REAL-TIME OBSTACLE DETECTION TO ASSIST WHEELCHAIR NAVIGATION

David Zhukovsky, Diego Suchenski Loustaunau, Aaron Tian, Charlotte Cain, Garyth Page-Violette, Rachel Bunsick, and Isabella Doyle

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Executive Summary

For individuals with visual impairment who need to use a wheelchair, navigation is incredibly difficult. Mobility for these individuals is an everyday challenge. In homes and familiar environments, objects can get in the way of the wheelchair and put the individual at risk. In new environments the individual may not feel comfortable on their own. In addition, public areas may not be accessible and pose new problems such as stairs and traffic. For most, these difficulties result in the need for a full-time caretaker or the inefficient use of a cane. In order to improve independence and safety, a sensor-based system will be designed to interpret the wheelchair's surroundings and identify potential hazards. This system would collect information from sensors mounted on the wheelchair and alert the user of risks using vibrations and/or sounds. Using both object and altitude detection, the system could alert the user of both obstacles (furniture, cars, etc.) and dangerous elevation changes (stairs, steep ramps, etc.). These individuals constantly find themselves in new, challenging environments and an adaptable solution would greatly aid in their navigation and quality of life.

Introduction

Statement of Problem

Almost ten percent of Americans who are legally blind also use a wheelchair or scooter (Simpson et al., 2005). In addition to facing the struggles of visual impairment, these individuals have to navigate unfamiliar environments in a wheelchair. This can create dangerous situations for not only the wheelchair user but those around them.

Six percent of wheelchair falls are caused by multitasking (Singh et al., 2020). When users with visual impairment are forced to navigate their environments using an inefficient device like a cane, there is a higher chance of a fall. Over three percent of all wheelchair users have reported a serious fall and this number is higher in users with visual impairment (Calder & Kirby Lee, 1990). These falls can cause severe injury and in some cases are fatal. The most common causes of their incidents include moving in and out of the wheelchair, going over an object or uneven ground, and falling on stairs (Singh et al., 2020).

Lack of accessibility in public areas, inefficient use of tools like canes, and lack of availability of a caretaker, reduce the mobility and safety of wheelchair users with visual impairment.

Target Audience

The device will be used by a client with visual impairment who uses a wheelchair. This device will enable the client to be more independent in their home and in new environments. It can be used by any person in a wheelchair, but it will specifically be designed for those with visual impairment. It will be used as both obstacle and altitude detection to ensure the user feels as safe as possible. It will be adaptable, able to fit onto any wheelchair- manual or automatic.

This device will be used by the individual in the wheelchair, but also might be used/maintained by a caretaker.

Design Requirements/Specifications

Level 1 design requirements (MVP)

The device shall:

- be able to detect any object in front or behind the wheelchair within a 1.5 meter range
- detect altitude drops greater than 2” in front of and behind the wheelchair
- alert the user to these changes in their environment
- communicate the proximity and danger of the wheelchair’s surroundings in an effective way
- attach to the wheelchair between the seats and the wheels, under the arm rests, or on the back of the seat
- cost less than $125
- be accompanied by an instructional manual which details the operation, capabilities, and installation of the device

Level 2 design requirements

The device may:

- detect objects ¾ of the way up from the floor to the top of the wheelchair
- propose an alternate path for the user to follow after the detection of an object
- function under dark conditions
- be integrable with a range of different sized wheelchairs (adaptable)

- weigh less than 5lbs
- be waterproofed and protected

Level 3 design requirements

The device could have a…

- remote alert system, which sends a text or alert to a trusted number or email if a collision is detected (or a rapid change in altitude)
- house mapping, which allows a crew to scan and map out the environment in three dimensions, assisting the level 2 requirement of alternative route planning
- alert system that is user-programmable (vibration vs. noise, etc)

We plan to meet regularly with our client and discuss our progress. We hope to establish an open line of communication. Once our product has been delivered, we will send the client surveys so that we can receive updates on how the product is working for them and if they have any new requests/ changes they would make.

