Senior Design 1 Divide & Conquer Document

Group 25

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1. Project Description

FORWARD (Feedback Oriented Routing and Walker Assistance with Responsive Direction) is an assistive walker enhanced with obstacle avoidance and adaptive speed control, designed to extend the mobility of its users. By harnessing the power of sensors, motors, and microprocessors, FORWARD brings the latest of electrical and computer technology to those who are in need, so that walkers can become more beneficial for not only the traditional user, but for those who are sensorily impaired.

1.1 Background and Goals

Walkers are a mobility aid commonly deployed in the environment of medical institutions such as hospitals and assisted living homes. They are also used daily by patients not just in the medical setting, but in neighborhoods, parks, shopping malls, and just about anywhere you can stroll.

There is a sizeable market for these support tools. If you include other devices such as canes, the market valuation exceeds $1 billion. There is a great need for these as the US elderly population continues to grow. Currently there are over 50 million people who are considered elderly, and some studies suggest that a quarter of these utilize walkers or canes.

The goal of this project is to use the latest of electrical and computer engineering technologies to develop a solution that vastly improves the functionality of walkers and to improve their user experience. We want to implement functionality that will be useful for both users with physical injury and users with sensory impairments. For instance, a blind person will greatly benefit from audio feedback that warns them of hazards or obstacles ahead. Additionally, a deaf person will be blessed by haptic feedback for the same purpose. In short, FORWARD helps to keep people safe independently of the user’s own spatial awareness.

1.2 Project Motivation

This project has the ability to help those who are physically impaired as a result of surgery recovery or have a more permanent hindrance such as blindness or deafness. This is also especially useful for people who both have a visual impairment and have also suffered a physical injury. In addition, FORWARD is a much cheaper option than a wheelchair so that the users have an affordable way to get around.

At the core, conventional walkers do little to assist the user outside of bearing their weight and providing a barrier between them and any obstacles. The user is still susceptible to tripping and falling because of an obstruction the walker collides with. This is especially harmful for those with sensory impairments because, if they are injured, they will not be able to have the same mobility as before. For example, people who are blind use a white cane to feel the ground in front of them while walking, which is not feasible to do when both hands are being used to support their weight.

It will be a great learning experience for learning how to implement a variety of different technologies that we are not yet accustomed to, including computer vision, sensor fusion, and guidance systems. We will also be able to gain more practical experience to apply what we have learned in our classes about embedded systems, programming, and control systems. There are even aspects of linear circuits that we will be able to apply, such as power limitations between components and wiring a PCB.

With the technology available today, the opportunity exists to improve the quality of life and safety for walker users and enable them to have a faster and more secure lifestyle while travelling. Spend less time worrying about injury and more time enjoying the company of family and friends.

1.3 Project Function

The function of FORWARD is threefold. 1) obstacle detection, 2) object identification, and 3) obstacle avoidance. The walker, without the use of GPS or pre-determined pathing, will be able to autonomously identify and notify the user of obstacles in advance, characterize the obstacle and notify the user, and reactively steer and guide the user to avoid collision. At a certain range, the computer vision camera will activate and begin the avoidance process. The motors are always responsive to reverse polarity or adapt their speed upon an interrupt triggered by the microcontroller. An on-board inertial measurement unit (IMU) will ensure the walker's stability with respect to its orientation.

This will allow the users to anticipate obstacles such as stationary obstructions, mobile obstructions, inclines, declines, and danger zones. This is enabled by audio and haptic feedback. Audio will be delivered via an earpiece while the haptic feedback will be administered through vibration in the handlebars. This is a fitting feature, as the visually impaired are known to have more reliable hearing or touch sensitivity or awareness than most. For this reason also, the haptics will serve to alert the system that the user is ready, and the audio may also be of the spatial format to provide the user with an enhanced sense of direction.

1.4 Related Work

This technology is part of an emerging market, as devices we rely on frequently become converted to their smart counterparts. In particular, the availability of smart walkers is just beginning. However, none of the ones commercially available feature object avoidance. The features they do have are automatic braking while downhill, automatic boosting while uphill, and lowlight-responsive headlights. There have been many research projects performed, one even at UCF (Zhou et al.), but our group hopes to surpass the success of all of these.

