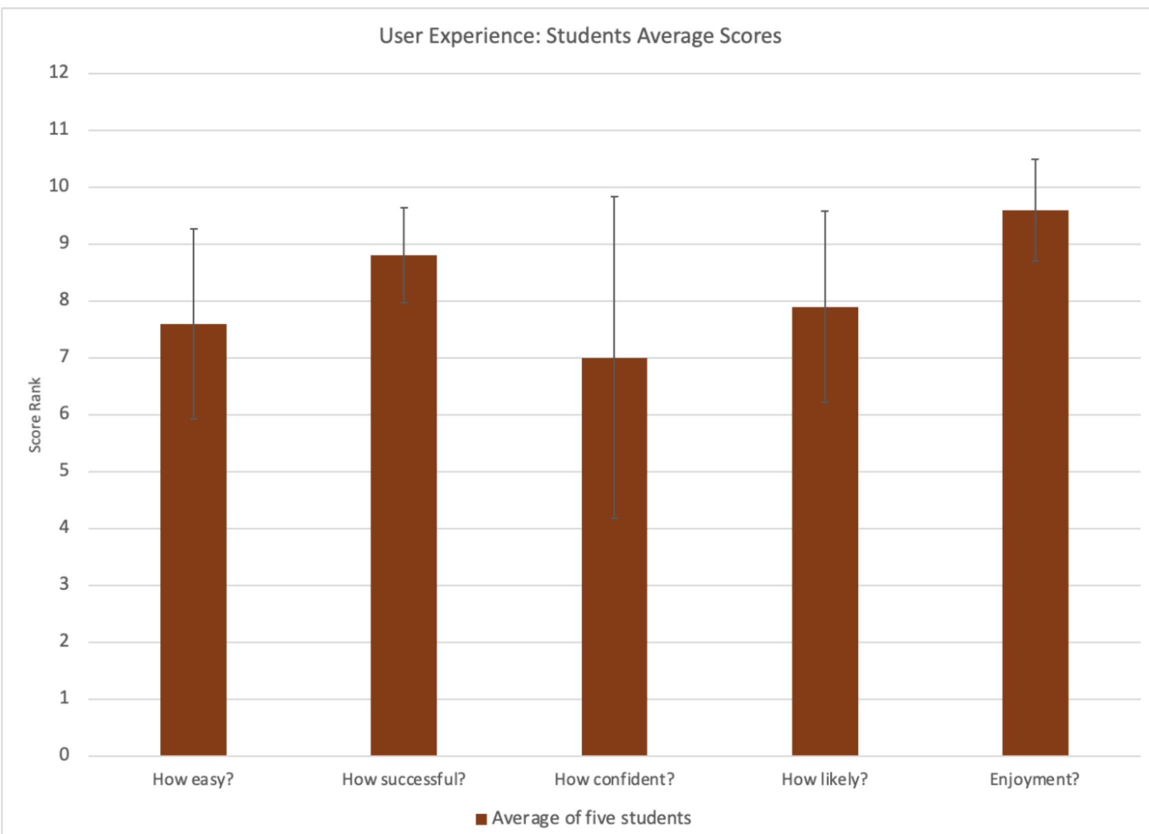

Figure 32. User Experience Part A average score of each question

All five objects and obstacles in the obstacle course were detected for every participant. Hence, there was a 100% success rate for detection. Participant C and Participant E chose to keep their eyes open for the obstacle course, whereas the other three participants chose to close their eyes for the entire test - which may have skewed the results. The rating score for each question per participant was recorded. The average score per question along with the standard deviation of each question was calculated as seen in Table 11. The average score for the first question was a 7.6 with a standard deviation of 1.673. The average score for the second question was 8.8 with a standard deviation of 0.837. The average score for the third question was 7 with a standard deviation of 2.828 (the highest of all questions). The average score for the fourth question was 7.9 with a standard deviation of 1.673. The average score for the fifth question was 9.6 with a standard deviation of 0.894. Figure 32 shows a visual representation of the average scores per question.

Part B:

Table 12. Recorded ratings of Visually Impaired Senior Participants with Average Responses for each question

Participant	How easy?	How successful?	How confident?	How likely?	Enjoyment?
1	10	8	8	10	10
2	10	9	10	10	9
3	10	10	10	10	5
4	5	5	10	8	8
5	9	9	9	3	9
6	8	10	9	10	10
7	10	10	10	10	10
Average	**8.86**	**8.71**	**9.43**	**8.71**	**8.71**
Standard Deviation	**1.86**	**1.80**	**0.79**	**2.63**	**1.80**