Design Concepts

The three separate designs that are proposed use either computer vision, sonar, or lidar sensors to measure surrounding obstacles that don't come into contact with the user's wheelchair. In addition, each system includes a sensory output subcomponent that relays to the user the degree to which objects are sensed in the three dimensions surrounding the wheel chair. As a result, each proposed design includes many subsystems that can be combined. For example, design one and two could be combined, so that camera vision is used to measure obstacles in front of the wheelchair, and a sonar sensor is used to measure obstacles below the wheel chair. Therefore each design is a culmination of separate design concepts.

Design Concept #1

Description

The wheelchair will be fitted with two Raspberry Pi Camera Module 5MP 1080p Webcam OV5647 Sensors. One is aimed parallel to the arm rests, and one aims perpendicularly to the lower portion of the seat. This detects objects in front of the user as well as any drops or bumps below the user (such as stairs). The design includes two vibrating armrest pads, which direct the user left or right to avoid any detected obstacles.

Real-time object detection on the parallel camera can be accomplished through the "You Only Look Once" (YOLO) method. The approach employs a trained Deep Convolutional Neural Network (CNN) to segment and perform classification on individual camera frames at upwards of 45 frames per second (Redmon et al., 2016). General object detection libraries and pretrained models exist for the purpose of developing YOLO networks (*Ultralytics/Yolov5*, 2022), enabling the possibility of utilizing transfer learning; however, further data relevant to the client's environment must be obtained and manually curated for further training.

