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Design of an Assistive Technology Adaptive Switch using an Inertial Measurement Unit

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Design of an Assistive Technology Adaptive Switch using an Inertial Measurement Unit

A thesis submitted in partial fulfillment
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Master of Science in Electrical Engineering

by

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Abstract

A new assistive technology switch for people with disabilities was developed utilizing an Inertial Measurement Unit (IMU) as the sensor technology. The hardware can be customized through firmware to provide custom switch activations on a person by person basis. The firmware is customized to recognize specific data features in the IMU data which identify the desired switch activation movement performed by the user. In this way, the switch can be adapted to activate based on the movements of the user. During this research, the generic hardware platform, including the IMU sensor technology and Bluetooth communications, was designed and tested. An Android application was developed to communicate with the Bluetooth enabled switch to acquire the IMU sensory data for analysis.

A case study was performed to recognize thumb and pinky movements as individual switch activations. This experiment tested the feasibility of using the designed switch with an InvoTek client. A training session was performed to acquire movement data of the thumb and pinky. The acquired data was analyzed in MATLAB and a unique data feature was identified. The switch firmware was updated with the necessary algorithm to recognize and differentiate the thumb and pinky movements. Lastly, the switch was tested with 100 repetitive access movements in which the switch accurately characterized and differentiated 100% of the movements.

Acknowledgments

This research would not have been possible without the support of InvoTek's staff: Thomas, Diane, and Erik Jakobs, Barret Ewing, Jerry Russell, and Eryn Johnston. Their dedication and selfless love for those that need assistance has affected me in more ways than anyone can imagine. I am truly thankful for the experiences I have gained by working with their team and the knowledge they have taught me about the disability and assistive technology field.

Through my research, I have come to know the InvoTek client which this switch was ultimately designed for. I am so thankful for the interactions I have had with her and her family. Every interaction left me humbled and amazed by seeing the deep love they share for one another as a family. The patience and hard work that they are willing to put forth is astounding and I am excited to see the impact of the new assistive technology in their life.

I would like to thank Robert Saunders for his willingness to accept me as his graduate student. Mr. Saunders has always worked through any issues that have occurred to ensure I would receive my degree. For that, I am most definitely thankful.

Dedication

First and foremost, all of this work is dedicated to God. This research has given me the opportunity to grow closer in my walk with Christ. Colossians 3:23-24 says “Whatever you do, work at it with all your heart, as working for the Lord, not for human masters, since you know that you will receive an inheritance from the Lord as a reward. It is the Lord Christ you are serving.” Daily I have been reminded that my research is not only for myself, but directly affects the lives of other people. This research has truly been a rewarding experience.

In addition, this work is dedicated to my wife, Kendra. Without her love and support I would not be where I am today. I pursued this degree in hopes that it will better our family for years to come. I am so appreciative of her understanding all the long nights and busy evenings we have had over the last few years. She is a godly woman who has provided more comfort and strength than she may ever know.

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I. Introduction

The goal of this thesis is to detail the design and preliminary evaluation of a new assistive technology switch. Assistive technology is a term used in the disability field to describe technology that mitigates disability. The hardware used for the switch is intended to be a generic platform for implementing unique switch activation methods via customizable software on a person by person basis. The sensor technology used to determine switch activations is an Inertial Measurement Unit which consists of a 3-axis accelerometer, gyroscope, and magnetometer. A case study involving the recognition of thumb and pinky movements for switch closures is included.

Assistive technology switches are utilized by people who experience a severe physical disability or limitation. Just as the name implies, an assistive technology switch is just a binary switch; the output of which is toggled on and off when activated. Using a switch provides a person with the ability to interact with devices or technologies that would otherwise be inoperable due to the required body movement.

For an example of the benefits of assistive switches, take the case of controlling a power wheelchair. Power wheelchairs require human input to determine controlled movements such as moving forward, backwards, left, right, or stopping. Most power wheelchairs are operated using a joystick controller. For an individual who cannot control upper limb movements, a joystick would be unusable. To address this issue, switches are used and activated by head movements, foot movements, or by breathing (Sip and Puff pneumatic switches) to gain the ability to control the power wheelchair. This technique is a common method employed for people with Amyotrophic Lateral Sclerosis (ALS) or Muscular Dystrophy (MD). In this case, switches are a key factor in the ability for a person to maintain independence.

Another common assistive switch use is in the ability to control consumer electronics such as cellphones, tablets, or computers. For people with physical disabilities, a mouse, keyboard, or touch-screen may not be a feasible input method. As an alternative, operating systems such as Windows, Android, and iOS provide switch access to control the device [1] - [3]. With switch inputs alone, the entire operating system and user interface can be controlled. Generally, this access method requires one or two switches as inputs depending upon the method of switch access selected.

Regaining or retaining the ability to access and control a computer provides a wide range of opportunities for assistive technology users such as communication, education, work, interaction with their surroundings, and entertainment. Ultimately, computer access can give the person a sense of independence that might have otherwise been lost due to their physical disability. This independence would not be possible without the use of assistive switch devices.

InvoTek, Inc., located in Alma, Arkansas, designs assistive technology ranging from image-processing based head-tracking systems to switch devices. InvoTek provided the needs assessment, funding, and design review support for creating the switch detailed in this thesis. The original concept for this device was stimulated by an InvoTek client who only has the ability to reliably control their thumb and pinky on one hand. InvoTek has previously designed a mechanical based switch platform which is currently used by the client to interact with an Augmentative and Alternative Communication (AAC) Device. During switch setup and use, the mechanical switch requires precise hand placement due to the client's extremely limited physical ability. This leads to the potential of poor reliability, complications during extended use, and the requirement of supervision to ensure the mechanical switch or hand does not shift. Coughing during use results in the device becoming completely inoperable.

The designed switch is intended to replace the client's mechanical switches and address all of the current limitations and concerns. In addition, new features were included in the designed switch, per request of the client, which included the ability to send a text message requesting assistance and have high switch recognition reliability to support navigation of a power wheel chair. Therefore, a case study was performed with the designed switch to analyze the ability to recognize and differentiate between thumb and pinky movements for switch activation. A firmware algorithm was created and implemented for use with the generic hardware platform that used an Inertial Measurement Unit (IMU) to identify the movements. An external IMU sensor was located on the middle finger while a magnet was placed on the thumb and pinky. The control circuitry was located on the wrist. This was necessary because the intended user has very small hands and the control box would likely interfere with their finger movements.

There are many types of assistive technology switches currently available on the market. Chapter 2 provides an overview of some common switches. The new aspect of the switch detailed in this thesis is the use of an IMU as the primary sensing technology and the ability of customized switch access to the abilities of the user. Besides InvoTek's specific client, the target users of the designed switch are those with unique body movements that prevent reliable operation of currently available switches. Examples of some potential users include people with an extremely limited range of movement or people with poor movement control.

By mounting an IMU consisting of a 3-axis accelerometer, gyroscope, and magnetometer to a user, the sensor's movement can be accurately monitored and analyzed in software. The benefit of using the IMU sensory data is the ability to customize the software to extract a specific feature set which identifies the controlled body movement intended to activate the switch. If the sensor is attached to the body where the user can perform controllable movement, then that specific body movement can be converted to a switch activation. In addition, the software can be customized to filter out body movements which are known to cause false activations for the user, such as coughing, which decreases the user error rate when using the device.

Another unique aspect of using an IMU as the sensing technology is the ability to sense the movement of magnets with the magnetometer. This provides the opportunity to sense movements near the IMU without the requirement of mounting switches so that they are accessible to the moving body part. By only needing to place a magnet, which can be extremely small, virtually weightless, and mounted non-intrusively on a moving body part, the reliability of access may be greatly improved.

The generic hardware design contains an onboard IMU sensor with the connections for an additional externally located IMU. Bluetooth communication is included to (1) provide the ability to communicate with an external device, such as a tablet or computer, and (2) export IMU data for analysis and indicate switch activations. The device is powered by a single-cell Li-ion battery with the necessary charging circuitry included. A 16-bit PIC24F microcontroller was selected as the onboard processor. The hardware is contained inside a 3D-printed enclosure of dimensions 2.1” x 1.6” x 0.5” which allows for easy attachment to the user.

The organization of this thesis is as follows: Chapter 2 provides a review of commonly used switches available on the market. Chapter 3 provides an analysis of the researched sensor technology candidates and details the selected IMU technology used in the designed hardware. Chapter 4 describes the generic switch hardware design and fabrication. Chapter 5 covers the general firmware developed for the generic hardware platform along with a description of a custom android app used to interact with the designed hardware. Chapter 6 provides a case study where the firmware is customized to recognize thumb and pinky movements for switch activation. Lastly, Chapter 7 concludes the thesis with a summary of the research performed and future work.

II. Overview of Assistive Technology Switch Devices

There are many types of assistive switch devices commercially available, each targeting a specific physical movement required to generate a switch activation. The goal of this chapter is to provide an overview of commercially available assistive switch technology and assistive technology utilized in computer access. In addition, this chapter highlights some device features which can be used to compare the effectiveness of switch devices in different situations. This information is intended to give the reader a fundamental understanding of available technology and provide the ability to compare the functionality and operation of the designed switch detailed in this thesis.

II.A Types of Assistive Technology

The most basic category of assistive technology switches is the mechanical switch. A mechanical switch operates by pressing or releasing the switch device which toggles the switch output. There are many variations of the assistive mechanical switches ranging in size, mounting, and target body movement. Assistive technology distributors and manufacturers, such as EnableMart and AbleNet, sell switches ranging from general push-button switches to specialty switches targeting chin or foot movement. The cost of mechanical switches range from $40 for basic push-button switches to a couple hundred dollars for complex switches or multi push-button switches.

Another commonly used switch device is the Sip and Puff switch. As the name implies, switch activation is accomplished by inhaling from (sip) or exhaling into (puff) a tube connected to a pneumatic sensor. Generally, the switch is worn on a headset or mounted on the device being controlled, such as on a wheelchair, and a straw extends to the person’s mouth. When the person desires to make a switch activation, they reach out with their lips and/or head to capture the straw in their mouth, form a seal on the straw with their lips, and inhale or exhale [4] [5]. Sip and Puff switches cost between $300 and $500.

A variation of the Sip and Puff switch focused more on computer use and cursor control is a joystick enhanced Sip and Puff switch. In this design, the joystick controller is the breathing straw. Moving the straw left, right, up, or down while in the users mouth correspondingly moves the computer cursor. Switch activation by sipping or puffing creates a left or right mouse click. Examples of this switch technology include the Jouse3 by Compusult and the QuadJoy 3 by QuadJoy [6] [7]. These devices cost approximately $1,500 and $900, respectively.

Two other available switch technologies are the voice activated switch and the EMG (electromyography) switch. The voice activated switch uses a microphone, generally placed near the mouth or on the throat, to listen for sounds above a user defined threshold to create the switch activation. InvoTek manufactures a unique voice switch which analyzes the sound input to trigger only on human voiced sounds. This decreases false activations caused by loud background noises. Voice switches cost a couple hundred dollars on average.

The EMG switch by Tinkertron uses electromyography technology to monitor muscle activity for switch activation [8]. To activate the switch, the user contracts a muscle which is monitored by electrodes on the skin over the muscle. The EMG switch costs over $1,000.

