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March 26, 2021

Dr. Craig Scratchley,
School of Engineering Science
Simon Fraser University
Burnaby, British Columbia, V5A 1S6

RE: ENSC 405W/440 Design Specification for the Pro-Tek

Dear Dr. Scratchley,

The following document contains the Design Specifications for the Pro-Tek. Our device aimed to monitor body posture during workouts (such as Deadlifts, Bench Press and Squats) will notify the user if body posture is improper. It will provide feedback to the users to correct their form through an app installed on their phones. Our wearable tracking device for an individual can decrease the chances of getting injured during a workout and will also help the users to correct their form while performing the exercise. Hence, the users can perform the exercise more effectively and efficiently.

The purpose of this document is to provide detailed specifications for the design of our product. This document consists of a design overview of the Pro-Tek, test plans, user interface design and plans for ENSC 440. It will detail the design requirements necessary for the proof-of-concept, prototype, and production model.

GymSmart is composed of six engineering science students: Junjie Xu, Pei Ning, Kwok Liang Lee, Xiaoyi Zhao, Mitch Edema and Harpreet Kaur. Every team member possesses different skills and contributed based on their extensive hardware and software experience.

Our company members appreciate the time you have taken to review our design specifications document. If you have any comments or questions about our product, please feel free to contact me by direct line at (604)805.4001 or via hharpree@sfu.ca.

Sincerely,

Harpreet Kaur
Chief Communications Officer
GymSmart Inc.

Abstract

Injuries sustained during workouts are incredibly common, yet preventable. If the improper form is used for a long time while exercising, it could lead to life-threatening problems. Our proposed solution is the Pro-Tek form trainer, which is a device that uses IMU, Bluetooth modules and optical sensors to measure joint angles and orientations. These measurements are used to determine whether the improper form is performed; and if yes, then the user is notified using a LED notification and vibration on the module itself. The initial calibration procedure is used to make our device detections more robust based on the different body types. The user can choose from different exercise options using the app installed on the user's phone. The mobile app has the functions such as exercise history, workout repetitions counter and more detailed information about the improper form and how it can be corrected. This document outlines all the design specifications, and it is intended to be used as a reference for GymSmart Inc. The design specifications for the project consist of three main components: the hardware design of the wearable device, detection algorithm used for improper form detections and the software design for the Android application.

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Glossary

TERM	DEFINITION
Accelerometer	It is an electromechanical device used to measure acceleration forces.
Gyroscope	It is a device used for measuring rotational changes or maintaining orientation.
Inertial measurement unit (IMU)	It is an electronic device that measures and reports a body's specific force, angular rate, and sometimes the orientation of the body, using a combination of accelerometers, gyroscopes, and sometimes magnetometers.
Inter-Integrated Circuit (I2C)	It is a very popular and powerful bus used for communication between a master (or multiple masters) and a single or multiple slave device.
Light-emitting diode (LED)	It is a semiconductor light source that emits light when current flows through it.
Magnetometer	It is a device that measures magnetic field or magnetic dipole moment.
Microcontroller	Compact integrated circuit designed to govern a specific operation in an embedded system.
USB	Universal Serial Bus.
Bluetooth LE	The full name is Bluetooth Low Energy, it was introduced in 2010 and bought standards for Bluetooth devices that consume very low energy.

Section 1 - Introduction

Whether you have been exercising for years or are just starting a fitness program, it is important to avoid injuries so you can keep moving closer to your fitness goals. The most common way of getting injured is improper form while weightlifting exercises, especially when the wrong form continued for a longer period. The Pro-Tek form trainer is a device that can prevent such injuries by providing notification to the user when they are performing an exercise in a bad posture. It allows the user to keep track of exercise repetitions as well.

The Pro-Tek is a wearable device that contains IMU, Bluetooth modules and optical sensors to measure joint angles and orientations. It has three main subsystems: First, once the device is ready to go, exercise data is collected through forearm modules (secondary units) and hip module (primary unit); afterwards, the detection algorithms are used to check if the exercise form is correct and to track the exercise repetitions. The notification will be displayed using LED and vibration on the module itself. Lastly, the data is displayed on the user's device through an app that is connected to the primary module through the Bluetooth connection. The Pro-Tek design is explained in more detail in section 2: Design Overview of this document.

Figure 1: Main stages of system

1.1 Background

Weightlifting injuries are a common occurrence for numerous individuals who engage in this activity to improve their health. The standard for preventing these injuries is having another individual, such as a personal trainer who can analyze and critique the form during an exercise. However, personal trainers can be a bit expensive, especially if they are not entirely required. Our device is not attempting to replace a personal trainer, but aid the user enforce proper form, without the need of another individual. This device can be used at any time, at any location, without requiring another person to be present. The added benefit of this device is the ability to historically track form information, repetitions, and movement velocity, increasing the usefulness and utility of such a device.

A few common weightlifting exercises that can be analyzed by this device are the bench press, deadlift, and squats. During the bench press, a proper form is essential in preventing injury development. An example of one aspect of proper form would be the angle of the elbows, relative to the bar. If the elbows are pushed too far outwards, this can cause an unnecessary amount of force applied to the shoulders, which can lead to a risk of injury. This is illustrated in Figure 1.1. By using the inertial sensors, the orientation of the forearms, the position of the elbows is estimated. If the elbows were then detected to be pushed too far outwards, the sensors would measure this event, and inform the user to fix their form using LED notification, vibration and through the app notification.

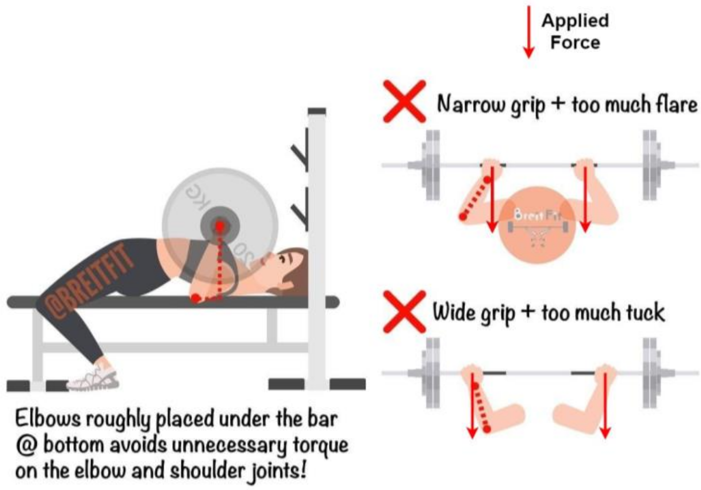

Figure 1.1: Example of downward forces applied during improper elbow angle [1]

1.2 Scope

This document intends to outline the technical design specifications for the Pro-Tek form trainer. These specifications will describe the various design choices that were made under the functional requirements for the product, as outlined in the Pro-Tek Requirements Document [2]. Each of the major system and subsystem sections will provide detailed justifications for these design decisions and the specific design processes on how the corresponding systems shall be implemented.

The document also includes a User Interface Appearance Appendix that summarizes the requirements for Pro-Tek appearance and usability. Also, in the appendix are supporting test plans to verify detailed design specifications for the subsystems and components of Pro-Tek.

1.3 Intended Audience

This document serves as Pro-Tek design specification for GymSmart Inc. members, its potential clients and partners, Dr. Craig Scratchley, Dr. Andrew Rawicz, Dr. Shervin Jannesar, Dr. Michael Hegedus and Chris Hynes. Future revisions will draw from the framework detailed in this document.

1.4 Design Classification

The requirements in this document will follow the following convention:

Des {Document Section}-{Design Requirement Number}-{Stage of Development}

The encoding alphabets for the three stages of development are outlined in table below:

Encoding	Stage of Development
P	Proof of Concept
M	Beta (MVP)
F	Production

Table 1.4: Encoding alphabets for development stages

Section 2 – Design Overview

Pro-Tek is a set of modules that work together for tracking the form of its user. With the proper point of attachments, such as forearm and hip, Pro-Tek can obtain the user's position data and monitor if that specific movement is in an acceptable range.

Pro-Tek is come with three modules. Each device's dimension is about 60 mm long, 40 mm wide and 20 mm high. The dimension specifications are not fix and might be changed as the product moving from prototype stage to final product. All the three modules have an accelerometer, gyroscope, Bluetooth module, and microcontroller, but the two sub-unit will have an additional proximity sensor included. Once Pro-Tek is connected to user's phone device, any recorded data from the two forearm units will first transmit to the primary unit and then be sent to the user's phone. Data analysis will be done on each unit's microcontroller, and suggestions will be provided.

Pro-Tek is powered by rechargeable lithium battery and connecting to user's device via Bluetooth connection. In user's device, a simple app will be used to display the recorded data of user after the exercise session ends. Figure 2.1 below is a simplified representation of the connections of Pro-Tek and user's device.

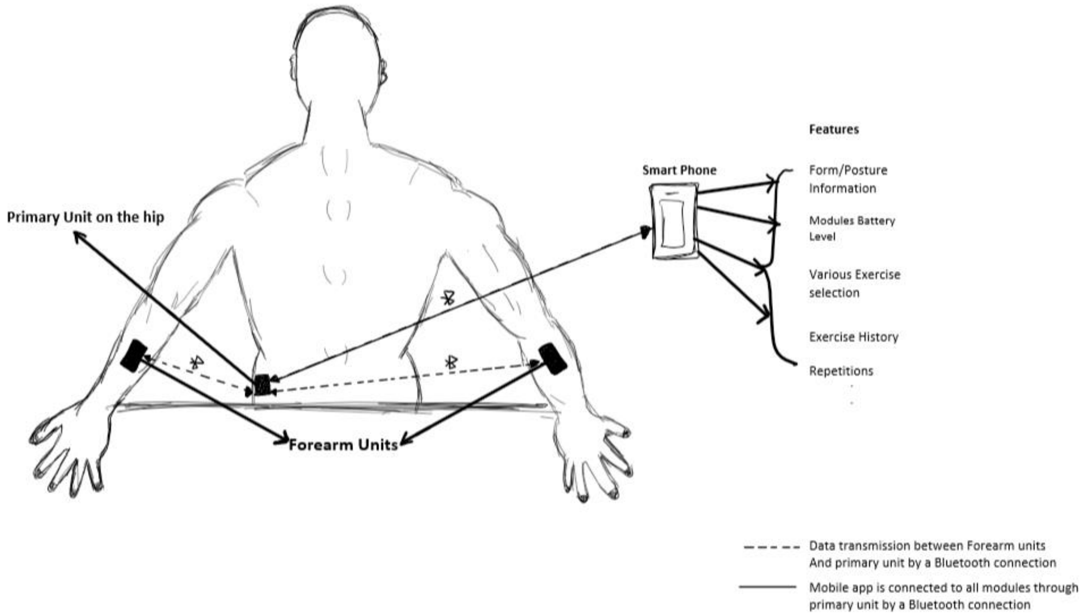

Figure 2.1: Representation of the connections of Pro-Tek and user's device

A more descriptive diagram of the internal components for primary and forearm units is shown below, with some discussions about the system modules.

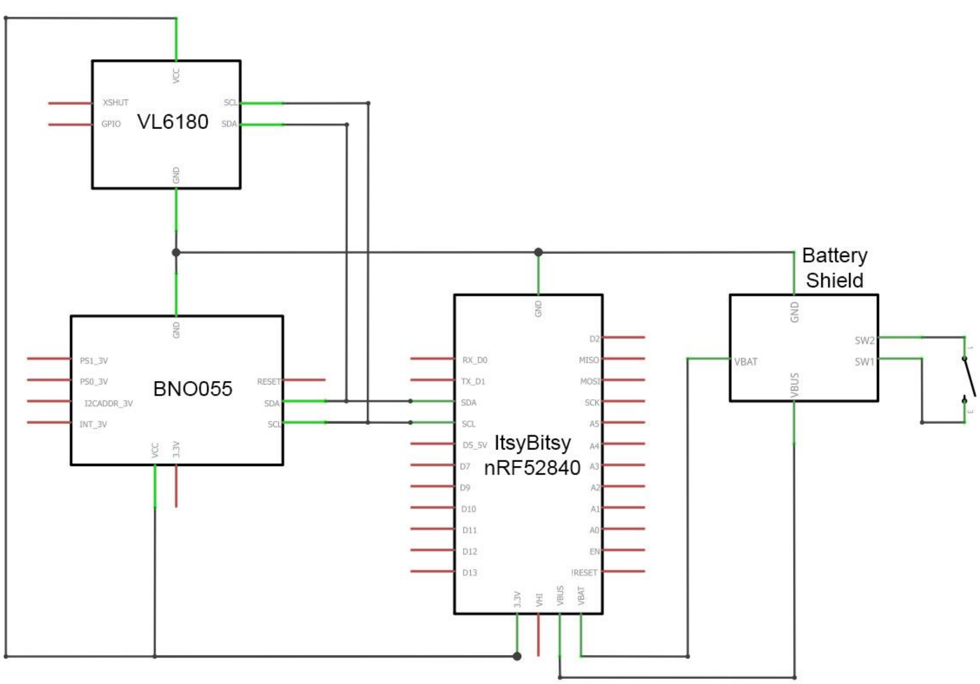

Figure 2.2: System diagram of forearm unit

The forearm unit features a BNO055 IMU sensor, providing the orientation measurements for the unit. The optical distance sensor used in measuring the wrist is shown as the VL6180, using a laser and optical sensor. These devices interface with the ItsyBitsy nRF52840, which features an onboard Bluetooth module. To power the unit, a battery shield is used, interfacing the microcontroller with a LiPo rechargeable battery. This battery shield also facilitates battery charging through the micro-USB port available on the microcontroller.

