

Smart Brace

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Report Summary

The main goal of the Smart Brace is to design and build a knee brace that an ACL patient could use to track and monitor their rehab progress. Using a potentiometer to measure range of motion, and a gyrometer to measure angular velocity, the Smart Brace will send the data over Bluetooth to a user's smartphone, and display the results for the user to see. In order to be considered helpful to the user, the Smart Brace has to meet many design requirements. The system has to be light and small enough to not affect the user's movement during exercise. In addition, a user interface has to be created that is easy for the patient to use. They have to be able to see the max values, as well as the rest of the data throughout the exercise. Finally, the brace has to contain enough memory and battery life to last throughout an entire rehab workout. After taking all of these things into consideration and performing necessary calculations, all the components were finalized and purchased. In the winter term, a functioning prototype will be created that ACL patients will be able to use.

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1. Introduction

Knee injuries are prevalent in today's society. For example, over 200,000 ACL tears occur each year (1). In order to return to daily and recreational activities, ACL patients first have to go through an exercise rehabilitation program. These programs include stretches and exercises for the patient to complete every single day. Each week, the program outlines goals that the patient should try to reach. However, a huge problem with these rehab programs is that they are not geared towards the specific individual recovering from injury. Everyone recovers at a different pace. Some people make faster progress and are ahead in schedule in their rehabilitation process. On the other hand, others take a longer time to reach the weekly goals. This raises the question: Is there a way to track how a person is progressing during their rehabilitation program, so they can alter their workout plan accordingly?

To fix this problem, I have come up with the Smart Brace. This wearable knee brace will have sensors to measure the range of motion and velocity of the user's knee during rehab exercises. According to Emory Healthcare, regaining full range of motion is very important and is one of the main goals in an ACL rehabilitation program (2). In addition, UW Health stated that knee rehab exercises should increase from low velocity to higher velocity throughout the course of rehabilitation (3). Through Bluetooth, the Smart Brace will transmit data to a smartphone app for storage and analysis. By analyzing this information over a period of several days, the user can determine if they are progressing at a good pace, or if they are not

progressing at all. Subsequent changes to their workout plan can be made accordingly.

The remainder of this report is organized into four sections. Section two reviews ACL injuries and discusses previous smart knee braces. In addition, it also discusses the ethical issues for the project. Section three describes the requirements that the Smart Brace must meet in order for it to be a helpful product to the user. Section four talks about the design alternatives for all the hardware and software systems. Finally, section five explains the proposed final design for the Smart Brace.

2. Background

2.1 What is the ACL?

ACL is an acronym for the anterior cruciate ligament. It is one of the four main ligaments in the knee that connects the tibia to the femur. It is located diagonally in the middle of the knee. The purpose of this ligament is to keep the knee stable. It provides rotational stability to the knee, as well as prevents it from hyperextending.

The ACL can be torn in many ways. The main causes of injury are when the knee is twisted, bent side to side, or is hyperextended. These things can occur when changing direction rapidly, landing incorrectly from a jump, or when there is a collision directly to the knee.

ACL injuries are prevalent in sports that require a lot of stop and go movements. For example, this injury is prevalent in sports like soccer, football, basketball, and tennis (3).

2.2 Treatment of Injury

Without treatment, the injured ACL is less able to control knee movements. As a result, there exists two ways to treat an ACL tear. If the patient is older and not active, they may choose the nonsurgical treatment for their injury. However, the ACL will not completely heal this way. Thus, the doctor will recommend that the patient brace their injured knee. Bracing it will defend the knee from instability.

Choosing this type of treatment allows the patient to return to a much quieter lifestyle.

On the other hand, majority of patients choose the surgical treatment for their injury. This treatment will ultimately allow them to return to their normal way of life. The surgery consists of the doctor replacing the torn ligament with a tissue graft. This tissue is often taken from either the patella tendon in the knee, or the hamstring tendon. Surgery to the ACL is performed using an arthroscope that is inserted into the joint using small incisions (4).

2.3 Recovery Process

After surgery, the doctor assigns every patient a rehab program to follow. Emory Healthcare states that the goal in every post operation ACL rehabilitation program is “to return the patient to a normal and complete level of function in as short a time possible, without compromising the integrity of the surgically reconstructed knee” (3). In addition, the patient should strive to retain full range of motion, reduce swelling, and retain muscle size and strength. To achieve these goals, a normal rehab program consists of stretches and exercises for the patient to complete. Some examples of exercises include leg extensions, flexions, and lifts. Ideally, by successfully completing the program, a patient can return to full activity in six to nine months (2).

2.4 Previous Work

Previous attempts have been made to track a person's rehab process from knee injuries. Researchers from the Fraunhofer Institute for Manufacturing Engineering and Automation IPA in Stuttgart, Germany have come up with a knee brace that uses sensors to record knee movement. Even though the brace is not commercially available, it is able to archive the degree to which the knee rotates (5).