An additional category of commercially available assistive technology are head and eye trackers. This technology compares to the joystick based Sip and Puff in functionality where mouse control of computers is desired. Head and eye tracking systems are used to correlate head or eye movements into corresponding cursor movements. Mouse clicks are performed by dwelling over an object on the screen or using an additional switch such as the Sip and Puff. This technology utilizes camera sensors and, most often, retroreflective material to perform the tracking. Systems range from $1000 to multiple thousands of dollars. Some examples of these systems include InvoTek's AccuPoint Absolute Head Tracking System, Origin Instruments' HeadMouse, and Tobii Dynavox's eye tracking systems.

II.B Features and Qualities of Assistive Technology

Given the above brief overview of commercially available switch devices and their uses, a few features can be used to highlight the differences in effectiveness of the various switch technologies. Some physical disabilities prevent the ability to use certain switches. For example, the mechanical switch requires the user to have the ability to accurately and reliably move their body to target and press the switch. Motor planning with some physical disabilities can be challenging and result in difficulty pressing a button in a timely fashion. For the Sip and Puff switch, an obvious requirement for users is the ability to control their breathing patterns to be able to provide the sip or puff to activate the switch. While minimal air pressure changes are required for switch activation, repetitive switch activation would require abnormal exhaling or inhaling which can become problematic if the user has breathing issues or is on a ventilator. Another limitation of using the Sip and Puff switch is the requirement for the user to control their lips and/or head to reach out and insert the straw into their mouth and form a seal on the straw. For the EMG switch, the user must be able to selectively choose to activate a muscle, which is not always possible. These switches are also susceptible to false activations through inadvertent muscle activity.

A quality which could be used to compare switch devices is ease of device set up. Most assistive switch devices must be mounted and positioned by the user's caregiver. Asking for assistance to setup a switch device requires the caregiver's time and effort and requires the caregiver to do yet another task for the person with the disability. The more complicated or longer the process, the less frequent a device will be utilized by the individual. Mere minutes of setup can change the attitude of a device user and caregiver. Therefore, the simpler and faster the setup, the better. The EMG switch has a potentially lengthy and complex setup time and high intrusiveness. Generally three electrodes must be placed on the skin in a specific location depending upon which muscle is being monitored. Before placing the electrodes, the skin must be prepped and cleaned with alcohol, which can make set up a time consuming process and can cause irritation with continued use.

When using a mechanical switch, if a person has a physical disability resulting in an extremely limited range of motion, mounting the switch requires precision. This leads to a potential source of error for the user. A slight shift or movement in switch location or the user could result in the switch becoming out of reach for the user and inoperable. Undesired switch movement or shifting could occur from coughing, for example, which could be unavoidable. Setup of the Sip and Puff switch consists of placing the straw in the proper location for the person to reliably and comfortably reach.

Other distinguishing features between switch devices include device cost and reliability. Excessive cost can prevent people from obtaining the assistive technology. Errors due to a failure to activate or inadvertent activation during device operation can become frustrating for a user and prevent or reduce device use. For illustration, take a device which performs with 95% switch activation accuracy. On paper, this accuracy seems very promising, but from the perspective of a person using this device for all their communications and interactions, this accuracy may not be high enough. For example, if this device was being used to type, on average one out of every twenty characters would be performed with an error. For a person who takes multiple seconds to complete one switch activation, this accuracy would cause frustration during use. Obviously, the higher the accuracy, the less errors, frustrations and complications arise during device use.

III. Sensor Technology Selection

Several sensor technologies were researched for the new switch detailed in this thesis. Based on the qualities described in Chapter 2 for switch devices, as well as the analysis provided below, an Inertial Measurement Unit (IMU) was ultimately selected as the sensor technology. The IMU provides a robust method of monitoring and analyzing movement and offers a wide set of possible data features for customizable switch activation. This chapter serves to detail the sensor technology candidates (including the IMU) which were researched during the sensor selection.

III.A Researched Sensor Technologies

Electromyography (EMG) was researched as a potential sensor technology. EMG measures nerve impulses during muscle activation through the use of electrodes. A benefit of using EMG is the flexibility of being able to sense any controllable muscle near the surface of the skin, regardless of whether the muscle moves or not. With high resolution equipment, a variety of muscles can be sensed such as facial, arm, and leg muscles [9]. Another benefit is the ability to sense muscle activation even if the muscle attempting to move cannot actually move. Major shortcomings of EMG included the requirement of placing electrodes on the skin in very specific locations, skin prepping, excessive setup time, and the likelihood of false activations. In addition, the electrodes are a common source of skin irritability and the electrode wires and equipment could be considered intrusive to the user. Using EMG alone does not provide an easy method of filtering out false activations from coughing or involuntary muscle spasms. Cost of research and development equipment for EMG units ranged from $1,000 to over $6,000. Ultimately, due to the intrusive nature of an EMG system and the complexity of setup, EMG was not selected as the sensor technology.

Another type of technology researched was piezoelectric sensors. Piezo materials have unique properties where force applied to the material can generate a voltage or change the material's resistivity. Flex sensors have been developed utilizing this concept [10]. For a switch device, flex sensors could be placed near a moving joint. If the sensor was anchored on either side of a joint, as the joint is rotated by bodily movement the sensor would flex and produce a signal which could be used as a switch activation. The shortcoming of this approach is the mounting requirements. Reliably anchoring the device on either side of a joint could be difficult and invasive to the user. In addition, for people with extremely limited mobility, the movement may not generate enough joint rotation to produce a reliably detectable signal with the flex sensors. Another concern would be that the equipment may interfere with the user's normal range of movement, depending upon the anchoring and device packaging. Due to the potential complications and limitations of the piezoelectric sensors, this technology was not selected.

Hall effect sensors were analyzed for their effectiveness in monitoring movement. The output of a Hall effect sensor is a signal relative to the strength of the magnetic field passing through the device. Two types of sensors are available: analog and digital. Analog sensors output a voltage proportional to the strength of the magnetic field. Digital sensors output a logic high or low depending on whether the magnetic field strength is greater or less than a preset threshold value [11]. For an assistive switch device, this output signal could be used to determine the proximity of a body part to the sensor. For example, if a magnet was placed on the controllable body part, say an arm, and a Hall effect sensor was fixed near the resting position of the arm, as the individual moved their arm, the sensor's output signal would vary or toggle. A threshold could be set for an analog sensor or an appropriately sized digital sensor could be used to create the switch activation. This would allow for a practical switch that doesn't require difficult motor planning for the user in comparison to other technologies. In addition, the only item that would need to be attached to the user is a magnet, which is lightweight and small in size.

An improvement to an individual Hall effect sensor is a magnetometer. A magnetometer is an integrated circuit which combines three Hall effect sensors into one device. A magnetometer consists of three sensing axes, aligned in the common orthogonal axis system. A benefit of using a magnetometer over an individual Hall effect sensor is the ability to determine the relative distance and location of a magnet relative to the sensor. By sensing the magnetic field along three axes, magnet movements can be resolved in one-, two-, or three-dimensional space. This allows for more customizable switch activation methods which are explored in the case study detailed later in this thesis.

Two other sensor technologies explored were accelerometers and gyrometers or gyroscopes. Both of these sensors have the option to be purchased as single axis sensors and integrated 3-axis sensors. Just like the magnetometer, the 3 axes of the accelerometers and gyrometers are also aligned in the common orthogonal axis system. Accelerometers output signals relative to acceleration experienced along an axis. For switch activations, accelerometers could be used in two ways. One way would be to monitor for specific acceleration changes generated by sensor movement. If the sensor was attached to a controllable body part, movement in a specific direction could be identified and activated upon. With current accelerometer technologies constructed from microelectromechanical systems (MEMS), accelerometers have the ability to accurately sense acceleration changes down to less than a hundredth of a g. With the availability of such high resolution accelerometers, the ability to capture small bodily movements is possible. The second option would be to monitor the change in sensor inclination. By using a 3-axis device, the vector resulting from the three axes would correspond to the direction and magnitude of gravity while the sensor was stationary. Switch activation could be calculated from changes in sensor inclination. A gyrometer measures the angular velocity or rotation experienced by the sensor around a defined axis. Similar to the accelerometer, the gyrometer could be attached to a controllable body part and switch activation could be determined from a distinct rotation.

III.B Selected Sensor Technology: IMU

The final sensor technology analyzed, which was implemented in the designed switch device, was an Inertial Measurement Unit (IMU). The IMU fuses the data from a magnetometer, a 3-axis accelerometer, and a 3-axis gyrometer which results in a nine degree-of-freedom (DOF) device which can be used to model dynamic movements. The data from the IMU can be used to create unique movement patterns that can be identified to create a switch activation. In addition, the data can be used to describe the orientation of the sensor. Just like the other data features, changes in orientation could also be used to determine switch activation. Using an IMU as the sensor technology also helps achieve a future InvoTek goal of designing a new head tracker based on orientation data. The designed generic hardware would also serve this purpose.

With all the available data provided by an IMU sensor, the designed hardware allowed for a unique and extremely customizable switch that can be adapted to the user’s existing movement capabilities. The IMU sensor is available in integrated circuit packaging which enables the development of a small, lightweight, non-intrusive switch device.

IV. Hardware Design

This chapter details the main hardware components selected for the designed assistive switch. The hardware was designed to have the ability to operate wirelessly through battery power and Bluetooth communication. By incorporating Bluetooth, the device is capable of communicating and controlling other Bluetooth capable devices, such as computers and tablets, by using accessibility switch access methods which were described in Chapter 1. A custom Android application was developed by InvoTek which communicated with the switch device through Bluetooth to (1) export IMU data from the switch, (2) customize variables within the switch's firmware, and (3) provide the capabilities to send a text message from a switch activation. To create a switch activation for a desired movement, a custom algorithm must be developed utilizing the necessary IMU data to identify the movement. This algorithm is implemented by downloading new firmware into the embedded microprocessor. Once a specific algorithm is installed, variables within the algorithm, such as averaging variables or thresholds, can be optimized using the Android app, and communicated back to the switch through Bluetooth. The Android application along with the on-board processor firmware is detailed further in Chapter 5.

Figure 1 details an overview of the main sections of the designed hardware and their signal path interconnections. Each section is described in detail throughout the remaining of this chapter. To achieve wireless capabilities, the designed hardware is powered by a 600 mAh Li-ion battery. Two Texas Instruments chips manage the charging and discharging of the battery:, a dynamic power-path management IC (TI BQ2407), and, a single cell Li-ion battery fuel gauge (TI BQ27510-G3). The power-path management IC controls the charging of the battery from USB power and ensures power consumptions does not exceed the USB standard. External USB power is provided by means of a USB 3.0 connector detailed later in this chapter.

