ENSC 305W/440W Grading Rubric for Design Specification

Criteria	Details	Marks
Introduction/Background	Introduces basic purpose of the project.	**/05%**
Content	Document explains the design specifications with proper justification for the design approach chosen. Includes descriptions of the physics (or chemistry, biology, geology, meteorology, etc.) underlying the choices.	**/20%**
Technical Correctness	Ideas presented represent valid design specifications that will be met. Specifications are presented using tables, graphs, and figures where possible (rather than over-reliance upon text). Equations and graphs are used to back up/illustrate the science.	**/20%**
Process Details	Specification distinguishes between design details for present project version and later stages of project (i.e., proof-of-concept, prototype, and production versions). Numbering of design specs matches up with numbering for functional specs.	**/15%**
Test Plan	Provides a functional test plan for the present project version. (Note that project success will be measured against this test plan.)	**/10%**
Conclusion/References	Summarizes functionality. Includes references for information from other sources.	**/05%**
Presentation/Organization	Document looks like a professional specification. Ideas follow in a logical manner.	**/05%**
Format Issues	Includes letter of transmittal, title page, abstract, table of contents, list of figures and tables, glossary, and references. Pages are numbered, figures and tables are introduced, headings are numbered, etc. References and citations are properly formatted.	**/10%**
Correctness/Style	Correct spelling, grammar, and punctuation. Style is clear concise, and coherent. Uses passive voice judiciously.	**/10%**
Comments		

November 17th, 2013

Prof. Lakshman One
School of Engineering Science
Simon Fraser University
8888 University Drive,
Burnaby, BC, Canada V5A 1S6

RE: ENSC440 project Design Specification for Smart Walker System

Dear Prof. One,

Enclosed is a design specification of Smart Walker system developed by our company. The Smart Walker is designed to assist the elders that are visually challenged and rely on the walker to walk. The design specifications in this document details the main system of our product consists of the auto-brake, the obstacle detection sensors, the Android application and the user recognition system.

The design specification outlines the system overview of our Smart Walker and details designs of each software and hardware component. This document is applied as a guideline and an instruction to integrate and test our prototype. It also highlights the differences and improvements from our functional specification.

Our company is founded by four motivated and enthusiastic engineers Junfeng Xian, Hongkyu Ahn, Andy Back, and Seung Yeong Park. We believe that our dynamic team is able to accomplish the project within the intensive schedule.

If you have any questions regarding the design specification, please feel free to contact us via email at *jxian@sfu.ca* or phone at *778-862-7238*.

Sincerely,

Junfeng Xian
Chief Executive Officer
NBS^2 Solution

Enclosure: *DESIGN SPECIFICATION FOR SMART WALKER SYSTEM*

NBS^2 Solution

Design Specification: Smart Walker System

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EXECUTIVE SUMMARY

At NBS^2, we aim to develop a roller walker that alerts and notifies the user with visual difficulties whenever it detects an obstacle. Our roller walker prototype, called Smart Walker, will help reduce the risk of elderly people having accidents, such as tripping over the edge of the road, when they are out for a stroll. With more and more baby boomers retiring, the number of elderly people would increase substantially, and thus this product will be essential for them [1].

The main system of our product consists of following four modules: the auto-brake system to assist elderly people to reduce the speed of the walker in case of emergency, the obstacle detection sensors to detect any obstacles ahead, the Android application for the user to see the current status and the user recognition system to have multiple user settings on the system. All these modules are integrated together as one product to assist elderly people from dangerous incidents, such as tripping over the edge of the road.

This document details and outlines the design and implementation for the Smart Walker. Current version of Smart Walker will be produced by using this document, and but for the future prototype, we aim to have a design that is more efficient, cost-effective, and user friendly. Moreover, more features, especially on the application side, will be considered to be added additionally.

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Glossary

GPIO	General Purpose Input/Output
HDMI	High-Definition Multimedia Interface
USB	Universal Serial Bus
GND	Ground
OpenCV	Open Source Computer Vision Library

1. INTRODUCTION

NBS^2's Smart Walker is designed to protect elders with visual difficulties from any dangers and guide them to their destination safely. The Smart Walker is capable of detecting obstacles in front of it, applying auto-brake to the wheels, and notifying the user any hazards through a tablet. The design of our product has been broken into three components; the electrical software/hardware, mechanical, and user interface design. For each component, the detailed design specifications and choices will be described in this documentation.

Scope

This document presents the design specifications/choices for the Smart Walker prototype system. The design specification will only provide the technical points of the prototype, thus, not every detailed mathematical theories are not covered in this document.

Intended Audience

The intended users of this document include any potential stakeholders of this project including health care professionals and electronics manufacturers. Managers, developers, testers who are involved in this project may use this design specification as a guide to proceed.

2. SYSTEM OVERVIEW

In this section, the system overview of Smart Walker is outlined with the block diagram.
The number of elderly people is exponentially increasing [2]; therefore, more people will be in need of daily-life supportive devices. A walker is one of the devices to help elders walk outside. Although some walkers come with the safety features, such as a manual brake, these minimal safety features might not be enough to protect the users. For example, the existing walkers might be dangerous to use for many elderly people with vision problems. For this reason, we are going to create a device that detects any dangerous obstacles or staircases and warns elders to protect themselves from any potential dangers. Based on the assumption that most of users for walkers are seniors, we will also include some simplified personal services like email and schedules. With the proper recognition of the user, the email including the location and schedule data of the

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user will be automatically sent to one of the family members.

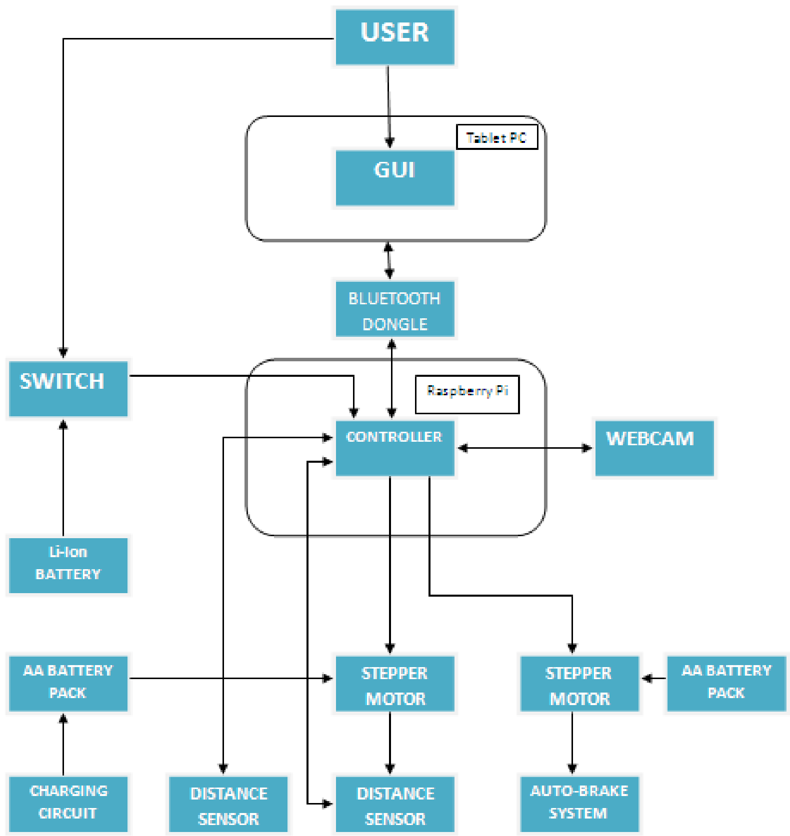

FIGURE 1 BLOCK DIAGRAM OF SYSTEM OVERVIEW

Figure 1 shows the block diagram of our system overview. Our project consists of four major design components: the auto-brake system, the obstacle detection with sensors, the user interaction applications and the user recognition system. The main functionality of the auto-brake system is to protect and warn the user by slowing down the speed of the walker. If any obstacles are detected, a signal will be generated to stepper motors through Raspberry Pi and the stepper motors will apply an adequate amount of torque to initiate the auto-brake. The detailed auto-brake mechanism can be found in Section 5. These stepper motors are powered by a 9.6V AA battery pack. The brake will be applied as soon as distance sensors detect any obstacles. Two distance sensors will be used to detect any obstacles both in vertical and horizontal directions, then be interfaced with Raspberry Pi.

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In order to cover the wide range horizontally, one of the distance sensors will be attached to the stepper motor. This motor will be powered by a 5V AA battery pack and we built a battery charging circuit for this battery pack. The other distance sensor will be used to perform the horizontal obstacle detection. If anything is detected, an audible and visual warning will be generated through a tablet PC.

The user interaction application will provide useful information including maps and weather during the normal operation. Moreover, this application will also provide a personalized schedule based on who the user is. Also, it will auto-generate the email including location and schedule and send it to the family member.

In order to know who the user is for the application, we added new features that detect and recognize the user by utilizing a webcam to capture the user image. Additionally, we newly created the power saving mode which is triggered when the user is not using the walker for more than 2 minutes.

Figure 2 below is the SolidWorks 3D model of our Smart Walker.