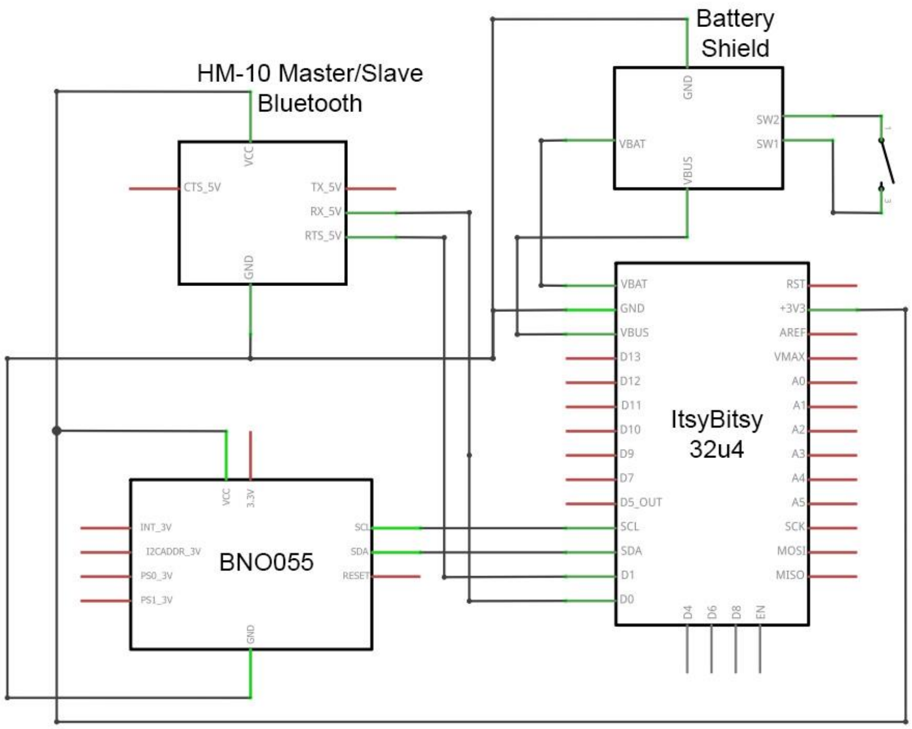

Figure 2.3: System diagram of primary unit

The primary unit features identical IMU and battery shield modules but has a different means of wireless communication. Because this unit needs to act as both a Bluetooth master and a slave, a more specialized module is required, that being the HM-10 module. This module allows communication between the smartphone and the forearm units, creating a bidirectional connection for the entire system. The microcontroller is then substituted for the non-Bluetooth version of the forearm microcontroller, creating a consistency of components. These components all work together to acquire data, detect its characteristics, and produce a real-time response, that can later be viewed in the smartphone application. Each component will be described in further detail in the next section.

Section 3 – Hardware Specifications

The main hardware components involved in our system are inertial measurement units (IMU), optical distance sensors, Bluetooth modules, and microcontrollers. Each unit on the forearm is fitted with an IMU, optical distance sensor, microcontroller, and Bluetooth module. The primary unit, located on the hip, will contain only an IMU, a microcontroller and master/slave Bluetooth module. The primary unit will then use the Bluetooth module to connect to a mobile device and transmit the data to be stored on the device. On the primary unit itself, the on-board microcontroller will apply the rules of a specified exercise to the incoming data. If the data passes certain conditions, the primary unit will inform the forearm unit, subsequently illuminating an LED and producing a vibration to notify the user of their improper form.

3.1 General Design Requirements

3.1a Common

Des 3.1a-1-P	Each unit must have an IMU.
Des 3.1a-2-P	Each unit must have a microcontroller.
Des 3.1a-3-P	The IMU must be installed within each unit with its y-axis pointing upward, and x-axis pointing to the right.
Des 3.1a-4-P	All sensors must be connected to the microcontroller, with the required intermediate components.
Des 3.1a-5-P	All sensors will communicate to the microcontroller via I2C.
Des 3.1a-6-P	All sensors must be properly calibrated, to ensure high accuracy measurements.
Des 3.1a-7-P	Each unit must have a voltage regulator, to ensure proper power is supplied during charging.
Des 3.1a-8-M	Each unit must have a power button to manually activate the device.

Table 3.1a: Common Design Requirements

3.1b Forearm Units

Des 3.1b-1-P	Each unit must have an optical distance sensor.
Des 3.1b-2-P	The optical distance sensor must be installed facing toward the back of the hand.
Des 3.1b-3-P	Each unit must have a slave Bluetooth module.

Table 3.1b: Forearm Units Design Requirements

3.1c Primary Unit

Des 3.1c-1-P	The primary unit must have a master/slave Bluetooth module.

Table 3.1c: Primary Unit Design Requirements

3.2 Electronics Requirements

3.2a IMU Specifications

A primary hardware component of this system was the IMU, used to measure the orientations of the forearms and hip unit. There are many variations of these types of sensor modules, containing different numbers of total sensors. A module having more inertial sensors will result in an increase of degrees of freedom, allowing measurements to be made in more directions. The outputs from each sensor in an IMU can be fused to produce angle values, ultimately required by the detection algorithms as stated in [Req 3.2-9-F]. The design specifications for the IMU sensors are presented here, as well as our selection with its benefits and drawbacks discussed.

Des 3.2a-1-P	Each IMU must have an accelerometer.
Des 3.2a-2-P	Each IMU must have a gyroscope.
Des 3.2a-3-P	Each IMU must have a magnetometer.
Des 3.2a-4-P	Each IMU must communicate with the microcontroller over the I2C bus protocol.
Des 3.2a-5-P	Each IMU must be capable of a sample rate of at least 100 Hz.
Des 3.2a-6-P	Each IMU must not incur significant drift over time.
Des 3.2a-7-M	Each IMU must consume less than X mA during normal operation.
Des 3.2a-8-M	Each IMU must require an input voltage of less than 5V.

Table 3.2a.1: IMU Design Requirements

BNO055

The tested sensor module that produced the most ideal results was the BNO055. This module gave high accuracy, real-time angle measurements that suffered very minimally from drift. The sensor fusion algorithms are calculated on board the sensor module, providing either quaternion or Euler angle outputs for angle data. This module is a 9DOF sensor, containing an accelerometer, gyroscope, and magnetometer. Each one of these sensors can be queried individually, allowing for more than just angle measurements. The angle measurements, however, are very accurate and responsive in any orientation. The only drawback of this sensor module was the relatively slow sample rate. For this application in particular, the sample rate was found to be sufficient, as human movements are typically not faster than 100 Hz. Because this sensor satisfied the requirements in [Req 3.2-2-P] and [Req 3.2-8-F], it was chosen to be used in further development. The technical specifications of the IMU are shown below in Table 3.2a.2.

Module Name	DOF	Available Sensors	Sample Rate	Input Voltage	Communication Protocol
BNO055	9	Accelerometer, gyroscope, magnetometer	100 Hz	2.4V-3.6V	I2C serial communication

Table 3.2a.2: Specifications for the BNO055 IMU

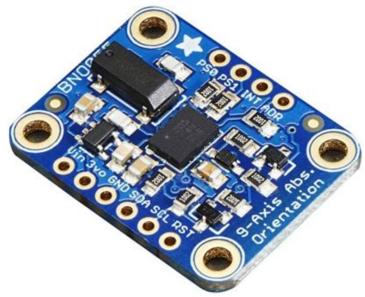

Figure 3.2a: BNO055 Absolute Orientation IMU [3]

The pinout designations for the chosen BNO055 IMU are shown below in Table 3.2a.3.

Pin Name	Pin Function	I/O	Notes
Vin	Input voltage	Input	Voltage must be 5V
3vo	Output voltage	Output	Output voltage of 3.3V from the board
GND	Ground	Input	Common ground with microcontroller
SDA	Serial data	Output	Serial data line transferring IMU data
SCL	Serial clock	Input	Serial clock line for synchronization with microcontroller
RST	Reset	Input	Reset's sensor when pulled to ground
PS0/PS1	Mode change	Input	Changes the communication mode of the device (UART or HID-I2C)
INT	Interrupt	Output	Generate an interrupt signal when an event occurs
ADR	Address alt.	Input	Assigns an alternate I2C address

Table 3.2a.3: Pinout designations for BNO055 IMU

Each unit requires an accelerometer and gyroscope such that the orientation of the forearms and hip can be measured. These sensors used in conjunction with each other can augment the accuracy of each individual sensor and provide a much better measurement of limb orientation. The microcontroller is also required for the processing of the incoming data, as well as the enforcement of certain sensor rules for specific exercises. These microcontrollers will interface with a Bluetooth module, to allow for communication between the units, and a centralization of the data processing. Lastly, the Bluetooth module is required to transmit data to a mobile device, such that the user can review their performance. All of these components will be powered by a battery present in each unit, that can be recharged as needed. Each component plays a crucial part in the functioning of this device and will be discussed in further detail in the following requirements.

3.2b Distance Sensor

For measuring the twist angle of wrist and minimize the uncomfortable effect to users, a distance sensor is used. Figure below shows the theorem for measuring the twist angle by using distance sensors.

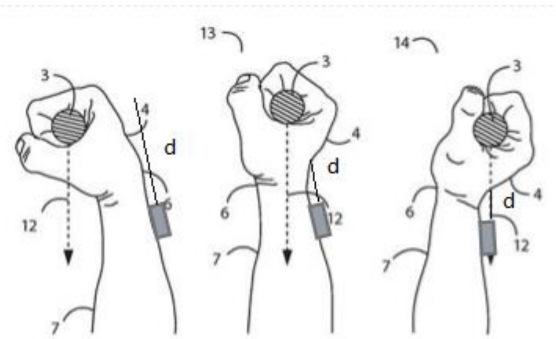

Figure 3.2b.1: Distance Sensors for Twist Angle Measuring, adapted from [4]

As Figure 3.2b.1 shows, the distance between back of the hand and the sensor is different when wrist has different twist angle. To avoid unproper behavior during exercise, algorithm will monitor the distance by using the data collected by the distance sensors to make sure the twist angles are in the safe range.

Des 3.2b-1-M	Distance sensor should be able to measure 50-100 accurately.
Des 3.2b-2-M	The input voltage for distance sensor must lower than 5V.
Des 3.2b-3-M	Sensor module should be compatible with Arduino.

Table 3.2b.1: Distance Sensor Design Requirements

Adafruit VL6180

The distance sensor which matches the requirements is Adafruit VL6180 Time of Flight Distance Ranging Sensor.

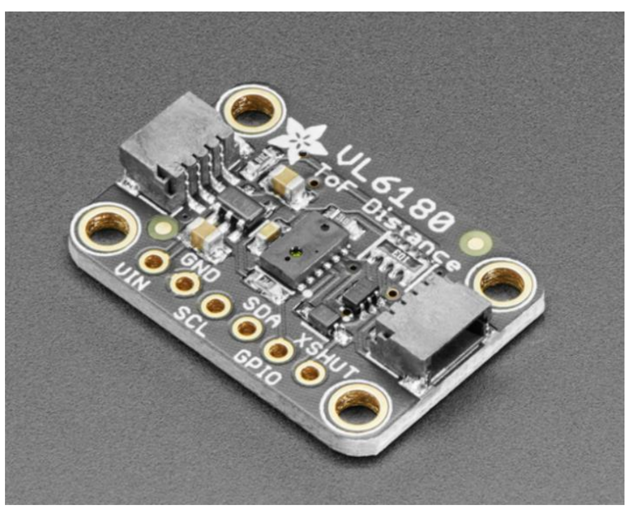

Figure 3.2b.2: Adafruit VL6180 [5]

Module Name	Available Sensor	Normal Measuring Distance	Maximum Available Distance	Input Voltage	Communication Protocol
VL6180	Laser Sensor	5mm to 100mm	200mm	2.8V - 5V	STEMMA or I2C bus protocol

Table 3.2b.2: Specifications for the Adafruit VL6180

VL6180 has good performance on short distance measurement. The tiny laser sensor locates on the center of the module can measures the distance of only the surface directly in front of it. Comparing with ultrasonic distance sensors, laser sensors have a narrower detecting range, but it has shorter response time and data it measured is more accurate. Comparing with traditional infrared sensors which measuring the distance by using the reflection of light, laser sensors is more precise when the distance is very short because laser sensors do not have linearity problems or double imaging.

Since laser sensor lays at the center of the VL6180 module, the module must be fixed perpendicular to the arm skin so that laser sensor is towards to the back of hand. The power supply of VL6180 and data transmission are based on the microcontroller which will be introduced in the next part.