Figure 1

Design Concept #1 Drawing

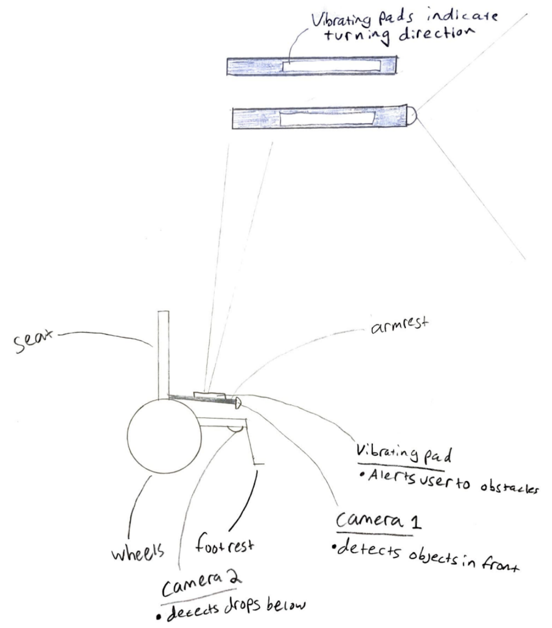
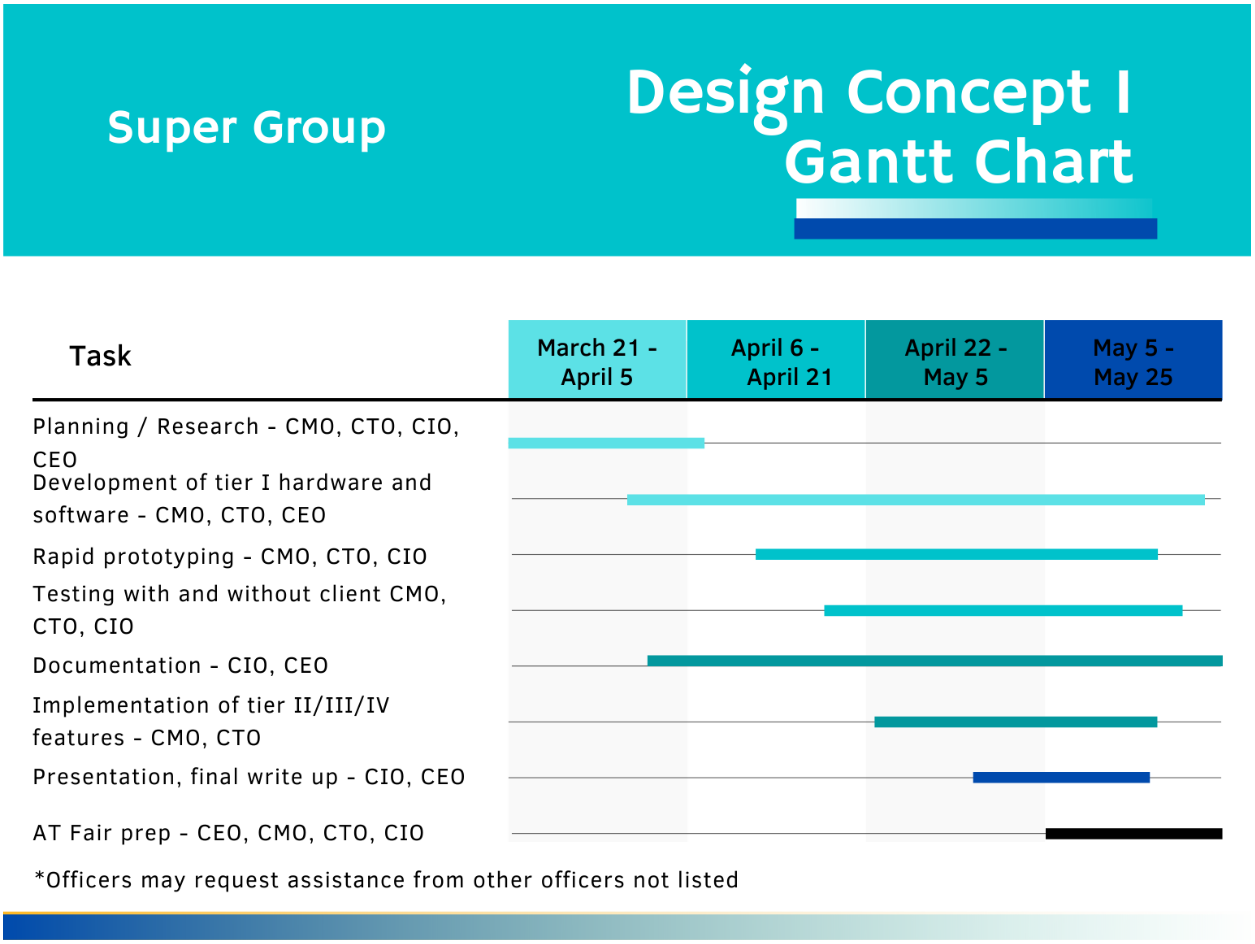


Diagram of a camera-based analyzation and vibration output system.

Two additional buzzer modules would be attached to the arm rests to alert the wheelchair user to any objects detected in the path of motion. They would direct the user left or right to avoid any detected obstacles. Although the initial design uses a simple model where the arm rest vibration indicated a turn in its respective direction, this could be reprogrammed according to client specifications or requests.

Timeline and Expectations



Resources and Budget

The resources that are needed for this project are outlined below. Except for the resources that the team already possess, other resources will be purchased by equally splitting the overall costs. If the total cost were 125USD, individual costs would be a little over five dollars.

Table 1: *Resource and Budget List - #1 Design*

Item	Supplier	Quantity	Unit Cost	Total
Raspberry Pi	Already in	1	-	$0

Model B+	possession			
Raspberry Pi Camera Module 5MP 1080p Webcam OV5647 Sensor	Walmart	2	$12.35	$24.70
Buzzer Module	Tatoko	1 Pack (10pcs)	$10.69	$10.69
Wires, Solder, Electrical Tape, 3d printing filament	Already in possession	-	-	$0
20800mAh Compact Rechargeable Battery for Raspberry Pi	PiShop.us	1	$24.95	$24.95
Arduino Uno	Already in possession	-	-	$0
				$60.24

Analysis

The implementation of a deep learning-based model for object detection requires extensive data collection and preprocessing this makes it less suitable for completely new environments. However, using a camera means that the types and contours of the surrounding obstacles can more easily be determined, allowing for potentially more sophisticated extensions. In addition, the device is affordable, which is beneficial in terms of its added capabilities.

