BU Department of Electrical & Computer Engineering

# Boston University

# Electrical and Computer Engineering

## EC 464: Senior Design Project

# User Manual

# Flextend

FLEXTEND


Written By

Team 24: Flextend

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# Executive Summary

*Carmen Hurtado*

The knee is one of the most injury-prone joints in the body. Frequently, knee injuries require surgery and physical therapy alongside constant monitoring for rehabilitation and recovery. Current monitoring systems are costly and do not provide appropriate accommodations for the individual. FLEXTEND is an at-home, self-administered device that will measure the flexion and extension of the knee in degrees and track results for the users. FLEXTEND will provide a cost-efficient and accommodating option for active adults, the elderly, and any others with pre existing knee conditions. Featuring a cross-platform mobile application and on-device screen, our product will be user-friendly, interactive, and customizable to the user's recovery goals.

## 1. Introduction

*Jack Halberian*

The knee joint is extremely susceptible to injury because it is put under continuous stress during normal activity. In fact, knee injuries are one of the most frequent causes of pain among individuals of all ages according to MayoClinic. When the knee is injured, it is common to seek help from a doctor and a physical therapist to assess the injury and to restore knee functionality. To assess knee health, physical therapists will often measure the knee extension and flexion of the patient as a reflection of the range of motion of the joint, which is an excellent indicator for knee health. With this information, the physical therapist is able to establish exercises and routines that help the patient's knee heal. This method, while effective at restoring knee health overall, is costly and sometimes inaccessible for patients. Many who struggle with knee health issues do not have a physical therapist nearby, and if they do, therapy is often cost prohibitive.

Flextend strives to eliminate this barrier for patients by providing a method for measuring knee extension and flexion at home. With this device, users can keep track of their knee health by measuring the range of motion of the knee, and use this information with a medical professional to assess the situation and inform further action. Flextend is an electromechanical device which comfortably straps to the user's thigh and shank and allows the user to take measurements without the aid of a physical therapist.

The device is paired with a cross platform (Android and iOS) mobile application to allow the user to interactively track their progress. In the app, users can create an account, see their previous measurements, set goals and calendar reminders, and ascertain their flexion and extension values relative to others with similar body metrics. The data collection for flexion and extension also takes place in this application, which is automatically stored for the user to track their progress.

In the following sections of this manual we will describe the functionalities of the application and the device, how to operate the product, the technical background, the technical specifications of the product, and a cost breakdown of the product.