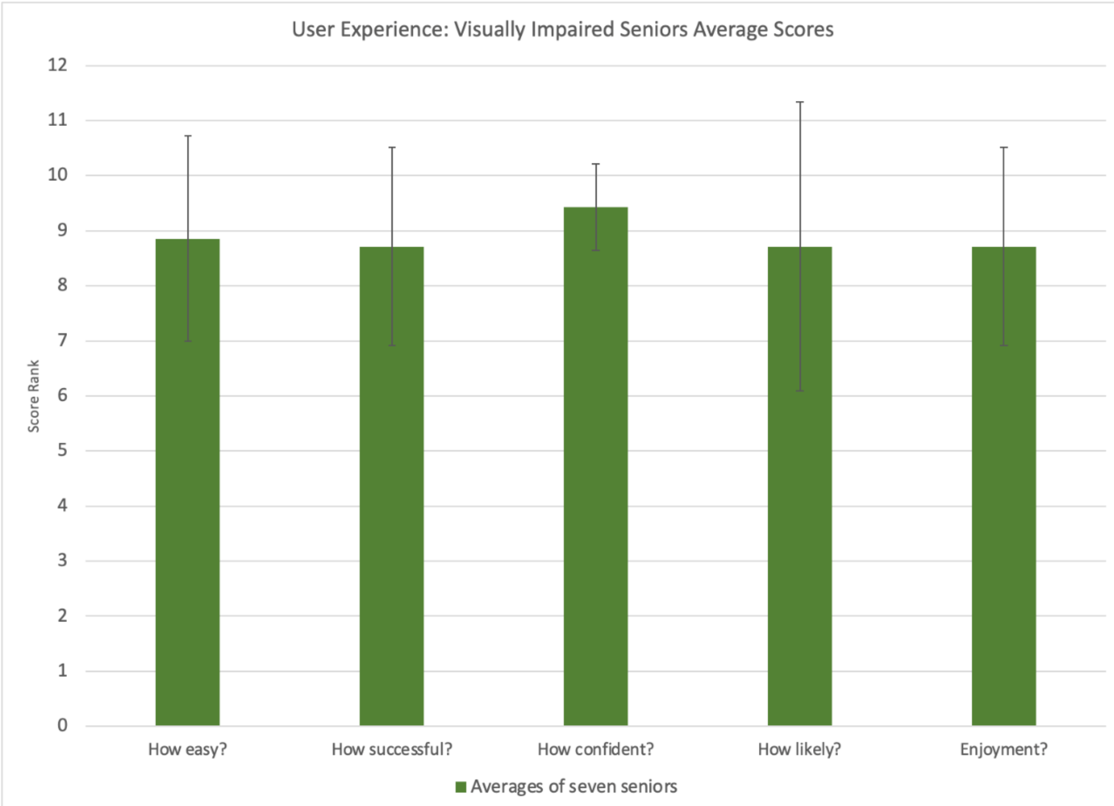

Figure 33. User Experience Part B average score of each question

All five objects and obstacles in the obstacle course were detected for every participant. There was a total of seven participants in this trial. The rating score for each question per participant was recorded. The average score per question along with the standard deviation of each question was calculated as seen in Table 12. The average score for how easy the rollator is to use recorded 8.86 with a standard deviation of 1.86. The average score for the second question was 8.71 with a standard deviation of 1.80. The average score for how confident the participant was while using the device was 9.43 with a standard deviation of 0.79. The average score for the fourth question was 8.71 with a standard deviation of 2.63. The average score for the last question was 8.71 with a standard deviation of 1.80. All average scores ranked at least 8.70 or higher. Figure 33 shows a visual representation of the average scores per question.

Discussion and Next Steps

Part A:

The results indicate that we received positive ratings 92% of the time, which meets the acceptance criteria. This is because out of the total twenty-five ratings that were recorded, only two ratings were less than 6 which is the unsuccessful threshold. The questions with the highest ratings and lowest standard deviations were about the success of the device in communicating obstacles and how much participants enjoyed the testing experience. That being said, whether the participants opened or closed their eyes may have impacted their results. Both of the low ratings came from participants who chose to keep their eyes closed, and both were for their confidence score as they were scared to navigate without the advantage of sight. This question additionally had the greatest variation in responses. Much of the more specific feedback we received focused on the need to incorporate additional ultrasonic sensors to improve the rollator's ability to detect obstacles at the sides and on a diagonal, as well as making the design more aesthetically pleasing while covering the wires. We also received feedback that the changes in vibration felt subtle to some volunteers but more obvious to others. We modified our design based on these results before testing with our senior volunteers.

Part B:

The results from this test again indicate that reviews of our product thus far are overwhelmingly positive. Specifically, 88.5% ratings were greater than 6, which meets the acceptance criteria. More specific feedback from this test included suggestions to increase the intensity of the haptic feedback, as some users had trouble feeling it initially. Additional haptic feedback adjustment ideas included potentially making the difference in vibration between each tier of distance more noticeable. We also received suggestions to incorporate additional methods of feedback such as audible communication, although there was disagreement across the entire volunteer group over whether this should be incorporated. Based on these results, the next steps would be to modify the design based on volunteer feedback. Specifically, we will incorporate additional ultrasonic sensors on the sides of the rollator to detect objects on the left and right, and test whether the combination of all sensors can detect objects at a diagonal as well. We could also modify our Arduino code such that the rollator handles vibrate individually depending on whether an object/obstacle is located on the right or left and adjust the amount of haptic feedback sensors in the handlebars for increased intensity. Lastly, additional methods of feedback (such as audible with SHOKZ headphones) could be incorporated.