Extensions

There are many possible extensions that could be made to design. This includes but is not limited to the use of an app on a mobile phone that performs the same actions as the Raspberry pi camera module. The benefit of this is that more data regarding a new environment could be stored for future navigation in that environment, and sms messages could be sent directly from the phone to other cellular devices. In addition, a set of vibrating bracelets could be implemented as a replacement for the vibrating arm rests. This system could be integrated with current technology such as an apple watch to provide directional sensory feedback to the user.

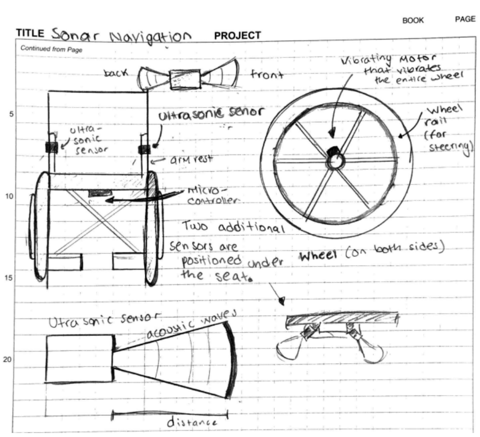
Design Concept #2

Description

Ultrasonic sensors are one of the sensors that can be utilized to measure objects within a close range of ten meters (Burnett, 2021). The type of sensor emits and receives acoustic waves, above human hearing. By measuring the time it takes for the wave to travel back to the receiving end of the sensor, the distance between the sensor and the nearby obstacle can be determined. At its greatest sensitivity, the spread of the wavelengths emitted by an ultrasonic is nine degrees. This means that specificity of the objects that are detected further out decreases. At four feet, any object that is within fifteen inches of the plane perpendicular to the sensor will be detected. Though at a location that is within a foot of the sensor, objects are only detected within roughly a four inch range (Sedgwick, 2012). Thus, sonar sensors are beneficial for detecting the general proximity of objects further out, and multiple sonar sensors could be used upfront to generate an image of where objects specifically are. In the above design, unobstructed clampable sonar sensors are attached to the wheelchair's arms. The sensors can be used to refer to the general locations of an object by vibrating the wheel rail aligned with the object at different vibrations based on the object's proximity, which can either be in front of or behind the wheel chair. In addition, ultrasonic sensors or infrared sensors, which use infrared waves instead of acoustic waves, can be positioned under the wheelchair at angles in order to detect changes in the elevation of the floor in front of and behind the wheelchair. An additional buzzer module would be attached to alert the wheelchair user of this specific obstruction by creating a series of beeps. The communication and information processeing relies on a microcontroller, such as an arduino or a raspberry pi that can make decisions based on the information from the sensors.