LiDAR and Sonar technologies are deployed in numerous fields already. There are many self-navigating robots and other guidance settings where ranging and object detection are utilized. Additionally, microcontrollers are so widespread now that practically every system with digital data or connection of computer to the analog world requires them. Motors are also a reliable technology, and they are able to be implemented into the system control method.

2. Project Objectives, Requirements, and Standards

2.1 Objectives

FORWARD shall be able to recognize obstacles present and by using sensor fusion to resolve the measurements by the LiDAR and Sonar sensors, determine an accurate reading of the range to the obstacle. This ranging system must be able to work regardless of the material properties or nature of the obstacle, whether incline, decline, or freestanding object. The ranging subsystem should also transmit the LiDAR and Sonar sensor data to the MCU and a turn-on signal to the system camera to capture a photograph of the current surroundings to send to the computer vision/AI image processing model.

FORWARD obstacle identification (CV) shall be able to implement AI Image processing and Computer Vision to correctly identify the current obstacle as well as the threat level presented to the user. The model shall take as an input a photo captured by the system camera and process this photo to correctly identify the item in the path of the user. The system shall classify the item into one of three categories: 1) Emergency Stop – meaning a continuance could put the user's life in danger, 2) A Reroute - meaning without guidance the user will run into the identified obstacle, and 3) Non-threatening - meaning the item can be ignored. The system will then send the needed information to the necessary outputs, such as guidance control and audio feedback.

FORWARD must be able to avoid obstacles detected within the sensor range accurately and safely, finding another path for the walker to take when there is an obstacle in the way of the current path. Initially, the FORWARD system will be moving forward at a steady walking pace with the use of DC motors all operating at a constant pace. Once an obstacle is both detected and identified, the speed will decrease on either the left or right DC motors, and the walker will steer toward the side in which the motors are running slower. Thus, once finding a safe path to avoid the obstacle, the FORWARD will go around the obstacle and then return to the normal walking pace. If the FORWARD is unable to safely go around the obstacle, instead the motors will slow down to a stop, indicating to the user that they need to stop as well. The way that the motors will be driven is by an MCU coupled with a motor shield, which will use data from the sensor system to decide the speed of each motor. When programming the MCU, it will be necessary to implement pulse width modulation (PWM) to adjust the motor speeds.

As a stretch requirement, we would like to implement tip-over prevention, which is a stabilization protocol. If the IMU detects the tilt limit is exceeded, thus indicating instability of the user, a motor command is sent that will turn the wheels to restabilize the walker, or an emergency brake activates to stop the wheels so that friction can allow the walker to support the falling user. So, whenever the user falls forward, there will be attempt made by the walker to prevent them from scraping their knees.

As an advanced feature, FORWARD will also activate headlights in lowlight environments, fulfilling similar requirements to what is required by law for bicycles at night. We will use a photoresistor to detect the surrounding lighting conditions, so when darkness is detected for a certain duration, the LED headlights will illuminate the ground in front of the walker. This involves a simple reading and processing of the light input by the MCU and setting the output LED to on.

FORWARD shall implement audio feedback to inform the user of the current surroundings and hazards. When a hazard is identified, the CV model will detect the hazard and transmit the object audibly over Bluetooth to the ambient hearing piece. The hearing piece will be in one ear only to maximize user hearing in our efforts to prioritize safety.

FORWARD should be affordable. Currently, other smart walkers cost thousands of dollars. Oftentimes their physical footprint is obstructive, and they are laborious and heavy. Our system will provide a solution that is minimally noticeable and does not add an excessive amount of weight. It also will drastically reduce the cost by making more efficient use of the component technologies available.

2.2 Requirement Specifications

The table below contains constraints for 1) hardware functionality, 2) software techniques, 3) system performance metrics, and 4) physical footprint. Some of these requirements will be further defined and derived in the longer research paper. The main constraint is time, as this project needs to be completed in the 8-month period concurrent with the senior design I & II courses. One other constraint is the use of a pre-built walker. We are not mechanically designing the walker frame itself.