Summary/Conclusion

The population of Americans who are elderly, visually impaired, and have mobility issues is gradually increasing. This community often has trouble traveling from place to place due to difficulties in navigating while visually impaired and also reliant on a mobility device. Our senior design team designed a smart autonomous rollator to address this community's concerns. It successfully detects objects, obstacles, and curbs in a user's path and warns them when they approach such hazards. It has also met several of our initial design requirements. These include safety, as it cannot cause bodily harm unless wires break or become exposed to the elements; marketability, as the target audience is satisfied with the product and perceives it as safe; low production cost, as it fell well within our $2000 budget; and simple technology/design, as it is discreet and easy to use without requiring user manipulation. Although durability, weight endurance, and long-lasting design were not directly tested, the device is on track to meet these requirements as it has been maneuvered on several surfaces in addition to occasional collisions during testing without breaking, has individually supported the weight of all testing volunteers and members of the senior design team, and has been able to run for several hours non-consecutively on the same battery back.

Our device uses ultrasonic sensors connected to an Arduino Mega 2500 to detect the distance to the nearest object/obstacle/curb. This system communicates the presence of each pending hazard via coin vibration motors that provide haptic feedback in the handles. The haptic feedback increases in intensity as the user gets closer to the hazard. Since many of our target users are comfortable using a cane, we have also included a 3D-printed attachment in our rollator that can hold a cane while the device is in use. Our smart autonomous rollator has been tested by young, healthy students as well as members of the target population with overwhelmingly positive results. Potential users are excited about the prospects of the design and expressed interest in supporting further development of the product. Next steps would be to test the function of the side sensors and potentially incorporate additional types of feedback. This could include an Arduino-compatible Bluetooth module connected to SHOKZ bone conduction headphones for audible feedback, as well as a camera with an image-detection algorithm that can identify exactly what each potential hazard is. Ultimately, our senior design team has created the early stages of a solution to aid navigation of the mobility-challenged and visually impaired.

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Appendices

Appendix A: Team Member Roles and Responsibilities

Team Member	Role	Responsibilities	Final Report Contributions
Grace Kim	Chief Electrical Engineer	Manages construction of circuits in the system. Handles all statistical analyses for tests. Manages 3D model drawing and 3D printing. Assists with coding and mechanical components of rollator. Assists with testing in general and invention disclosure application.	Table of Contents, Executive Summary, Final Design, Results for all tests in Verification & Validation section
Miranda Romano	Chief Systems Engineer, Team Manager	Main communicator with clients, mentor, and IRB. Completes 3D designs and printing. Assists with troubleshooting and writing code as well as electrical and mechanical components of rollator. Responsible for budget and procurement of materials.	Requirements & Specifications, Metrics, Final Design, curb detection portion of Verification & Validation
Medhini Sosale	Chief Software Engineer	Manages Arduino code and assists with electrical / mechanical aspects of the product as needed. Assists with brainstorming of 3D printing designs. Managed user testing and assists with testing in general. Manages invention disclosure application.	Standards, Final Design, user experience portion of Verification & Validation, Summary/Conclusion
Rachel Wilson	Chief Mechanical Engineer	Manages construction and the maintenance of the product, including soldering. Assists with coding and electrical components of rollator. Assists with 3D designs and completes 3D printing. Completes testing and troubleshooting for device.	Problem Statement, Background / Relevance, Final Design, haptic feedback portion of Verification & Validation

Appendix B: Budget to Date

Item	Quantity	Unit Price	Total Price
Rollator	2	$66.99	$133.98
Removable grips	2	$9.99	$19.98
Velcro roll	1	$15.79	$15.79
Arduino camera	2	$25.99	$51.98
TPU 3D printing filament	2	$26.99	$53.98
Coin vibration motor	1	$12.99	$12.99
SHOKZ Bone Conduction Headphones	1	$114.95	$114.95
Baitaihem folding cane	1	$15.99	$15.99
WASPT telescopic blind cane	1	$43.85	$43.85
Arduino Bluetooth module	1	$12.99	$12.99
Wire protectors	1	$17.99	$17.99
Arduino ultrasonic sensor	3	$29.89	$89.67
Extra Arduino wires	1	$6.98	$6.98
Heat Shrink Thin Wall Tubing (Shrink Ratio 2:1)	1	$4.99	$4.99
¼" Thin Wall Polyolefin Heat Shrink Tubing	1	$1.99	$1.99
Total		**$408.36**	**$598.10**