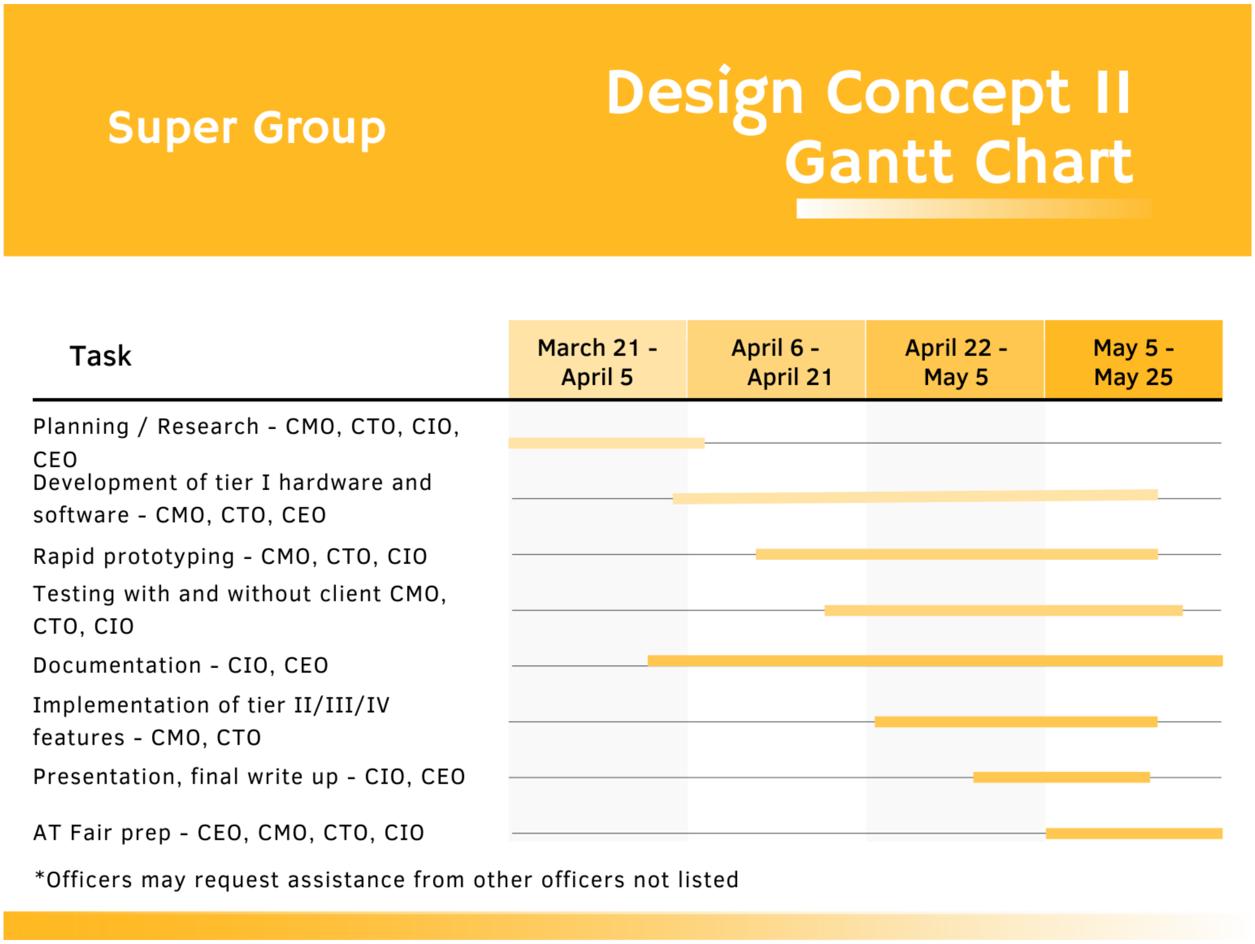
Figure 2.

Design Concept #2 Drawing



Sensor and subcomponent drawings of an ultrasonic-based sensor system on a wheelchair.

Timeline and Expectations



Resources and Budget

The resources that are needed for this project are outlined below. Except for the resources that the team already possess, other resources will be purchased by equally splitting the overall costs. If the total cost were 125USD, individual costs would be less than sixteen dollars.

Table 2: *Resource and Budget List - #2 Design*

Item	Supplier	Quantity	Unit Cost	Total

Raspberry Pi Model B+	Already in possession	1	-	$0
Buzzer Module	Tatoko	1 Pack (10pcs)	$10.69	$10.69
Ultrasonic Sensors	WGCD	1 Pack (10pcs)	$14.99	$14.99
Vibrating Motors	Tatoko	1 Set (2pcs)	$10.99	$10.99
Wires, Solder, Electrical Tape, 3d printing filament	Already in Possession	-	-	$0
20800mAh Compact Rechargeable Battery for Raspberry Pi	PiShop.us	1	$24.95	$24.95
				$61.62

Analysis

The major benefit of this overall design is its inexpensive cost. It costs less than $65.00. However, that comes with decreased precision compared to other designs. In shorter ranges, the ultrasonic sensors would fail to find obstacles in certain spots due to the gaps between the sensors.