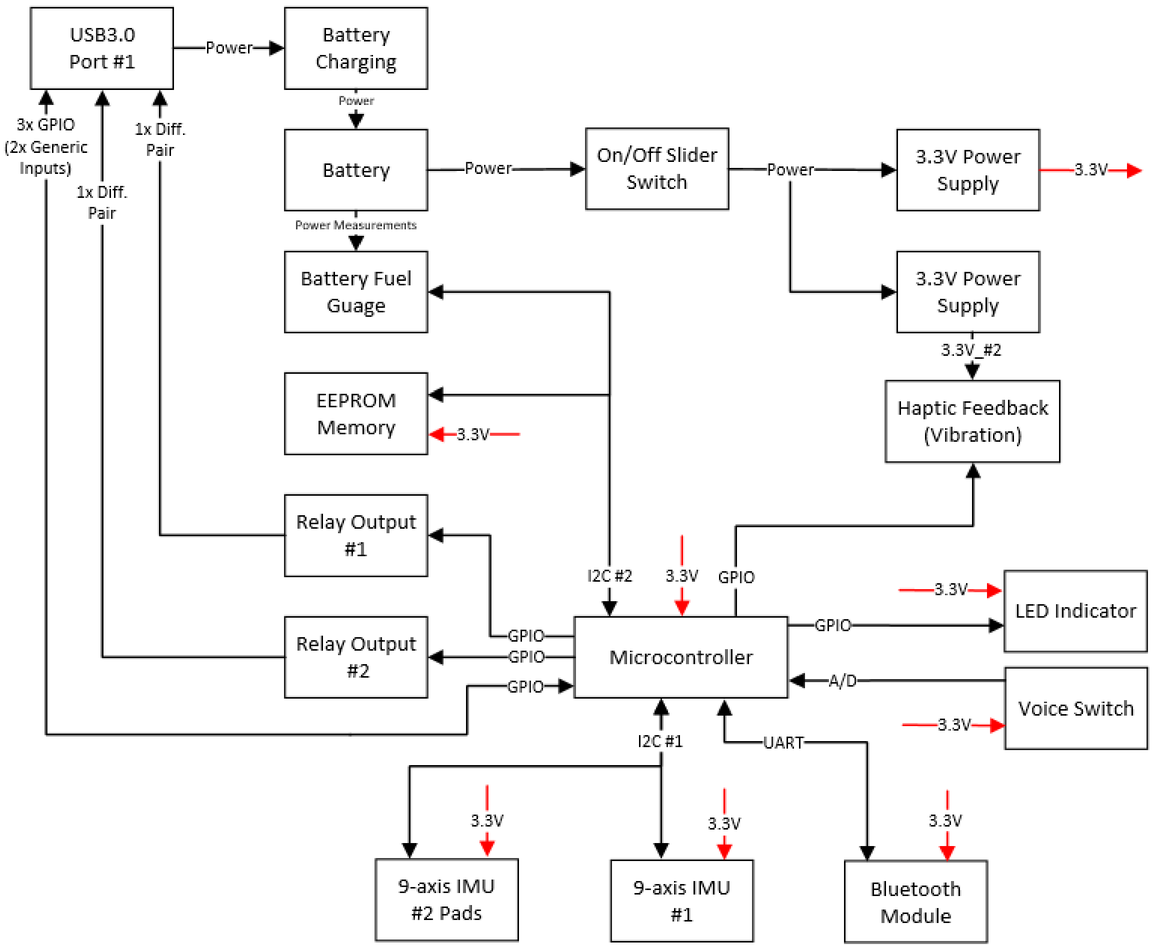


Figure 1: Hardware Block Diagram

The fuel gauge monitors the status of the battery, providing accurate state-of-charge information in the form of battery percentage to the main embedded processor through an inter-integrated circuit (I^2C) bus. The fuel gauge provides additional battery management features by signaling the power management IC when to disable the battery output and power the system down to prevent over-discharging the battery. Battery management is extremely important when using Li-ion technology due to the inherent volatility if over-charged or over-discharged.

Two voltage regulators were used to supply 3.3V from the battery to the rest of the system. The Microchip MCP1252, a switched capacitor regulator, was selected due to a minimal part count and inductorless design which enables a small footprint. The MPC1252 is capable of regulating a

3.3V output over the complete range of expected battery voltage. One voltage regulator was used to power the vibration motor, detailed later in this chapter, and the other was used to power all the additional components on the PCB.

A PIC24FJ128GA010 Microchip microcontroller was implemented as the onboard processor. The PIC24F device operates at a maximum of 32MHz and contains 128kB of program memory, 8kB of static RAM, I^2C, and Universal Asynchronous Receiver/Transmitter (UART). The selected microcontroller provides more than enough computational capabilities to perform the desired algorithms and adequate control of all aspects of the design. The selected package was a 100 pin device which allowed for all necessary I/O connections and interfacing to peripherals on the PCB.

To supplement the microcontroller memory, a 24AA64 EEPROM IC by Microchip was included to provide and an additional 8kB of memory. This non-volatile memory was used to store user settings such as thresholds and other firmware variables.

The IMU selected was InvenSense's MPU-9250. As discussed in Chapter 3, the IMU contains a 3-axis magnetometer, accelerometer, and gyrometer all in one small package. The data is available to the microcontroller through an I^2C bus. A solder pad jumper with the connections for power and an additional I^2C bus was made available for the attachment of an external IMU sensor, when desired.

The switch was designed with only one external connector on the PCB: a USB 3.0 female micro B. The USB 3.0 micro B connector allows for a relatively small package yet contains nine individual signals. A USB 3.0 cable was modified to separate the nine wires into four separate functions effectively allowing for four different external connections to be made from one PCB connector. The PCB size requirements were significantly decreased by combining four external connections into one physical PCB connector.

Two wires were terminated to the V_{BUS} and GND of a USB 2.0 type A female connector to enable charging of the device by common USB chargers and ports. This power was routed to the power-path management IC previously discussed. Three additional wires were terminated to a 3.5mm female stereo jack to allow for two switch inputs to the device. The intent for these inputs was to allow the switch device to act as a Bluetooth hub, where external switches could be translated into Bluetooth switch activations and received by other Bluetooth devices. The last four wires were terminated to two separate 3.5mm mono jacks, the industry standard for assistive technology switch devices.

The device was designed to output switch activations through optocoupled and Bluetooth. The two mono jacks are connected through optocouplers on the PCB that act as relays. This allows other assistive technology devices to be controlled by this device. The optocouplers are controlled by the microprocessor to provide the continuity during switch activation and allow for isolation from external devices. The mono jack is an industry standard for assistive technology switch connections.

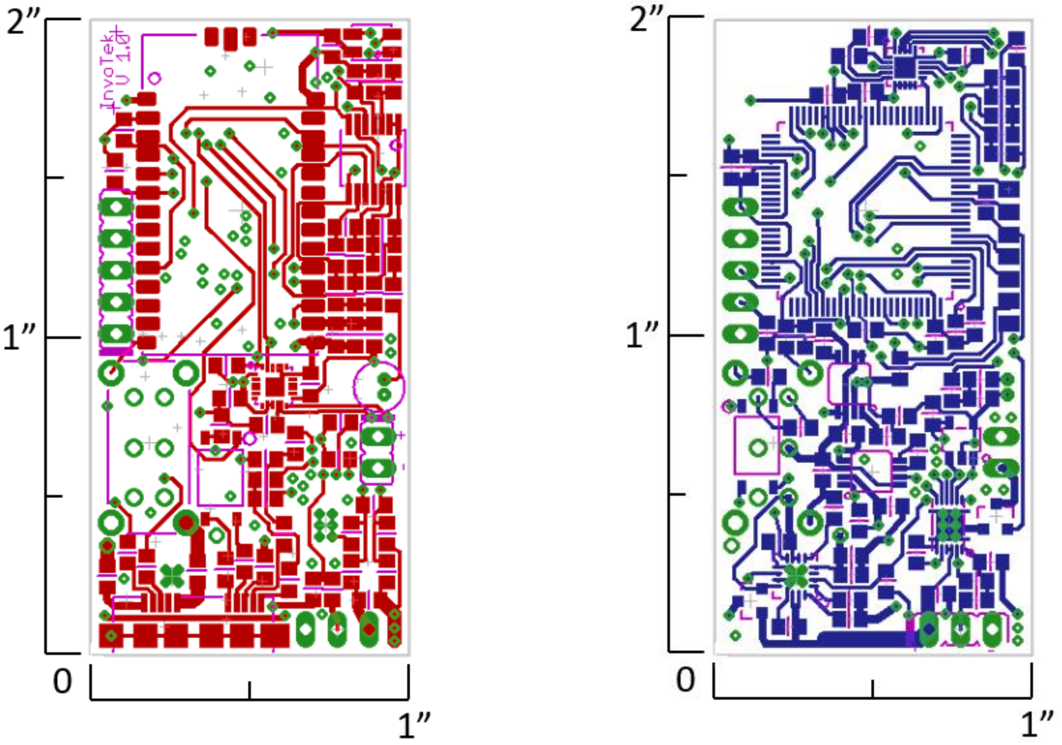
Bluetooth communication was incorporated through the use of Bluegiga's WT12 Bluetooth module. This module runs Bluetooth 2.1 through Bluegiga's proprietary iWrap Bluetooth stack

Figure 2: Outputs from the Modified USB 3.0 Cable

which significantly simplifies development and implementation of Bluetooth communications. InvoTek has previously used the WT12 module and has developed an API which was used in the microcontroller's firmware. The WT12 was controlled by the microprocessor through UART.

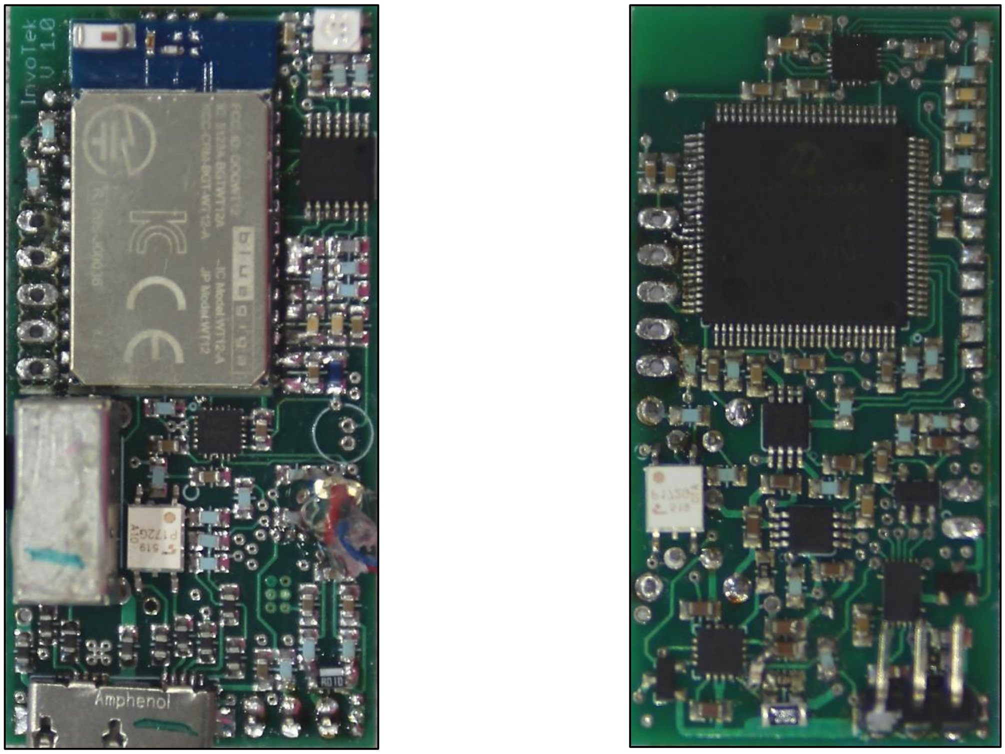
Other components included LEDs and a vibration motor. A tri-colored LED and LED driver was included to provide user feedback and indicate the status of device operation. The vibration motor was activated during a switch closure to provide haptic feedback to the user. The necessary hardware for InvoTek's voice switch was also incorporated into the PCB. This allowed for a voice input option if the user desired.