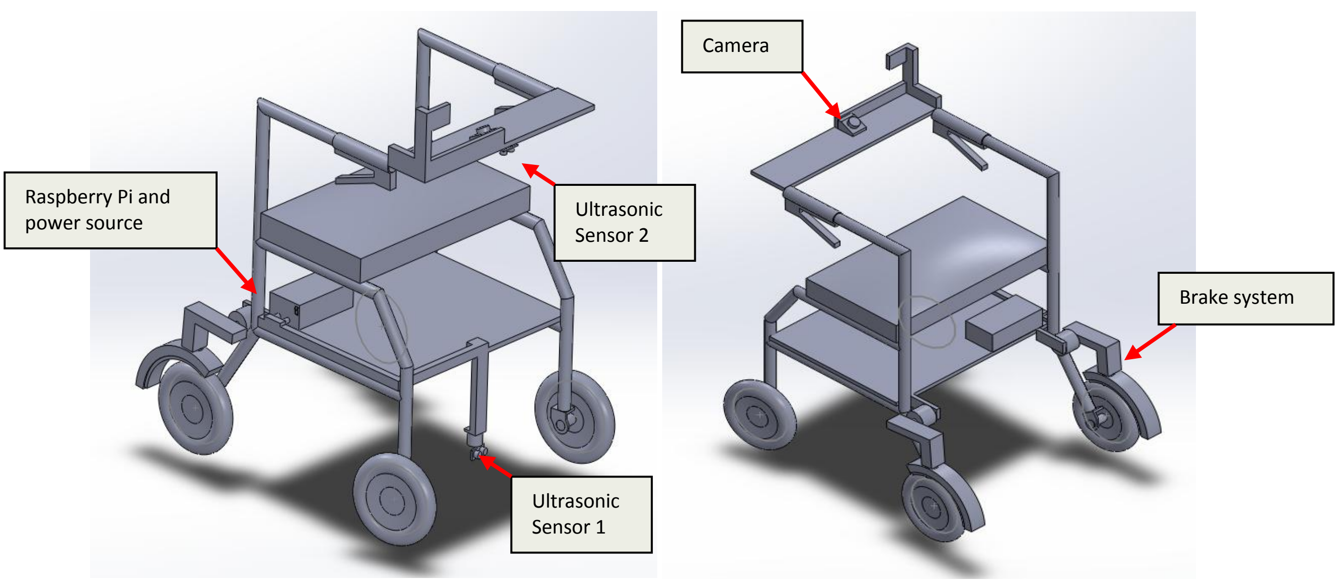

FIGURE 2 3D MODEL OF SMART WALKER (FRONT AND BACK)

3. ELECTRICAL HARDWARE DESIGN

Smart Walker has an excellent electrical hardware system to ensure it can function for various applications. This hardware system contains a micro-controller, a distance sensor circuit, a stepper motor circuit, a webcam input and a Bluetooth output.

3.1 CENTRAL MICROPROCESSOR DESIGN

The main function of microprocessor on Smart Walker is to recognize obstacles, to perform warning, and to interact with user through a mobile device application. Moreover, there is a new feature that can allow Smart Walker to recognize the registered user via a webcam.
The microprocessor unit of Smart Walker is Raspberry Pi model B. This model is developed by Raspberry Pi Foundation and has a Broadcom BCM2835 system-on-a-chip with an ARM1176JZF-S 700 MHz processor [3]. The model is a card-sized device which is powered up with 5V and 700mA DC power input. Raspberry Pi has 2 Type-A USB ports and 17 general purpose input/output (GPIO) pins on the board to communicate with external device. Also, it has HDMI, RCA and Ethernet jacks, but they will not be used in the smart walker. Compared to other micro-controller boards, Raspberry Pi model B has faster processing speed, smaller board size, lower cost and, most importantly, more GPIO configurable pins. Smart Walker is able to take advantages of all these features on Raspberry Pi. Figure 3 shows the detailed board layout of Raspberry Pi.

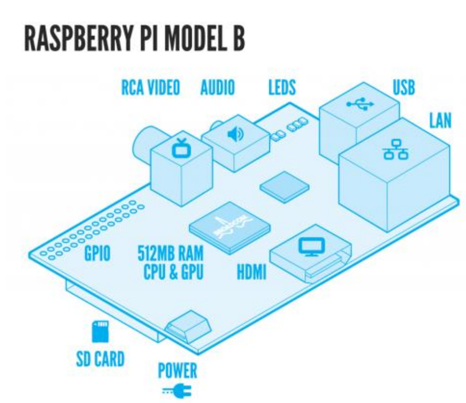

FIGURE 3 RASPBERRY PI MODEL B LAYOUT (SOURCE: RASPBERRY PI FOUNDATION)

There are seventeen GPIO pins on Raspberry Pi. The GPIO pins on Raspberry Pi are bi-directional, so they should be configured as either input or output pins before using. The GPIO pins are shown in Figure 4.

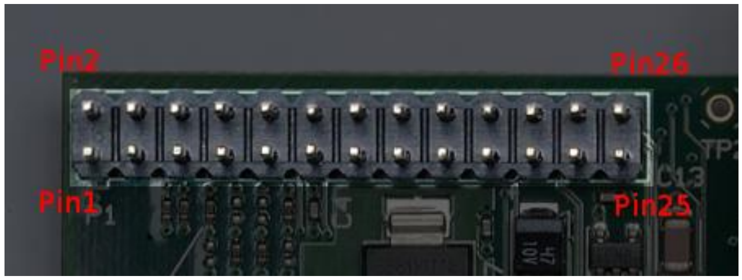

FIGURE 4 GPIO PIN LAYOUT (SOURCE: ELINUX)

Since Smart Walker has two ultrasonic sensors to measure the range, two stepper motors to enable the brake system, one smaller stepper motor to rotate the sensor, and one rocker switch to shut down the system, our product occupies thirteen GPIO pins in order to communicate with all of them. Table 1 represents the GPIO configuration for Smart Walker.

GPIO Pins	Input/output Direction	External Circuits
GPIO 11	output	ultrasonic sensor 1
GPIO 23	input	
GPIO 18	output	ultrasonic sensor 2
GPIO 24	input	
GPIO 25	input	switch
GPIO 7	output	stepper motor of ultrasonic sensor 1
GPIO 8	output	
GPIO 9	output	
GPIO 10	output	
GPIO 4	output	stepper motor of auto brake system
GPIO 17	output	
GPIO 21	output	
GPIO 22	output	

TABLE 1 GPIO CONFIGURATION

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Besides GPIO, Smart Walker also uses 2 Type-A USB ports. One port is connected to a webcam, while the other is used to connect a Bluetooth dongle.

3.2 OBSTACLE DECTECTION CIRCUIT DESIGN

Detecting obstacles in front of the walker is the most critical function of Smart Walker. Obstacles can be categorized into two types. One is an object higher than the ground such as up-stair or block, and the other is a surface lower than the ground level such as down-stair or walkway curb. At the prototype level, our product uses distance sensors to detect obstacles due to cost and complexity consideration.

There are two common types of distance sensors, but we prefer ultrasonic sensor rather than infrared sensor because infrared sensor is not suitable in outdoor ambient environment [4]. On the other hand, ultrasonic sensor is not dependent on the surface color of the object and response time to sensing signal is linear [5].

FIGURE 5 UNTRASONIC SENSOR [28]

Ultrasonic sensor in this design is Ultrasonic Ranging Module HC-SR04, which is small, lightweight, and most importantly, has the maximum range of four meters [28]. HC-SR04 has 4 pins attached on the board (see Figure 5). Vcc and ground (GND) pins are utilized to power up the sensor, while Trig and Echo pins are used to exchange signals. Once a 10us voltage pulse is received on Trig pin, the circuit will transmit a 40 kHz 8-cycle burst from its transmitter speaker; at the same time, it raises Echo signal to high voltage. Echo signal will be low again when receiver speaker senses the burst bounced back from an object. Therefore, by calculating the time interval of the Echo pulse width and applying the equation (3.1), the sensor returns the distance of the object.

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$$d = \frac{v * t_{echo}}{2}, \quad (3.1)$$

where d is the distance between sensor and object;

v is the speed of sound which is 343m/s;

t_{echo} is the time interval of the Echo signal pulse width which can be measure through Raspberry Pi GPIO INPUT pin.

In our functional specification, Smart Walker is proposed to utilize camera and distance sensors to detect obstacles [6]. Since camera response and image processing take longer than the expected time and camera cannot give real-time detection information to the walker, we overcome this drawback by using ultrasonic sensors instead of camera in this design specification. To detect an object higher than the ground, one ultrasonic sensor is placed at the front to sense distance horizontally. In order to sense the down-stair or curb, another ultrasonic sensor is used to measure the vertical distance between the sensor and the ground (see Figure 2). Also, the ideal design of obstacle detection is to place enough number of ultrasonic sensors to sense distance horizontally and vertically [6]. However, due to the limited number of GPIO pins and the reduction of production cost, utilizing many ultrasonic sensors is not practical. The solution to this issue is to attach an ultrasonic sensor to a stepper motor, so the ultrasonic sensor can scan the wider range in front of the walker when motor is rotating.

For the horizontal sensor, we came up with the line scanning trajectory design and this line scanning approach is able to minimize the blind area and increase the obstacle finding probability. Figure 6 below demonstrates the line scanning approach.