# 2. System Overview and Installation

## *2.1. Overview Block Diagram*

*Carmen Hurtado*

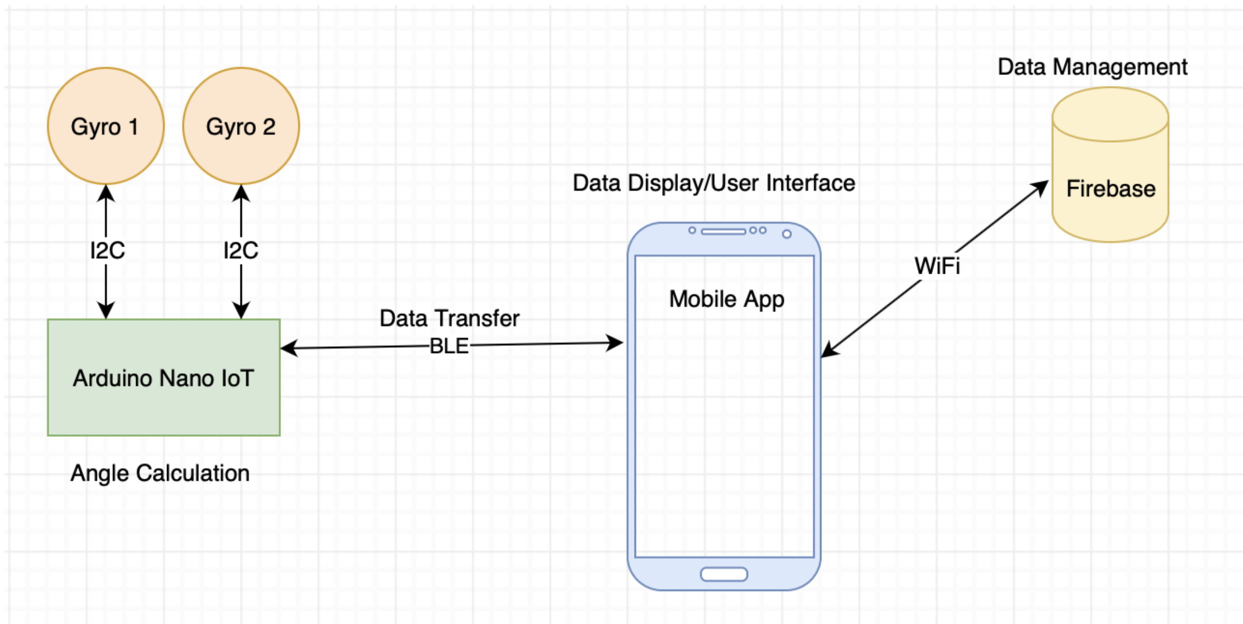



Figure 1: *System Flow from left to right: The main board is the Arduino Nano IoT which reads data taken from the gyroscope sensors. The angle is calculated in the Arduino and that data is sent to the Mobile Application through a BLE connection. Any data that is saved from the Mobile Application to the Firebase database is done through a WiFi connection.*

## *2.2. User Interface*

*Thomas Scrivanich*

The team has built a mobile cross-platform application that runs on both iOS and Android operating systems. The user is able to register a new phone number if it is their first time using the Flextend application. If the user has already registered, they can simply login with their phone number.

Upon successful login/registration, the user is directed to the home page. The home page allows a user to begin a measurement, quickly access their most recent results, or sign out. The "most recent results" screen displays two progress rings. There is also a button which displays the user's initials. If the user clicks on that button, they are directed to their profile page.

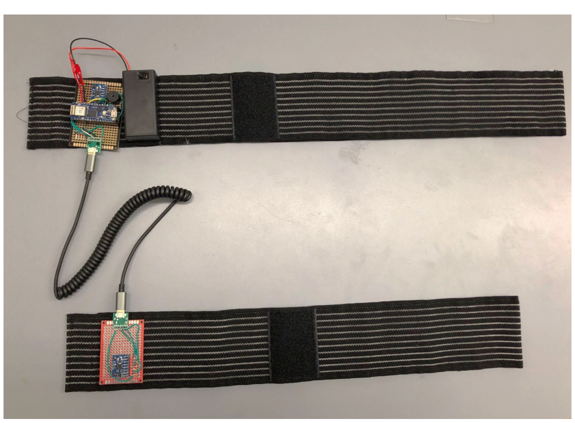
From the profile page, the user can update their avatar image, enter body metrics, track their progress over time, set up reminders, and set goals. On iOS, the avatar image selection will open the user’s Photos app to select an image. Similarly, the reminder screen will open the user’s Calendar app. On Android, the avatar image selection will open Google Photos to select an image. The reminder screen will open Google Calendar. The progress screen will display two bar graphs with an additional option to generate a report based on the data.


Figure 2: *Our mobile application’s user interface shown through four images. From left to right these images are: Login Screen, Registration Screen, Home Screen, and Profile Screen. These images were captured on an Android device.*

## *2.3. Physical Description*

*Murat Sencan, Carmen Hurtado*

The device has three separate pieces: two elastic velcro straps and one micro USB to micro USB cable. Each of the elastic straps has an MPU6050 sensor, and the thigh strap also has the Arduino board and battery case. These velcro straps can be adjusted and will stretch based on your upper/lower leg size. There is a switch on the battery case that is used to turn on and power the electronics. The battery is pre-installed and does not require any charging; however, it will need replacing once it uses all its power.



### *2.4. Installation, Setup, and Support*

**Installation:** The Flextend device comes in three separate pieces that the user needs to put on their leg. The user will strap on both elastic velcro straps and then connect the micro USB to micro USB cable to the opening in the electronics cases. To power on the device simply flip the power switch on the top of the battery case.

The Flextend mechanical device will connect to the mobile application via Bluetooth when the user navigates to the “Start Tracking” screen. The device should be in close proximity to the mobile phone running the app so that the device can pair successfully.

**Setup:**

1. Download the Flextend mobile application from the Google Play store (Android) or the App Store (iOS).
2. Register a new user account with a phone number.
3. Power on the Flextend device.
4. To measure, navigate to the “Start Tracking” page and make sure the device successfully paired with the app.