3.2c Microcontroller Specifications

Another crucial component of this system is the microcontroller. The microcontroller has many responsibilities including supplying power to the sensors, acquiring data from each sensor, and performing any processing tasks to the sensor data. It also is required to interface with the Bluetooth modules, transmitting data between slave and master/slave units, as well as between the master/slave unit and the smartphone. This component acts as a control center for the system, facilitating the transfer and processing of information between all units. The requirements for the microcontroller are shown below.

Des 3.2c-1-P	Each microcontroller must be capable of supplying 3.3V to each sensor.
Des 3.2c-2-P	Each microcontroller must be powered with a supply voltage of 3.3V.
Des 3.2c-3-P	Each microcontroller must have Tx and Rx UART ports for Bluetooth communication.
Des 3.2c-4-P	Each microcontroller must be capable of communication with sensors over the I2C bus protocol.
Des 3.2c-5-P	Each microcontroller must have a baud rate of at least 9600 baud.
Des 3.2c-6-P	Each microcontroller must have a clock speed of at least 16 MHz.
Des 3.2c-7-P	Each microcontroller must be capable of digital output to control an LED indicator.
Des 3.2c-8-M	Each microcontroller must draw less than 40 mA of current.
Des 3.2c-9-M	Each microcontroller must be maximum dimension 40 mm x 20 mm.

Table 3.2c.1: Microcontroller Design Requirements

These requirements are critical in the operation of our system, as they facilitate the desired power, speed, data transfer, and functionality constraints. Because this component is a central hub for sensor inputs and data transmission, it must be capable of the power and data transfer requirements as stated above. It also needs to be capable of other necessary functions in terms of notifying the user. By evaluating these requirements, microcontrollers were chosen for testing and the final selection will be discussed below.

Microcontroller	Processor	Input Voltage	Storage	Clock Rate	UART+I2C	Bluetooth
Adafruit ItsyBitsy 32u4	Atmega32u4	3.3V	28KB of flash	8 MHz	Yes	No
Adafruit ItsyBitsy nRF52840 Express	nRF52840	3.3V	1MB of flash	64 MHz	Yes	Yes

Table 3.2c.2: Specifications for Adafruit ItsyBitsy nRF52840 microcontroller

An ideal microcontroller to be used in this system is the Adafruit ItsyBitsy. This microcontroller comes with the option of an onboard Bluetooth module that is capable of all the required functionalities stated in [Req 2.2a-3-P, Req 2.3a-1-P]. This microcontroller satisfies all the above design requirements and is an optimal combination of the other considered microcontrollers, discussed in Appendix C.1.

Adafruit ItsyBitsy 32u4

The Adafruit ItsyBitsy is a small form factor microcontroller that is compatible with the Arduino IDE for development and testing. This microcontroller supports native USB capabilities, not requiring an additional serial-to-USB chip. It also is capable of data transmission through both I2C and UART protocols, allowing it to easily interface with many MEMS sensors and Bluetooth modules. In terms of power supply, the ItsyBitsy 32u4 can interface with a battery shield, allowing the device to be powered from an external battery. This battery shield also facilitates battery charging through the micro-USB port, already available on the microcontroller. This was the optimal solution for the primary unit, as it had a desired form factor with all the required functionalities.

Adafruit ItsyBitsy nRF52840

Because the primary units need a specialized master/slave Bluetooth module, the HM-10 was used instead of the onboard nRF52840. However, the forearm units did not have this requirement and could benefit from having an in-built Bluetooth module. A large amount of space is conserved by the ItsyBitsy nRF52840, as external Bluetooth modules are not required. Space conservation is very desired in this application and makes this microcontroller an ideal solution. This microcontroller is essentially an improved version of the ItsyBitsy 32u4, providing more storage and a higher clock rate.

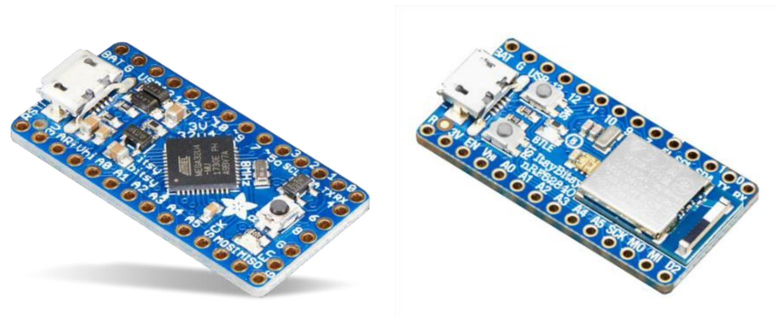

Figure 3.2c.1: Adafruit ItsyBitsy 32u4 (left) and nRF52840 (right) microcontrollers [6, 7]

Pin Name	Pin Function	I/O	Notes
3V	Voltage output	Output	Onboard regulated 3V output
Vhi	Voltage output	Output	Chooses higher voltage between USB and BAT
G	Ground	Input	Common ground with microcontroller
SDA	Serial data	Output	Serial data line transferring IMU data
SCL	Serial clock	Input	Serial clock line for synchronization with microcontroller
Rx	Serial receive	Input	Receives serial input
Tx	Serial transmit	Output	Transmits serial output
RST	Reset	Input	Reset's sensor when pulled to ground

Table 3.2c.3: Pinout designation for Adafruit ItsyBitsy 32u4 and nRF52840 microcontrollers

Because the Adafruit ItsyBitsy satisfied all the design requirements, as well as [Req 2.2b-1-P, Req 2.2b-2-P, Req 2.3b-1-P, Req 2.3b-2-P], it was selected as the microcontroller for all three units. The forearm units were of the nRF52840 variant, whereas the primary unit was the 32u4 version.

3.2d Bluetooth Module Specifications

The Bluetooth module will be responsible for exchanging the data between primary modules and secondary modules, as well as receiving commands from the Phone App and pushing the detection results. Therefore, the module must be able to interface with the selected microcontrollers, transfer data in a high rate and can form a one-to-many network. The selected module should be also able to fit inside the proposed enclosure. The following are the design specification of the Bluetooth Module.

Des 3.2d-1-M	The size of the module should be within 30mm x 15mm x 5mm.
Des 3.2d-2-P	The module must have a minimum baud rate of 9600.
Des 3.2d-3-P	The module must have a serial receive and serial transmit pins.
Des 3.2d-4-P	The module must be able to operate under 3.3V or 5V.
Des 3.2d-5-P	The module must support connection with multiple devices.
Des 3.2d-6-P	The module must be compatible with majority of Android devices.
Des 3.2d-7-P	The module must have a minimum transfer speed of 100Kbits/s.

Table 3.2d.1: Bluetooth Module Design Requirements

The above design requirements ensure that the module being used can be connected to the microcontroller board and communicate between different modules at a reasonable speed. An ideal model is HM-10 from DSD Tech, which is introduced below.

DSD Tech HM-10 Bluetooth Module

The HM-10 module conforms to the Bluetooth 4.0 LE standard, which was estimated to cover over 90% of the cell phones which have Bluetooth capabilities [8]. It consumes a very small amount of power which is a desirable to decrease the frequency of charging the battery.

Figure 3.2d.1: DSD Tech HM-10 Bluetooth Module [9]

The DSD Tech HM-10 module, its key specifications are listed below.

Bluetooth Module	Bluetooth Version	Input Voltage	Input Current	Baud Rate	Transfer Speed
DSD Tech HM-10	Bluetooth 4.0 LE	2.5 - 3.3V	8.5mA	9600 – 230400 Configurable	2Mbits/s

Table 3.2d.2: Specifications for DSD Tech HM-10 Bluetooth Module [10]

Comparing to other potential candidates, the HM-10 module is superior because of the higher coverage while using a relative new Bluetooth specification, and it has a great transfer speed, which makes it fulfil the stated design requirements. In addition, the module's size is 27mm x 13mm x 2.2mm so it could be fitted into the enclosure in the future.

3.2e Vibration Motor Specifications

The vibration motor is to provide indication to the user during the exercise when improper forms are detected. The only function that the motor needs to include is vibration when activated, since the microcontroller is used to control all the sensors. Other than that, the dimension of the vibration motor cannot be too big, so that the overall size of module will not be too large and decrease the comfort level of user experience.

Des 3.2e.1-P	Maximum dimension of vibrator motor is 18 mm x 18 mm.

Table 3.2e.1: Vibration Design Requirements

Vibration motor	Voltage (DC)	Termination style	Communication protocol
DFRobot - DFR0440	5 V	PCB board	PWM
Vibrator motor - 316040001	3 V	Wire leads	-

Table 3.2e.2: Specifications for DFRobot – DFR0440 and vibration motor – 316040001

Vibration motor – 316040001

The vibrator motor that is used in our design is vibrator motor – 316040001. Since the microcontroller can control the activation of the vibration motor, having extra components on the motor will only be a waste of efficiency. There is not requirement for 316040001 vibration motor in communication protocol makes the connection to the microcontroller much simpler. Also, 316040001 vibrator motor is overall much smaller than DFR0440, makes it more flexible to fit into a compact space.

Figure 3.2e.1: Vibrator Motor – 316040001 [11]

3.3 Power Requirements

3.3a Battery Specifications

Each unit will be powered by an external battery that can be recharged as necessary [Req 2.1b-1-P, Req 2.1b-3-M]. This battery must last for a sufficient period of time, requiring the capacity to be carefully considered [Req 2.1b-7-F]. However, due to the size constraints of each unit, the battery size is fairly limited as to not impose a large footprint. The requirements for the battery, as well as the design selection, are described below.

Des 3.3a.1-P	Each battery must provide a stable voltage of 3.3V to the microcontroller, as required in [Des 3.2c-2-P]
Des 3.3a.2-P	Each battery must be a Lithium-Ion Polymer battery
Des 3.3a.3-M	Each battery must last for 4 hours while system is active
Des 3.3a.4-M	Each battery must last for 10 hours while on standby
Des 3.3a.5-P	Each battery must have a capacity of at least 200 mAh
Des 3.3a.6-P	Each battery must have a JST connector
Des 3.3a.7-M	Each battery must have a lifetime of at least 300 charging cycles

Table 3.3a.1: Battery Design Requirements

Electronic Unit	Current Consumption
Microcontroller	20 mA
BNO055	12.3 mA
VL6180	1.7 mA
Bluetooth Module - nRF52840	16 mA

Table 3.3a.2: Battery Design Selections

To calculate the required battery capacity, the individual current consumptions of each module was taken and used in calculations. These calculations are shown below.

$$(20\ mA + 12.3\ mA + 1.7\ mA + 16\ mA) = 50\ mA$$
$$50\ mA * 4\ h = 200\ mAh$$

To ensure the battery supply would be sufficient for at least 4 hours during active operation, the capacity of 250 mAh was selected, being slightly higher than the theoretically required value. Using a battery shield, the battery can be connected to the microcontroller with a JST connector. The shield will transfer the power to the microcontroller, ultimately powering the entire unit. The shield can also support a button to turn the device on or off, as required in [Req 2.1b-6-M]. While the system is off, the current consumption will be minimal, allowing the system to remain charged for a longer period of time.

Lithium-Ion Polymer Battery - 3.7V 250 mAh

Lithium-ion batteries are quite standardized, coming in varying capacities. The main constraints for a battery are its capacity and connector. In our case, its capacity must be able to supply sufficient power for the specified time period. Our application required a battery capacity of at least 200 mAh, which would be satisfied by a 250 mAh battery. A JST connector was also required to interface with the JST connector of the battery shield [Des 3.3b-6-P] specified in the next section. This battery satisfied all the above requirements and was chosen for implementation.

Figure 3.3a.1: 250 mAh battery with JST connector [12]

3.3b Charging Specifications

In order to charge the LiPo battery as it depletes [Req 2.1b-4-M], a charging port and voltage regulator are needed. For both the Pro Trinket and ItsyBitsy nRF52840 microcontrollers, there are battery shields that can interface between the battery and microcontroller. The shield can transfer power between the battery and microcontroller, powering the system. An added benefit of certain battery shields is that they can recharge the battery using the available micro-USB port already present on the microcontroller. These shields remove the requirement for additional charging circuitry, as the circuitry is already incorporated into the shield. Because each unit needs to be relatively small, this feature is highly desirable as space is saved.

Des 3.3b.1-P	The battery shield must transfer power from the battery to microcontroller.
Des 3.3b.2-P	The battery shield must be compatible with the microcontroller.
Des 3.3b.3-P	The battery shield must supply a regulated voltage of 3.3 V to the microcontroller, as required in [Des 3.2c-2-P]
Des 3.3b.4-P	The battery shield must be capable of receiving up to 6V input voltage.
Des 3.3b.5-P	The battery shield must be capable of supplying a current of 100 mA or 500 mA to the battery for charging.
Des 3.3b.6-P	The battery shield must have a JST connector.

Table 3.3b.1: Battery Charging Design Requirements

Adafruit LiIon/LiPoly Backpack Add-On for Pro Trinket/ItsyBitsy

This PCB facilitates the transfer of energy from a connected battery to the microcontroller, also allowing the battery to be charged from the microcontroller's USB port. Space is saved as a result of this PCB as both battery charging and regulation can take place on a single board. The MCP73831 chip is responsible for managing the battery charging. If a battery larger than 500 mA is required, the supply current can be changed to support this greater capacity. The voltage from the battery, connected by JST connectors, will be regulated to 3.3 V which is required by the microcontroller. For power indications, there are 2 LEDs. While the device is charging the red LED is illuminated and when charging is complete the green LED is illuminated. The battery shield and system diagram are shown below.