Figure 3 below shows the completed PCB layout of the top and bottom sides of the board. The PCB was four layers with the two interior layers providing ground and power planes. The board dimensions are 2" by 1". Figure 4 shows the top and bottom sides of the PCB, with parts on both sides, and Figure 5 details the 3D printed enclosure holding the completed assembly. The packaged switch measured 2.1" long, 1.6" wide, and 0.5" tall, and weighed approximately 0.1 lbs.



(a) (b)

Figure 3: PCB Layout: (a) Top Side and (b) Bottom Side



(a) (b)

Figure 4: Populated PCB: (a) Top Side and (b) Bottom Side

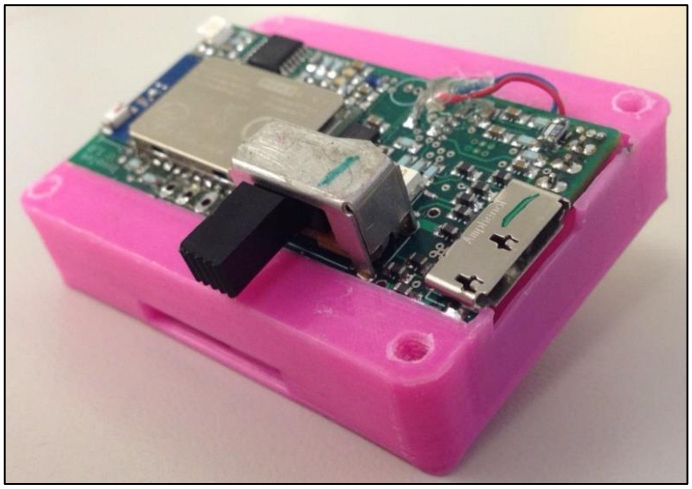


Figure 5: Packed Switch in 3D Printed Housing without Lid

V. Microcontroller Firmware and Android Application Overview

InvoTek intends to use the designed switch as a replacement to an existing set of mechanical switches for the client described in Chapter 1. With this in mind, the developed firmware and Android application was designed in such a way to (1) achieve all of InvoTek's and their client's desired functionality and goals: (2) have the ability to collect movement training data for analysis to determine the best switch algorithm, (3) be able to implement a switch algorithm to recognize thumb and pinky movements as two different switch activations, (4) use the switch device with the two hardwired outputs to control an AAC device, and (5) have the capability to send out a text message from a switch activation requesting help. While designing the PIC24F firmware, collaboration was required with InvoTek's software engineer who designed the Android application named "TextAlert".

V.A Overview of TextAlert in Normal Mode

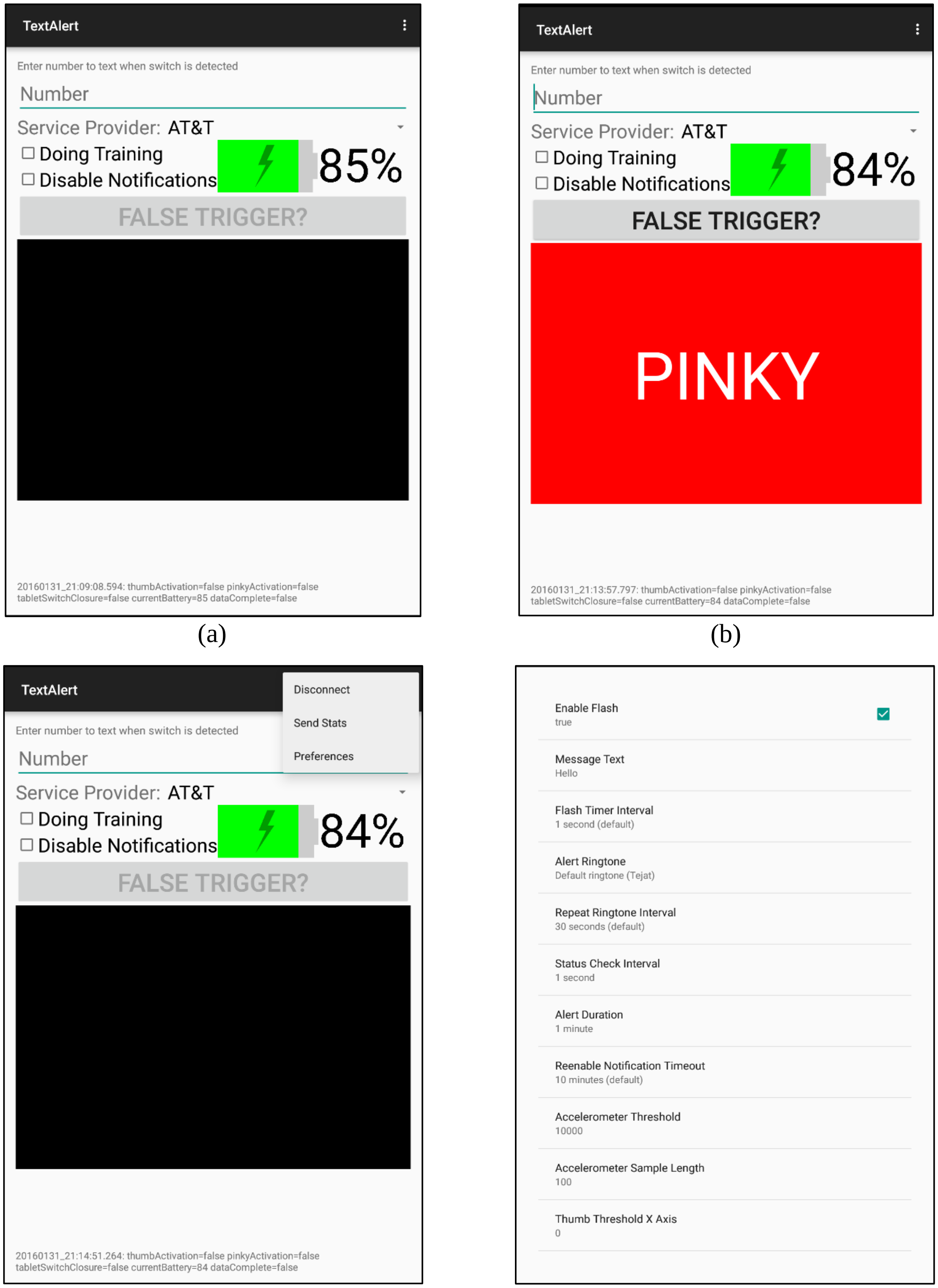
A screen shot of TextAlert running in normal mode is shown in Figure 6(a). From here, the user can input a phone number and select the associated wireless carrier of a caretaker who wishes to receive text messages from switch activations. The battery percentage of the connected switch device is shown on the top right side of the screen. By clicking the "Doing Training" check box, the application and switch will change from normal mode into training mode. By clicking the "Disable Notifications" check box, switch activations will be prevented until re-enabled manually or automatically by a timer. This feature is included in the application in case a caregiver is directly talking to the client. In this case, the client communicates through the use of their thumb and pinky. During this communication, switch activations would not be desired. A timer to automatically re-enable the notifications and allow switch activations was included in case the caregiver forgot to manually re-enable the notifications. Without the timer, disabling TextAlert would result in preventing switch activations indefinitely until manually changed, leaving the client with no way of requesting help when she was left unattended.

On the bottom of the app screen is an area where Bluetooth communication information continually updates indicating the last data packet transferred or received. This is included for debugging purposes and to give a sense of feedback to the tablet operator that the tablet and switch are actually communicating. Above the large black area is a “FALSE SWITCH” button. This button is pressed by the tablet operator if a false switch activation occurred, which instructs the app to log the error to assist in evaluating the performance of the switch. The black area in the middle of the screen is used to generate visual attention that a switch activation has occurred. This is performed by flashing red and black and overlaying the words “THUMB” or “PINKY” depending upon which finger was recognized as performing the switch activation. An example is shown in Figure 6(b) for a pinky switch activation.

Figure 6(c) shows the expansion of the ActionBar menu which drops down by pressing the three vertical dots in the top right corner of the app. In this menu, the user can connect or disconnect to the Bluetooth enabled switch, send acquired training data through email, or enter into the main preference menu. By clicking “Send Stats” an external email application opens with all the acquired training data bundled in a zip folder attached to an email for easy transfer from the Android device to another computer for analysis.

Figure 6(d) shows a screenshot of a portion of the parameters and settings available to the user. Table 1 lists all the parameters available which affect only the TextAlert application behavior.

Table 2 lists the available user preferences which modify variables within the switch’s firmware. Once these parameters are changed, they are exported to the switch through Bluetooth and updated in the switch’s firmware and stored in the on-board EEPROM.



Enter number to text when switch is detected

Number

Service Provider: AT&T

☐ Doing Training

☐ Disable Notifications

```
20160131_21:09:08.594: thumbActivation=false pinkyActivation=false
tabletSwitchClosure=false currentBattery=85 dataComplete=false
```

(a)

Enter number to text when switch is detected

Number

Service Provider: AT&T

☐ Doing Training

☐ Disable Notifications

```
20160131_21:13:57.797: thumbActivation=false pinkyActivation=false
tabletSwitchClosure=false currentBattery=84 dataComplete=false
```

(b)

Enter number to text when switch is detected

Number

Service Provider: AT&T

☐ Doing Training

☐ Disable Notifications

```
20160131_21:14:51.264: thumbActivation=false pinkyActivation=false
tabletSwitchClosure=false currentBattery=84 dataComplete=false
```

(c)

Enable Flash ☑
true

Message Text
Hello

Flash Timer Interval
1 second (default)

Alert Ringtone
Default ringtone (Tejat)

Repeat Ringtone Interval
30 seconds (default)

Status Check Interval
1 second

Alert Duration
1 minute

Reenable Notification Timeout
10 minutes (default)

Accelerometer Threshold
10000

Accelerometer Sample Length
100

Thumb Threshold X Axis
0

(d)

Figure 6: TextAlert Screenshots: (a) Normal Mode, (b) Pinky Activation Example, (c) ActionBar Menu, and (d) Partial Preferences Menu

Table 1: Customizable Parameters Modifying TextAlert Application Behavior

Variable	Description
Enable Flash	Enables the activation of the tablet’s camera flash during a switch activation to provide additional visual feedback
Message Text	The message which is sent by text message upon a switch activation
Flash Timer Interval	Rate at which the screen flashes red and black upon a switch activation to provide visual feedback
Alert Ringtone	Sound (ringtone) played upon a switch activation
Repeat Ringtone Interval	Rate at which the ringtone will repeat after a switch activation until acknowledged by a caregiver
Status Check Interval	Rate at which the switch is polled for the switch status and battery information
Alert Duration	Length of time the screen flashes and the ringtone repeats after a switch activation
Re-enable Notification Timeout	Length of time till the tablet will automatically re-enable notifications and allow switch activations to occur