Extensions

This system would be strengthened with the addition of more ultrasonic sensors, which could be used to algorithmically determine the location of objects in front of the wheelchair at a closer range. This would be done by having the sensors overlap in order to determine the specific regions in front of the wheelchair, where objects lie. In addition, bump sensors could be fitted to the wheelchair to detect a collision, which could then be used to notify others with an SMS message from the raspberry pi.

Design Concept #3

Description

This proposed design relies on TFmini-S LiDAR sensors, HC-SR04 Ultrasonic sensors, and a processor, such as a raspberry pi to create a 3d map of the space in front of and behind the wheelchair. The lidar sensor, and all the electric componentry except for the vibrating pads, placed on the left and right side of the wheel chair's seat, can be mounted on a board directly under the seat of the wheelchair. The design incorporates lidar sensors, which have a max sensing range of 12 meters. Each lidar sensor is mounted between each foot rest, so that its view is not obstructed. Each mini lidar sensor can be attached to a servo motor that pivots up and down 45 degrees to create a topographical scan of the environment. If an object is within a certain range, pads beneath the wheel chair will vibrate at different frequencies based on the proximity of that obstruction. A series of LED lights on the armrests could be used to accompany this. Like the previous design, ultrasonic sensors are only required to measure depressions in the ground with decreased specificity. And, this subsystem in each of the designs would use alerts from a buzzer module to discern for depressions in the ground.