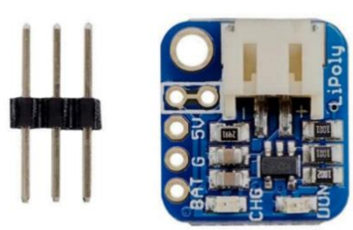

Figure 3.3b.1: LiIon/LiPoly battery shield with JST connector port [13]

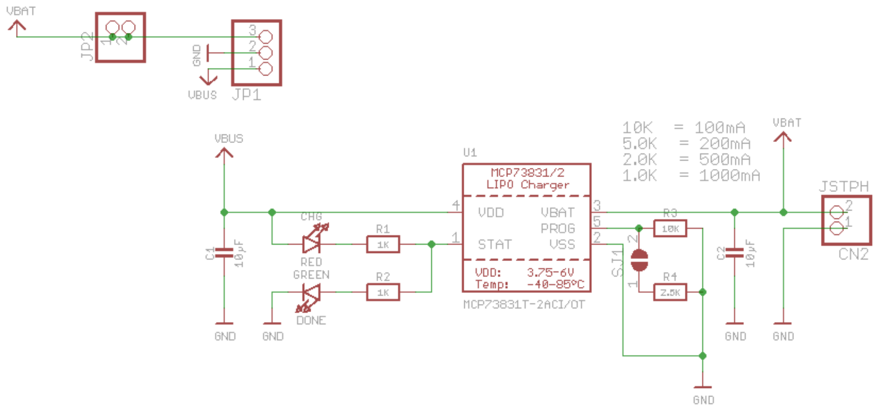

Figure 3.3b.2: LiIon/LiPoly battery shield system diagram [14]

This PCB is an ideal component for this system as it saves significant amounts of space by requiring fewer components. It has been developed to work seamlessly with the ItsyBitsy nRF52840, our microcontroller of choice. This will be the component used for each unit's power management as the alternatives are not nearly as ideal. Further testing will be conducted to ensure proper battery charging and voltage regulation is taking place.

3.4 Compression Shirt

Des 3.4-1-M	The compression shirt must be made from synthetic fiber such as spandex.

Table 3.4: Compression Shirt Design Requirements

The compression shirt that is going to hold the units is made from synthetic fiber such as spandex, so that it conforms to the shape of the user. It is also flexible, as to not impede the movements of the user. Because it is being used in an exercise setting, it can withstand larger tensile forces, as well as be minimally affected by moisture. In terms of holding the units, there are 3 pockets - 2 for forearm units and one for hip unit that can tightly affix the units to the user. Pocket size is based on modules size. Each pocket has open and close button to ensure the sensors will be placed tightly and its removable as needed.

Section 4 – Software Specifications

4.1 General

Des 4.1-7-M	App must get the phone's Bluetooth permission for data communication.
Des 4.1-7-M	Microcontroller programming must be done using the Arduino IDE.

Table 4.1: General Software Design Requirements

For the Software included in the product, it includes the detection algorithm running on the microcontroller of sensor modules and the phone app that provides users with a graphical user interface. It must also allow for the primary and forearm units to communicate to each other wirelessly and combine their data for the same instant of time. To transfer the data over Bluetooth, UART is required, to ensure data is transferred reliably. An added feature is to automatically turn on the forearm units when the primary unit is turned on. Each unit will have an individual power button as a contingency, in the event that it is not turned on by the primary unit. This function can be reached by setting secondary modules to be sleep mode and once the command sent from primary is over 8 bites, secondary units will be active. If a unit is then disconnected, the system will notify the app, such that the user can manually turn on the device if needed.

The Detection Algorithm will be responsible for fetching data from the assorted sensors, interpreting the acquired data to estimate the current status of limbs accurately, then determining whether the exercises forms are proper or not. Since the correctness of the detection result is critical in order to prevent danger when exercising, the algorithm must not be prone to error and use cautious when producing results. Apart from the accuracy, speed of the detection must also be emphasized to timely inform user and minimize the time user operating in the improper form. A flow chart for the proposed algorithm sequence is shown below in Figure 4.1.

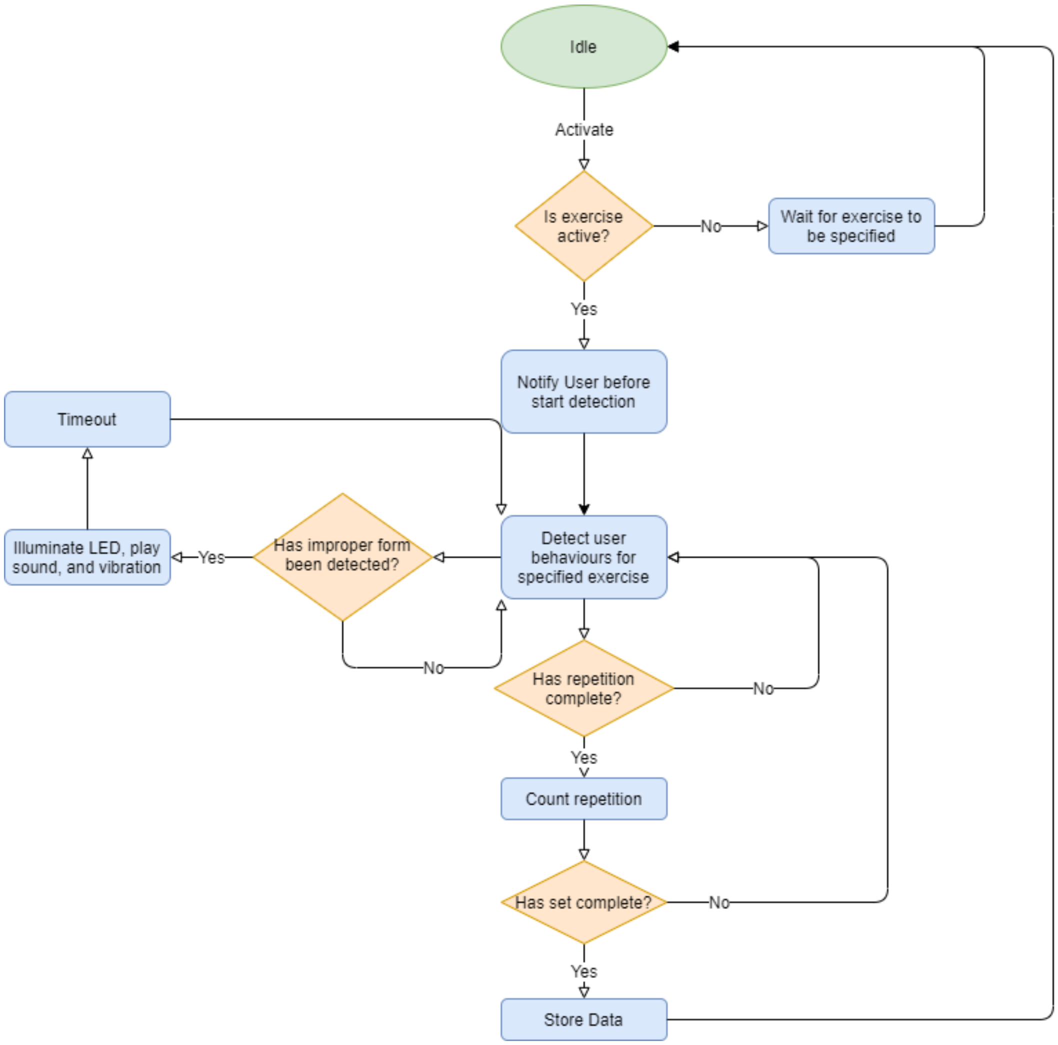

Figure 4.1: Pro-Tek Algorithm flow chart

4.2 Detection Algorithms

4.2a Forearm Data

The data coming from the forearm units consists of the IMU measurements (angles) and the optical distance sensor measurements (distance to wrist). This information needs to be sent from each forearm unit to the primary unit for processing. The main detection algorithms will take place on the primary unit itself, combining the data from all sensors on each unit. Because the detection is occurring in real time, these algorithms need to be efficient and accurate, ensuring the user is using proper form. The detection will only begin after providing the user with a notification, coming in the form as a flashing LED and vibration sequence. This notification is required, as to not enforce detection rules on the natural movements of the user. Calibration procedures will take place during the first exercise session while using the Pro-Tek system, and in some cases, before a certain exercise is started. This will ensure that the detection is robust for varying body types that exhibit different biomechanics. Improper form will be notified to the user through an LED indicator, encoding information about the form that needs to be fixed.

Des 4.2a-1-P	The forearm unit must be able to receive commands over Bluetooth to start data transfer or illuminate an LED.
Des 4.2a-2-M	The forearm unit must transfer all improper form events and exercise data to the primary unit over Bluetooth on exercise completion.

Table 4.2a.1: Design Requirements for software executed on forearm units.

Des 4.2a-3-P	The forearm detection algorithm must compare the incoming angle data to a specified angle range, ensuring values are within this range.
Des 4.2a-4-M	The forearm velocity must be calculated by integrating the accelerometer values for each repetition.
Des 4.2a-5-P	The algorithm must notify the user with LED and vibration notifications to indicate that form detection is starting, after an exercise is selected.
Des 4.2a-6-P	The algorithm must generate an LED and vibration notification in the event that forearm angles exceed the specified range.
Des 4.2a-7-P	After a notification event, the algorithm should have a timeout of 100 ms.
Des 4.2a-8-P	The algorithm must generate its response within 10 ms of an improper form event.
Des 4.2a-9-P	The algorithm must apply different angle ranges for different exercises.
Des 4.2a-10-P	The algorithm must use the linear accelerometer data to count repetitions, depending on the exercise.
Des 4.2a-11-P	Algorithms must be able to calibrate the starting wrist angle and limb orientations.
Des 4.2a-12-P	The algorithm must use the initial calibration data to subtract any offsets from attachment angle.

Table 4.2a.2: Design Requirements for forearm detection algorithm, executed on forearm units

4.2a.1 Forearm Angle Algorithm

Due to the large variations in human biomechanics and anthropometrics, devising a consistent angle detection algorithm is made quite difficult. These difficulties are remedied by performing initial calibrations, removing undesired offsets, and applying a generic reference frame for measurements. After calibration, described in Section 4.2a.3, the forearm unit is in the reference frame of an arm that is perpendicular to the surface of the earth in both horizontal directions. This reference frame will be the same for any user with any attachment angle. This standardized orientation can then be used in the detection algorithm, to compare the angle values to standardized values. When angles are measured to be outside of the specified range, an event will occur, notifying the user to fix their improper form.

4.2a.2 Wrist Angle Algorithm

To make sure the wrist twist angle is in a proper range, the distance between the module and the back of hand should be considered. During the calibration step, the module will get an average value of distance names dc = 8 mm. And the laser sensor locates at the center of the PCB, the height names h. The theoretical average wrist angle for a health person is 12.1 degree (range 5-20 degree) [15] and the maximum twist angle is set as the theoretical angle plus 15 degrees. When the theta increases, the distance decreases.

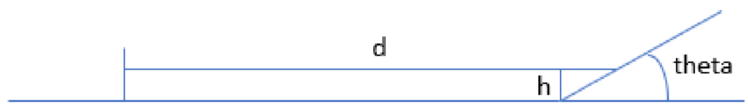

Figure 4.2a.2: Twist Angle Calculation

The equation below shows the minimum distance to obtain the corresponding maximum theta:

$$d_{min} = d_{calibration} + \frac{h}{\tan\left(\theta_{theoritical} + 15\right)} - \frac{h}{\tan\left(\theta_{theoritical}\right)}$$

This equation will be used in the algorithm and once the detected distance for wrist is less than the threshold distance, it means unproper movement is detected and should have further reactions.

4.2a.3 Initial Forearm Calibration

To ensure consistency in angle measurements between individuals with differing physical characteristics, an initial calibration is performed [Req 3.2-7-P]. This calibration process will instruct the user to hold their forearms in a specific position while samples are collected. After all samples are acquired, they will be averaged and used in the algorithm to account for any initial offsets. The intended calibration procedure will be described in further detail.

A standardized forearm positioning is required to perform a consistent, reliable calibration between various users. After Pro-Tek is fixed on the forearm, the procedure devised was to have the user hold a dumbbell weight, such that their arm was pulled directly downward. The weight of the dumbbell was comparable to the weight of a human arm. By using gravity to ensure that the arm was being pulled directly downward, the slight offset angle could be measured and removed from further calculations. Taking several samples, then summing each sample together, and finally dividing the summed result by the number of samples, the average offset forearm angle was calculated. A diagram depicting the calibration posture is shown below in Figure 4.2a.3.

