Load Manager

4BI6 Project Proposal

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# Problem Statement

Injuries are something everyone has to deal with. Athletes specifically are susceptible to more injuries due to the nature of their profession. Generating and receiving large forces can cause a lot of wear and tear on your body and this is the reason why so many athletes get hurt. Currently, there is no device or system out on the market that is able to predict or warn about a possible injury in the future. This is the basis of our idea and the motivation behind the Load Manager.

In the NBA, players are sitting out for “load management” (looking at you Kawhi Leanord, thanks for the championship though) more than ever. The idea is that this solution will prevent injuries related to overloading and overuse of muscles, ligaments and tendons; allowing any microtears to heal. Knee injuries are some of the most serious and most common injuries in all sports. Constantly jumping, landing and making quick and sudden movements are all it takes to tear your ligaments or tendons. Patellar tendonitis (jumper's knee) and tendonosis is a result of overuse and not enough rest to allow the microtears in your patellar tendon to heal. Valgus forces cause your knee to cave inwards and can cause your anterior cruciate ligament (ACL), medial collateral ligament (MCL) and medial meniscus to tear. Load management is the only combat that sports franchises currently have. So what if there was a device that was able to quantify different measurements related to the knee and provide feedback regarding its health? Say hello to the Load Manager.

Thanks to Dr. Noseworthy, we were able to reach out to Dr. Dinesh Khumbare at St. Joseph’s Hospital. He is currently a professor at the University of Toronto and a former team doctor for professional organizations such as the Hamilton Bulldogs and Hamilton Tigercats. He has a lot of experience when it comes to athletes and injuries. We presented our ideas to him and explained our inspirations and proposed solution. We would like to target the knee specifically and look at preventing some of the serious injuries listed above. One thing that Dr. Khumbare mentioned was to look at the muscles supporting the knee, in particular the Quadriceps and Hamstrings. He mentioned that it is when these muscles start weakening and fatiguing, that’s when knee injuries start to occur as forces are not being absorbed by those muscles and instead being sent straight to the knee. This was another perspective we could incorporate into our design of the Load Manager.

So what is the Load Manager? This device will be a knee compression brace that includes different sensors that record and measure different things related to the knee. These measurements include pressure, position and maybe sound. We will go into more detail in the proposed solution. The next step is to get the data and send it to an app which is then capable of displaying the measurements on screen in real time. Thus when a player is playing with the brace on, a staff member can monitor the health of their knee on the sidelines through the app by analyzing the different measurements.

This project will require a strong understanding of Biomedical Engineering concepts. It will test our understanding of anatomy, biomechanics, programming, circuit design and data processing.

# System Specifications

|  |  |
| --- | --- |
| **Specification** | **Sub Specification** |
| 1. Able to detect the motion the knee is undergoing. | 1.1 Detect the pitch, yaw, and roll of the knee.  1.2 Detect the linear acceleration of the knee in three axis. |
| 1. Able to determine the weakness of the muscles moving the knee. | 2.1 Collect the pressure exerted by the muscle on the knee brace  2.2 Collect the imbalance of the muscles affecting the knee |
| 1. Wireless | 3.1 Be able to transmit the data obtained from specifications 1 and 2 to a PC without the use of wires. |
| 1. Portable | 4.1 Must be isolated from the power grid  4.2. Total weight kept under 1 kg  4.3 Able to run min 5 hours on a single charge |
| 1. Identify key events from the data | 5.1 Compare active data to a baseline and identify abnormalities  5.2 Compute the speeds the knee is achieving  5.3 Identify and quantify high stress events on the knee (jumping, quick stops, etc) |

# Proposed Solution

The load manager will include several sensors that need to be positioned strategically and acquire data that can be sent to an app to be analyzed. The following is information about the system:

## Sensors/Hardware Design

## 

## Power

In order to ensure that the device is portable, it should run on a battery. Based on the small size three battery types were considered; thin film, coin cell, and lithium ion batteries. Thin film batteries and coin cells do not have as large of a capacity when compared to lithium ion. Furthermore, since lithium ion batteries are easy to recharge they were chosen as the main power source. The battery that was chosen for the system was found on ADAfruit: <https://www.adafruit.com/product/1781>. It is a 2200 mah battery and relatively low cost.