1.1	FORWARD FOV (field of vision) shall have object detection with a maximum range of 3 meters at 15 degree aspect
1.3	FORWARD shall be able to detect tilt instability of 10 degrees
1.4	FORWARD Walker should support speeds from 0 MPH to 6 MPH
1.5	FORWARD Walker shall be able to brake from max speeds to a complete stop in under 1 second
1.6	Battery full recharge time < 10 hours
1.7	FORWARD shall have a battery life of 15 miles
2.1	The CV model will identify and classify the hazards with accuracy greater than 90%
2.2	The MCU will process sensor data through I2C (or SPI) with a refresh rate greater than 1000 Hz (1millisecond)
3.1	The sensor ranging solution shall be able to detect hazards with accuracy greater than 80%
3.2	Feedback latency shall not exceed 100 milliseconds

4.1	FORWARD walker shall not exceed 60 pounds but be greater than 20 pounds in total weight

Figure 2-1 Engineering Requirements

2.3 Related Standards

FORWARD must comply with all IEEE-related standards relating to sensors, motors, computer vision, and image processing. Taking a brief look at the specifics, none are immediately seen as hindrances to the proceedings of FORWARD's research. Should an issue arise with IEEE-related standards later in the project, future documentation will indicate that.

The ADA (American Disabilities Act) also has stipulations for environments to make accommodations for these assistive vehicles including walkers and electric wheelchairs. However, none of these should affect our design process, given that our product is safe to operate around other people and in busy environments.

2.4 Constraints

The major constraint of this project endeavor is time, as it must be completed during the 8-month time frame of the senior design 1 and 2 courses. In this case, project management software is key; GitHub will be used for version control and source code storage, and LaTex will be utilized for the lengthy research paper to make it more manageable for collaboration with our team. GitHub also has a built-in project board where we will assign tasks for both research and testing.

Another constraint is two-wheel drive, which is necessary for steering and tip over prevention. This will require uninstalling the wheels that come with the walker and fitting them with DC motors. Cost also comes into play here, as motors can be expensive, and four-wheel drive is double the price.

2.5 House of Quality

The figure below shows the weighted importance of the project deliverables and their relation to each other. The main marketing requirements are user mobility, user safety, tip-over stabilization, reliability, affordability, and assisted turn. Each of these features are discussed in the previous parts of this document. The main priorities of FORWARD are safety and mobility.

Note that our house of quality diagram roof is diagonally placed. In essence, each diagonal axis is comparing its left neighbor to each other parameter it crosses as it traverses vertically. For instance, the topmost diagonal just under the roof line is comparing cost to system feedback latency, then to sensor FOV, and so on. The next diagonal is comparing system feedback latency to sensor FOV, CV accuracy and so on.

Also note that the engineering requirements from Figure 2-1 are encapsulated on the house of quality as cost, system feedback latency (end-to-end, sensing to user feedback), sensor FOV, CV accuracy, object avoidance (primarily refers to steering protocols), battery life, weight, top speed, and braking time. The ability to efficiently reconcile the marketing requirements with these engineering requirements will spell a great product after design is completed.