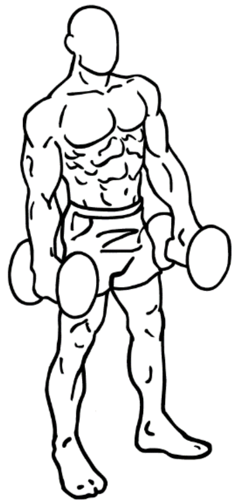

Figure 4.2a.3: Calibration Posture [16]

4.2a.4 Repetition Counting

Repetition counting is another feature of the Pro-Tek system [Req 3.2-5-M], allowing users to automatically keep track of their workouts. An algorithm to count repetitions was devised, such that repetitions would be counted accurately and reliably. Careful consideration went into this implementation, as repetitions should only be counted during certain exercise movements, not the natural movement of the user. To ensure proper results, counting will only begin when the user starts a selected exercise. Once the counting logic has been activated, it will begin to detect the user's movements and wait for certain conditions. The proposed algorithm flowchart is depicted in Figure 4.2a.4.1below.

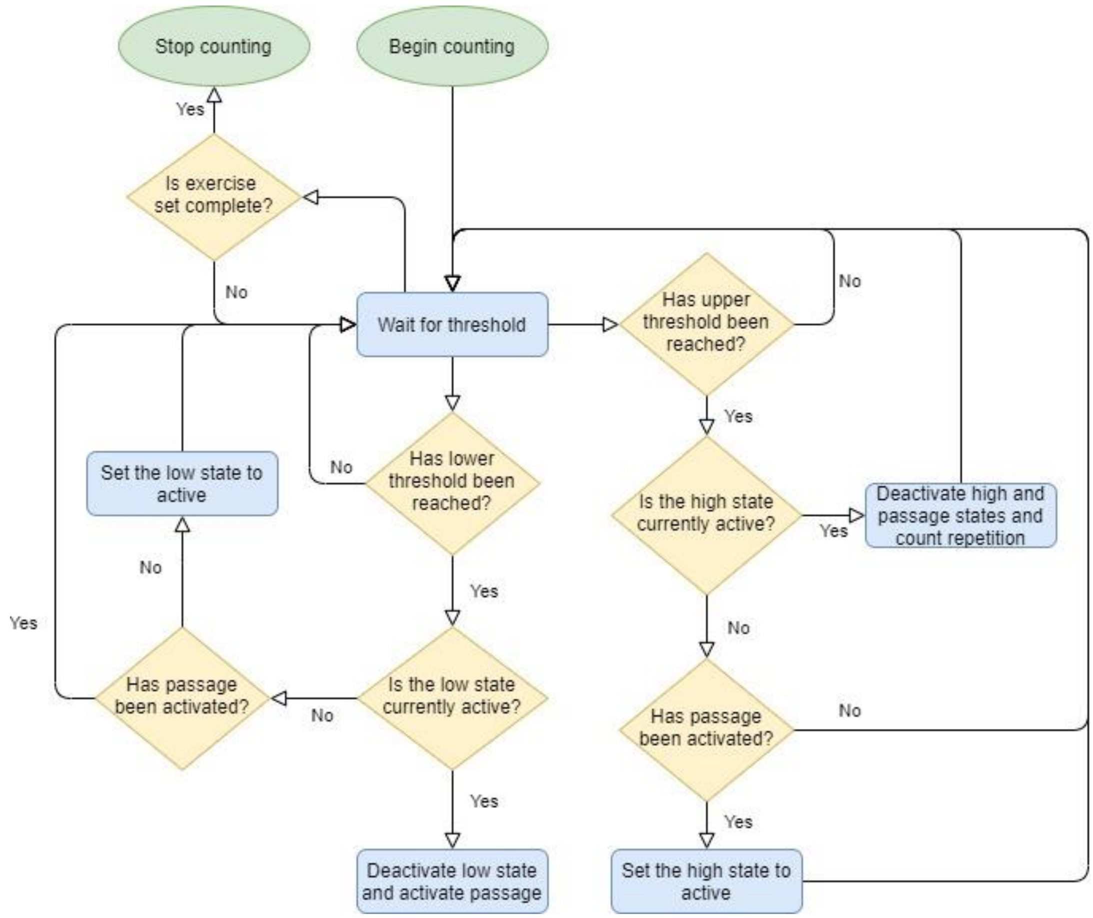

Figure 4.2a.4.1: Repetition Counting Flowchart

This algorithm was adapted from [17], to suit our purposes. The algorithm proposed here consists of two main states, a low state, and a high state. There is also a passage state, set to indicate the passage between the two previously mentioned states. Depending on the exercise, the algorithm will first look for either the low or high state. In the flowchart of Figure 4.1, the algorithm first looks for a low state, waiting for the accelerometer values to drop below a certain threshold. Once this threshold has been reached, the algorithm will determine whether the low state is already active. If it is inactive, as well as the passage state, it can then be set to active as no other states are currently active. The linear acceleration value will typically overshoot the threshold and return to 0 as the movement stops. The algorithm will wait until this value returns to the threshold, while the low state is active. Once this has been achieved, the low state will be set to false, having the passage state activated. A visual depiction of this behavior can be observed in Figure 4.2a.4.2. A very similar process will be completed with the high state, with the difference that the passage state must be activated before any further activity. Once both states have been detected, the repetition will be counted, and the cycle will restart.

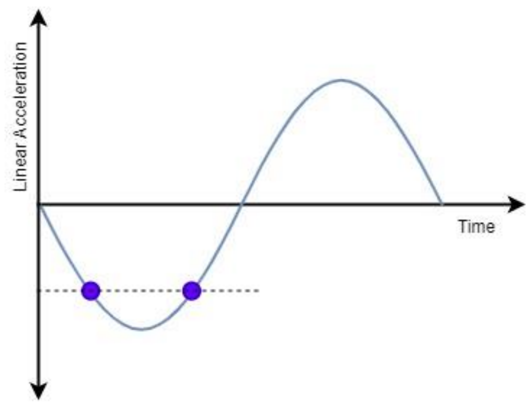

Figure 4.2a.4.2: Linear acceleration threshold overshoot and restoration

By virtue of this state detection, the upward and downward phases of the exercise could be detected, satisfying [Req 3.2-4-M]. For example, in bench press, the bar moves up and down in a vertical manner. The upward and downward movements could be recognized based on the positive and negative inflections of the linear acceleration. This way, different conditions could be applied for different phases, allowing a more nuanced detection of exercise form.

4.2a.5 Quaternion to Euler Calculations

IMU orientation data is commonly presented in one of two forms, either in quaternion form or Euler form. Euler angles provide information about the orientation of the IMU in 3D space by giving three angle measurements, one in each axis. This is the desired format in our application, as it is representative of real space and can be used to measure joint orientations. However, the Euler outputs of the BNO055 are only to be used for compass measurements and should not exceed 45 degrees in the “pitch” and “roll” directions. A visual indication of pitch and roll directions are shown below in Figure 4.2a.5.

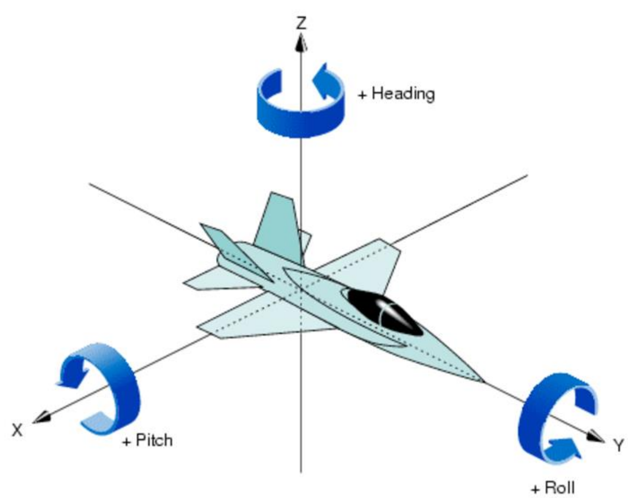

Figure 4.2a.5: Depiction of roll, pitch, and heading directions in 3D space [18]

Because this angle restriction severely limits the range of measurement, another way of calculating angles was required. This was the purpose of the quaternion data. Quaternions are a mathematical representation of orientations and rotations in 3D space. They can be converted to Euler angles, allowing measurements of angles at any orientation in 3D space. The range for the BNO055 after conversion spanned from –180 degrees to 180 degrees in the pitch direction and –90 degrees to 90 degrees in the roll direction. This result was much more satisfactory for our needs. The conversion itself, however, is quite involved and will be described below.

Quaternions are represented as an extension of complex numbers, with a scalar adding to the three basic quaternions. A usual representation of a quaternion is as follows.

$$q = q_0 + q_1\boldsymbol{i} + q_2\boldsymbol{j} + q_3\boldsymbol{k}$$

To then convert this form into the more recognizable Euler angles, trigonometric identities are used [19]. This conversion is shown below.

$$\begin{bmatrix} \phi \\ \chi \\ \psi \end{bmatrix} = \begin{bmatrix} \tan^{-1}\dfrac{2(q_0q_1 + q_2q_3)}{1 - 2(q_1^2 + q_2^2)} \\ \sin^{-1} 2(q_0q_2 - q_3q_1) \\ \tan^{-1}\dfrac{2(q_0q_3 + q_1q_2)}{1 - 2(q_2^2 + q_3^2)} \end{bmatrix}$$

The result of this conversion is used in all detection algorithms as it gives a valid geometric representation of the orientation angles without any constraints. The conversion is also quite simple, not requiring any complex or time-consuming algorithms to generate a result. This implementation was completed in the software, simply using the in-built mathematical libraries.

4.2b Hip Data

The primary unit is to be placed on the hip, measuring the orientation of the torso from this location. This data will be similarly used in the detection algorithms to ensure that the torso is within specified angle ranges. Because the hip unit is also the primary unit, all processing will occur here, combining the data from each individual unit. This unit also needs a calibration, ensuring consistency across different users. The requirements for the hip detection algorithm are shown below.

Des 4.2b-1-P	The hip detection algorithm must compare the incoming angle data to a specified angle range, ensuring values are within this range.
Des 4.2b-2-P	The algorithm must notify the user with LED and vibration notifications to indicate that form detection is starting, after an exercise is selected.
Des 4.2b-3-P	The algorithm must generate a notification in the event that torso angles exceed the specified range.
Des 4.2b-4-P	The algorithm must use the initial calibration data to subtract any offsets from attachment angle.

Des 4.2b-5-P	The algorithm must use the linear accelerometer data to count repetitions, depending on the exercise.
Des 4.2b-6-P	The algorithm must apply different angle ranges for different exercises.
Des 4.2b-7-M	The algorithm must generate its response within 10 ms of an improper form event.
Des 4.2b-8-P	The algorithm must transfer commands to the UART terminals, to be sent to the forearm units through Bluetooth.
Des 4.2b-9-P	The primary unit must send commands to forearm units over Bluetooth to initiate calibration or form detection.
Des 4.2b-10-M	The primary unit must receive commands from the smartphone and send exercise data to the smartphone over Bluetooth.

Table 4.2b: Design Requirements for Hip Data Collection

4.2b.1 Torso Angle Algorithm

Similar to the difficulties presented in Section 4.2a.1, the torso detection too can be difficult to predict due to the variations in biomechanics. A calibration is also used in this instance to remedy this issue, with calibrations sometimes occurring before a specific exercise to establish a baseline orientation. Due to the lack of required constraints, biomechanical models can be difficult to devise as there are several variables that are not always constant. Examples of these variables include varying equipment dimensions and user abilities. With these calibrations however, the units will be placed in a standard reference frame, allowing their measurements to be compared to standard values. Also, for the pre-exercise calibrations, the units will be calibrated to the user's specific characteristics, tailoring the detection to the specific individual. Similar to the forearm modules, if the torso is measured to be outside a certain range, a notification event will occur to notify the user to fix their form.

4.2b.2 Initial Hip Calibration

A similar process to that described in Section 4.2a.3 is used to perform the hip calibration. When calibrating, all three units can be calibrated at once if the user assumes the posture depicted in Figure 4.2a.3. The user interface will prompt the user to ensure that their posture is straight, such that the calibration will remove the initial offsets due to attachment on a straight posture. The same averaging procedure will take place, generating a good estimate of the initial offset angle.

For certain exercises, a calibration may need to take place at the beginning of the set, due to the inherent variations in human limb length and exercise equipment size. The user will be prompted to calibrate before beginning the set, to ensure that proper angle range enforcements are being made. An example of this situation is during the deadlift. Because users having varying limb lengths will require a different torso angle when setting up for a repetition, the initial angle must be calibrated. The units will flash green three times to notify the user to properly set up before the calibration begins. During the calibration process, the units will hold a solid purple color to inform the user that calibration is occurring. Once complete, the user can proceed to continue with their exercise, having properly calibrating the units.

Des 4.2b.1-1-P	Each unit must be able to perform a calibration for a specific exercise.
Des 4.2b.1-1-P	The forearm units must flash green three times to inform user of upcoming calibration.
Des 4.2b.1-1-P	The forearm units must hold a solid purple color while calibration is taking place.
Des 4.2b.1-1-P	Each unit must acquire samples during the calibration period and perform an overall averaging once calibration is complete.

Table 4.2b.1: Design Requirements for Initial Hip Calibration

4.2c User Notification

Two main mechanisms of user notification will be used in this system, one being LED notifications and the other being vibration notifications. Because the units may not be always visible, tactile notifications are used to ensure that the notification is perceived. For both LED and vibration notifications, the notification will be encoded to contain information about the improper form event. Varying vibration pulse durations and sequences, as well as LED colors will be used to encode this information. All of these encodings will be present in the application and user manual and will be designed in such a way to not overload the user.