**Support:** The user might have difficulty pairing the device with the mobile phone. If the device does not seem to be paired, please try these steps:

1. From the “Start Tracking” screen, navigate back to the Home screen.
2. Turn off then turn on the Flextend device and wait a few seconds.
3. Navigate to the “Start Tracking” screen again. The application should look for the Flextend device upon navigating to this page and pair successfully.

## 3. Operation of the Project

### *3.1. Operating Mode 1: Normal Operations*

*Carmen Hurtado*

Under normal operation, the user will interact with the device as follows:

1. The user will put on the top part of the device to the thigh above the knee joint by adjusting the flexible velcro strap. Then, the user will adjust the positioning of the sensor to be aligned with the center of the leg. The arrow marking on the sensor should be pointing down.

2. The user will put on the bottom part of the device to the shank below the knee joint by adjusting the flexible velcro strap. Then, the user will adjust the positioning of the sensor to be aligned with the center of the leg. The arrow marking on the sensor should be pointing up.
3. The user will connect the micro USB cable to both sensors.
4. The user will turn on the device which will give a sound to signify this.
5. The user will open the mobile application and register/login to the home screen.
6. The user will navigate to the measuring screen. The user should wait for a confirmation that the app has established a Bluetooth connection with the device. Tapping the "Calibrate" button will start the calibration process. The user should remain still until the calibration is finished, which will be announced to the user via an alert box on the app and a buzzer sound from the device. Afterwards, tapping the "Start Measuring" button will begin the measuring process and record Flexion and Extension angle values.
7. After the above process is finished, the user should be able to see the measurement on the current screen.
8. The user can then navigate through the application's features such as data management, progress view, and reminders set up.

The user will have the choice to watch short guidance videos in the mobile application's screen on the steps above. The user will see angle measurement of Flexion and Extension in degree values in the mobile application's screen.

### *3.2. Operating Mode 2: Abnormal Operations*

*Carmen Hurtado*

A list of abnormal operations and how to resolve them is provided below:

1. The physical knee device runs out of battery: The mobile application will notify the user. The user should charge the device.
2. The Bluetooth connection between the mobile application and the device is lost while measuring: The user will be notified through the mobile application and should wait for the device to reconnect. This process will activate automatically. The calibration and measurement processes will start from the beginning.

3. The mobile application loses access to the internet: This will not affect the live measurement. Data received during this time will be saved locally and pushed to Firebase once the connection is restored. The user does not need to act on this.
4. The device calibration is not configured correctly: The user will be notified through the mobile application's screen that calibration failed and that he or she should start the process again before continuing to measure.

### *3.3. Safety Issues*

*Carmen Hurtado*

The user should be sitting down when strapping on the device as they may lose balance. It is suggested to be in a sitting position while flexing and extending the leg to avoid losing balance.