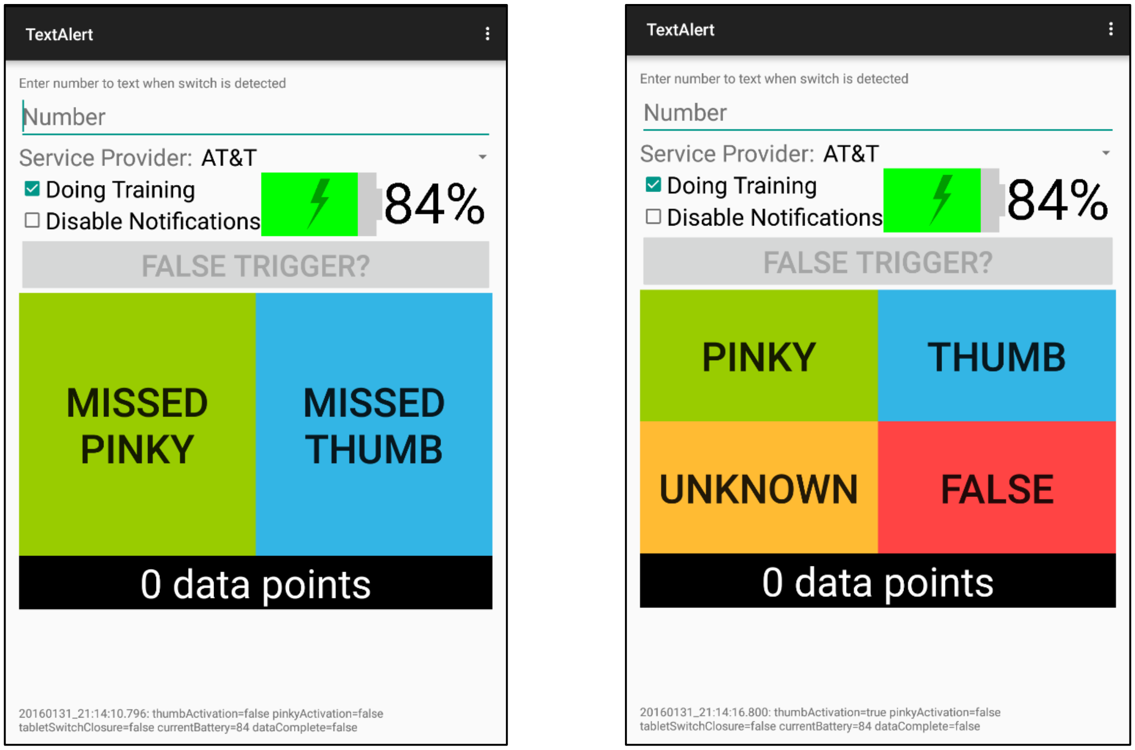
Table 2: Customizable Switch Parameters Transferred from the Tablet to the Switch

Variable	Description
Magnetometer Average Length	Length of simple moving average for magnetometer data
Thumb x Threshold	Threshold settings for implemented algorithm detailed in Chapter 6
Thumb y Threshold	
Thumb z Threshold	
Pinky x Threshold	
Pinky y Threshold	
Pinky z Threshold	
Accelerometer Average Length	Length of moving average for accelerometer data
Accelerometer Threshold	Threshold settings for algorithm detailed in Chapter 6
Vibration Motor Enable	Enable or disable embedded vibration motor activation upon switch activation
Vibration Length	Length of time the vibration motor should vibrate upon a switch activation, if enabled
Relay Closure Time	Length of time the hardwire switch outputs should be active when a switch activation occurs

V.B Overview of TextAlert in Training Mode

Figure 7 shows screenshots of TextAlert operating in training mode. The idea behind training mode is for the tablet operator to visually observe the user's movement and then press an associated button to log and characterize that movement. The logged training data is then analyzed in MATLAB to identify unique features which can be used to build an algorithm to recognize the movements.

Figure 7(a) details the buttons available in training mode when no switch activation has been acknowledged. For the case study performed in Chapter 6, if the tablet operator sees the switch user move their thumb or pinky and the switch did not activate, the "Missed Pinky" or "Missed Thumb" button would be pressed and the last four seconds of movement data stored on the switch would be transferred to the device. Figure 7(b) shows the buttons available if the switch recognizes



Service Provider: AT&T
☑ Doing Training
☐ Disable Notifications

```
20160131_21:14:10.796: thumbActivation=false pinkyActivation=false
tabletSwitchClosure=false currentBattery=84 dataComplete=false
```

(a)

Service Provider: AT&T
☑ Doing Training
☐ Disable Notifications

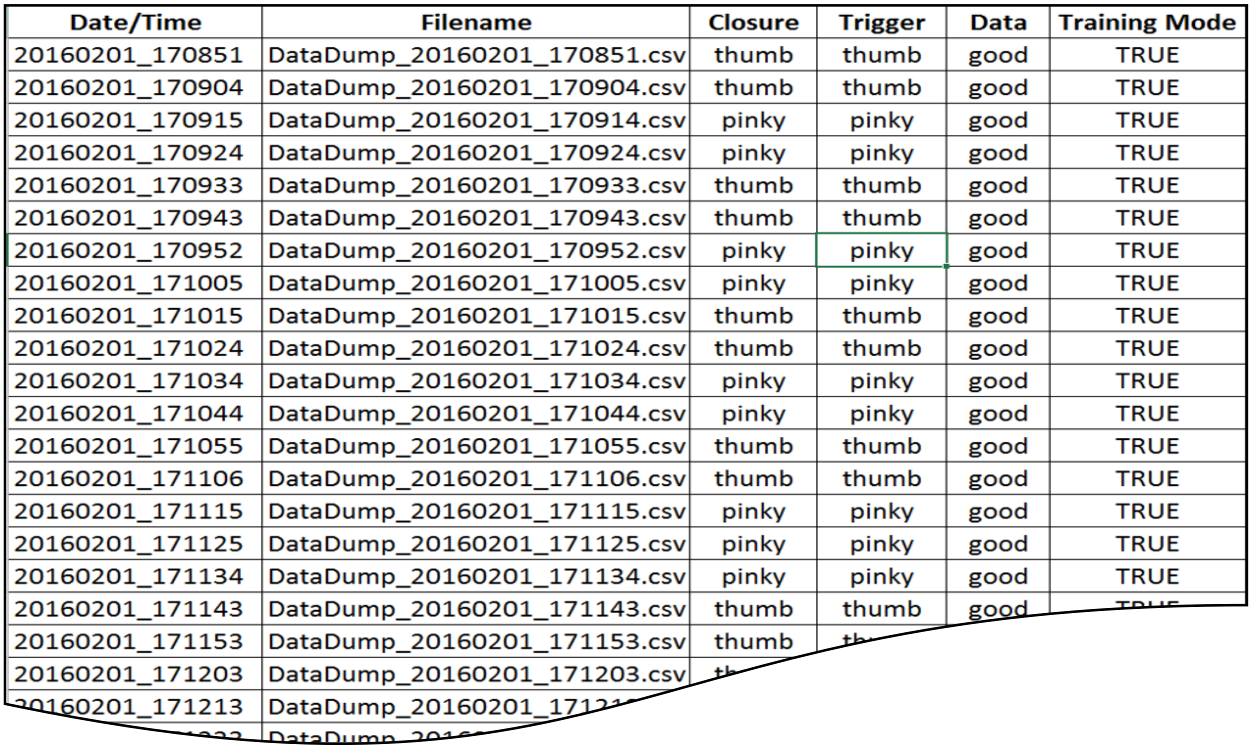
```
20160131_21:14:16.800: thumbActivation=true pinkyActivation=false
tabletSwitchClosure=false currentBattery=84 dataComplete=false
```

(b)

Figure 7: TextAlert Training Mode: (a) Missed Buttons Available Prior to Switch Activation and (b) Classification Buttons Available After a Switch Activation

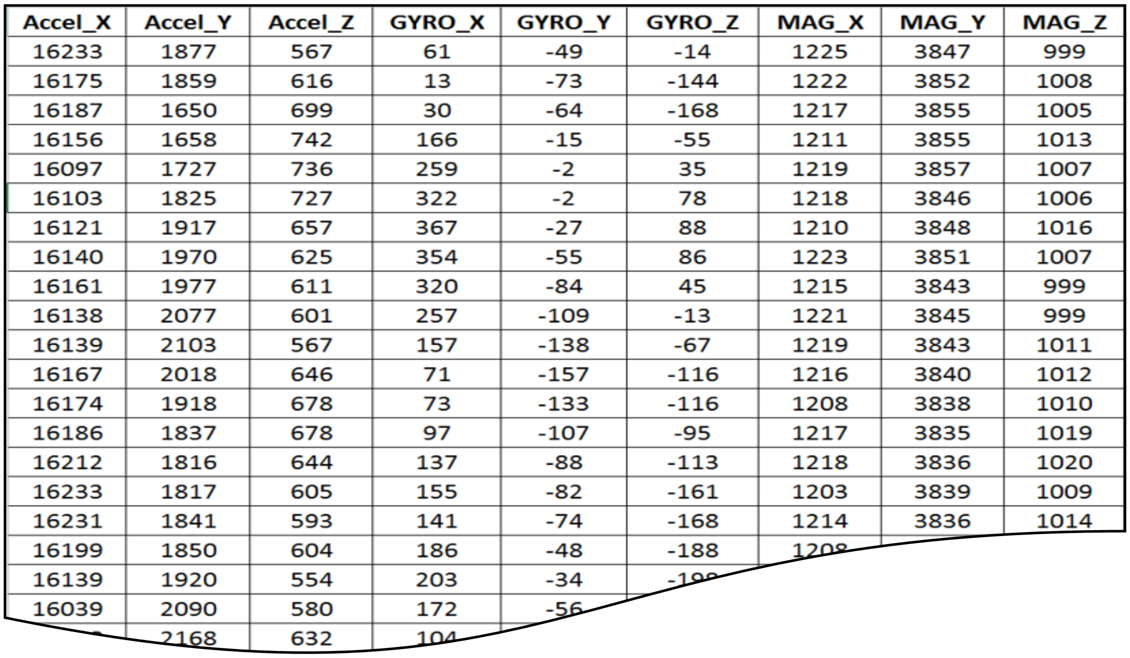
and activates upon a movement. “Pinky” is pressed if the pinky was used to generate the switch activation. Likewise, “Thumb” is pressed if the thumb was used to generate the switch activation. “Unknown” is used if the tablet operator failed to visually observe the switch user’s movement. Lastly, “False” is pressed if the switch activated but no movement was performed by the switch user.

By classifying and logging the movement data, an analysis can be performed on the data to determine unique features which can be used to identify the specific switch activation movements. Figure 8 shows a section of a log file stored with the training data while Figure 9 shows a section of the stored switch activation data.