Des 4.2c-1-P	The detection algorithm must generate LED notifications to indicate improper form.
Des 4.2c-2-P	The forearm LED must be illuminated as amber if the arms are in an improper orientation.
Des 4.2c-3-P	The algorithm must illuminate the forearm LED as red if the wrists are in an improper orientation.
Des 4.2c-4-P	The algorithm must illuminate the forearm LED as blue if the torso is in an improper orientation.
Des 4.2c-5-P	The algorithm must send a command to the forearm units to illuminate the forearm indicator LED during an improper torso form event.
Des 4.2c-6-P	The algorithm must be able to send a vibration notification, specific to the type of improper form.
Des 4.2c-7-P	One long vibration pulse must be sent by the forearm unit in the event of improper forearm orientation.
Des 4.2c-8-P	Two short vibration pulses must be sent by the forearm unit in the event of improper wrist orientation.
Des 4.2c-9-P	One long vibration pulse must be sent to the hip unit in the event of improper torso orientation.

Table 4.2c: User Notification Design Requirements

As stated in [Req 3.2-9-F] and [Req 3.2-12-P], the Detection Algorithm must communicate with the user clearly and within a short interval of time. By illuminating LED in different colors, it allows the Detection Algorithm to deliver notification without ambiguity, while placing the LED on the forearm unit maximize the visibility to the user. At the same time, vibration could relay the message more directly and thus adds another method to reliably inform the user of the form detection result, which further reinforce the fulfilment of the corresponding Requirements.

Section 5 – Engineering Standards

To sell Pro-Tek in Canada or even the worldwide market, the CAN/CAS, ASTM, and IEEE standards are explored and expected to be strictly followed to ensure the safety and health.

STANDARD	DESCRIPTION
CAN/CSA-C22.2 No. 61508-1:17	Functional safety of electrical/electronic/programmable electronic safety related systems – Part 1: General requirements [20].
ASTM D5511-18	Standard Test Method for Determining Anaerobic Biodegradation of Plastic Materials Under High-Solids Anaerobic-Digestion Conditions [21].
ASTM D5526-18	Standard Test Method for Determining Anaerobic Biodegradation of Plastic Materials Under Accelerated Landfill Conditions [22].
CAN/CSA C22.2 NO. 107.2-01	Battery Chargers.
10.1109/ICEEE. 2018.8533993	Methodology for the registration of human movement using accelerometers and gyroscopes [23].
IEC 61010-1 Ed. 3.1 b:2017	Safety requirements for electrical equipment for measurement, control, and laboratory use - Part 1: General requirements CONSOLIDATED EDITION.
IEEE 802.151-2002	Specific requirements – Part 15.1a: Wireless Medium Access Control (MAC) and Physical Layer (PHY) specifications for Wireless Personal Area Networks (WPAN) [24].

Table 5.1: Engineering Standards

Section 6 – Conclusions

Pro-Tek enables the possibility of people to do exercises safely to maximize the experience. Through Bluetooth connection, the user's information during exercise sessions will be transmitted to the connected mobile device and the app can display the repetition count, a graph and improper form details if there were any.

The following is a summary of the mentioned design specifications:

1. Hardware Design Requirements
    - Microcontroller design
        - Primary unit microcontroller will be connected to app and forearm module through Bluetooth module.
        - Forearm unit is connected to primary unit by Bluetooth module.
    - Sensor's design:
        - Forearm unit
            - IMU: It provides the orientation measurements for the unit and applies the detection algorithm on the collected data and sends the data to the primary unit by using microcontroller.
            - Distance Sensor will be used to measure the twist angle of wrist and sends the measurements to forearm unit.
        - Primary unit
            - It is located at the hip and is used as an intermediate between forearm units and the mobile app.
    - Bluetooth Module
        - This module allows communication between the smartphone and all three modules, creating a bidirectional connection for the entire system.
    - Vibration motor
        - It is used to provide notifications to the user if one's exercise form is incorrect. All the modules contain this unit.
    - Battery
        - Lithium-Ion Polymer battery will provide power to the Microcontroller and will last approximately 4 hours (while the system is active) and 10 hours (the system is on standby)
2. Software Design Requirements
    - Front-end design
        - App will be connected to primary unit using Bluetooth module.
        - Android application will be used to display the exercise selection and user info options.
        - Graph will be provided at the end with exercise summary.
        - Repetition count will also be displayed to keep track of exercise history.

- Back-end design
    - Calibration
        - Initial Forearm Calibration: is used to make sure device can do right measurements apart from having different individuals with different physical characteristics. All calibrations are done directly on the microcontroller.
        - Initial Hip Calibration: It is also used to make sure there is no previous offsets which can cause error in the hip measurements.
    - Detection algorithms
        - Wrist Angle Algorithm: it is used to make sure wrist angle is in the proper range. If the user's exercise form is incorrect then it is indicated by LED lights and vibration on the module.
        - Forearm Angle Algorithm: This algorithm will make sure the horizontal angle is in the proper range.
        - Torso Angle Algorithm: It is used to make sure angle of torso with respect to ground is in the proper range.
        - Repetition counter algorithm: It allows the users to automatically track their workouts and this data is sent to mobile app through primary unit to display the information at the end of exercise.
    - Data transfer over Bluetooth
        - Primary unit contains special HM-10 Bluetooth module which acts as Bluetooth master and a slave. Forearm units are connected to primary unit by Bluetooth connection and the primary unit is connected to mobile application through another Bluetooth connection. So, there is no direct connection between forearm and app.

This document outlines all the design specifications of Pro-Tek, and it is intended to be used as a design reference for GymSmart inc team. This document provides detailed insight into the hardware and software designs required for our product to be intuitive and valuable for the user. However, the specification details in this document may be slightly modify as the project progresses.

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Appendix A: Test Plan for Proof of Concept

Mobile app

Des 9.1.1-P	User information	Date: / /
Test procedure: Type in basic information in the portfolio section.		
Expected Outcome: The information can be reviewed after being stored.		
Result: (Pass/Fail) and comment		

Des 9.1.2-P	Calibration	Date: / /
Test procedure: In the calibration section, user is prompt to follow specific instructions for data collection.		
Expected Outcome: Calibrating process is done and collected data is shown.		
Result: (Pass/Fail) and comment		

Des 9.1.3-P	Bluetooth connection	Date: / /
Test procedure: Connect the module by opening Bluetooth in smart phone.		
Expected Outcome: Bluetooth status in the mobile app is shown as "Bluetooth connected".		
Result: (Pass/Fail) and comment		

Des 9.1.4-P	Data display	Date: / /
Test procedure: After connecting to the module, rotate and move the module around.		
Expected Outcome: The angle and velocity information should be shown as line graph.		
Result: (Pass/Fail) and comment		

Des 9.1.5-P	Warning display	Date: / /
Test procedure: Start with an exercise type and move with improper form during the exercise session.		
Expected Outcome: Warning messages will pop out and user can review it after the exercise session ends.		
Result: (Pass/Fail) and comment		

Hardware Design

Des 9.2.1-P	Drop Test	Date: / /
Test procedure: Drop the module at a height about 90 cm from the ground.		
Expected Outcome: The module should stay in one piece and still functionable.		
Result: (Pass/Fail) and comment		

Des 9.2.2-P	Dust Test	Date: / /
Test procedure: Bury the module in a container filled with sand.		
Expected Outcome: The module should isolate most of the sand from going into the module and still functionable.		
Result: (Pass/Fail) and comment		

Des 9.2.3-P	Waterproof Test	Date: / /
Test procedure: Spray water on the module.		
Expected Outcome: The module should prevent water going into the module and still functionable.		
Result: (Pass/Fail) and comment		

Des 9.2.4-P	Clip Test	Date: / /
Test procedure: Attach the module on the body part and jump/run with the module attached.		
Expected Outcome: The module should not fall off during the test.		
Result: (Pass/Fail) and comment		

Electronics Testing

Des 9.3.1-P	Power supply	Date: / /
Test procedure: Press the power button.		
Expected Outcome: Each of the module should be powered by one power supply.		
Result: (Pass/Fail) and comment		

Des 9.3.2-P	Battery	Date: / /
Test procedure: Charge the module at 5V and 100 mA.		
Expected Outcome: 250 mAh battery should charge fully, regulating 5 V down to 3.7 V to charge the battery. The red charging LED light should turn on.		
Result: (Pass/Fail) and comment		

Des 9.3.3-P	Battery life	Date: / /
Test procedure: Fully charged the module.		
Expected Outcome: The module should last 10 hours with idle state.		
Result: (Pass/Fail) and comment		

Form detection test

Des 9.4.1-P	Form detection	Date: / /
Test procedure: Test the module on same exercise with different individuals.		
Expected Outcome: Warning messages should pop out for improper forms from different individuals. LED light should turn on and vibrator will vibrate.		
Result: (Pass/Fail) and comment		

Appendix B: UI and Appearance Design

B.1 Introduction

The Pro-Tek form trainer consists of physical and software components, both requiring consideration for the interface and appearance design. This design intends to maximize the product's ease of usage, allowing users to seamlessly interact with the system and use it effectively. The "Seven Elements of UI Interaction" presented by Don Norman were used to devise these design requirements. These seven elements extensively lay out the required characteristics of an effective user interface. By following these design principles, our goal is to achieve a seamless product that can be proficiently used to improve the health of many.

B.2 Purpose

The purpose of this document is to outline the various hardware and software appearances and the UI design choices that are made while designing our product. It will discuss the implementation of such features and justify each. Examples of how a user will interface with the product will also be discussed.

B.3 Scope

This document will consist of various sections discussing the UI design. These sections are the user analysis, technical analysis, engineering standards, analytical usability testing, empirical usability testing, and a graphical presentation of the proposed designs.

B.4 User Analysis

The Pro-Tek form trainer is intended to be used by any individual who wants real-time form feedback, as well as workout tracking and analysis. The user simply needs to attach each unit to its designated location and connect it with a mobile application. From there, the user will interact with a mobile application to either select the desired exercise or view the history of prior exercise sessions. The user will be required to use their previous knowledge of using mobile devices and applications to operate this app. It will be intuitively designed with the different functions and features labeled clearly, such that the user does not require extensive knowledge of the system. As the user uses the app, they will begin to reinforce workflows that they can continually recall when using the system. There may be certain terminologies that are specific to weightlifting that the user may not know. Simple diagrams depicting specific actions will be used as necessary, allowing information to be conveyed visually rather than through text. To perform the connections between the mobile phone and the units, a Bluetooth connection needs to be established. This pairing process will benefit from the user knowing how to connect a mobile device to a Bluetooth device. The app itself will have simple instructions on how to perform such a task if the user is unfamiliar with the process. Any other required processes, such as the calibration procedure, will also be descriptively detailed within the app for the user to intuitively follow.

In terms of the units themselves, they will all have a power button, as well as an LED indicator. The power button will be labeled appropriately with a corresponding icon. The LED indicator, however, will require some acquired knowledge that the user will gain through reading the instructions and using the system. Because information will be encoded in the colour of the LED indicator, there must be a legend that the user can refer to. This will be stored in the app, for the user to reference at any time. Also, if the user were to miss a notification during a set, the app would keep a record of problematic repetitions and the improper form associated with them. The user can later review their workout set and identify where one can improve. Operation of the units themselves is quite simple, however, the understanding of the conveyed information received from them may be more complex.

Finally, with respect to physical abilities, our system itself is not very physically demanding, however, the activities associated with it are. The user will be required to insert each unit into a designated location on a compression shirt that is easily accessible while being worn. These locations will also be specified within the app and user manual, to ensure each unit is properly placed and oriented on the user. No inherently complex physical abilities are required to operate our product, allowing it to be used without excessive amounts of effort.