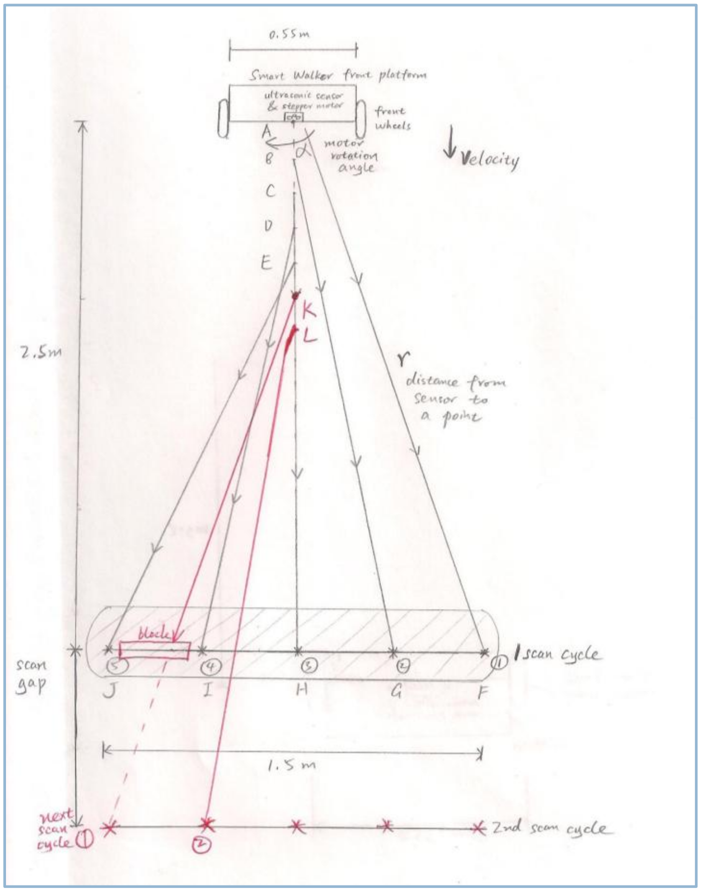

FIGURE 6 LINE SCANNING APPROACH

According to the user research and walker test observation, the elders can drive our walker at 0.4 m/s to 0.72 m/s. Assuming the Smart Walker is moving at 0.56 m/s, and fully stopping the walker without hard braking takes 3 seconds, so the walker requires approximately 1.5m to stop. Assuming the safe distance between the user and the obstacle should be at least 1m to bypass the obstacle, it implies that the sensor should be able to detect any obstacles within 2.5m. Also, the width of the walker is 0.55m. Adding the safe distance on both side of the walker will set the sensing width to be 1.1 m. Moreover, since ultrasonic sensor cannot be rotated when measuring distance, which means it detects object in a discrete pattern, ultrasonic sensor can only sense some certain points on the scanning line depending on the speed of motor rotation. For the first prototype of Smart Walker, the sensor is designed to measure 5 points on the scanning line.

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Considering the speed of moving walker, we know the ultrasonic sensor position is changing from A to E sequentially in Figure 6. Thus, one scan cycle produces four different right triangles. Applying Pythagoreans theorem and trigonometric functions, we can obtain the distance r from sensor to one of the five points and the motor rotation angle α. Even though the speed of walker is uncertain, and the point may not be aligned with others, the sensor can detect an obstacle as long as the obstacle blocks on of these five ultrasonic rays. One of the most significant advantages of the line scanning approach is that it can narrow the scan gap, so it can give the fastest response to the walker when the obstacle is detected inside the range.

Due to discrete scanning pattern of this ultrasonic sensor and stepper motor combination, there are some blind areas between the five sensing points on one scanning line. In our design, the walker has the blind area of 0.22m. If a block has width with of less than 0.22m, the walker is still able to detect it during the next scan cycle like the red line shown in Figure 6. However, this situation may cause a problem when the walker and obstacle distance is much less than 2.5m. If applying the second sensor with motor beside the first one for the future development, enabling them at the same time at the same rotation speed but setting different detection points, the blind area can be narrowed to half of 0.22m.

For the vertically detecting, Smart Walker utilizes one ultrasonic sensor which is attached beneath the tablet holder. Since the maximum measuring angle of ultrasonic sensor is 15 degrees; thus, it is only able to detect down-stair or curb which is the maximum of 20 cm in front of the walker. In this case, the walker will apply a hard brake and alert the user immediately since the obstacle is so close. If the receiver speaker can be tilted a few degrees and sense lower dB of the ultrasonic signal, it might be possible to increase the measuring angle and so can enlarge the distance between walker and sensing point. We did not implement this for our prototype design; however, it can be improved during the future development.

Lastly, Raspberry Pi GPIO pins to ultrasonic sensor Echo pin connection requires a 5V-to-3.3V voltage shifter or a voltage divider, because the ultrasonic sensor Echo pin output voltage is 5V while Raspberry Pi GPIO input pins only accept 3.3V [3].

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3.3 STEPPER MOTOR FOR THE DISTANCE SENSOR

FIGURE 7 STEPPER MOTOR FOR THE DISTANCE SENSOR (SOURCE: ADAFRUIT INDUSTRIES)

The auto-brake mechanism for our project requires the precision control of motors. Controlling the rotational speed was crucial in order to prevent the brake from sudden application. Also, the position of the brake should be controlled accurately in order to improve the precision of the auto-brake system. Overall, the stepper motor was the most suitable choice for motors in order to easily control rotation angle, speed and position. Please refer to Appendix A for the detailed operation of stepper motors [7].

Rotating the distance sensor for our prototype does not require a high torque. In order to minimize the cost and the power consumption, we chose to use 5V stepper motor with a low hold torque.

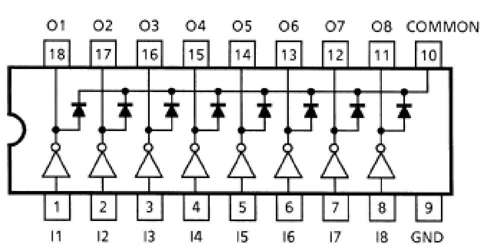

FIGURE 8 INTERNAL SCHEMATIC FOR ULN2803 (SOURCE: ULN280 DATASHEET)

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Because the max current limit of a GPIO pin is 16mA [3], we need an amplifier to supply the enough current to stepper motors. At the prototype level of our product, we utilized ULN280 Darlington amplifier. Referring to the above Figure 8, the function of the ULN2803 is to amplify both voltage and current [8]. The ULN2803 sinks currents to protect current going back to raspberry GPIO. The current will be amplified through the chip to output 350 mA. The voltage at the GPIO is 3.3V and the ULN2803 will amplify the voltage to 5V.

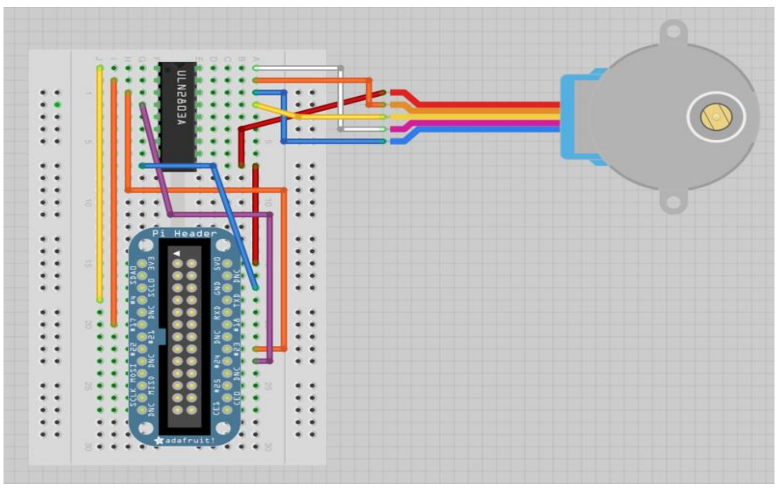

FIGURE 9 WIRING FOR STEPPER MOTOR AND ULN2803 (SOURCE: ADAFRUIT INDUSTRIES)

The circuitry of how the pins are configured is described as in Figure 9 where we utilize the power source from Raspberry Pi GPIO pins. For our prototype design, we can also consider using the external power battery pack. As long as we provide the same input voltage of 5V to the motor, the amount of torque will not change [7].

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3.4 STEPPER MOTOR FOR THE AUTO-BRAKE

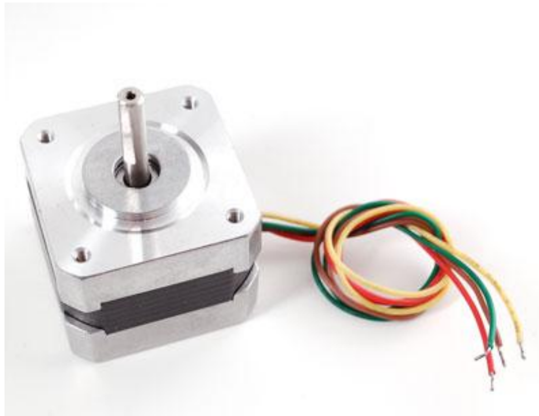

FIGURE 10 STEPPER MOTOR FOR THE AUTO-BRAKE SYSTEM (SOURCE: ADAFRUIT INDUSTRIES)

The motor shown in Figure 10 can supply 2Kg*cm holding torque which is sufficient for our auto-brake mechanism. Please refer to Section 5 for the detailed brake mechanism. Referring to section 3.3, we utilized the same amplifier chip (see Figure 8). The circuit configuration is basically same as the one in Figure 9, except that the recommend input voltage of this stepper motor is about 12V [7]. At the present prototype level, we utilized 8 AA batteries to supply the voltage to this motor.

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3.5 WEBCAM

FIGURE 11 LOGITECH C210 WEBCAM (SOURCE: LOGITECH)

In order to take a snapshot for the face detection and recognition, we utilized the Logitech webcam C210 as shown in Figure 11. This webcam is fully UCV compliant; therefore, it does not require any additional drivers for Linux operating system, and it is verified to interface with Raspberry Pi errorlessly [9].