Date/Time	Filename	Closure	Trigger	Data	Training Mode
20160201_170851	DataDump_20160201_170851.csv	thumb	thumb	good	TRUE
20160201_170904	DataDump_20160201_170904.csv	thumb	thumb	good	TRUE
20160201_170915	DataDump_20160201_170914.csv	pinky	pinky	good	TRUE
20160201_170924	DataDump_20160201_170924.csv	pinky	pinky	good	TRUE
20160201_170933	DataDump_20160201_170933.csv	thumb	thumb	good	TRUE
20160201_170943	DataDump_20160201_170943.csv	thumb	thumb	good	TRUE
20160201_170952	DataDump_20160201_170952.csv	pinky	pinky	good	TRUE
20160201_171005	DataDump_20160201_171005.csv	pinky	pinky	good	TRUE
20160201_171015	DataDump_20160201_171015.csv	thumb	thumb	good	TRUE
20160201_171024	DataDump_20160201_171024.csv	thumb	thumb	good	TRUE
20160201_171034	DataDump_20160201_171034.csv	pinky	pinky	good	TRUE
20160201_171044	DataDump_20160201_171044.csv	pinky	pinky	good	TRUE
20160201_171055	DataDump_20160201_171055.csv	thumb	thumb	good	TRUE
20160201_171106	DataDump_20160201_171106.csv	thumb	thumb	good	TRUE
20160201_171115	DataDump_20160201_171115.csv	pinky	pinky	good	TRUE
20160201_171125	DataDump_20160201_171125.csv	pinky	pinky	good	TRUE
20160201_171134	DataDump_20160201_171134.csv	pinky	pinky	good	TRUE
20160201_171143	DataDump_20160201_171143.csv	thumb	thumb	good	
20160201_171153	DataDump_20160201_171153.csv	thumb			
20160201_171203	DataDump_20160201_171203.csv				
20160201_171213					

Figure 8: Sample of Training Mode Log File



Accel_X	Accel_Y	Accel_Z	GYRO_X	GYRO_Y	GYRO_Z	MAG_X	MAG_Y	MAG_Z
16233	1877	567	61	-49	-14	1225	3847	999
16175	1859	616	13	-73	-144	1222	3852	1008
16187	1650	699	30	-64	-168	1217	3855	1005
16156	1658	742	166	-15	-55	1211	3855	1013
16097	1727	736	259	-2	35	1219	3857	1007
16103	1825	727	322	-2	78	1218	3846	1006
16121	1917	657	367	-27	88	1210	3848	1016
16140	1970	625	354	-55	86	1223	3851	1007
16161	1977	611	320	-84	45	1215	3843	999
16138	2077	601	257	-109	-13	1221	3845	999
16139	2103	567	157	-138	-67	1219	3843	1011
16167	2018	646	71	-157	-116	1216	3840	1012
16174	1918	678	73	-133	-116	1208	3838	1010
16186	1837	678	97	-107	-95	1217	3835	1019
16212	1816	644	137	-88	-113	1218	3836	1020
16233	1817	605	155	-82	-161	1203	3839	1009
16231	1841	593	141	-74	-168	1214	3836	1014
16199	1850	604	186	-48	-188	120		
16139	1920	554	203	-34	-19			
16039	2090	580	172	-56				
	2168	632	104					

Figure 9: Sample of Stored Movement Data

V.C TextAlert Firmware Structure and Flow Diagram

TextAlert and the switch firmware perform handshaking though Bluetooth during operation and switch activations. The handshaking was organized through a byte command structure, where the first byte received in a packet determined the command. The available commands included request board status, retrieve parameters, set parameters, and export sensory data. Using the request board status command, TextAlert polls the switch for status information every second. During this status poll, TextAlert informs the switch if it is operating in normal or training mode, can request an immediate data transfer, and if switch activations are currently allowed. In response back, the switch informs TextAlert if there has been a thumb switch activation, a pinky switch activation, if a data transfer is ready, and the current switch battery percentage.

The retrieve parameters command is called at the beginning of the Bluetooth connection. This command transfers the stored parameters on the switch's EEPROM to the connected tablet. Set parameters command is used anytime the user modifies a parameter on the tablet to update the firmware variables. Lastly, the request sensory data command is used when a data transfer takes place by forced request (pressing a "missed" button in training mode) or after a switch activation occurs. This command transfers four seconds worth of movement data for all 9 axes of the sensor.

Figure 10 shows a flow diagram detailing the overall organization of the switch's firmware. Upon powering the switch device, the code initializes the peripherals, ports, timers, and other necessary components of the microcontroller. This includes the UART and I^2C busses used to communicate to external IC chips such as the EEPROM, LED driver, and Bluetooth module. Once the microcontroller has been properly configured, user variables and preferences which are stored in the on-board EEPROM memory are loaded into the firmware.

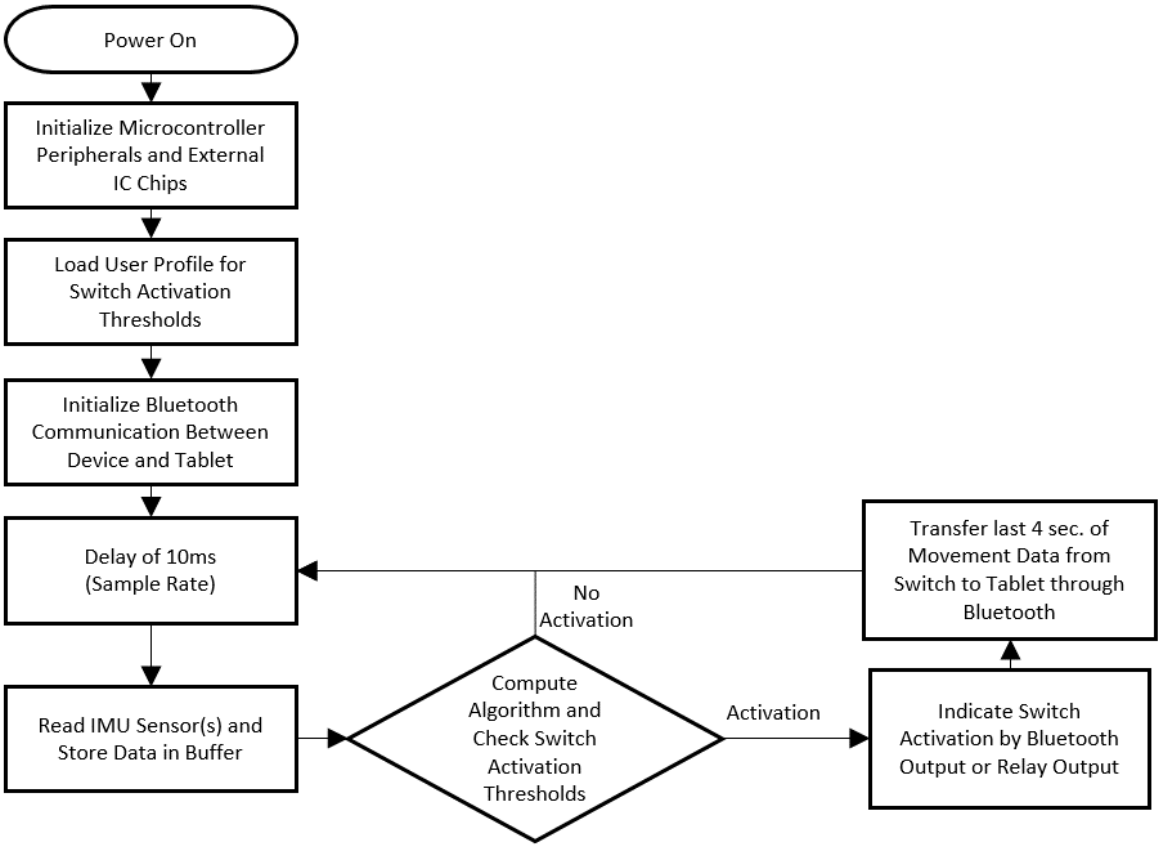


Figure 10: Generalized Firmware Flow Diagram

After loading the preferences, the switch waits for an Android tablet running TextAlert to attempt a Bluetooth connection. Once the connection has been formed, the switch device collects data from the IMU sensor at a rate of 100Hz, or every 10ms. Each IMU read consists of eighteen bytes of data, two bytes for each of the nine axes. Four seconds worth of data, totaling 7200 bytes, is stored on the switch in the EEPROM in a revolving buffer. This data is stored to be used in the determination of a switch activation. Upon a switch activation or during training mode, this data is also exported to the Android tablet for analysis.

After each read of the IMU, the implemented switch activation algorithm is checked. If the algorithm determines that a movement correlating to a switch activation has occurred, the relay outputs are toggled, the embedded vibration motor is activated, the LEDs are changed, and the tablet is informed of the activation through Bluetooth. If the firmware determines no desired movement has been performed, the switch waits 10ms and reads the IMU again and repeats the above process.

Once there has been a switch activation or the tablet requests data from a “missed” button being pressed, the last four seconds of movement data is transferred from the switch to the tablet for additional analysis. During this time, the tablet classifies the observed movement as a thumb or pinky movement with the training mode process previously described.

Outside of the main functions above and the generalized flow diagram in Figure 10, additional activates do occur. The battery fuel gauge is polled every minute to update the battery state-of-charge and relay this information to the tablet. The Bluetooth commands from the tablet previously described can also interrupt the normal operation of the switch to perform their desired functions such as force a data transfer or update the stored EEPROM preferences.

VI. Case Study of Thumb and Pinky Recognition

A case study was performed to determine the switch's ability to recognize thumb and pinky movements as independent switch activations. The switch hardware was expanded to include an external IMU and a magnet was placed on both the thumb and pinky. A training session was performed to record the desired movements and the data analyzed to determine a unique movement feature. Once the feature was determined, the switch's firmware was customized to look for this feature to determine an activation. The switch was then evaluated for performance in recognizing the thumb and pinky with the customized firmware. In this evaluation, the switch was capable of accurately recognizing and classifying 100 out of 100 thumb and pinky movements.

VI.A Case Study Setup and Training Process

Figure 11 shows the modified hardware. In comparison to the packaged hardware shown in Chapter 4, the switch contains an external IMU sensor embedded in a 3D printed ring. The ring is designed to be place on the middle finger. Two additional 3D printed rings were designed to each hold a magnet, also shown in Figure 11. These two rings were placed on the thumb and pinky. The complete setup placed on the hand is shown in Figure 12(a). The control circuitry is located on the wrist is shown in Figure 12(b).