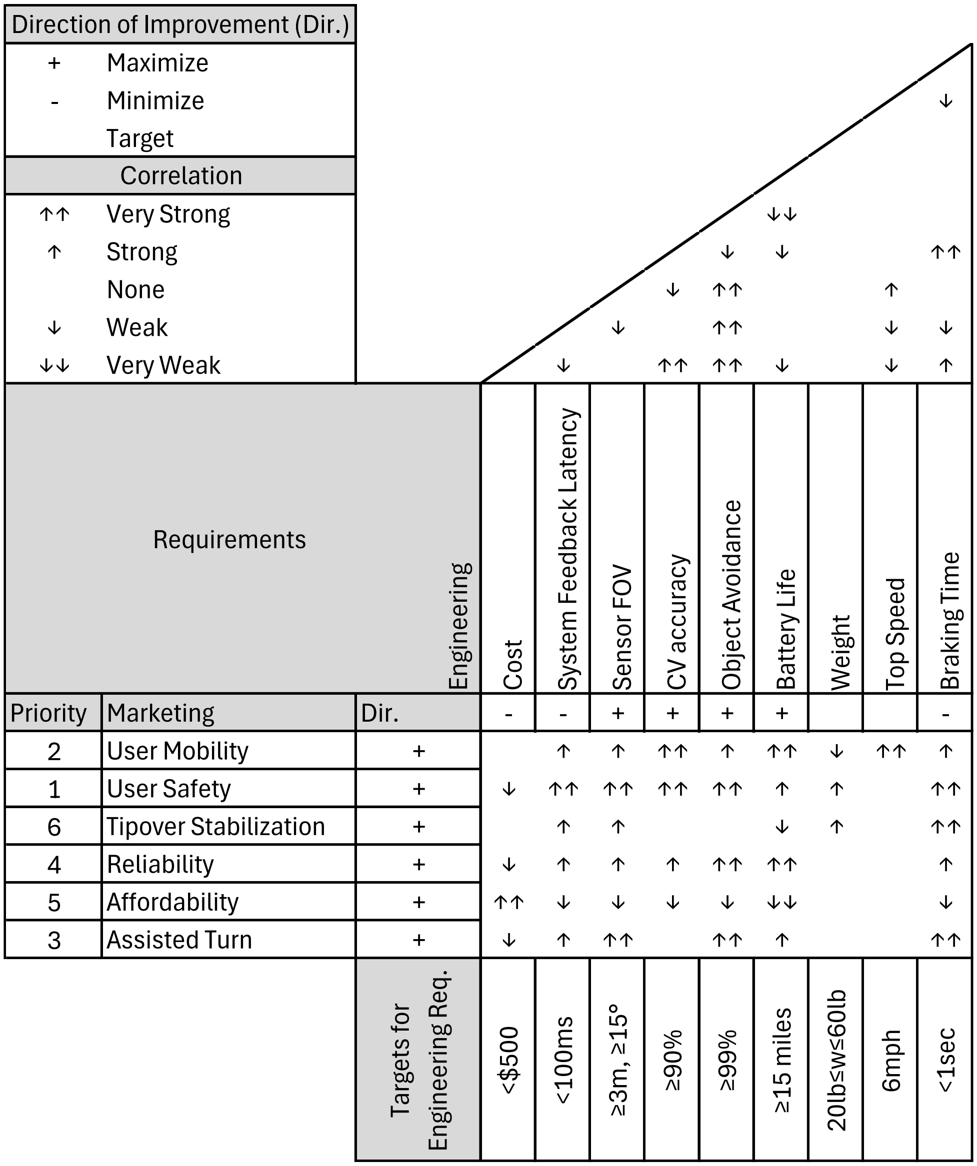

Figure 2-2: House of Quality Analysis

3. Project Block Diagram

The peripherals, depicted in the diagram by circles, are functionally sensors and feedback for user guidance. The microcontroller unit will receive and transmit data from the peripherals while also communicating with the motor controller to steer and drive. In turn, the position determination algorithm, coupled with the speed and steering control, comprise the object avoidance function. Additionally, the computer vision system will be able to recognize objects; it too contains a peripheral camera – depicted by the blue circle below. Headlights are an optional feature configured to turn on in lowlight environments. Finally, an implicit element of the diagram are the power inputs from the battery supply. The work breakdown is shown in the key below. Tobiah, being a signal processing EE will be covering all of the sensor and signal subsystems, Morgan, being an EE interested in robotics and power will be covering all subsystems under those categories, and Matthew, being the only CpE will be focusing on much of the software, including the embedded programming and computer vision software and algorithms.