The main focus on choosing webcam is to minimize the cost while still producing sufficiently good quality of pictures for image processing. This webcam features 15 fps of frame rate with 1.3MP photo resolution with features like Autofocus and Automatic White Balance [10]. With the $11 of cost, this webcam produces the clear output images with the maximum resolution of 640x480. Moreover, it can be powered directly through USB 2.0 on the Raspberry Pi without requiring any external USB power hubs [10].

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3.6 BLUETOOTH USB ADAPTER

FIGURE 12 IOGEAR BLUETOOTH 4.0 USB ADAPTER [SOURCE: IOGEAR]

Figure 13 shows the Bluetooth dongle of our choice. Bluetooth technology is used for the communication method between the Raspberry Pi and the Android tablet. This Bluetooth dongle is powered through USB 2.0 port on the Raspberry Pi requiring no external USB power hub [9].

Also, this dongle supports the Serial Port Profile (SPP) that enables the communication between Android devices and Raspberry Pi with the Bluetooth v4.0 technology [11]. It supports the 3Mbps data transfer rate, which is sufficiently fast for the production model for the quick transfer of small files from the Raspberry Pi to the tablet device.

3.7 POWER SUPPLY

For the smart walker power supply, Raspberry Pi will power all components such as sensors, webcam and Bluetooth USB adapter dongle except stepper motors. According to the Raspberry Pi foundation, Raspberry Pi Model B will require maximum of 700mA when using networking and high-current USB peripherals [9].In order to maximize the battery life, we are utilizing the different power sources for stepper motors. The stepper motors for operating the auto-brake requires 9.6V input while one for sensor rotation requires 5V power input. Please refer to Table 2 for the detailed estimation of power consumption.

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System	Maximum Current Consumption (mA)	Maximum Power Consumption (W)
Raspberry Pi	700	3.5
2 X 12V stepper Motor(1)	350 each	3.36 each
1 X 5V stepper Motor	<95	0.5

TABLE 2 MAXIMUM POWER CONSUMPTION OF MAIN COMPONENTS

(1) The recommended voltage for the stepper motor is 12V in order to get the maximum torque, however, the 9.6V input supply provides the adequate amount of torque for the auto-brake system.

System	Battery type	Voltage	Capacity (mA)	Estimated Battery life (hours) (1)	Features
Raspberry Pi	5V Li-Ion Battery Pack	5V (regulated)	4400	6.3	Chargeable
12V stepper Motor	1.2V AA NiMH Battery (8 of them in series)	9.6V	2450	7	Chargeable, Replaceable
5V stepper Motor	1.2V AA NiMH Battery (4 of them in series)	5V	2450	27	Chargeable, Replaceable

TABLE 3 ESTIMATED BATTERY LIFE

(1) Please note that the actual battery life might be longer since we made an estimation based on the maximum current consumption.

3.7.1 BATTERY LIFE CONSIDERATION

a. Referring to table 3, we picked battery sources to meet the minimum of 6 hours of battery life. The actually battery life will be longer after enabling power-saving mode referring to d in this section.

b. By using the AA batteries for motors, we ensured the cheap and easy replacement of new batteries.

FIGURE 13 RECHARGEABLE NI-MH AA BATTERY (SOURCE: SANYO ENELOOP INFORMATION)

c. The power source of Raspberry Pi has to be regulated to 5V; therefore, we utilized a rechargeable Li-Ion battery pack.

FIGURE 14 RASPBERRY PI BATTERY PACK FROM ADAFRUIT (SOURCE: ADAFRUIT STORE)

d. At the prototype stage, the power saving mode will be enabled in case the user is not using the walker for more than 2 minutes. It will be implemented with the face detection algorithm. The power saving mode disables the screen of the tablet. Also, all the components except the Raspberry Pi itself will be disabled to maximize the battery life.

3.7.2 BATTERY CHARGING

For the battery charging solution for the production, our ultimate goal is to charge all three battery packs wirelessly. As for the prototype at this stage, we built a charging circuit including an inductive coil for 5V Ni-MH AA battery Pack. The battery charging is implemented and controlled with a standalone linear NiMH/NiCd fast battery charger [12].

3.7.2.1 LTC 4060

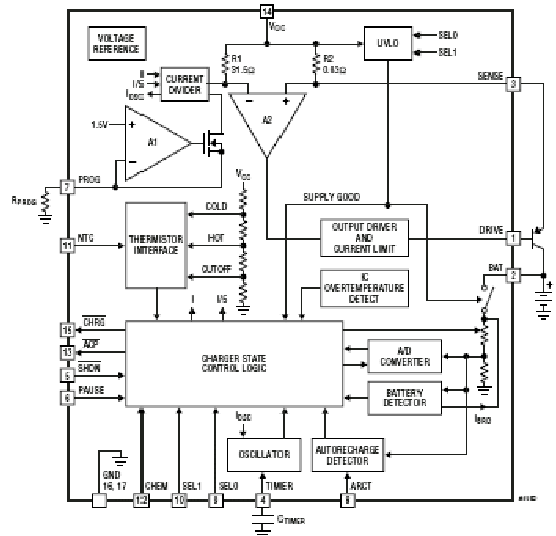

FIGURE 15 BLOCK DIAGRAM OF LTC4060 FROM LINEAR TECHNOLOGY WEBPAGE (SOURCE: LTC4060 DATASHEET)

This IC chip from Linear Technology enables the complete charging system for NiMH batteries. Figure 4 shows the block diagram of LTC4060. This chip can be applied to a variety of equipment for portable electronics and charging docks. The main reason why we picked up this chip is because it provides many standalone features and requires only a few external components. [12] This chip enables some useful features to charge the batteries safely and efficiently. Based on the LTC4060 datasheet [12], this chip allows the input supply voltage range to be between 4.5V to 10V. In order to include a QI compatible wireless charging solution at the later production level, having a generous range of 4.5V to 10V was critical point in choosing this chip. According to the QI standard, the inductive receiver circuit produces 5V output [13]; however, we noticed that it could slightly vary depending on the inductive coils.

3.7.2.2 BATTERY CHARGING CIRCUIT

The following figure 5 is the charging circuit diagram for the 4 X AA NiMH batteries;

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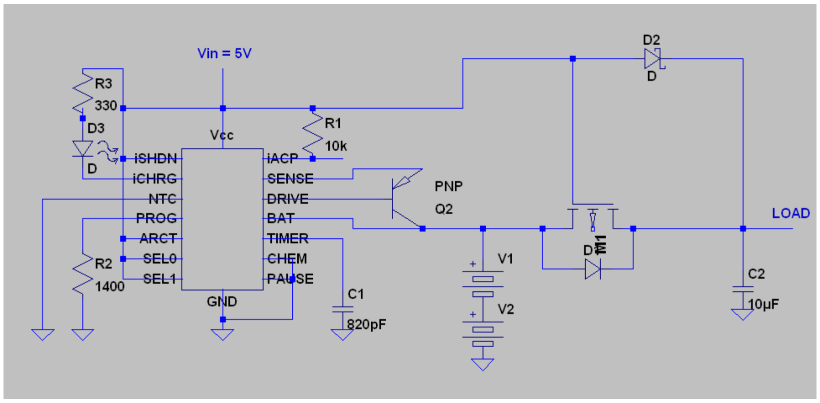

FIGURE 16 NIMH BATTERY CHARGING CIRCUIT DIAGRAM WITH LTC4060

Please refer to Appendix E for the actual circuit implementaion.

3.7.2.3 SAFETY CONSIDERATION

The input supply voltage in our charging circuit will be provided from the inductive wireless charging receiver; therefore, it might not as stable as having a DC input from other 5V power sources like USB port, which is fairly stable. By having a LED indicator at ACP pin, we are able to notice in case the input supply voltage causes any malfunctions. Also, the chip features the automatic detection of battery. The chip will shut down when the battery isn't present. [12]

3.7.3 QI COMPATIBLE WIRELESS CHARGING

3.7.3.1 WIRELESS CHARGING THEORY

According to the Qi standard proposed by the Wireless Power Consortium, wireless charging can be done with the principle of electromagnetic induction. When altering current flows through the transmitter inductive coil, the magnetic field will be generated base on the Lenz's law [14]. This will induce the voltage in the receiver coil. In short, electromagnetic induction between two coils will transmit energy.

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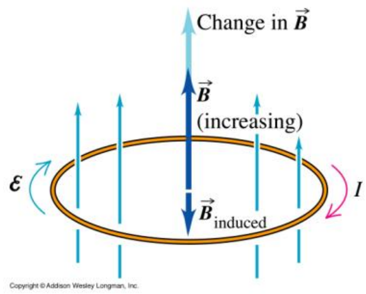

FIGURE 17 GRAPHICAL DEMONSTARATION OF LENZ'S LAW [14]

3.7.3.2 LIMITATION

The main limitation of inductive electrical power transfer distance is 1.6 inches [13]. In other words, the receiver should be placed as close as possible to the transmitter. With the QI wireless charging standard, all the batteries can be charged with any commercial QI transmitters.

3.7.3.3 WIRELESS CHARGING RECEIVER

The receiver with an inductive coil is commercially available to enable wireless charging features for the smartphones. The following figure is the one of the commercially available wireless receiver products [15]. This receiver can be attached into the input supply pin of LTC4060 for our prototype design.

FIGURE 18 EXAMPLE OF WIRELESS CHARING RECEIVER (SOURCE: EBAY)

For the present production stage, we are utilizing the product in figure3 for our wireless charging solution.