The system is expected to have a low current draw, but once all of the sensors and microcontrollers are bought, the power consumption should be investigated. Due to the constraint that the device should be able to run for at least 5 hours, the total current draw from the system should be at maximum 440 mA. In regards to the voltage rail for the circuit, the battery voltage should be around 3.7V nominally, but fluctuates as it discharges. As such a DC/DC converter module should be used to ensure that the 3.3 V is always supplied on the power rail. Since the battery voltage could potentially go below 3.3V, a buck boost converter is the most suitable type.

## Wireless Communication

The protocol that was decided was Wifi. The main reason was that the group had previous experience with the protocol, which would shorten development time significantly. The other reason Wifi was chosen was the ability to connect to many different systems at once meanwhile bluetooth can only have 7. Looking forward, if we wanted to gather data from an entire team of players, we would only be able to accomplish this using Wifi, even though this is out of scope for this project.

## Microcontroller

The microcontroller that was chosen was the ESP32-PICO-KIT development board. This development board was chosen for three reasons. The first is that it has a small size (7.00mm x 7.00 mm x 0.940 mm). If the microcontroller is mounted to the knee brace, then it should take up the least amount of space possible. The other reason it was chosen was that it had Wifi built into the device. This will make development easier, as we wouldn’t need to get a separate module for the communication. The third reason was that it was relatively low cost. The module only cost around $15.00 together, which is a reasonable cost for this project. It should also be noted that the microcontroller is also compatible with bluetooth, so if it is decided that bluetooth is the better protocol, it shouldn’t be difficult to switch.

## Sensor Description and Reasoning:

Pressure Sensor: The pressure sensor will be used to measure how much force both the hamstring and quadriceps are putting on the knee brace. The idea behind this is to quantify the amount of contraction in the muscles. We would then take this data and determine the fatigue of those muscles as we start to detect an imbalance in the contraction. This can then be used to create notifications, on the app to give feedback suggesting that the player is tired.

Accelerometers: The accelerometer’s purpose is to determine what the athlete is doing. This includes jumping, walking, and running. This will allow us to quantify how much work is being done by the athlete’s knee and create a normal use limit. Once this normal use limit is reached the athlete will be pulled out from the game. The accelerometer will also determine high impact events on the knee to take the athlete out of the game if a force is determined to be large enough to cause or risk injury.

Gyroscope/Magnetometer: The gyroscope along with the magnetometer will help to measure the athlete’s gait as well as the athlete’s knee angle. To measure the knee angle we will use two gyroscopes one at each side of the joint. This will give us a better understanding of the knee’s typical range of motion and help us determine if the athlete ever undergoes a force that will cause the knee to leave its typical range of motion.

EMG: The EMG is a nice to have feature that will serve as a backup to the pressure sensors to determine muscle fatigue. We would like to measure the EMGs of the quadriceps and hamstrings as these muscles support the knee joint and Dr. Khumbare told us the fatigue of these muscles lead to injuries. Some possible issues that may or may not cause issues are motion artifact and the ability of the electrodes to stay adhered to the skin.

EBI (Electrical Bioimpedance): This sensor will be used to measure the amount of swelling in the knee tissue. As the swelling increases the amount of blood to the area increases the bioimpedance. The amount of swelling would relate to any injuries occured in the area. Electrical Bioimpedance as well as a microphone was used in an article where they created a similar knee brace to prevent and detect injuries. Based on the results of this study we thought that these two features would be nice to have in our design.[1]

Microphone: The microphone will determine if any unnatural noises are emitted by a knee joint. These noises could help determine if an injury has occurred.

## 

## Necessary

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Sensor** | **Quantity** | **Location** | **Reasoning** | **Interface** |
| Pressure (P) | 2 | Quads + Hams | Determine muscle fatigue | ADC/GPIO |
| Gyroscope (G) | 2 | Medial thigh and medial tibia | Positioning of the knee (flexion, extension) | I2c/SPI |
| Accelerometer (A) | 2 | Medial thigh and medial tibia | Valgus force detector | I2c/SPI |
| Magnetometer (M) | 2 | Medial thigh and medial tibia | Used to normalize the data between the earth's magnetic field and sensor, for accurate gyroscope readings | I2C/SPI |
| ucontroller | 1 | Attached to the sleeve | Read the data and send it to application | N/A |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Sensor** | **Link** | | | |
| Pressure (P) | https://www.interlinkelectronics.com/fsr-402-short | | | |
| 9-dof (G/A/M) | https://www.sparkfun.com/products/13944 | | | |
| uController | https://tinyurl.com/y4hkbucn | | | |