B.5 Graphical Presentation

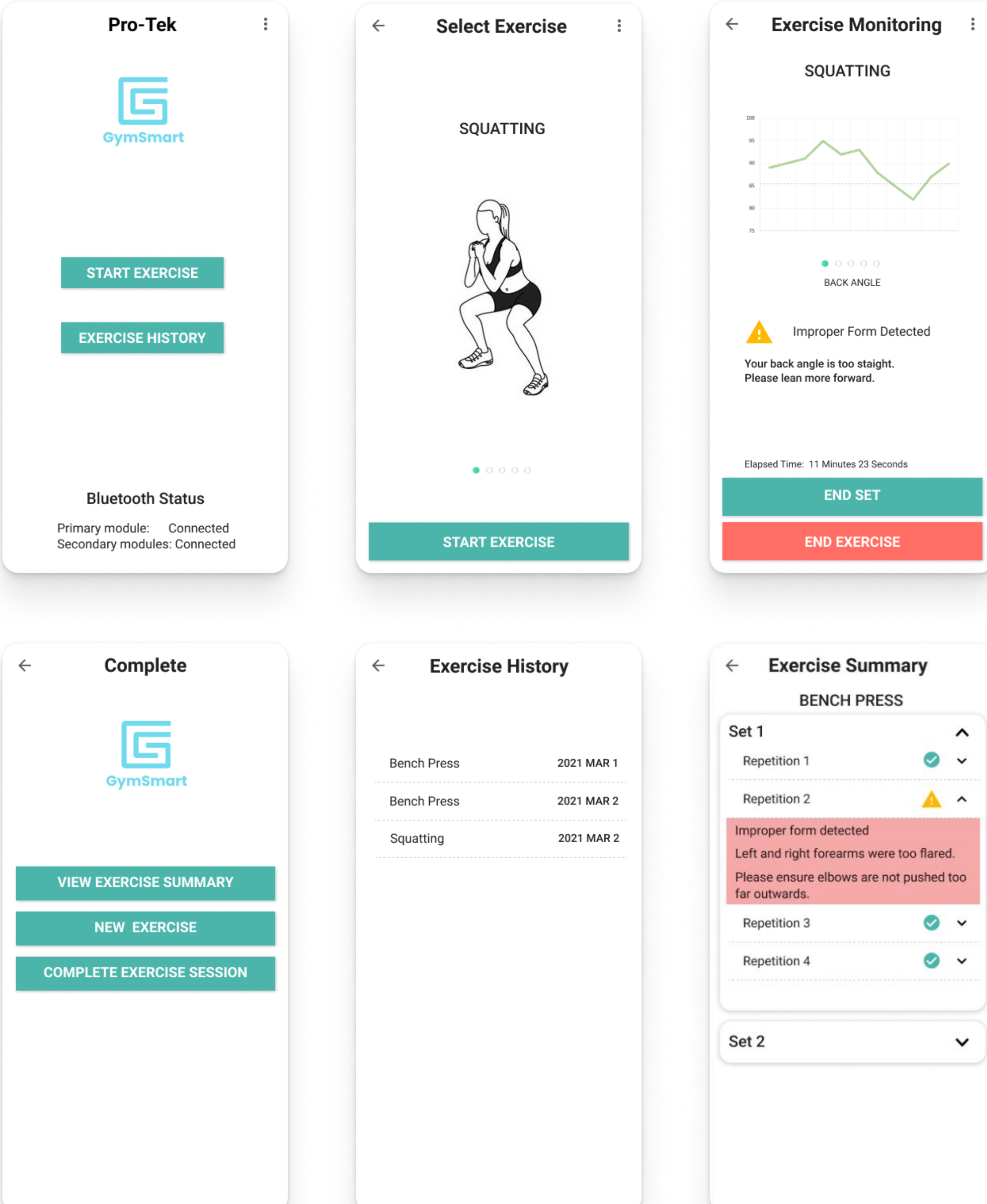

Figure B.1: Layout of Pro-Tek Android App [25]

Figure B.1 displays the layout of the Pro-Tek App, which is designed through Figma Android UI Kit [26]. The main page shows the options users can choose and status for the connection between the phone and the product. If the connection is successfully established, the user can click to start the exercise or check for exercise history. The second page allows users to choose an exercise that Pro-Tek supports and start the session. The Exercise Monitoring page demonstrates how the app will display the data sent from Pro-Tek and notify the user if improper form is detected. After ending the exercise, the App will display a screen asking users if they want to check exercise summary or want to start a new exercise or end their exercise session. The fourth page shows how the exercise history will be displayed. Finally, the last page shows which set/repetition the user had improper form and it also displays a detailed message about the problem and what could be done to improve it. During the exercise, if an improper form is detected, the user will also be notified by a LED notification on the hardware device itself.

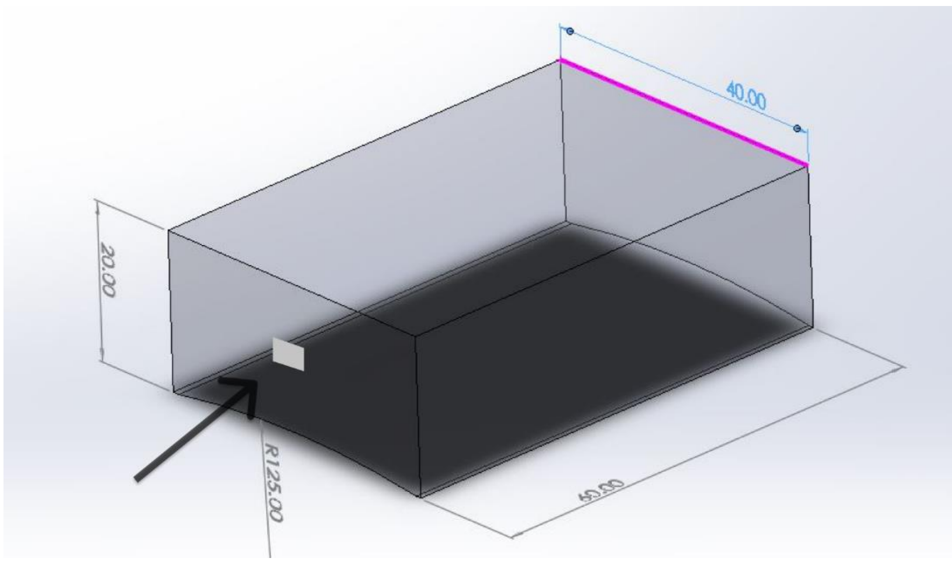

Figure B.2: Design of Pro-Tek in 3D model

Figure 2 is the 3D model of the Pro-Tek. This model will be used specifically for wrist location. The indicated design will contain IMU sensor, Bluetooth module and optical distance sensor. The small window pointed by an arrow on the front view is for the optical distance sensor to sense the distance between the module and back of the palm. While the module for hip and forearm will have the same outlook but without the window. The dimension of the module is 60 mm long, 40 mm wide and 20 mm high.

B.6 Technical Analysis

From Don Norman's Book "The Design of Everyday Things" it discusses 7 main criteria for everyday deigns: Discoverability, Feedback, Conceptual Models, Affordance, Signifiers, Mapping, and constraints. [27]. Here we will discuss how we have taken these topics into account for our device.

B.6a Discoverability

For user's convenience of using the Pro-Tek, sensor modules should be easily fixed on user's body. The ON/OFF button on the primary unit is able to control all sensors on secondary units. Once all modules are on, users can connect sensor system with phone by Bluetooth.

App main page checks Bluetooth connection state and buttons' functions are obvious. Each button goes to a corresponding new page and back arrow at upper right corner can go back to the pervious page. All data collected from sensors should be presented by chart form and reminding for improper behavior must be obvious even when user is not looking at the phone.

B.6b Feedback

Feedback is required to provide user confidence while interacting with the Pro-Tek system. In our system, this feedback can be twofold. The first feedback mechanism is the communication to the user that some action is being completed, as per their request. This allows the user to have confidence that their actions are having effects within the system and performing their desired request. Visual indicators such as loading spinners or application state changes will be implemented within the application to give a user feedback. In terms of the sensor units, LED indicator lights corresponding to powered operation or battery charging will be used to inform the user of the current device status. The second feedback mechanism is the primary function of the Pro-Tek system, being improper form notification. As the user engages in improper form, an LED indicator light, separate from the charging/operation light, will be illuminated as a certain color. This color will encode information about which limb is in an improper orientation such that the user can take the action. The color coding will be intuitive, as to not incur a significant load on the user in terms of memorizing the various encodings. The feedback indicators for the prototype device are listed below.

Hardware Units

- A solid green LED labeled "POWER" will indicate the powered operation of the device.
- A solid red LED with the label "POWER" will indicate the unit is charging.
- A flashing red LED with the label "POWER" will indicate that the device is below 10% battery level.
- A solid blue LED with the label "FORM" will indicate issues with the back angle.
- A solid red LED with the label "FORM" will indicate issues with the wrist angle.
- A solid amber LED with the label "FORM" will indicate issues with the arm angle.
- All LEDs off indicate the device is powered off.

Mobile Application

- During an exercise set, a graph displaying each unit's angle values will be presented.
- After the set is complete, the user can view their performance for the set, with repetitions that exhibited improper form labeled with a recommendation.
- The battery status of the units, as well as their connection status, will be displayed.

- Errors or issues will be displayed as an in-app notification.

B.6c Conceptual Model

A conceptual model is how the user understands a system to work and is important for giving the user a sense of control. In the case of Pro-Tek, its app is designed for easy navigation to exercises selection and exercise history with clear menus. The users can easily access this app on any android device.

B.6d Affordances

Affordances of Pro-Tek shows the quality of this product. Since it will be used in work out environment, all electronic components can withstand certain pressure. The weight of sensor units is quite low so they will not be a burden during the exercise. Bluetooth module uses BLE 4.0 (Bluetooth Low Energy) technology, and all smartphones produced after 2009 are able to support this technology. Affordances also represent the way in which the user should interact with the device. The forearms units will have a subtle curvature to match the rounded organic shapes of human individuals. This indicates that they are to be placed on the arms in a comfortable manner. They also will have a single button to power the device, as no other actions are required by the user on the units themselves. The application will also have clear indications that the system is to be used in a weightlifting environment, displaying relevant useful diagrams.

B.6e Signifiers

Signifiers in Pro-Tek App clearly instruct users for their functions. The arrow at upper right corner represents back to pervious page and arrow signifiers for the list help to expend the list or close it. The button labels tell user the function they do, and the borders of labels and background color help separating buttons from text. On the physical units, the power button will be clearly labeled with a recognizable icon, with the LED indicators appropriately labeled.

B.6f Mappings

The idea of mapping is creating a relationship between a certain control and its effect on the system. An example of this is having real time feedback of user behaviors. When user twist the wrist, the twist angle will be shown at the center of screen. In terms of each individual unit, the LED corresponding to a specific function will be clearly labeled. For example, any LED indications relating to power will have a "POWER" label beside it. The LED indicator relating the form detection will have the label "FORM" clearly beside it. The power button itself will have a descriptive icon that the user can easily recognize.

B.6g Constraints

To avoid the situation that users are burdened with too many contents, the App needs to constraint information displays on the screen. One function corresponds to exactly one page and users do not need to scroll the page up or down. Button labels use the simplest word to describe the function of the button so that control pages look clean. Also, the constraints of hardware are the range of measured data. For example, if the rotation angle of the wrist is out of range, the App can only report 'out of range' rather than a value.

B.7 Engineering Standards

Table B.7 shows the Engineering standards chosen for the Pro-Tek. The left-hand column represents the Standard ID given by the following Engineering standards organizations: IEC, ISO, ASTM and IEEE.

STANDARD	DESCRIPTION
CAN/CSA-C22.2 NO. 61508-1:17	Functional safety of electrical/electronic/programmable electronic safety related systems – Part 1: General requirements [20]
ASTM D5511-18	Standard Test Method for Determining Anaerobic Biodegradation of Plastic Materials Under High-Solids Anaerobic-Digestion Conditions. [21]
ASTM D5526-18	Standard Test Method for Determining Anaerobic Biodegradation of Plastic Materials Under Accelerated Landfill Conditions. [22]
10.1109/ICEEE. 2018.8533993	Methodology for the registration of human movement using accelerometers and gyroscopes. [23]
IEC 61010-1 ED. 3.1 B:2017	Safety requirements for electrical equipment for measurement, control, and laboratory use - Part 1: General requirements CONSOLIDATED EDITION.
IEEE 802.151-2002	Specific requirements – Part 15.1a: Wireless Medium Access Control (MAC) and Physical Layer (PHY) specifications for Wireless Personal Area Networks (WPAN) [24]

Table B.7: Engineering Standards

B.8 Analytical Usability Testing

Throughout the development stages of the Pro-Tek form trainer, the user experience (UX) while interacting with the system will be carefully considered. However, every aspect of the UX may not be addressed within this time, therefore requiring usability testing to be conducted. Analytical usability testing will ensure that any potential UX issues are identified, and properly addressed. This testing will consist of each company member receiving a subsystem of the Pro-Tek system and completing a set number of specific procedures. Each member will carefully document their experience, to be discussed and acted upon by the corresponding system division. The UI may be still in progress during the proof-of-concept phase. therefore, the hardware and software subsystems will be tested independently.

Heuristic Evaluation

A heuristic evaluation will be applied to test the various aspects of our product, to ensure that our system can be used with efficiency and consistency. Errors should be as minimal as possible, with a reasonable recovery process in the event of an error. The results of this evaluation will be applied to further developmental progress on the proof of concept and prototype. The evaluation metrics are shown below.

Proof of Concept:

1. Forearm units are reliably able to detect forearm orientation with respect to the ground.
2. Forearm units will send data to the primary unit for processing.
3. Primary unit is reliably able to detect back orientation with respect to the ground.
4. Primary unit can perform processing for all 3 sets of input data.
5. Primary unit can send commands to each forearm unit to illuminate LED when improper orientation is detected.
6. Primary unit will communicate with mobile application, receiving information about selected exercise and transferring data about detected form issues and counted repetitions.
7. Each unit will count repetitions depending on the selected exercise.
8. Each unit is mounted firmly to the user.
9. Application will allow for selection of desired exercise.
10. Application will facilitate Bluetooth connection with the primary unit.

Prototype:

1. Each unit can be powered with a single button.
2. Each unit is placed inside a compression shirt pocket, ensuring proper orientation.
3. Application will store user workout history and previous form information.
4. Application will display improper repetitions identified within each set.
5. Application will make suggestions on how to improve form.
6. Clear instructions and user manual will be included within application.