3.7.3.4 WIRELESS CHARGING TRANSMITTER

All commercially available QI compatible transmitters listed in WPC will work [15]. The specification of the wireless charging transmitter can be found in Appendix B.

As for the prototype, the capacity of the rechargeable AA batteries we are using is 2550 mAh [16]. According to the specifications of the QI wireless charging solution, it will take up to 7 hours to fully charge the batteries of our choice. This charging time is fully acceptable since the charging can be fully done during the night.

3.8 SWITCH CIRCUIT DESIGN

In our design specification, there are two types of switch. One is push-button switch that is used to restart the system; the other is a rocker switch used to halt the system.

The restart switch is directly connected to Raspberry Pi reset pins. Thus, it can start Raspberry Pi from halt state or restart the walker program when system is activated.

The halt switch is connected to a 3.3V GPIO output power pin and a GPIO input pin. The circuit is shown as Figure 19. If the switch is toggled by users, GPIO input pin can sense a voltage rising edge or a falling edge. Therefore, the Raspberry Pi notes the user wants to terminate the program and does so.

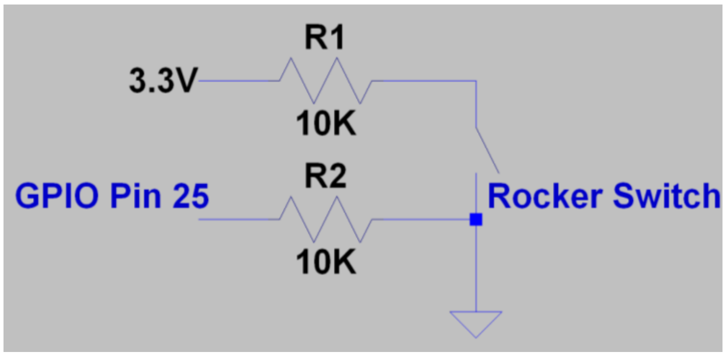

FIGURE 19 SCHEMATIC FOR SWITCH

3.9 ID CARD

The following figure 10 shows the front and back of the ID card design at the production stage. The size of ID is identical to the other regular ID cards, so that the user can easily store it in a wallet or any other covers. We made this ID cards with papers as for the proof-of-concept;

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however, the face images can be printed on any other materials like a plastic. In case of losing this card, the user can easily reproduce it by simply printing the face image either colour or black and white. The backside of the ID card contains the contact information of the user in case of any medical emergency situation while using the product.

FIGURE 20 IMAGE OF ID CARD (FRONT AND BACK)

4. System Software Design

Since our Smart Walker uses Raspberry Pi model B as the central microprocessor unit, the system software relies on the Raspberry Pi Operating System Raspbian. Raspbian is a user-friendly OS with many open source references. In order to develop a Smart Walker program smoothly, we installed Raspbian Version-wheezy updated on 2013-09-25 on our prototype.

The Smart Walker program is developed in Python scripting language. The program can be divided into three parts: GPIO configuration, sub-functions, and main function. It is running over three parallel threads: main thread, face detection thread and sensor thread.

When the walker is powered up and Raspberry Pi is activated, the program automatically starts. The first sub-function called by our program is the face recognition function. Once the walker recognizes the registered user face via camera, it then triggers all three threads: the main thread to call vertical distance sensor function, the face-detection thread to call user face detection function, and the sensor thread to call horizontal distance sensor function. These three functions are called in loops on each thread but whenever the vertical or horizontal distance sensor function detects the obstacle, it puts face detection and the sensor thread into the pause loop where they wait for main thread to do obstacle handling. During this obstacle handling period, the main thread will enable auto-brake system motors and send messages to Android mobile device in order to inform user that there is an obstacle ahead. After waiting some delay time for user reaction, the main thread goes back to the sensing loop and also notifies the other two threads to resume the loops.

Meanwhile, the face detection thread calls user face detection function to observe user face continuously. In case the user face detection function cannot detect the face for a certain number of times, the system will suspend two sensing loops on main and sensor threads assuming the user is not there. If face detection function detects the face again, the system will resume its normal operation. To terminate the program, the user can simply turn off the rocker switch, which will send a "Halt" event signal to the program.

4.1 DISTANCE SENSOR FUNCTION

As mentioned above, ultrasonic sensor would not be triggered until its Trig Pin receives 10us voltage pulse from Raspberry Pi GPIO Output Pin. Distance sensor function has to follow the Figure 21 below to enable the hardware correctly.

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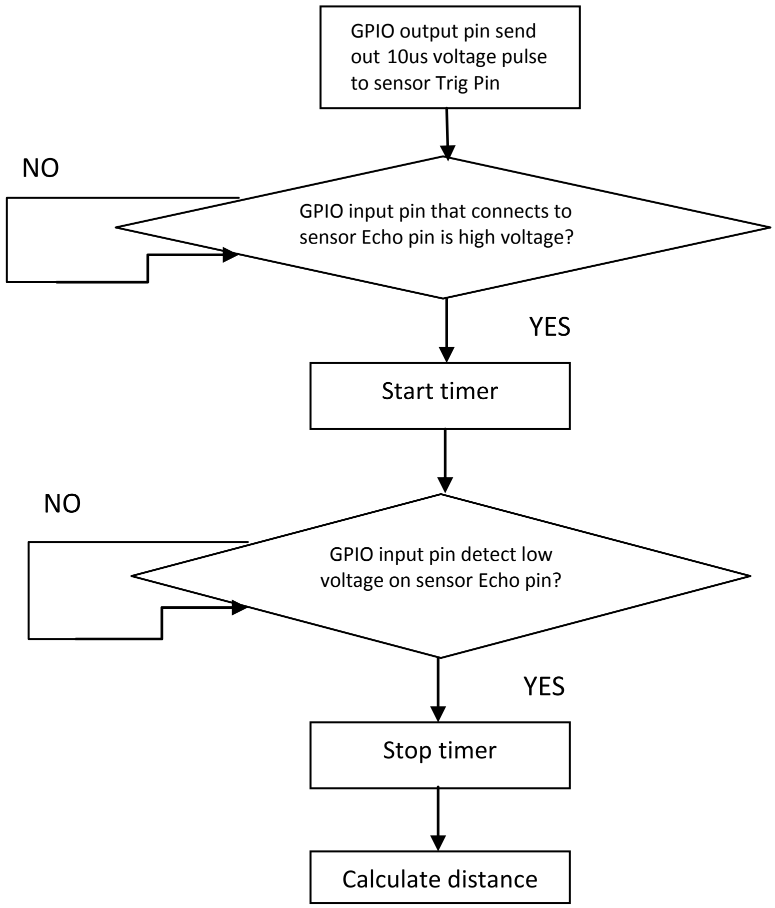

FIGURE 21 FLOWCHART FOR DISTANCE SENSOR SYSTEM

4.2 STEPPER MOTOR FUNCTION

Smart Walker has 3 stepper motors and they are all controlled by Raspberry Pi via GPIO output pins. According to the motor circuit design described above, stepper motor requires 0/1 signals from GPIO output pins as well as delay time of each step and step numbers. Therefore, as long as Raspberry Pi GPIO pins sequentially output 0/1 signals to the 4 leadings of the stepper motor wires in a certain pattern, the motor would start rotating at a certain speed and orientation.

4.3 Face Detection Function

This feature was newly added during the development process in order to enable the power-saving mode.

At the stage of the production version, we mainly used OpenCV 2.4.6 (Open Source Computer Vision Library), which is an open source library under a BSD-license and developed by Intel [17]. Specifically, the face detection algorithm in the OpenCV library utilizes classifier class called Haar Cascade Classifier that detects faces in a video stream [18]. The main function of the Haar Cascade Classifier is to detect the object based on the change in contrast between surrounding groups of pixels [18]. We will skip the detailed explanation about how the Haar Cascade Classifier works.

The following figure 22 shows how the face detection works in a high level;

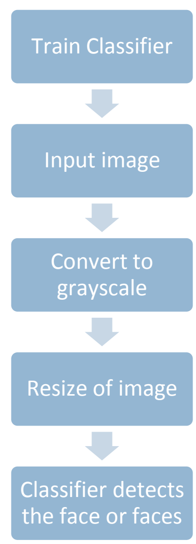

FIGURE 22 FLOWCHART OF FACE DETECTION

Initially, the Classifier should be trained with few hundred negative and positive images. Positive images refer to the ones that contain face and negative images refer to the ones without face contained. The AdaBoost algorithm and Haar feature algorithms should be implemented in order to train the classifier. [18].These implementations are included in OpenCV library [17].

Once the Classifier is trained, it will detect face or faces from the input images [17].

In order to reduce the processing time, we chose to work with pictures with the resolution of 640x480 rather than a video stream. To achieve the minimized delay, we let the webcam capture snapshots every three-second and tried the face detection to be completed in between. We noticed that the resizing of image to smaller size leads the significant reduction of processing time; however, the accuracy of face detection drops when the size of the image reduces by ¼.

4.4 FACE RECOGNITION ON ID CARD

During the development, we decided to add some personalized features like email and schedules and those features require users to login. In order to simplify any login processes, we implemented the face recognition process using Eigenface algorithm. There are easier alternatives for login process such as finger print detection or password, however, face recognition is advantageous in terms of the development cost since it does not require any additional components. Also, minimal user interaction can also be achieved since the user can simply place the ID card in front of webcam without inputting any numbers or pressing any buttons.

This face recognition process detects the face in the user ID and finds the closest face image from the pre-stored images in the Raspberry Pi. Please refer to section 5 to see the details about the ID card.