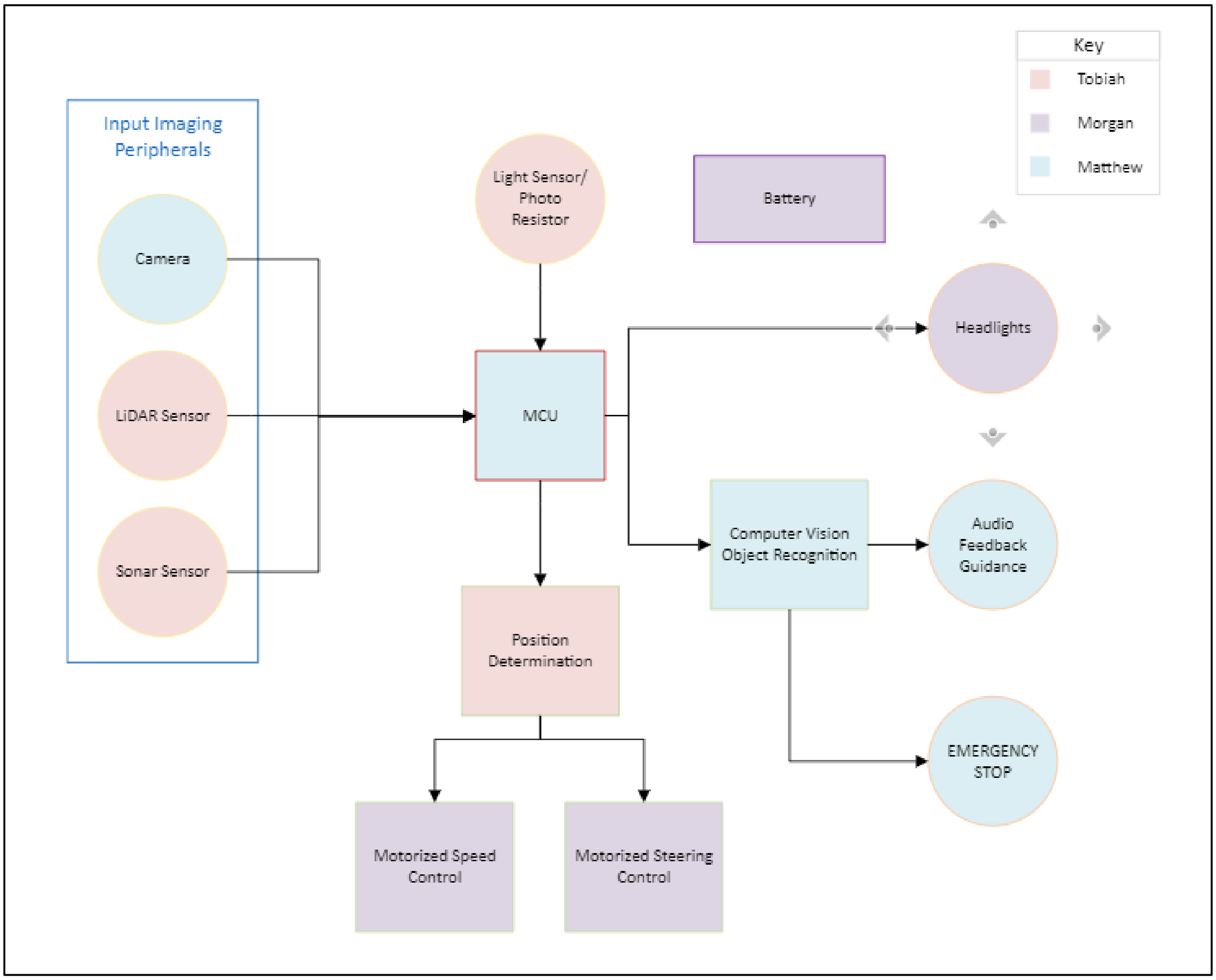

Figure 3-1: System Block Diagram

4. Project Budget and Funding

The table above shows the tentative budget for FORWARD. We have yet to select specific models for the components. As we continue to research and develop, there will likely be changes made to this table. The project will require a pre-built walker as well as 5 peripheral components, 2 motors, and 2 controllers, as well as wiring and PCB housing.

Component	Type	Quantity	Unit Price Allocated	Total	Link
Walker	housing	1	$60	$60	Amazon
All-Terrain Wheels	housing	4	$12	$48	
LiDAR sensor	peripheral	1	$40	$40	AliExpress
Ultrasonic sensor	peripheral	1	$5	$5	AliExpress
CV Camera	peripheral	1	$15	$15	Amazon
IMU	peripheral	1	$15	$15	AliExpress
DC Motors	motor	2	$26	$52	Amazon
Motor shield	controller	1	$18	$18	Amazon
MCU	controller	1	$20	$20	
Wires	wiring	4	$2	$8	AliExpress
PCB	housing	1	$25	$25	
Audio feedback	peripheral	1	$40	$40	
Vibrating disk	haptic	4	$2	$8	Adafruit
				$346	

Table 4-1: Tentative Bill of Materials

5. Initial Project Milestones

The figure below shows various project milestones with their estimated start and end dates. The duration is given in days. There is also a Gantt chart generated by this data. The paper should be incrementally completed throughout the first semester, progressing towards a subsystem demo before an official full system prototype is made on a breadboard. After that is done, the printed circuit board will be ordered and the entirety of the second semester will be dedicated to integration and final testing and assembly.