## 4. Technical Background

### *4.1. Hardware Component*

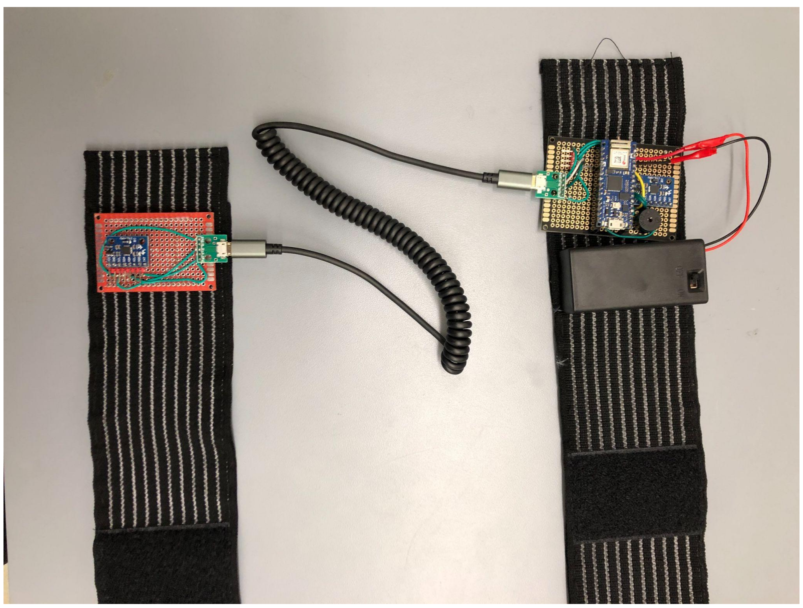
***Sohaib Ansari, Murat Sencan***

The Flextend utilizes an Arduino Nano IoT and two gyroscopes to operate the hardware functionalities. A Nano IoT connects the hardware components of the device and provides built-in WiFi and Bluetooth connectivity for software integration. The main programming language used to code the microcontroller was the Arduino IDE interface. To measure the angle for the knee, the two gyroscopes work together. One gyroscope is used as a reference at the thigh and the other is placed at the axial rotation of the knee joint. The angular tilt of each gyroscope is measured using its X, Y, and Z position and through a formula, the angle is calculated and subtracted from the reference. Integrated calibration is achieved by having the gyroscopes placed in a neutral position. The expected values are then adjusted to the measurements to display accurate data. The calibration method is triggered by a button and an accompanying buzzer sound. The measuring button allows measuring for about 20 seconds. These components are all powered by a 9-volt battery.

### *4.2. Mechanical Component*

*Murat Sencan*

The Flextend device consists of two two parts, upper leg and lower leg components. Longer velcro is connected to the upper leg and shorter velcro connected to the lower leg. These are made of flexible velcros in order to fit different leg sizes while maintaining a high mobility. Both upper and lower leg velcros have their own circuit placed in a plastic box made of acrylic. Acrylic boxes, manufactured by laser cutting, protect the circuit from potential damages. Two circuit boxes are connected with an extendable cable. Other electronic components are soldered together and connected to the boxes with silicon and super glue. The 9v battery is placed in a plastic box with an on/off switch.



### *4.3. Software Component*

*Thomas Scrivanich*

Our software component is divided into two parts: the front-end and the back-end. For the front-end, the Flextend application utilizes React Native, an open-source JavaScript framework used to develop native cross-platform applications for both iOS and Android mobile devices. Our user interface was developed using the various tools provided in the framework. For the back-end, our application uses Google Firebase, a back-end service provided by Google that our team uses for user authentication and data storage.

Our application has a secure login/registration process that is managed by Google Firebase to ensure the security of user data. Both processes are divided into two steps:

1. Entering a valid 10-digit US phone number
2. Entering a unique 6-digit code sent only to the phone number entered in step 1

The Google Firebase authentication module will validate the phone number by checking the US country code (+1) as well as the area code (first three digits after the +1). After confirming the phone number is valid, Google Firebase will perform a reCAPTCHA analysis to ensure the user is a person and not a robot. If the login/registration process is repeated within a short timeframe, the user may be asked to select matching images to confirm they are a person. reCAPTCHA uses advanced risk analysis techniques to prevent abuse and spam. The user will then receive a one-time-use 6-digit code in their messages application. This verification code has a time limit and will expire if the user does not enter the code in the mobile app. When the user enters the verification code, Google Firebase will ensure it matches the code that was sent to the user. If there is a match, the user will be logged into the application. If not, an error message will display.

Our application also uses Google Firebase Firestore for data storage. Firestore is a document-based database. This means that data for every user is stored in a unique document. The document identifier is the user's phone number. Below is an image of a test user-document in Firestore:

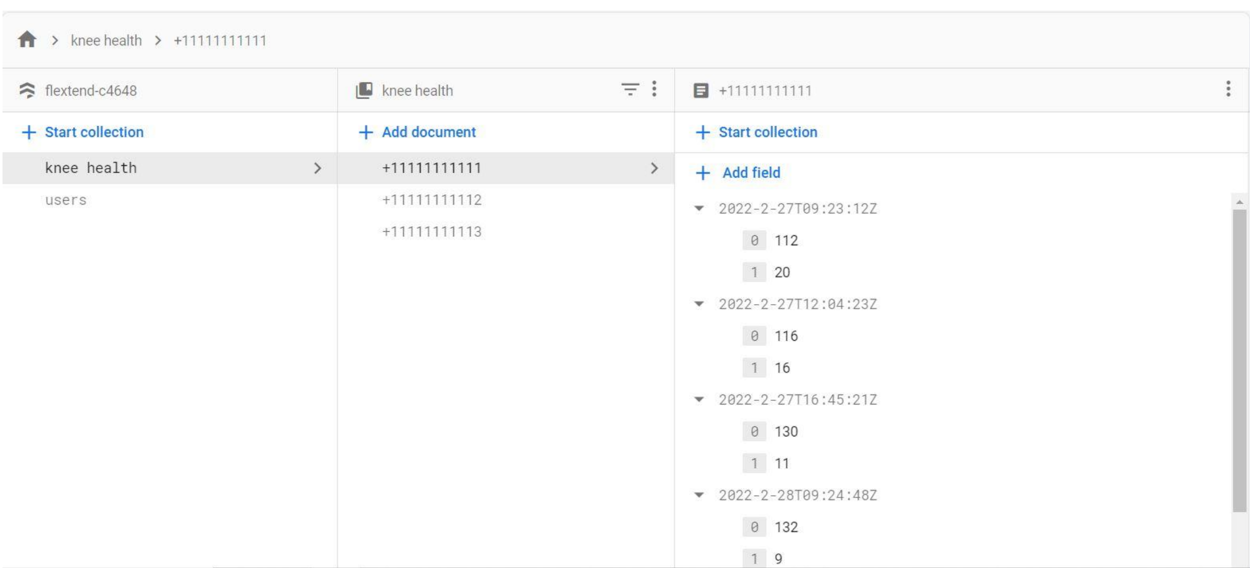



Figure 3: *Test user document in Firestore*

These documents are all stored in the “knee health” collection. This collection contains all results for every user registered in the Flextend application. The other, “users” collection, contains information about each user in our system. Here is an image of a test user-document in the “users” collection:

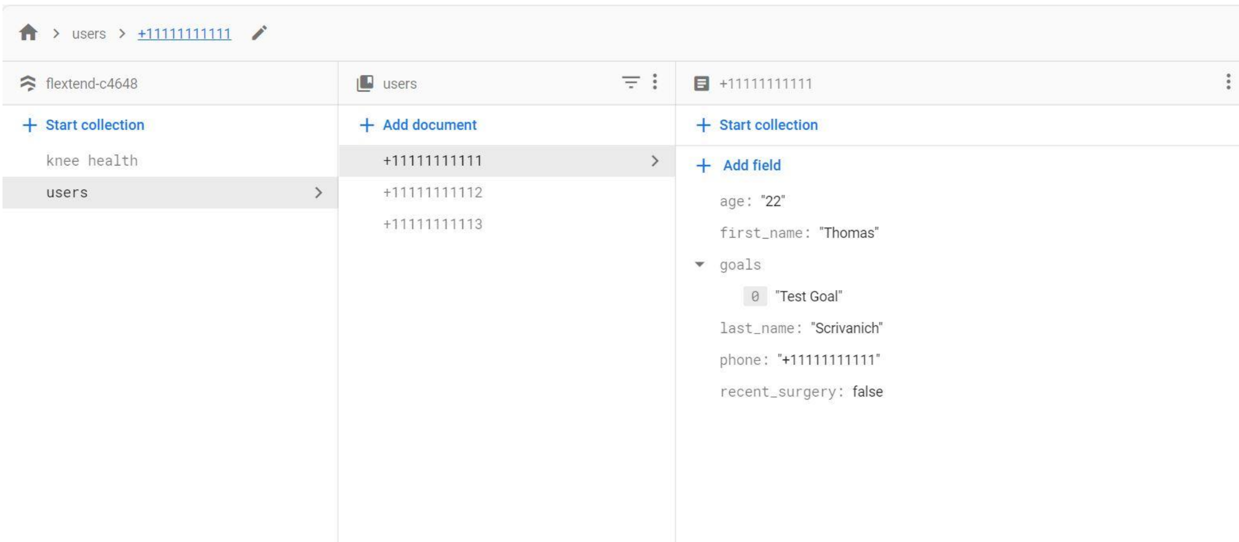



Figure 4: *Test user document in the users collection*

Lastly, our application receives data from the hardware via Bluetooth Low Energy (BLE). Our mobile app does not require a robust Bluetooth connection because the hardware only sends two degree values. Therefore, our team decided to use a simple and cost effective communication protocol. The specifications for Bluetooth Low Energy can be found in Appendix A Table 1.

The minimum time needed to send data and the maximum range for BLE is longer and shorter than the basic Bluetooth rate, respectively, however the power and current consumption is much lower. Taking into account our hardware’s materials and its low power consumption, we decided BLE was the best choice for the Flextend device.