As for the prototype, we stored 4 facial pictures in the Raspberry Pi based on the assumption that a personal walker might not be shared with more than 3 or 4 people; however, there is no specific limitation on the number of different users. Moreover, the entire face recognition process takes about 5 seconds to complete although it can be significantly varied depending on the processor on Raspberry Pi models. At the production stage later, we will include more sets of facial pictures.

4.4.1 EIGENFACE

Eigenface is an algorithm to recognize the face by comparing the characteristics of the faces and it is proposed in 1991 [19], Eigenface algorithm considers the location of each pixel to be a separate dimension; in other words, images with 10000 pixels will be considered to have the 10000 dimensions.

The main idea of Eigenface starts from the fact that the information of interest, which is the face difference can usually be represented with a much smaller dimension than the entire dimension. [19] Based on this idea, face images can be represented as lower dimensional subspace by finding "principal component" of the images.Specifically, Eigenface Algorithm uses Principal

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Components Analysis (PCA) to reduce the dimensions.[20] More details about Eigenface can be found in Appendix C.

4.4.2 IMAGE FILTERING TO IMPROVE THE FACE RECOGNITION ACCURACY

Figure 23 shows the general steps of image filtering application to improve the recognition accuracy.

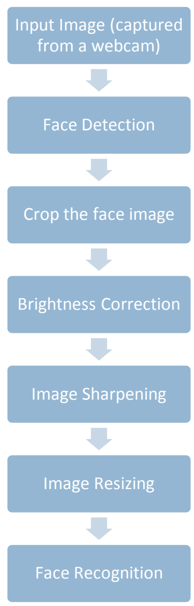

FIGURE 23 GENERAL STEPS FOR FACE RECOGNITION INCLUDING PRE-IMAGE PROCESSING FILTERS TO IMPROVE THE FACE RECOGNITION ACCURACY

4.4.2.1 FACE DETECTION AND IMAGE CROPPING

The above face detection algorithm was implemented in order to crop the facial image and discard unnecessary background. This process helps removing any errors coming from background; but the ultimate purpose of this process is to reduce the processing time by reducing the size of the image by discarding unnecessary pixels without losing much image quality.

4.4.2.2 IMAGE FILTERING

Due to the limitation of Eigenface Algorithm, the accuracy of the face recognition significantly drops if the input image was captured in an extreme environment like excessive brightness [21]. In order to overcome this issue and improve the accuracy of face recognition, the following

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image filtering was performed before the face recognition stage at the current stage as a prototype.

4.4.2.2.1 BRIGHTNESS CORRECTION

Having an excessive brightness or a lack of brightness drops the face recognition accuracy due to the limitation of Eigenface [19]. Each pixel is represented with a number in a range of 0 to 255. Depending on the brightness of the input image, this brightness correction filter will add or subtract a certain number to all pixels in the image.

4.4.2.2.2 IMAGE SHARPENING FILTER

Sharpness of image can be defined as the contrast of edge; therefore, image sharpening is performed to enhance the line details in an image. [23]

In order to perform the filtering, the following 3x3 matrix can be convolved with the input image;

$$\begin{bmatrix} 0 & -1 & 0 \\ -1 & 5 & -1 \\ 0 & -1 & 0 \end{bmatrix}$$

If a pixel is brighter than the surrounding pixels, the brightness of the pixel will be enhanced. Similarly, the darkness of pixel will be enhanced if it is darker than the surrounding pixels. It is known that the increasing sharpness causes the increase in the overall contrast as well. [24]

4.4.3 PERFORMANCE CONSIDERATION

While the Eigenface algorithm produces a sufficiently good result for our project, there are many ways to improve the accuracy further. For instance, the more complex image filtering, such as a face alignment, can be implemented in order to achieve much accurate face recognition result. Also, the Fisherface algorithm based on Linear Discriminant Analysis will also produce better results since it is less sensitive to image background or lighting conditions [25]; however, we did not implement it for our current smart walker prototype due to limited time. The comparison of the Eigenface and Fisherface algorithm can be found in Appendix D.

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5. MECHANICAL DESIGN

One of our product's features is the auto-brake system. This brake mechanism will be attached to a motor shaft. Frictional brakes are most common and can be divided broadly into "shoe" or "pad" brakes. Friction brakes are often rotating devices with a stationary pad. Its configuration is similar to drum brake that uses friction against a rotating surface.

Figure 25 below shows the brake pads that will generate friction on the wheel. As seen in the figure, a thin layer of sponge is attached to the bottom of the pad. This sponge will prevent the walker from stopping suddenly as it will help to apply brake gradually. Please note that our auto-brake is intended to apply brake slowly so that elders do not feel any discomfort when braking.

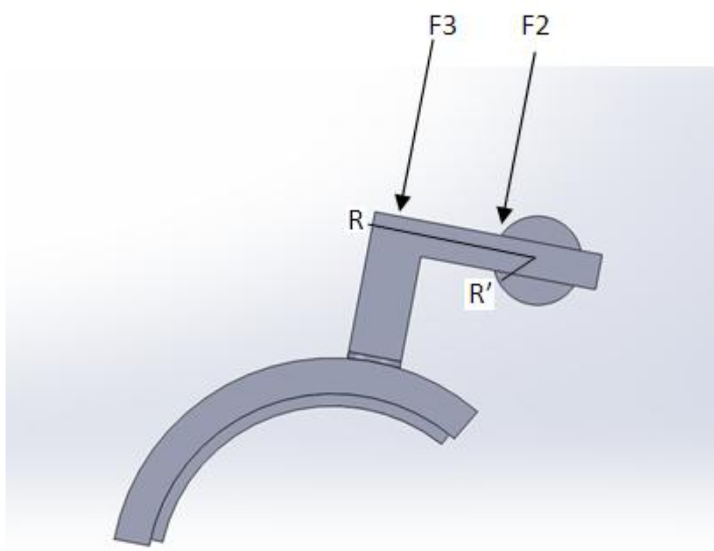

FIGURE 24 BRAKE SYSTEM WITH MOTORS

Before we build the design, we first need to find out what type of motors may be used for the brake. For this specific design, we decided to use stepper motors. With motors, we can simply vary the rotational speed of the shaft in order to apply brake slowly on the wheels. Other types of brake, such as pumping brakes or electromagnetic brakes, are either too expensive to implement or do not meet our brake system requirements.

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First, we will need to calculate the approximate torque/force that will apply to the wheels when a user pushes the walker. Figure 26 shows the torque applied to the wheel when pushed.

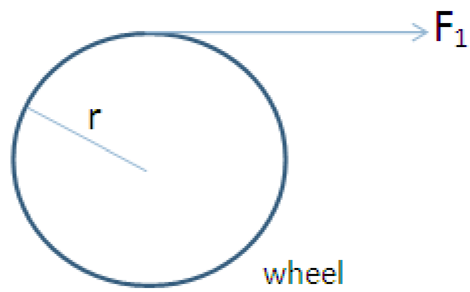

FIGURE 25 TORQUE APPLIED TO WHEELS

We may assume that elders with visual problems are unlikely to walk fast. In other words, they will be walking slowly and the force exerted on the wheel is small. Also, there is not much friction between the wheel and ground, therefore, force required to push the walker is small. With some experiments, we found that the force required to push the walker is about 10N (F_1 from Fig 26). Then, the torque of the wheel is

$$\tau_1 = F_1 * r \tag{5.1}$$

where *r* is the radius of the wheel(10cm).

Keeping the result of equation (5.1) in mind, now the force applied to the wheel by the brake pads must be calculated.

The figure below shows the brake pads that will generate friction on the wheel. As seen in the figure, a thin layer of sponge-like material is attached to the bottom of the pad. This will prevent the walker from stopping suddenly; in fact it will help to apply brake slowly. Please note that our auto-brake is intended to apply brake slowly so that elders do not feel any discomfort when stopping.

In order to avoid immediate stop, F_1 must be larger than F_f. In contrast, if force of friction is larger than pushing force F_1, the walker will stop immediately.

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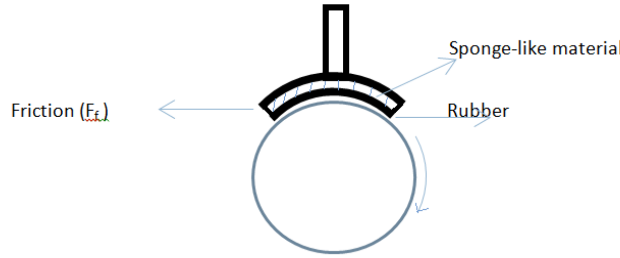

FIGURE 26 FRICTION FORCE ACTING ON THE WHEEL

As you can see from Figure 27, the friction force depends on the torque of the motor and friction coefficient μ. Rubber will be used to generate friction with wheels. Real force is applied at F_2, but actual force acting on the wheel is F3. The actual force F3 calculated from the torque at real force F_2 divided by R. Torque (real) is

$$\tau_2 = F_2 * R' \quad (5.2)$$

The actual force F3 can be calculated from the torque at real force F_2 divided by R.

$$F_3 = \tau_2 / R \quad (5.3)$$

Force of friction acting on the wheel is

$$F_{friction} = F_3 * \mu \quad (5.4)$$

Finally, we need condition of $F_1 >> F_{friction}$ in order to apply brake slowly.

Approximating force F_1 (pushing force), F_3 (down force required on the wheel), and friction coefficient μ, we can calculate the amount of force or torque needed at the motor.
To calculate, we need approximate and reasonable forces for F_1 and F_3.