	Start Date	End Date	Duration (days)	Duration (weeks)
Brainstorming and Project Scope	8/19	8/30	11	1.6
Divide and Conquer	8/29	9/6	8	1.1
Individual Research	9/6	10/21	45	6.4
60 pages complete	9/6	10/25	49	7
120 pages complete	9/6	11/26	81	11.6
Subsystems Proof of Concept Dev.	9/13	10/25	42	6
Full System Breadboard Prototype	10/25	11/26	32	4.6
PCB Design and Ordering	11/26	12/6	10	1.4

Figure 5-1 Senior Design 1 Milestones

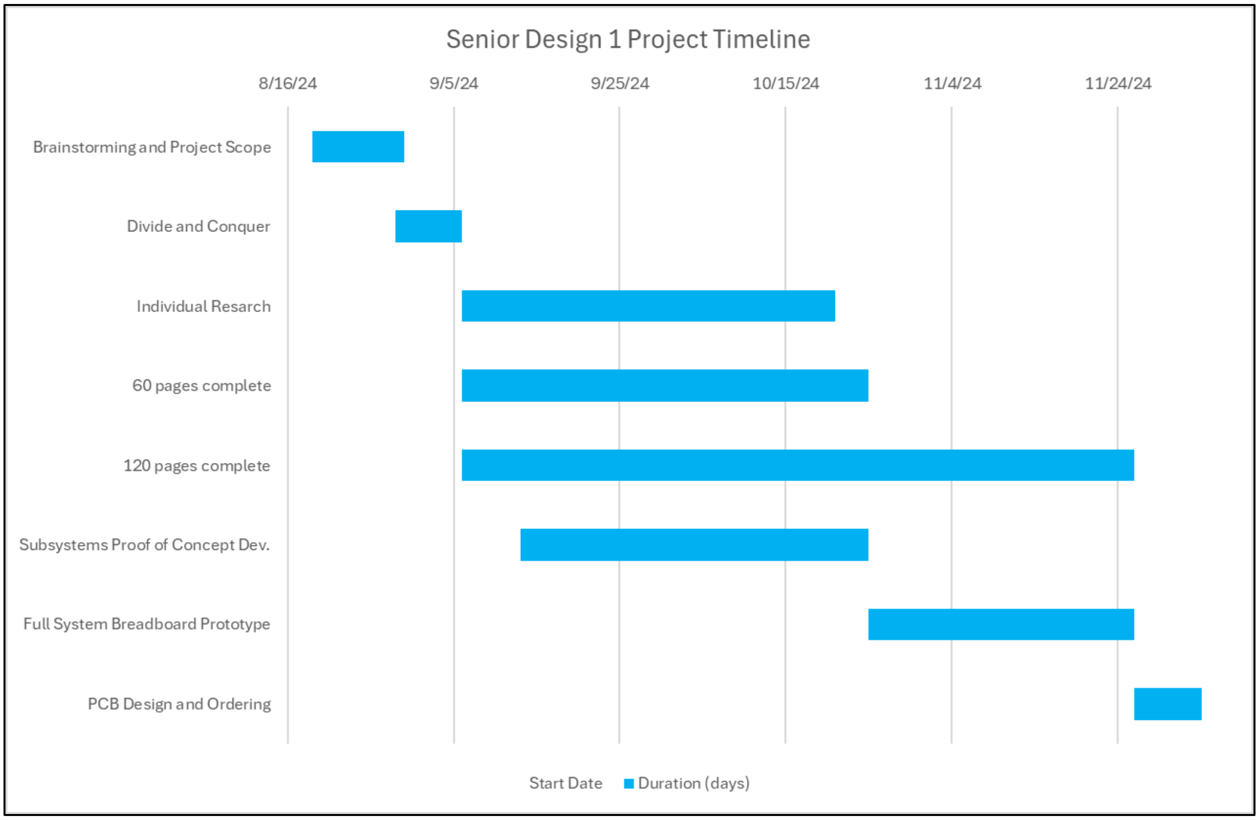

Figure 5-2 Senior Design 1 Gantt