B.9 Empirical Usability Testing

Internal Testing

Pro-Tek will conduct the usability testing among its member first to locate any obvious problems. The full set of -Tek modules will be wore by each member and the tester will comment on if it can be fit tightly and how comfortable it is to wear. The tester will also examine the Android phone app and test its responsiveness and behaviour correctness. Then the tester will perform a set of exercise that is supported by Pro-Tek, other members will monitor the readings reported back to the phone app and determine if the form detection result is correct. After the exercise, the tester will comment if the modules are fixed and if they will affect the movements. Finally, the tester will check if the exercise statistic stored on the phone app can be accessed.

End User Testing

Pro-Tek will enlist help from people with no prior knowledge of the Pro-Tek. Users will be asked to use and provide feedback on the product to improve on the final design of the Pro-Tek.

End User Testing- Survey: These questions will be reworded into a user-friendly feedback form consisting of rating scale from 1-10, allowing users to rate each category.

1. Was the device easy to wear?

2. Was the device easy to setup?

3. Was the device comfortable to wear?

4. What was your first impression of the device?

5. Would this be something you are willing to wear every day? If not, why?

6. Was the App intuitive to use? If not, what could be done to improve it?

7. Would you recommend Pro-Tek to others? Explain.

User Feedback Form

Test Environment:										
Rating Scale: 1-10 (1: Bad and 10: Excellent)										
Questions:	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Ease of wearability										
Ease of setup										
Comfortability										
First impression of device										
Willing to wear every workout?										
How was the provided form feedback?										
How intuitive was it to use the device and user interface??										
Will you recommend the device to others?										

B.10 Conclusion

User Interface Design is a critical component of any product. UI will give consumers the option of learning and using the product quickly or making it difficult to the point where they will not want to use it. The UI Appendix explains the required UI components for the user's comfort and ease. Through the UI design, Pro-Tek enables the possibility of people to do exercises safely to maximize the experience. Through Bluetooth connection, the user's information during exercise sessions will be transmitted to the connected device and display in terms of real-time position. Users will be able to pick an exercise using a mobile app and will be able to see the exercise summary and history on the app. The person will also be notified by an LED indicator if the exercise form of a user is bad. The pro-Tek team will work closely with users to ensure that both the hardware device and the mobile application function as planned, gathering feedback and test results that will allow us to make design changes.

Appendix C: Design Options

C.1 Hardware Design Options

C.1a IMU Options

Module Name	DOF	Available Sensors	Sample Rate	Input Voltage	Communication Protocol
MPU-6050	6	Accelerometer, gyroscope	1kHz	2.3V-3.4V	I2C serial communication
MPU-9250	9	Accelerometer, gyroscope, magnetometer	100 kHz	1.95V-3.6V	I2C serial communication
BNO055	9	Accelerometer, gyroscope, magnetometer	100 Hz	2.4V-3.6V	I2C serial communication

Table C.1a: List of IMU options with specifications presented [28, 29, 30]

1. MPU-6050

The MPU-6050 was the first IMU that was tested. Because it only has 6 degrees of freedom, this limits the accuracy that it can achieve in terms of absolute orientation. The sensor outputs also suffer from drift, causing the values to "drift" away from their initial starting point over time. The angle measurements are a crucial part of this system and need to be as accurate and consistent as possible. Because the requirement was not fulfilled, the MPU-6050 was not considered as a viable option.

2. MPU-9250

The next sensor module that was tested was the MPU-9250. This module added a magnetometer, increasing the available degrees of freedom to 9. Significant accuracy improvements were made, and drift was largely diminished. More complex sensor fusion algorithms were required for this module as there were now 3 sensors to fuse. Also, the magnetometer needed an initial calibration, as is the case with most magnetometers. From initial testing, the sensor performed quite well and produced stable, accurate measurements that did not suffer from drift. However, when held in certain orientations, the measurements began to lag and not represent the current angle in real time. This posed a significant problem for our application, as a real time analysis of the data is required. Another issue with the sensor module was an initial inaccuracy in accelerometer values. For an unknown reason, the accelerometer displayed non-zero values in both horizontal directions that were not subjected to gravity. This may have been a calibration error or a sensor issue, nonetheless, we still decided to investigate other sensors due to the other mentioned non-idealities.

3. BNO055

The tested sensor module that produced the most ideal results was the BNO055. This module gave high accuracy, real-time angle measurements that suffered very minimally from drift. The sensor fusion algorithms are calculated on board the sensor module, providing either quaternion or Euler angle outputs for angle data. This module is a 9DOF sensor, containing an accelerometer, gyroscope, and magnetometer. Each one of these sensors can be queried individually, allowing for more than just angle measurements. The angle measurements, however, were very accurate and responsive in any orientation. The only drawback of this sensor module was the relatively slow sample rate. For this application in particular, the sample rate was found to be sufficient, as human movements are typically not outside of this range. Because this sensor satisfied the requirements in [Req 3.2-2-P] and [Req 3.2-8-F], it was chosen to be used in further development. The technical specifications of the IMU are shown below in Table 3.2a.2.

C.1b Microcontroller Options

Microcontroller	Processor	Input Voltage	Storage	Clock Rate	UART+I2C
Adafruit Pro Trinket	ATmega328	5V	28KB of flash	16 MHz	Yes
Metro Mini 328	ATmega328	5V	32KB of flash	16 MHz	Yes
Adafruit ItsyBitsy 32u4	Atmega32u4	5V	28KB of flash	16 MHz	Yes
Adafruit ItsyBitsy nRF52840 Express	nRF52840	3.3V	1MB of flash	64 MHz	Yes

Table C.1b: List of microcontroller options with specifications [31, 32, 33, 34]

1. Adafruit Pro Trinket - 5V 16MHz

The Pro Trinket satisfied all the requirements stated in Section X. Because of its small form factor, it was also an idea solution for a minimal final footprint. There were no inherent issues with this device, other than the fact that is has now become deprecated with other alternatives available. For development, it required an external serial-to-USB converter as there were none on board. This caused for a slight inconvenience in terms of development but resulted in a smaller size and a lower cost.

2. Adafruit Metro Mini 328 - 5V 16MHz

Due to the deprecation of the Pro Trinket, one of the newly recommended microcontrollers with a small form factor was the Metro Mini 328. This microcontroller also satisfied all the requirements stated above but made a few improvements to the Pro Trinket. Not only does the Metro Mini 328 feature a serial-to-USB converter on board but has slightly more storage and is better compatible with newer computers for development. These features do result in a slight increase in price, with the benefit of future proofing the system.

3. Adafruit ItsyBitsy 32u4

Another recommended microcontroller was the ItsyBitsy 32u4. This microcontroller too satisfied all the above requirements but was an optimal combination of the previous two microcontrollers. Not only is it smaller than the Metro Mini 328, but also has native USB capabilities, not requiring a serial-to-USB chip. It can also interface with a battery shield, allowing the device to be powered from an external battery. This battery shield also facilitates battery charging, through the micro-USB port available on the microcontroller. This was the optimal solution, as it had a desired form factor with all the required functionalities.

4. Adafruit ItsyBitsy nRF52840

The Adafruit ItsyBitsy nRF52840 is a small form factor microcontroller that is compatible with the Arduino IDE for development and testing. This microcontroller supports native USB capabilities, not requiring an additional serial-to-USB chip. It also is capable of data transmission through the I2C protocol, allowing it to easily interface with many MEMS sensors. Because there is an onboard Bluetooth module, a large amount of space is conserved as external modules are not required. Space conservation is very desired in this application and makes this microcontroller an ideal solution. In terms of power supply, the ItsyBitsy nRF52840 can interface with a battery shield, allowing the device to be powered from an external battery. This battery shield also facilitates battery charging through the micro-USB port, already available on the microcontroller.

C.1c Distance sensor Options

Module Name	Available Sensor	Normal Measuring Distance (m)	Typical Update Rate (Hz)	Accuracy	Input Voltage	Dimension	Interface
VL6180	Time of Flight distance sensor	0.01 to 0.1	26	± 5mm	2.8 - 5V	20.5mm x 18.0mm x 3.0mm	I2C
Sharp GP2Y0A21YK0F	IR distance sensor	0.1 to 0.8	50	+/- 1%	4.5 - 5.5V	13.5mm x 44.4mm x 18.7mm	analog
HC-SR04	Ultrasonic distance sensor	0.02 to 4	40	± 3mm	5V	45mm x 20mm x 15mm	PWN

Table C.1c: List of distance sensor options with specifications [35]

1. VL6180

The VL6180 is the first distance sensor we tested, and it is also the final choice we made. The VL6180 uses time-of-flight technology, which combining the IR emitter and range sensors to measure the time the light spends to travel to the nearest object and reflect to the sensor, therefore achieve the distance. For our module, this distance sensor satisfied all the requirements stated above. According to Des 2.1a-4-P, the distance sensor is supposed to be capable of communication with the microcontroller over the I2C bus protocol. The VL6180 met this requirement and could simply coordinate with other sensors which also used I2C communication protocol. The input voltage ranges from 2.8V to 5V also enables the sensor to accept variation errors from microcontroller. Besides, the size of this sensor is also the smallest among the different sensors, which saving the space of Pro-Tek. Since we only need to measure the distance to the back of hand, 10cm maximum measuring distance is enough and can perfectly realize the function and determine the twist angle.

2. Sharp GP2Y0A21YK0F

Sharp GP2Y0A21YK is the most widespread IR distance sensor [36]. It determines the distance to the object by returning an analog voltage and coming with a 12" long 3-JST interface wire. Comparing with the I2C connection between the sensor and Microcontroller, it is more complex and will take up more space. Admittedly, the most apparent advantage of IR sensor is that it provides the function to measure the distance of objects that have complex surfaces, but this seems not be exploited in our project since the target object is the human skin. This sensor also provides lots of noise and it is difficult to calibrate the sensor.

3. HC-SR04

HC-SR04 is one of the most popular ultrasonic sensors. Ultrasonic Sensor is regarded as the most common type of distance measuring sensor. It acts like bats and uses sonar to find out the distance to the object. The transmitter sends a high-frequency sound, and the sound signal will reflect and return to the receiver once it finds the object. Our module tends to be resistant to water and there is going to be a glass plate covering the distance sensor. To meet this requirement, two ultrasonic transducers in HC-SR04, which used to realize distance measurement will need largest hole as well as glass and have the greatest potential to have water leak.

C.1d Bluetooth Module Options

Bluetooth Module	Bluetooth Version	Input Voltage	Input Current	Baud Rate	Transfer Speed
HC-05	Bluetooth 2.0	5V	20mA	9600	160Kbits/s
DSD Tech HM-10	Bluetooth 4.0 LE	2.5 - 3.3V	8.5mA	9600 – 230400 Configurable	2Mbits/s
Nodic nRF52840	Bluetooth 5 LE	1.7 -5.5V	1.5μA @ 3V	-	2Mbits/s

Table C.1d: List of Bluetooth Module Options with Specification [10, 37, 38]

1. HC-05

The HC-05 module is commonly used in many Arduino projects thanks to its availability and high user base. It follows the Bluetooth 2.0 specification which is an older version, but it allows the maximum compatibility. Its transfer speed is adequate for the simple communication scenario, but it draws higher power which makes it less ideal for the design specification.

2. DSD Tech HM-10

The HM-10 from DSD Tech is another popular option and has rich documentation from the manufacturer which make it easy to configure. It uses the newer Bluetooth 4.0 LE standard which allows it to use much less power than classic Bluetooth device. Also, the transfer speed increases thanks to the updated Bluetooth standard, and can connect to most Android devices [8]. In all this module is more suitable for the project.

3. Nordic nRF52840

The Nordic nRF52840 is sophisticated Bluetooth module, capable of the Bluetooth 5.0 LE standard. Even though the module is running the Bluetooth 5 firmware, it is still backwards compatible with the previous versions of Bluetooth. For power consumption, its adaptive power management system can achieve exceptionally low power consumption, performing optimizations on the chip itself. Because this module is integrated into the Adafruit ItsyBitsy nRF52840, it allows the forearm unit microcontroller to be Bluetooth capable. This module is capable of the master/slave functionalities required by the primary unit but will be tested further before amending the design choice in this document.

C.1e Vibration Motor Options

Vibration motor	Voltage (DC)	Termination style	Dimension	Communication protocol	Rate speed
DFRobot – DFR0440	5 V	PCB board	33 mm x 22 mm x 18 mm	PWM	-
Vibrator motor – 316040001	3 V	Wire leads	Diameter 10 mm	-	10000 rpm (minimum)

Table C.1e: List of vibration motor options with specifications

1. DFRobot – DFR0440

DFR0440 is one of the most popular vibration motors that used with Arduino Uno. It is soldered on a PCB board and using 3 pin interface which can treated as a plug and play module. However, due to the size of the socket for wire connection and the dimension of the PCB board, it is much bigger in size comparing to vibration motor – 316040001. Other than that, its PWM communication protocol is different than the I2C connection protocol that the microcontroller that we are using.

2. Vibrator motor – 316040001

316040001 is a simple wire lead vibration motor. Due to its small size, it can be placed flexibly inside the module. Also, vibration indication is not crucial while user is lifting with heavy weights, so the strength of the vibration that the motor provides does not have to be too strong. Therefore, vibration motor solely with vibration feature is more than enough for our project since the microcontroller can be programmed to set the duration of the vibration.