Gravity = 10m/s

We approximated F_1 to be 10N; that is 10N/ (10m/s^2) = 1kg. One can think of the pushing force (F_1) on the wheel is as same as the amount of holding 1kg of mass.
Then $\tau_1 = F_1 * r$ = 10(10cm) = 100 N*cm. This is the torque of the wheel.

Now we need to approximate F_3. Since it is a vertical force, we may do some experiments with weights.

With some experiments with different weights on the wheel, approximate of 0.45kg is required to slow down the wheel. This means that F_3 = 0.45kg*(10 m/s^2) = 4.5N.

We know that in our design, R = 4cm, and R' = 1cm.

From the above equation (5.3),

$$F_3 = \tau_2 / R,$$

Then,

$$\tau_2 = F_3 * R = 4.5N*4cm = 18\ N*cm$$

τ_2 is the torque generated by the motor; therefore, 18N*cm/10kg = 1.8kg*cm.

With some uncertainty and errors, the system requires motors with torque between 1.5kg*cm to 2.5kg*cm.

To sum up, we have F_1 =10N, and F_3 = 5N. The friction coefficients μ for typical rubber is 0.8. Then,

$$F_{friction} = F_3 * \mu = 4.5*0.8 = 3.6N$$

Since F_1 = 10N acting to the right, and $F_{friction}$ = 3.6N acting opposite direction of F_1. Theoretically, the speed will be reduced by 36%.

For the choice of motors, we may use 5V motors and we can draw 5V from Raspberry pi GPIO pin. This could save the spacing and consume less power. However, the motor running at 5V produces torque of only 320g*cm which is not even close to amount of torque calculated to slow down the walker. Therefore, our choice is to use 12V motor which is capable of giving maximum of 2kg*cm of torque [7].

6. USER INTERFACE DESIGN

6.1 SOFTWARE OVERVIEW

As stated on the User Interface section from the Functional Specification for Smart Walker, we will be using an Android app running Android 4.3 Jelly Bean in order to provide Graphical User Interface to the user. Our engineering team has decided to use Android to create our application because Android is the most used mobile platform around the world [27].

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6.2 GRAPHICAL USER INTERFACE

The GUI is the only way for the user to interact and control Smart Walker. Because the main target audience for our device is mainly the elderlies, who are most likely not comfortable with using smartphones and tablets, our team developed an app in such a way that the user would only need minimal interaction with the tablet.

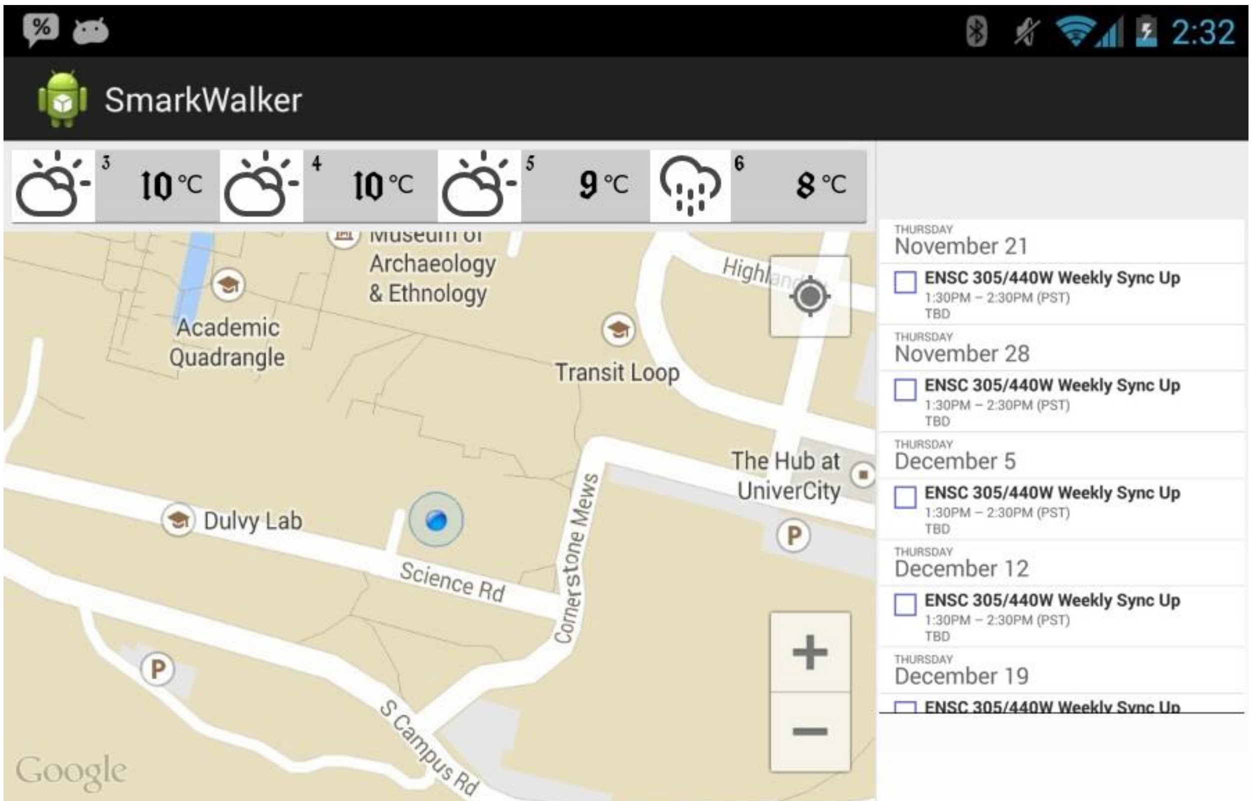

FIGURE 27 MAIN PAGE

6.2.1 MAIN PAGE

The main page (shown in Figure 28) is the primary screen that will be displayed upon the startup, and the user will see most of the times. Detailed information on each feature is explained next.

6.2.1.1 WEATHER INFORMATION

The weather section will include the weather information for the next 4 hours at the user's current location. For our alpha version of the app, it will include hours, temperature, and an icon that corresponds to the weather at that time.

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6.2.1.2 GOOGLE MAPS

The map section will display the Google Map, which is centered and zoomed at the user's current location. As the user moves from one point to the other, the map will follow the user.

6.2.1.3 SCHEDULE

The schedule section will display the schedule for the current user (explained in more detail in section 6.2.3.1). The app will gather the information from the Google Schedule.

6.2.2 ALERT PAGE

Whenever there is an obstacle in front of the Smart Walker, this page will be displayed on the screen of the tablet. In addition to the visual warning, the tablet will also vibrate, and make a warning sound through its speaker by default.

6.2.3 OPTIONS PAGE

From this page, the user will be able to control what types of warning they would like to receive. They can either toggle on or off on physical warning (vibration), and audible warning (speaker). Also, the user can access the accounts page from this page.

6.2.3.1 ACCOUNTS PAGE

This page will enable the user to view their accounts and information, such as email address, and phone number. The accounts will be used for displaying corresponding schedule, and sending an email containing current location of the user to specified email address.

7. TEST PLAN

We are going to test our product with various types of testing. This will ensure that, during the development, each module meets the functional specifications. Tests will be divided into sensors, motors, Raspberry Pi software, and user interface software. After the subsystem tests are completed, we will have an integration test on Smart Walker.

7.1 SENSOR TEST PLAN

- Sensors that are detecting the front will be able to detect obstacles in the triangle range with 1.1m wide and 2.5m far.
- It should always detects objects in the desired range (2.5m for horizontal detection, 1.2m for vertical)
- Sensors that are responding to Raspberry Pi in real-time.

7.2 MECHANICAL TEST PLAN

- The motor should turn when the ultrasonic sensor detects obstacles.
- The stepper motor and brake mechanism together must provide enough force to slowly reduce the speed.
- It is not necessary to completely stop walker.
- When user is walking, he/she should be able to feel that the brake is being operated.
- The brake has to be released after certain time.
- Mechanism is stable and should not fail for number of times.

7.3 RASPBERRY PI SOFTWARE

- Smart Walker recognizes the registered user automatically when the user ID card is placed in front of the camera
- Receiving the data measured from the distance sensor and give response to the controller if obstacle is detected
- Sending a signal to turn motors at a specific speed
- Sending a message to mobile device via wireless connection
- Taking pictures of the user face when user is driving Smart Walker

7.4 FACE DETECTION AND RECOGNITION

- The system detects if the user is using the product or not
- If the user is not using the product for a certain period of time, trigger the power saving mode
- The webcam properly captures the input user image
- If the user image is already stored in the dataset for the system, the recognition system accurately tells who the user is
- If the user image is not stored in the dataset for the system, the recognition system recognizes the user is not registered

7.5 USER INTERFACE SOFTWARE

- Navigation Test
  - Make sure option button, back button and accounts button navigates to expected pages
- Bluetooth connection test
  - Make sure user sees the prompt pop up whenever Bluetooth is off
- GPS connection test
  - Make sure user sees the prompt pop up whenever GPS is off
- Toggling on and off vibration and sound option from options page should turn on and off each option accordingly

7.6 BATTERY TEST

- Smart Walker will be powered by a battery pack for at least 5 hours of continuous operation
- Repeating the process of measuring distance, taking picture, and sending picture over a five hour period. This will verify that our product is capable of operating for this period

7.7 PHYSICAL TEST

- Smart Walker should be stable and all components attached on it should not get loose
- After integration, move the walker along a bumpy/rough surface to check if the components(sensors, cameras) are fixed tightly

7.8 SYSTEM TEST

- Putting an obstacle in order for distance sensor to identify an object
- Taking pictures of the object
- Sending a signal to the tablet so that user can decide if he/she wants to see the picture or not
- Using the GUI to manually see the picture/ Using the GUI to decline
- Continue scanning the distance
- Repeat this process for 5 hours to test the battery

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8. CONCLUSION

We clearly and concisely described the design specifications of our proud product Smart Walker. This document demonstrates the choices of software and hardware requirement of Smart Walker. The functionality of our Smart Walker is to protect people who have mobility difficulties and visual problem, from any potential hazard.