	Start Date	End Date	Duration (days)	Duration (weeks)
PCB Soldering & Testing	1/6	1/24	18	2.6
Embedded Control Algorithms Implementation	1/6	2/14	39	5.6
PCB Redesign & Reorder	2/14	2/28	14	2
Final Project Documentation	1/6	4/4	88	12.6
Full System Testing	2/28	4/14	45	6.4
Full System Integration (Mount electronics on walker)	4/14	4/18	4	0.6
Full System Deployment	3/28	4/25	28	4

Figure 5-3 Senior Design 2 Milestones

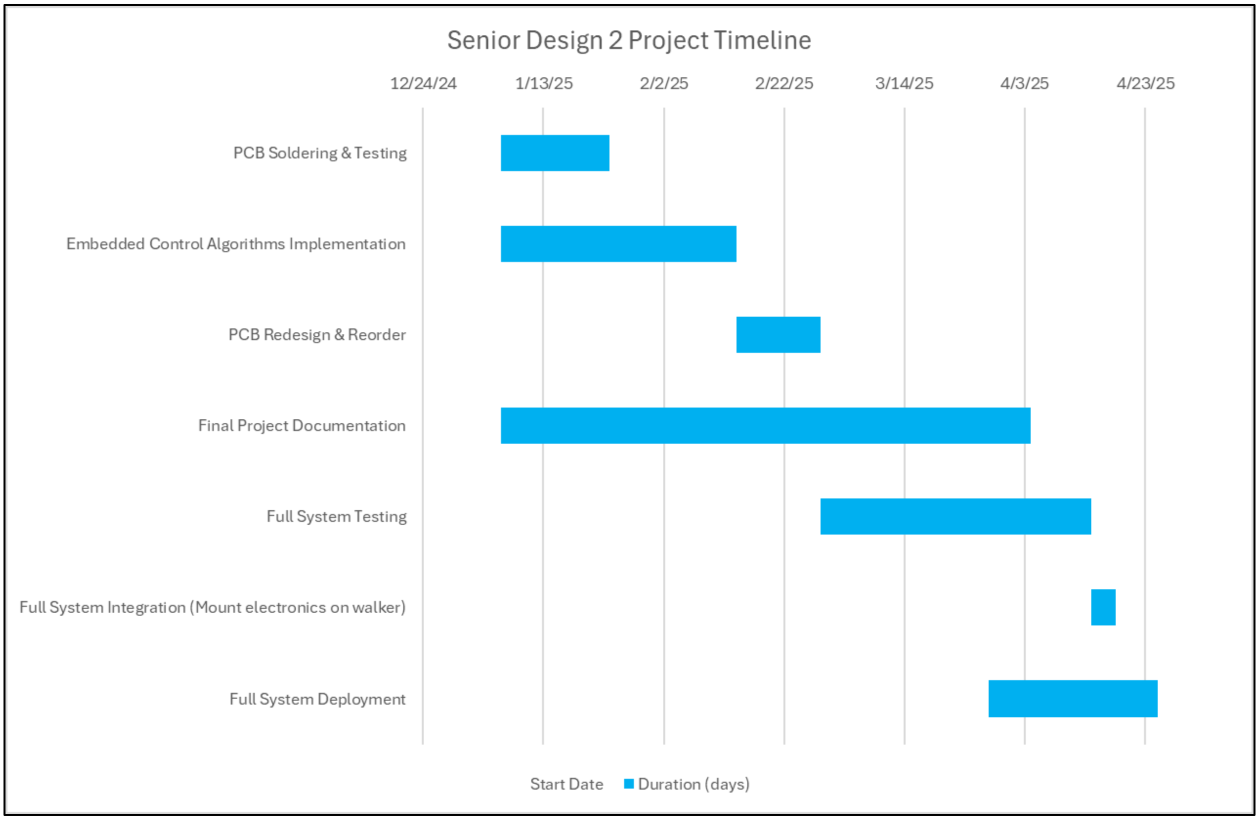

Figure 5-4 Senior Design 2 Gantt

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