|  |  |
| --- | --- |
| **Anterior View** | **Posterior View** |
|  |  |

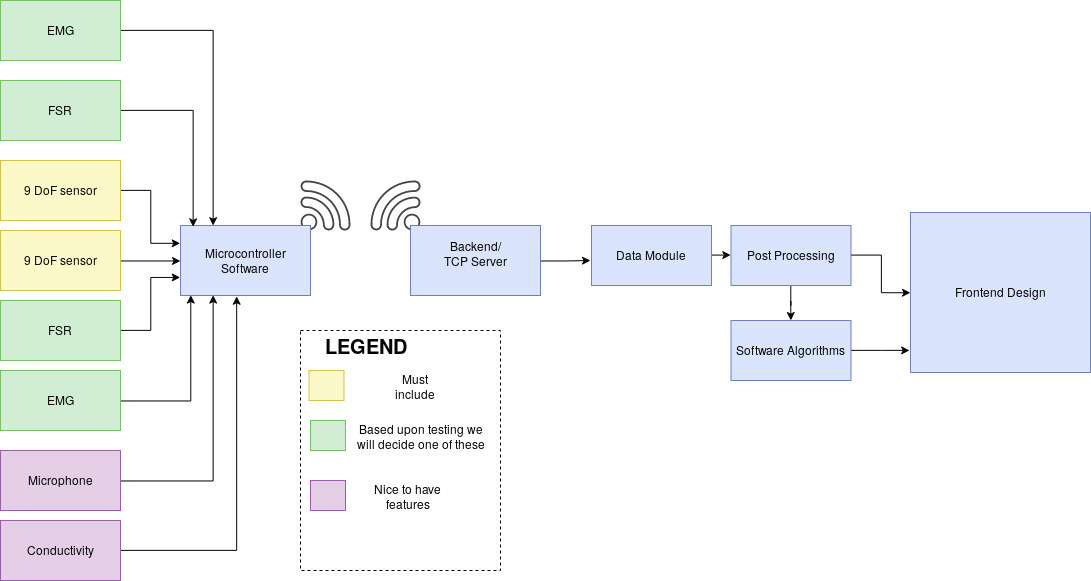
Figure 1: Anterior and posterior view of the left leg and the combination of sensors in the knee brace

## Nice To Have (Add/Test after Original plan works)

|  |  |  |  |
| --- | --- | --- | --- |
| **Sensor** | **Quantity** | **Location** | **Reasoning** |
| EMG(E) | 2 | Quads + Hams | Determine muscle fatigue, and better relationship to force produced by the muscles |
| EBI | 1 | Proximal of the Knee | Determine the amount of swelling in the tissue |
| Microphone | 1 | Patellar Tendon | Determine if there are unnatural sounds from the knee joint |

# 

## Overview of The Complete Software Design



The picture above demonstrates a block diagram of the software design. The blocks in blue are the software modules we would implement.

### Microcontroller Software

The microcontroller software will sample the registers from the sensors and convert the readings from the voltages to the data of interest, such as m/s^2 from the accelerometer. We will sample the sensors 100 times per second and store all the values in an array for the full second. This array would then be sent by wifi to the backend server. The microcontroller would continue in this loop and constantly send data to the backend server.

### Backend/ TCP Server

The backend/TCP server modules purpose is to continuously collect the data from the device. The server will use TCP because we believe the timing of the data collection is a key aspect to be able to tell when an injury occurs. If we were to use UDP, we would have to take into account the data packets not being aligned, and also perform some sorting algorithms which may further slow down the overall system. Finally, to make the server implementation easier we will consider using the MQTT protocol, and use an MQTT library in python.

### Data Module

The purpose of this module is to collect the data incoming from the device and temporarily store it in the memory. We expect the data that is transmitted to the application is arrived in a different format then the expected format for the post processing block. We expect to transmit all the data from all sensors about once every second. Hence, we will need to unpackage the data to its separate datasets for further processing.