The overall components of each specification will be implemented in order to meet the functional specifications detailed in the past document. The detailed calculations and plans in this document will guide implementations and plans. Some portions of the specification may be adjusted or changed during testing stage in order to complete the prototype. Through the test plans listed in the documentation, we can ensure that all of the required functionalities of our product are met.

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Appendix A

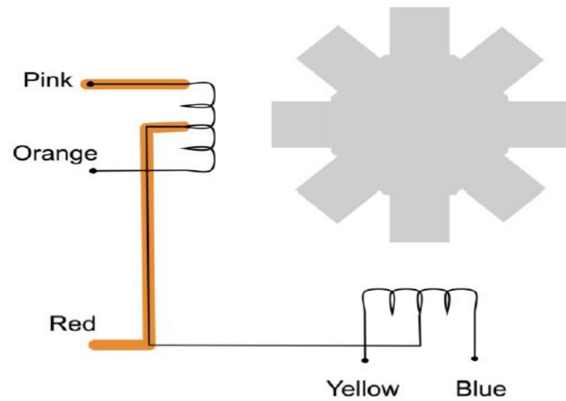

FIGURE 28 STEPPER MOTOR INTERNAL CONFIGURATION (SOURCE: ADAFRUIT INDUSTRIES)

The auto-brake mechanism for our project requires the precision control of motors. Controlling the rotational speed was crucial in order to prevent the brake from sudden application. Also, the position of the brake should be controlled accurately in order to improve the precision of the auto-brake system. Overall, the stepper motor was the most suitable choice for motors in order to easily control rotation angle, speed and position.

Rotation of the motor is configured by 5 pins as seen in Figure 7. Red pin is enable pin which drives 5V from either a Raspberry Pi GPIO pin or an external power source. Figure 7 above shows that it only requires 8 steps to turn 360^o. However, because a reduction gear box (1:64) is used, it needs 8x64 = 512 steps to rotate 360^o [7]. Reduction gear is a set of rotating gears connected to the cog to slower output speed. So, one step of 8 teeth above only rotates a wheel $360^o/512=0.7^o$.

Configuring pink, orange, yellow, and blue pins will control the rotation of the motor. The key concept of this configuration is that only half coils are energized at a time. Having a center pin (red) will allow the motor to either energize the upper or bottom side of the coil. This determines the direction of current. Both terminals (pink & orange or blue & yellow) are never grounded at the same time, which would energize both coils. The direction of coil determines north and South Pole of the magnet.

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For example, say red is enabled, pink is 1, and orange is 0. Then, there is no current going through the upper half of the coil because their potential at each ends are same. In contrast, there must be current going down to the bottom half of the coil because there is a potential difference between red and orange. Current going through a coil produces a magnetic field which attracts a permanent magnet rotor.

Consider the following sequence of pink, orange, blue, and yellow in order:

(1,0,1,0) -> (0,1,1,0) ->(0,1,0,1) -> (1,0,0,1)

For first configuration in the sequence, the direction of current of the left coil becomes downward and this makes bottom side of coil north pole and upper side south pole. The direction of current of the bottom coil points leftward and this makes left side of the coil north pole and right side south pole. Therefore, the motor stays still. When it is changed to (0, 1, 1, 0), current in the bottom coil still points leftward, but now the current of left coil moves upwards. This will rotate the rotor. Then, the next sequence (0, 1, 0, 1) will stop the motor by setting the north pole in opposite direction. This is the characteristic of a stepper motor. It moves one step at a time. We can simply loop this sequence as many times as we like in order to set the duration of the operation.

Also, the delay between these sequences determines the speed of the motor. The slower the delay, the faster the motor will turn.

Appendix B: Specification for Qi wireless charging transmitter

FIGURE 29 QI WIRELESS CHARGING TRANSMITTER FROM LG (LG WCP-300) [SOURCE: LG]

The following is the general specifications for the wireless charging transmitter [29].

1. Fully compatible with QI-Compatible devices (WCP Qi Specification 1.1)
2. It uses the standard 5 pin Micro USB cable for the power input
3. Input : DC 1.5V/ 1.8A, Output : DC 5V/ 1A
4. Approximately, 4 hours of charging time for 1,500 mAh battery

Appendix C: Eigenface algorithm

Eigenface consists of training and recognition stages [25]. In the training stage, a face model will be trained with a given set of face images. In the recognition stage, the trained model calculates the distance between an input image to the training images and picks the closest image [25].

The following is the summary of the training stage implementation and how PCA works [19];

1. Each image in the given set of face images is represented as a matrix. Then, each image canalso be represented as a single raw vector by concatenating the rows of each matrix.

2. In order to find the characteristics of each face image, the average matrix of each image can be subtracted to each image.

3. The covariance matrix has to be calculated wit the following equation;

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$$C = \frac{1}{M}\sum_{n-1}^{M} \Phi_n \, \Phi_n^T$$

, whereΦ_n is the resulting matrix from step 2.

4. For the last step of the training stage, the eigenvectors and corresponding eigenvalues of the matrix C should be calculated. The eigenvectors are also called eigenfaces [21]. These eigenfaces

represent the directional difference from the mean image; in other words, the higher eigenvalue means the greater characteristics on the face.

Referencing the Cognotics website [21], the following step is to show how Eigenface algorithm works in "recognition" stage. This Eigenface algorithm is implemented in FaceRecognizer function, and this function is included in the OpenCV library [17].

1. In Eigenface, the distance between two face images in the Euclidean distance between their projected points in a PCA subspace. A distance should be computed between the new image and each of the faces in the database by projecting on the eigenfaces found in the learning stage.
   The following equation shows the Euclidean distance between point p and q in n-space [30];

$$d(p,q) = \sqrt{\sum_{i=1}^{n}(q_i - p_i)^2}$$

2. The image that's closest to the new input image will be chosen
3. By setting up a threshold,the function will determine if the input face is recognized or not. For instance, this function will "recognize" only If the distance is above a threshold

Appendix D: Comparison between Eigenface and Fisherface

The mathematical steps for Eigenface is explained in Appendix C, however, we will exclude the steps for Fisherface for this document.

The following table shows the main difference between two face recognition algorithms.

	Eigenface	**Fisherface**
Main method difference	Principal components analysis for dimensionality reduction	Linear Discriminant Analysis for dimensionality reduction
Purpose difference	More suitable for representation	More suitable for classification
Recognition accuracy	Good as long as the input image is captured in idealized environment	Good even in a non-idealized environment
Limitation	Very sensitive to lightening condition	More complexity comparing to Eigenface Also, it requires more face images for dataset.

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Appendix E: Wireless charging implementation

Figure below is the implementation of the charging circuit;

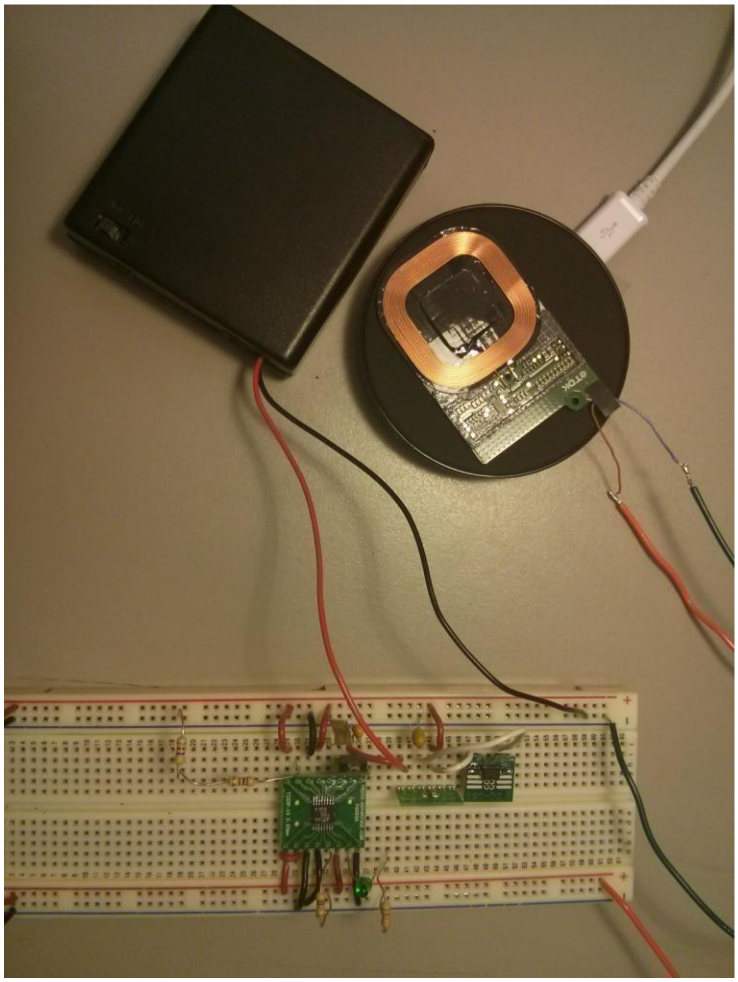

FIGURE 30 WIRELESS CHARGING PROTOTYPE