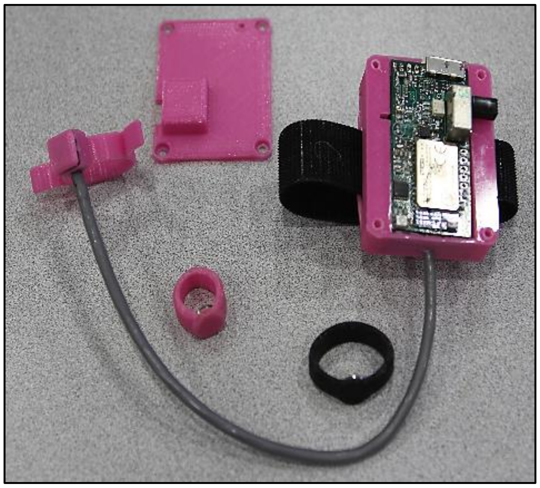
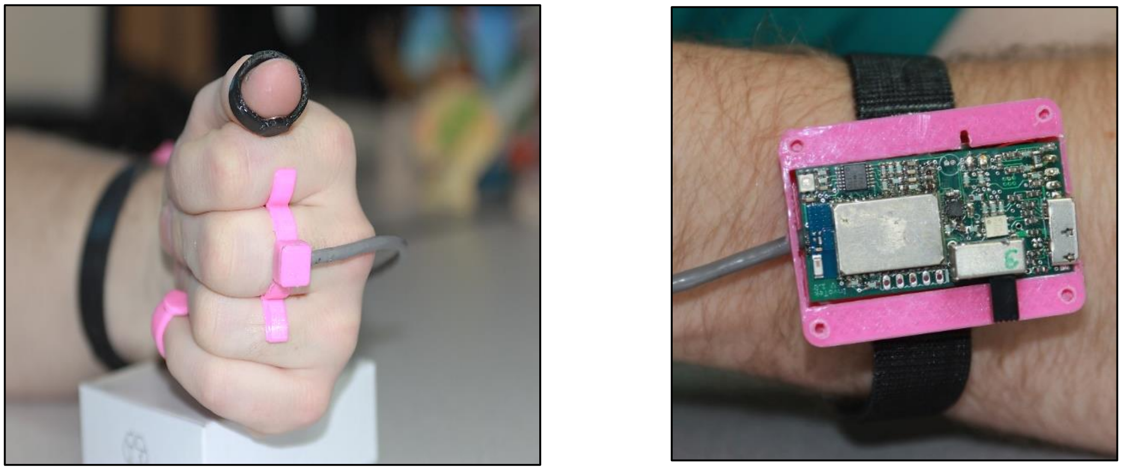


Figure 11: Modified Hardware with External IMU



(a) (b)

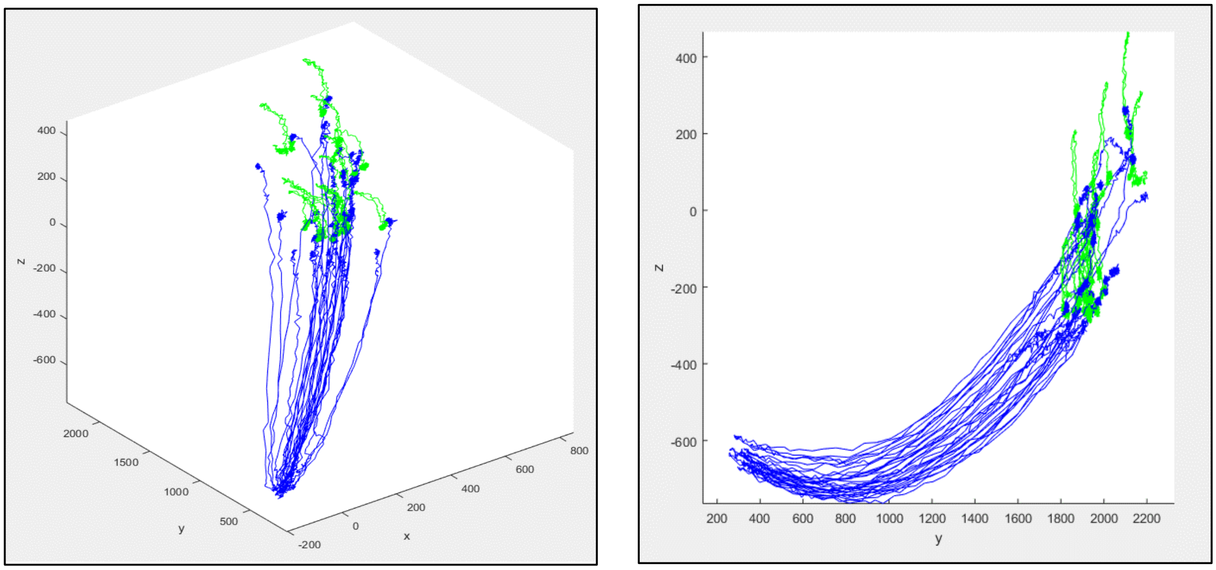
Figure 12: Complete Setup Assembled on: (a) Hand and (b) Wrist

(a) (b) (c)

Figure 13: Switch Activation Movements: (a) Resting Position, (b) Thumb Activation, and (c) Pinky Activation

Figure 13 shows the switch positions used where the thumb was slightly raised for a thumb activation and the pinky was flexed outward for a pinky activation. Once the switch was assembled on the hand and wrist, a training mode session was performed. Thirty movements, fifteen for each digit, were collected with TextAlert. The data was exported from the tablet to a computer for analysis. MATLAB was used to graphically view the data. The main sensory data used to determine the activation came from the magnetometer data. This data was graphed in 3D space, where the x, y, and z values represented the x-, y-, and z-axes values from the magnetometer. This is shown in Figure 14. It is important to note that this data was characterized by the tablet operator’s visual confirmation and pressing the associated movement button, not by the switch. In this step, the switch has no algorithm implemented to recognize the movement. The purpose of gathering this training data is to identify a feature which can be used for movement recognition. Each movement consisted of four seconds of data sampled at 100 Hz. The color of the movement was chosen based on the movement classification stored in the training log file. The values reported in all graphs are in units of Least Significant Bits (LSB) of the IMU sensor. Conversion to magnetic field strength or acceleration, used later, is not necessary for understanding the principle of operation and therefore, the conversion was not done.

Figure 14(b) shows the y-z plane of magnetometer data. This plane shows the best differentiation between the movements. Resting locations are represented by large “blobs” in the data. Resting locations can be found near $y = 2000, z = -100$. Thumb movement (blue) was found to always move in the negative z direction while pinky movement (green) always moves in the positive z direction. Therefore, this feature was used to differentiate and recognize the movements.



(a) (b)

Figure 14: Training Session Magnetometer Data where Blue is Thumb Movement and Green is Pinky Movement: (a) 3D View, (b) y vs. z Axis View.

After the data feature was identified, the switch's firmware was updated with the necessary algorithm. The z-axis magnetometer data was averaged over 100 samples (one second) to filter out any small movements and signal noise. This average represented the resting location of the thumb and pinky. Thresholds calculated from the average resting location were used to identify the movement: a positive z threshold was set for the pinky and a negative z threshold was set for the thumb. The current z-axis magnetometer data was then compared to the thresholds. A switch activation occurred if the z-axis value crossed a threshold and then the value returned back to the resting position within two seconds. By checking for the z-axis value to return back near the resting position and placing a time limit on the movement, potential false activations were prevented when the resting position of the fingers changed due to coughing or general shifting of the hand. Figure 15 shows a visual representation of the algorithm implemented with a set of training data.

VI.B Evaluation of Custom Algorithm

Once the algorithm was implemented, the switch was evaluated for the ability to recognize the thumb and pinky movements. The same setup as described before was performed again with 100 repetitive movements, approximately half being thumb movements and the other half being pinky movements. The data obtained is shown in Figure 16. In comparison to the training mode data, the color of the movement was selected based on the reported switch activation determined by the algorithm. In this session, all 100 movements were correctly classified as thumb or pinky.

In addition to the algorithm above, another data feature was researched to help prevent false switch activations during involuntary hand movements. During these movements, not only do the fingers themselves move but so does the whole hand. When the thumb and pinky are moved for switch activations, the whole hand should not move significantly. Since the IMU is located on