Figure 3

Design Concept #3 Drawing

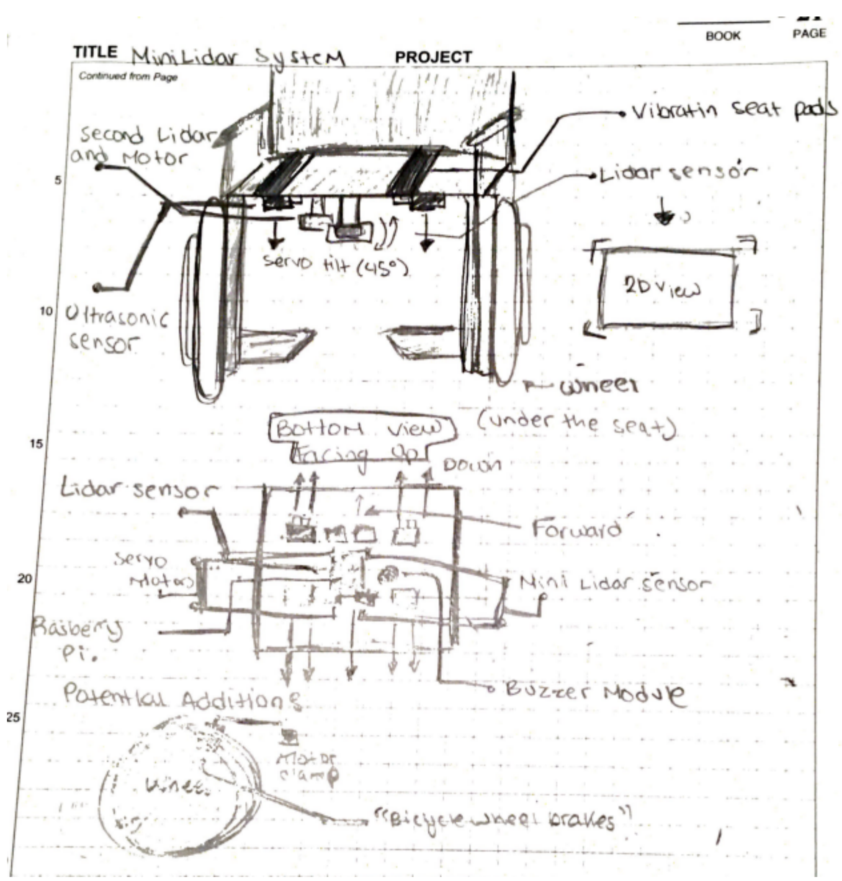
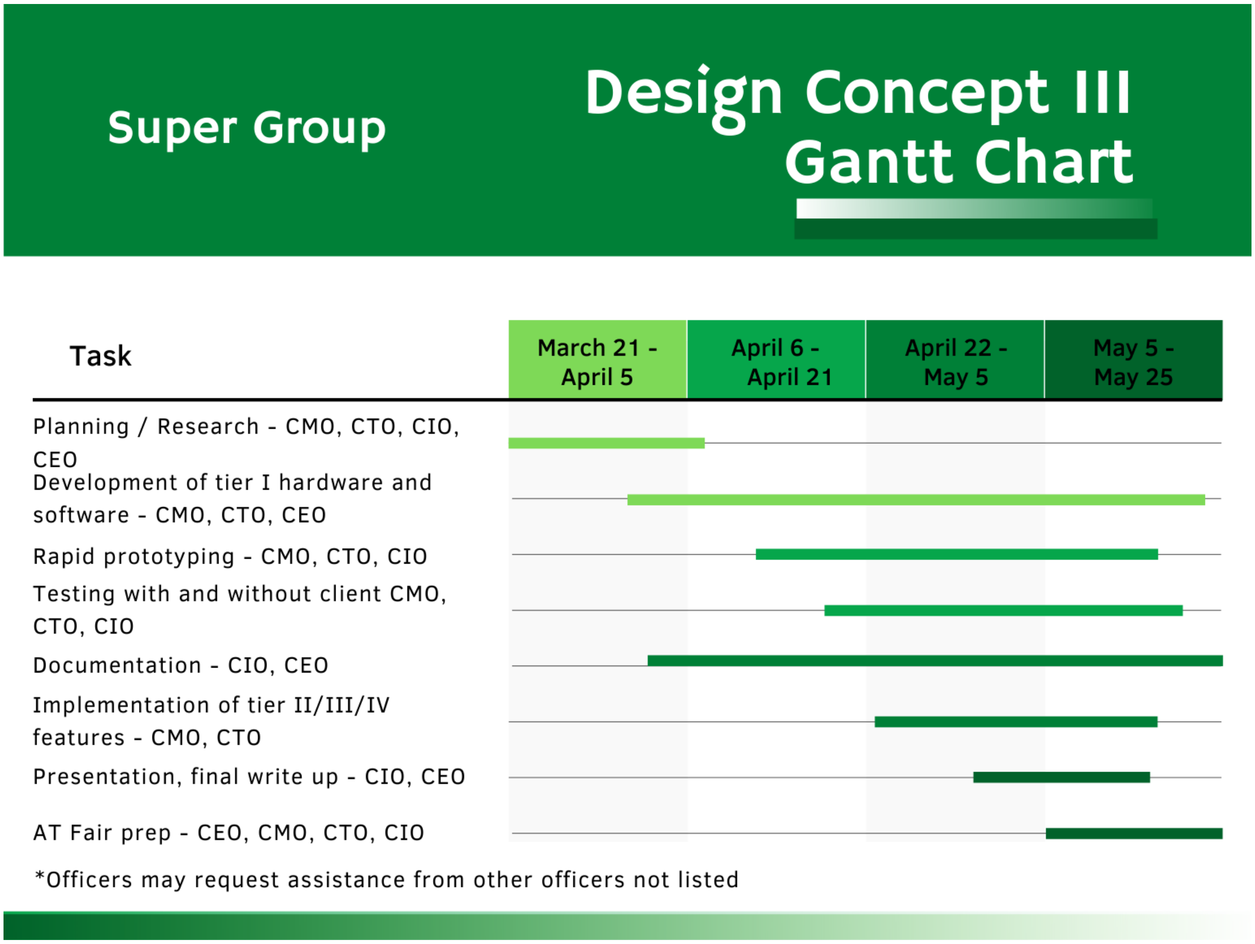


Diagram of the electronic componentry and its attachment to the wheelchair.