### Post Processing

In this section of the software we will filter the raw data before sending it to the software algorithms. This could include using smoothing functions, low-pass filters, band-pass filters and possibly notch filters. We will know how to filter the data when we start to test the sensors and understand what errors they could cause. The post processing would clean any misreading from the sensors and improve the quality of the software algorithms.

### Software Algorithms

The purpose of this module is to be able to pick out certain features from the processed data. The main features we are looking to determine are the knee angles and any high-impact events which could lead to injuries. As a starting point we will use threshold values to determine these events based on initial testing. If we have time we would like to create a training mode, where we collect the data for the user and create a classification model to determine the high impact events. The classification algorithms we will consider implementing are the k-nn and SVM due to their simplicity.

### Frontend Design

We envision the frontend to be an application which shows real time data from the sensors, and also shows a quantified value for the high-impact events which then is translated to a “health score”. The frontend will also give alerts to the user for any abnormalities detected in the gait or knee angles. The wireframes here show the basic idea of all the frontend features we would like to implement. However, we will probably design a desktop application instead of a mobile application with the same features. To do this we will use a python libraries such as tkinter or PyQt.

|  |  |
| --- | --- |
| Login Page | Notification System |
| Menu | Pressure Readings |
| Data from Accelerometer | Gyroscope Readings |

# Gantt Chart Timeline:

|  |  |  |
| --- | --- | --- |
| 14-Oct-19 | 3-Nov-19 | Project Proposal  Hardware selection |
| 4-Nov-19 | 17-Nov-19 | Hardware selection |
| 18-Nov-19 | 1-Dec-19 | Microcontroller Computer Interface (USB)/Sensor Testing  UI frontend design: pick the libraries and spend time learning  Project Presentation (1st) |
| 2-Dec-19 | 15-Dec-19 | Microcontroller Computer Interface (USB)/Sensor Testing  UI frontend design: pick libraries and spend time learning  Auto-Cad / 3D Print case |
| 16-Dec-19 | 29-Dec-19 | Holiday Break |
| 30-Dec-19 | 12-Jan-20 | Algorithm Creation  UI frontend design : start developing an initial design  Microcontroller to Computer interface (Wifi)  System Testing |
| 13-Jan-20 | 26-Jan-20 | Algorithm Creation  UI frontend design  Microcontroller to Computer interface (Wifi)  System Testing |
| 27-January-20 | 9-Feb-20 | Hardware Implementation (final version)  UI frontend design |
| 10-Feb-20 | 23-Feb-20 | Hardware Implementation (final version)  UI frontend design |
| 24-Feb-20 | 8-March-20 | Final Report |
| 9-March-20 | 22-March-20 | Final Report  Project Presentation (2nd)  Expo Presentation |
| 23-March-20 | 5-April-20 | ECE Expo  Final Report |

# Testing

In terms of testing there isn’t much material that we need. Once we are able to acquire the data from the different sensors, and finish the post-processing algorithms we should be able to test the system. We will test the device on ourselves by wearing the knee brace and perform different actions such as running and jumping. We will then analyze all of the data to see if the device is performing correctly and meeting our specifications.

# Bills of Material

\*only including the necessary items to purchase

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Part Name | Part Number | Quantity | Cost ($CAD/unit) | Supplier Link |
| Knee Brace/Knee Sleeve | 1 | 2 | Free | Vasav |
| Microcontroller | 2 | 2 | 15.24 | https://tinyurl.com/yyow6s2o |
| 9-dof (G/A/M) | 3 | 2 | 15.95 | https://www.sparkfun.com/products/13944 |
| Pressure Sensor (FSR) | 4 | 1 | 7.00 | <https://www.adafruit.com/product/166> |
| Lithium Ion Battery -Cylindrical 2200 mah | 5 | 1 | 9.95 | <https://www.adafruit.com/product/1781> |
| Buck boost converter | 6 | 1 | 9.95 | <https://www.adafruit.com/product/2190> |

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# References:

[1] O. Inan, D. Whittingslow, C. Teague, S. Hersek, M. Pouyan, M. Millard-Stafford, G. Kogler, and M. Sawka, “Wearable Knee Health System Employing Novel Physiological Biomarkers,” *Journal of Applied Physiology,* December, 2017. [Online serial]. Available: <https://ieee-dataport.org/sites/default/files/analysis/27/IEEE%20Citation%20Guidelines.pdf>. [Accessed Oct. 28, 2019]