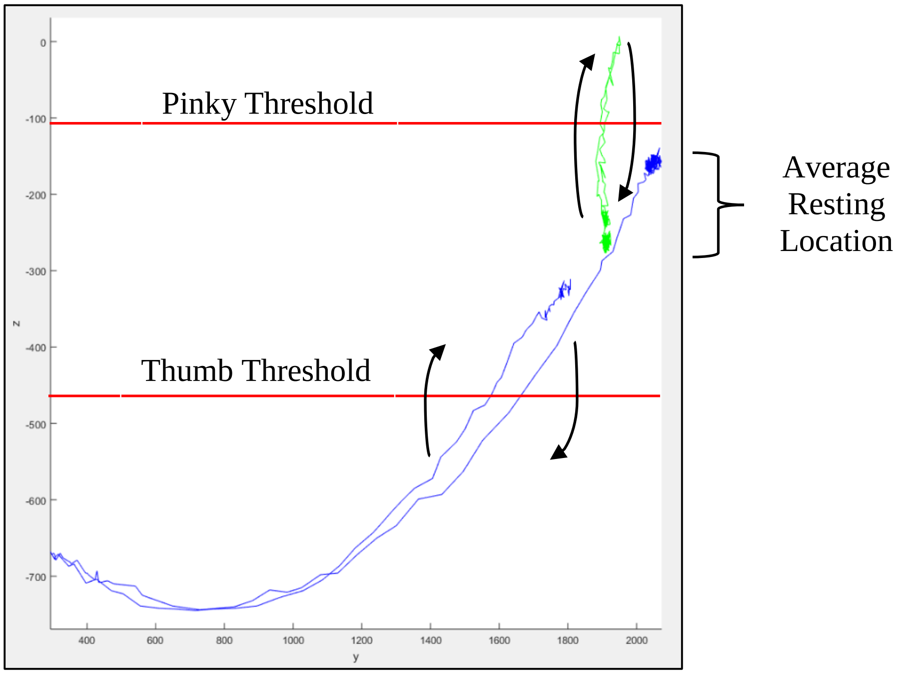


Figure 15: Visual Representation of Implemented Switch Algorithm

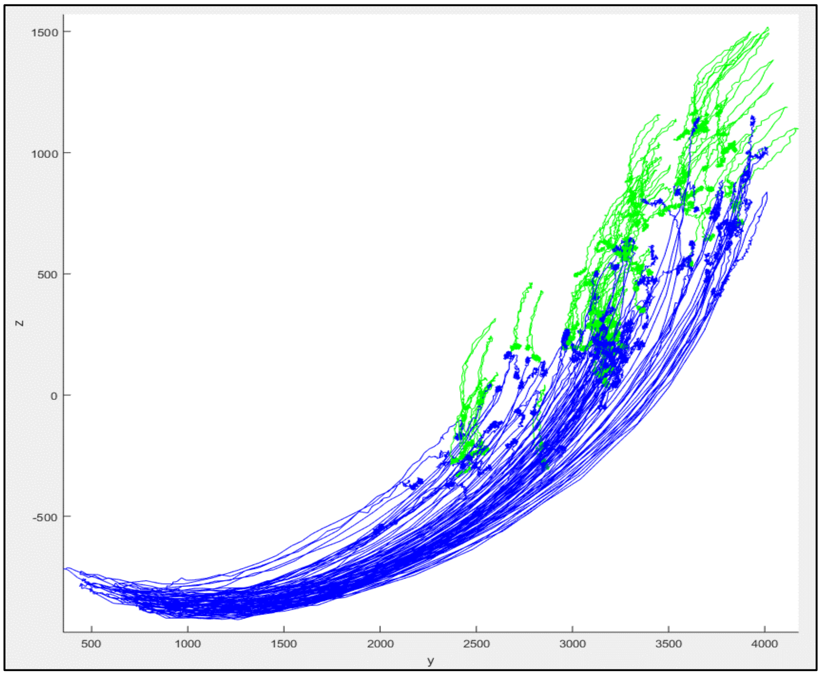


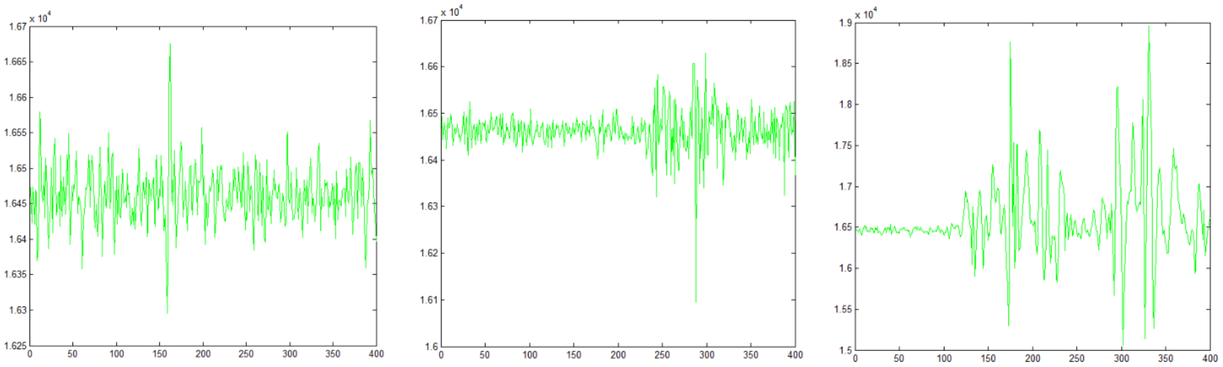
Figure 16: Movement Data Classified by Implemented Switch Algorithm

the middle finger, the accelerometer values should not be affected much during a thumb or pinky movement but should vary significantly when coughing occurs. Therefore, the accelerometer sensory data was used to monitor for whole hand movement since this should be a unique feature only experienced when a switch activation is not desired. The hand (and IMU) experiences 1G of acceleration due to Earth's gravity while at rest. When the hand is moving, the acceleration changes and is picked up by the accelerometer.

Similar to the z-axis magnetometer threshold algorithm, a threshold bound was used to monitor for movement resulting in the magnitude of acceleration being outside the 1G $\pm$ threshold bound. If the accelerometer magnitude exceeded a bound, switch activations were prevented for three seconds. After three seconds, the algorithm was checked again. If the accelerometer magnitude was still exceeding the boundaries, switch activations were prevented for an additional three seconds and the process repeated. If the accelerometer magnitude had settled, switch activations were re-enabled. The magnitude of acceleration was calculated using equation (1), where x, y, and z represent the x-, y-, and z-axis values from the accelerometer.

$$accel_{mag} = \sqrt{x^2 + y^2 + z^2} \tag{1}$$

Figure 17 shows the accelerometer magnitude during three different conditions. Figure 17(a) shows the accelerometer magnitude during rest, at approximately 1G. Figure 17(b) shows the accelerometer magnitude during a thumb movement. The movement picked up by the sensor is very small. Last Figure 17(c) shows the accelerometer values from simulated coughing. The hand movement is picked up by the sensor and crosses the boundaries and therefore prevents any switch activations from occurring for a minimum of three seconds. These boundaries can be set in the preferences of TextAlert giving the option to be more or less sensitive to movement.



(a) (b) (c)

Figure 17: Accelerometer Magnitude with Theoretical Boundaries During: (a) Rest, (b) Thumb Movement, (c) Involuntary Hand Movement

VII. Conclusion and Future Work

This thesis has detailed the research and development of a new assistive technology switch. The new feature of the designed switch is using an IMU as the sensor technology. By using an IMU, the hardware becomes a customizable switch through custom firmware. The firmware will be modified on a person by person basis to look for specific features in the IMU data which identify the desired switch activation movement. In this way, the switch can be adapted to the movements of the user. Through this research, the generic hardware platform was designed and tested, including the IMU sensor technology and Bluetooth communications. An Android application was developed to communicate with the Bluetooth enabled switch to acquire the IMU sensory data for additional analysis.

A case study was performed recognizing thumb and pinky movements as individual switch activations. This experiment was an evaluation of the feasibility of using the designed switch with an InvoTek client. A training session was performed which acquired movement data of the thumb and pinky. The acquired data was analyzed in MATLAB and a unique data feature was identified. The switch firmware was updated with the necessary algorithm to recognize and differentiate the movements. Lastly, the switch was tested with 100 repetitive finger movements in which the switch accurately characterized 100% of the movements.

The next step is for InvoTek to test this device directly with their client. While the case study performed for this thesis showed very promising results, the tests were performed in controlled environments with predictable movements from an able-bodied individual. The real test of this switch concept will be using the device with their client. The designed switch will be further reviewed and tested to ensure the device is operating at production quality with no bugs or defects.

There are other many InvoTek clients who are viable candidates for this technology. Using the switch with these clients will also be reviewed by InvoTek.

Due to the project success and potential impact this type of switch technology could have in the assistive technology field and for people with disabilities, InvoTek has decided to pursue a Small Business Innovation Research (SBIR) grant related to the designed switch. The proposal will focus on expanding and testing the capabilities of the switch to recognize a broader range of movements and moving the system into a production quality product and service. Machine learning will be incorporated into the switch capabilities. The intent is to automate the process of identifying unique feature sets in the movement data to create a switch activation.

Last, InvoTek intends to use the designed hardware to test the feasibility of using IMU technology as a head tracker. The designed hardware already includes all the necessary components to explore this concept. By using an IMU sensor as the main sensing technology instead of an image processing based approach, manufacturing and product costs could be decreased significantly. InvoTek will expand the functionality of the firmware to achieve this goal.

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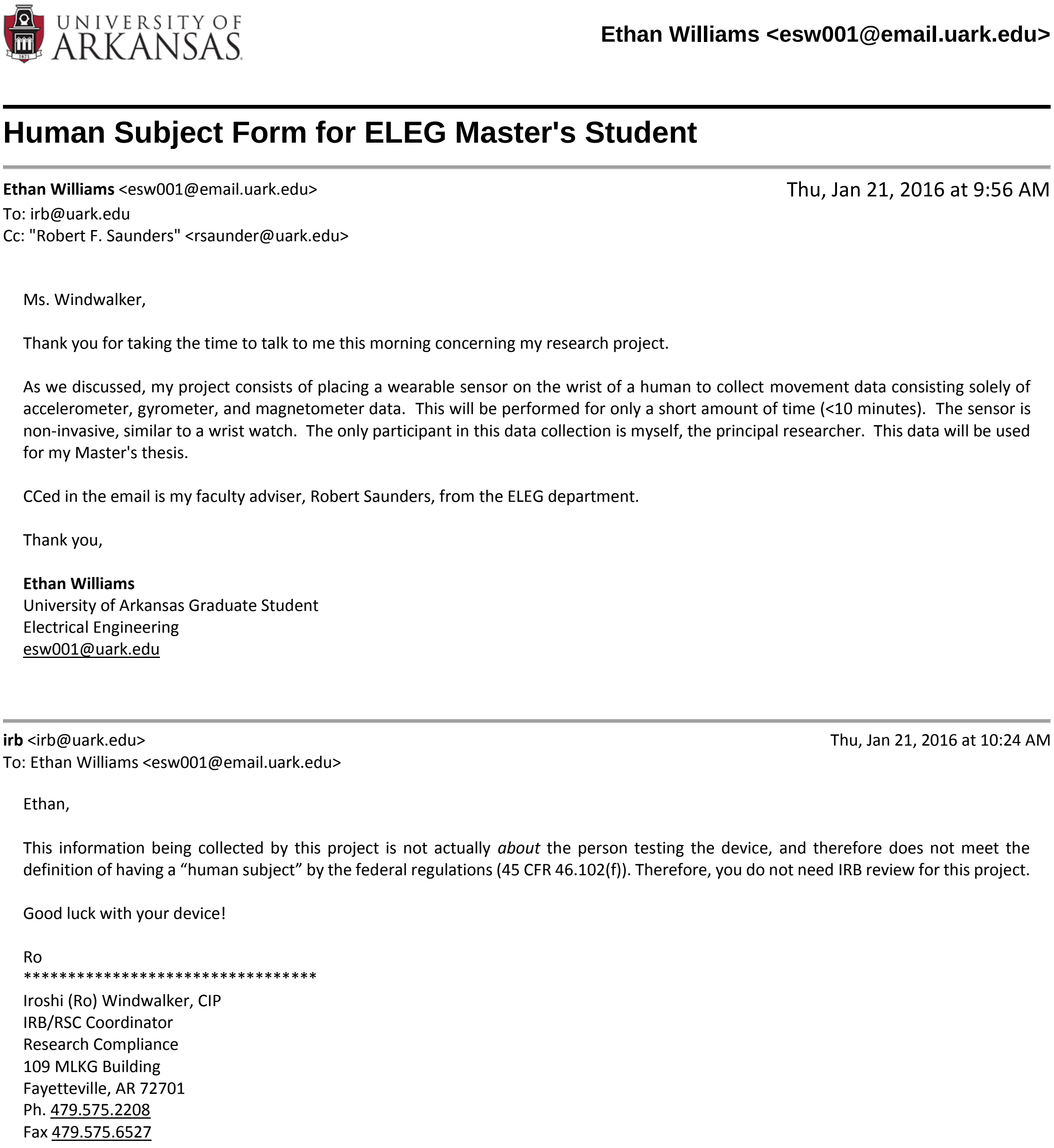
IX. Appendix - Exclusion from Human Subject Approval

The below email states that the research performed for this thesis does not meet the definition of "human subjects" and therefore does not need Institutional Review Board (IRB) approval.



Ethan Williams <esw001@email.uark.edu>

Human Subject Form for ELEG Master's Student

Ethan Williams <esw001@email.uark.edu> Thu, Jan 21, 2016 at 9:56 AM
To: irb@uark.edu
Cc: "Robert F. Saunders" <rsaunder@uark.edu>

Ms. Windwalker,

Thank you for taking the time to talk to me this morning concerning my research project.

As we discussed, my project consists of placing a wearable sensor on the wrist of a human to collect movement data consisting solely of accelerometer, gyrometer, and magnetometer data. This will be performed for only a short amount of time (<10 minutes). The sensor is non-invasive, similar to a wrist watch. The only participant in this data collection is myself, the principal researcher. This data will be used for my Master's thesis.

CCed in the email is my faculty adviser, Robert Saunders, from the ELEG department.

Thank you,

Ethan Williams
University of Arkansas Graduate Student
Electrical Engineering
esw001@uark.edu

irb <irb@uark.edu> Thu, Jan 21, 2016 at 10:24 AM
To: Ethan Williams <esw001@email.uark.edu>

Ethan,

This information being collected by this project is not actually *about* the person testing the device, and therefore does not meet the definition of having a "human subject" by the federal regulations (45 CFR 46.102(f)). Therefore, you do not need IRB review for this project.

Good luck with your device!

Ro
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