Timeline and Expectations



Resources and Budget

Table 3: *Resource and Budget List - #3 Design*

Item	Supplier	Catalog #	Quantity	Unit Cost	Total
TFmini-S LiDAR	DFRobot	DFR0315	2	$43.90	$87.90

HC-SR04 Ultrasonic Sensor	ACEIRMC	-	1 pack(5pcs)	$9.29	$9.29
Raspberry Pi Model B+	Already in possession	-	1	Raspberry Pi Model B+	$0
Wires, Sauter, Electrical Tape, 3d printing filament	Already in Possession	-	1	$0	$0
Mini Vibration Motors DC 3V	Tatoko	-	1 pack(20 pcs)	$14.99	$14.99
Digital Servo Motor	Already in Possession		1 set(4-pack)	$0	$0
20800mAh Compact Rechargeable Battery for	PiShop.us	-	1	$24.95	$24.95

Raspberry Pi					
Buzzer Module	Tatoko	-	1 Pack (10pcs)	$10.69	$10.69
					$147.82

Analysis

A major pro of this design is the ease at which it can be attached to any wheelchair. The electronic componentry can all be hooked/clipped to the bottom of the wheelchair. Wires do not have to run along separate metal parts of the wheelchair to sensors farther away from the processor; the vibrating pads simply need to be flipped over and onto the wheelchair's seat. And, the location of the electric parts under the seat means they are protected in wet and rainy environments. Ultrasonic sensors and lidar sensors are capable of functioning in darker conditions unlike computer vision. A major con of this design is its overall material cost compared to the rest; however the team will continue to brainstorm on bringing the costs down. Though expensive, the device is capable of forming a lateral topographic view of the space in front of and behind the wheel chair with the two lidar sensors. This specificity overall is beneficial for providing detailed sensory output. The design also includes the ultrasonic sensors used like the previous design to measure for depression in the surface of the ground.

Extensions

Due to the precision of the device, further extensions can be made to utilize this information. For instance, in a new environment data could be stored for future mobility in that specific location. Though, this would require additional lidar sensors, and more robust code. Additional information, such as the height of the objects could be relayed to the user with a series of LEDs close to the user's line of vision. And due again to its precision, brakes mimicking those on a bike could manually be attached to the wheel and actuated with a servo motor in the case that an obstacle is imminently close.

Team Qualifications and Strengths

Our situation is unique in the sense that we have the opportunity to combine two group goals into a large project that will ultimately provide a better result for our client. Because the topic that we have selected has so many components, we elected to break the device into subsystems, with each team working on different portions of the final product. This will mean keeping in close contact with open communication, regular peer reviews, and constant updates. To outline our goals, norms, and expectations, we have worked together to create a new contract that outlines the standards of our partnership.

On team 3, Bella is the CEO, Charlotte is the CIO, Rachel is the CTO, and Garyth is the CMO. Although these roles have been established, this group has decided that all team members will contribute in some capacity to all parts of the product.

On team 12, Aaron is CEO, Diego is CIO, and David is CMO. Although these roles have been established, this group has decided that all team members will contribute in some capacity to all parts of the product.

Individual Strengths

Bella:

- Organized
- Client Communication
- Some circuit experience

Charlotte:

- Organized
- Keeping track of paperwork
- Some CAD experience

Rachel:

- Experience with arduinos/circuits
- Developed working closed loop systems (hardware)
- Some CAD experience

Garyth:

- Power tools, wood working
- 3d Printing and some CAD
- Electronics- mainly arduino based projects

Aaron:

- Image processing (YOLO, segmentation, detection, etc)
- Python
- Communication with clients.

Diego:

- Some CAD

- Communication with clients
- Writing

David:

- Some Circuitry / electrical engineering experience
- Some CAD
- Interested in learning and contributing to object detection
- Prototyping

References

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