## 5. Relevant Engineering Standards

*Carmen Hurtado*

Wireless Standard (IEEE 802.11): This standard defines the communication using the wireless service WiFi. There are many subsections to this standard that have been revised for newer WiFi technologies. 802.11 standard provides up to 2Mbps transmission for the 2.4 Ghz band, 802.11b provides up to 11 Mbps transmission for the 2.4Ghz band, and 802.11a provides up to 54 Mbps transmission for the 5Ghz band.

Bluetooth Technology Standard (IEEE 802.15): This standard defines the groups of Wireless Specialty Networks such as Bluetooth, Internet of Things networks, and wearables, among others. Bluetooth technology includes FHSS or frequency hopping with a band of 2.4 Ghz, a modulation technique GFSK, data rate of upto 700 Kbps, and a maximum operating distance of 10 m.

## 6. Cost Breakdown

This is the estimated pricing of one unit of Flextend

| Item | Cost/Unit | Quantity | Total Cost |
|---|---|---|---|
| Arduino Nano 33 IoT | $20.7 | 1 | $20.7 |
| MPU-6050 3 Pack | $9.99 | 1 | $9.99 |
| 3V Gikfun Active Buzzer 10 PAck | $10.88 | 1 | $10.88 |
| HiLetgo 120pcs/3x40pcs Breadboard Jumper Wires | $5.99 | 1 | $5.99 |
| MCIGICM 400 Points Solderless Breadboard | $7.99 | 1 | $7.99 |
| Duracell 9V Battery 2 PACK | $13.59 | 1 | $13.59 |
| Wellgo 608-2RS Ball Bearings Skateboard | $9.95 | 1 | $9.95 |
| VIGAER 8"-12"-18"-24"-30" Reusable Fastening Cable Straps, 30 Pcs Securing Straps Adjustable Nylon Hook and Loop Cinch Cable Ties Down with Metal Buckle | $11.89 | 1 | $11.89 |
| Cylewet 20Pcs 5mm High Knob Vertical Slide | $7.98 | 1 | $7.98 |

| | | | |
|---|---|---|---|
| Switch 3 Pin 2 Position 1P2T SPDT Panel (Pack of 20) CYT1107 | | | |
| 50 Pcs Double Sided PCB Board Prototype Kit Soldering 5 Sizes 4 Colour Universal Printed Circuit Board for DIY Soldering and Electronic Project | $14.99 | 1 | $14.99 |
| Clear Scratch- and UV-Resistant Cast Acrylic Sheet, 12" x 12" x 1/2" | $33.98 | 1 | $33.98 |
| Clear Scratch- and UV-Resistant Cast Acrylic Sheet, 12" x 12" x 1/16" | $5.61 | 1 | $5.61 |
| Clear Scratch- and UV-Resistant Cast Acrylic Sheet, 12" x 12" x 3/32" | $5.77 | 1 | $5.77 |
| 18-8 Stainless Steel Dowel Pin, 1/4" Diameter, 3/8" Long, Packs of 10 | $3.65 | 1 | $3.65 |
| Dowel Pin, 4140 Alloy Steel, 5/16" Diameter, 3/8" Long, Packs of 10 | $10.16 | 1 | $10.16 |

| | |
|---|---|
| **TOTAL** | **$173.12** |

# 7. Appendices

### *6.1. Appendix A - Specifications*

| Specification | Value |
|---|---|
| Maximum Range | <100 m or <330 ft |
| Minimum Time to Send Data | 3 ms |
| Power Consumption | 0.01 - 0.50 W |

| | |
|---|---|
| Peak Current Consumption | <15 mA |

*Table 1: Bluetooth Low Energy Specifications.*

### *6.2. Appendix B - Team Information*

**Jack Halberian**

Worked primarily on the mobile application, with a specific focus on BLE data communication between the Flextend device and the mobile application. Also contributed to device design and conceptualization.

**Carmen Hurtado**

Worked on mobile application set up, navigation, UI, and some of the user profile functionality. Also worked on knee device design and implementation.

**Thomas Scrivanich**

Worked primarily with the back-end service, Google Firebase, to handle user authentication as well as handling all user data. In addition, worked on aspects of the UI for the application.

**Murat Sencan**

Worked primarily on development and manufacturing of the hardware and mechanical parts of the design. Chose sensors and soldered electronic components. Also, worked in the set up of libraries and programmed Arduino for measurement and calibration process.

**Sohaib Ansari**

Worked primarily on research, design and soldering of hardware components. Also, worked on programming of Arduino for calibration and use of communication of two gyroscopes with I2C.