Figure 1: Knee brace developed by researchers from Fraunhofer Institute

Bend Labs is another company that has attempted to track a person's rehab progress. Like the Smart Brace, Bend Labs' Smart Knee uses sensors to track knee movements and uses Bluetooth to send the data to a smartphone. The data includes the knee angle, hip angle, and altitude of the knee. In addition, the knee brace can track complex human movements in real time (6).



Figure 2: Smart Knee developed by Bend Labs

Both these devices, however, don't use the knee brace that the doctor prescribes after ACL reconstruction surgery. Instead, they use a soft brace that does not provide much support and protection. A person who has torn their ACL is 15 times more likely to re-tear their ACL within 12 months after their first surgery. Wearing the brace helps protect the recently healed knee from outside forces that occur during activity and everyday life (7). This assigned brace is used during rehab exercises. Thus, the Smart Brace is advantageous because it allows patients to track their rehab progress safely while wearing the same protective brace they are given after surgery.

2.5 Effects on Society

2.5.1 Social

Sports and exercise are two huge social aspects of today's society. People use these activities as ways to meet new friends, hang out with peers, and as a source of entertainment. However, when a person tears their ACL, they can no longer participate in these two events. Until they fully rehab and recover from their injury, they will not be able to be as social as they previously were. By using the Smart Brace, the patient can track their progress while rehabbing. They will be able to increase their rehab workload, which will possibly allow them to be able to return the social activities of sports and exercise in a shorter period of time.

2.5.2 Health and Safety

The Smart Brace will have a positive impact on the health and safety of individuals. Exercise is extremely important. According to Lets Move, an exercise program, geared towards raising a healthier generation, "Physical activity is an essential component of a healthy lifestyle. In combination with healthy eating, it can help prevent a range of chronic diseases, including heart disease, cancer, and stroke" (8). ACL injuries prevent people from exercising and living healthy lifestyles. By using the Smart Brace to rehab, patients will have a greater chance to recover from the injury sooner, allowing them to return to physical activity.

In addition, if a person comes back from an ACL injury too soon, they are at a higher risk of injuring it again (9). By being able to track the range of motion and

angular velocity of their knee, a patient will know how far along they are in their recovery. This will prevent them from jeopardizing their safety by returning too early.

2.5.3 Political

Over the next ten years, the cost of health care is expected to rise 5.8% each year (10). Consequently, the cost of going to rehab is going to increase as well. As stated earlier, rehab programs are often not geared towards specific individuals. Patients are often placed on preset rehabilitation programs. Consequently, they attend a preset number of rehab sessions, and progress at a predetermined rate. The Smart Brace will allow a patient to possibly recover at a faster, more individually based rate. Thus, the patient will possibly be able to attend less rehab sessions, saving a lot of money.

2.6 Ethics

Ethical issues naturally surround any product that claims to aide a patient's recovery. For example, it would be unethical to try to market and sell the Smart Brace without it first being cleared by the FDA. In order for this device to be put on the market, it first has to get cleared by a 510(k). A 510(k) requires that the new device be compared to similar lawfully marketed devices. It must be compared for safety and effectiveness. As the designer and developer, I would make sure that the Smart Brace is cleared by a 510(k) before selling it to any consumer.

In addition, it would be unethical for the Smart Brace to display inaccurate results. It cannot exaggerate a patient's recovery pace, with the hope that consumers will be satisfied and recommend the product to more people. As the designer, I have a responsibility to the clients and their health. Therefore, I am ethically obligated to ensure that the Smart Brace yields accurate results. To ensure accurate results, I would do several things. To confirm that the angle of rotation is accurate, I will measure the angle of a patient's knee using a potentiometer. I will then measure the angle of the patient's knee using a goniometer. A goniometer is a device used in physical therapy to measure the range of motion around a joint in the body. It is similar to a protractor (12). Testing will be performed with the knee at many different angles. If the angles measured using the potentiometer and the goniometer are the same, the data obtained for angle of rotation is accurate. Once I know the angle of rotation is accurate, I will use this data to determine if the angular velocity is also accurate. The change in angle determined by the potentiometer can be divided by the time to determine the angular velocity. This result will be compared to the result yielded by the gyrometer. If these two results are the same for many different trials, the angular velocity is accurate.

Furthermore, another ethical issue surrounding the Smart Brace involves the pricing of the product. In hopes of making a sizable profit off of this device, it would be unethical to raise the price to a level that is significantly higher than market value of a comparable knee brace. The knee brace that is commonly prescribed to patients is the Breg Fusion Knee Brace. According to The Brace Shop, the retail

price is \$530 (13). To ensure that the Smart Brace is priced fair and reasonably, I would make sure that I priced the brace appropriately according to these figures.

3. Design Requirements

The Smart Brace must meet certain requirements in order to be a useful product to the user. The development of a wearable smart brace will allow people to be able to measure the range of motion of their knee. In addition, the smart brace will also monitor the angular velocity when the user bends their knee. Through Bluetooth, the Smart Brace will be connected to an Android app. The microcontroller will send the taken data to the user's smartphone. The app will then update the max values of the range of motion and angular velocity of the knee. These values will be displayed to the user and stored for analysis. A block diagram of the overall project can be seen below.

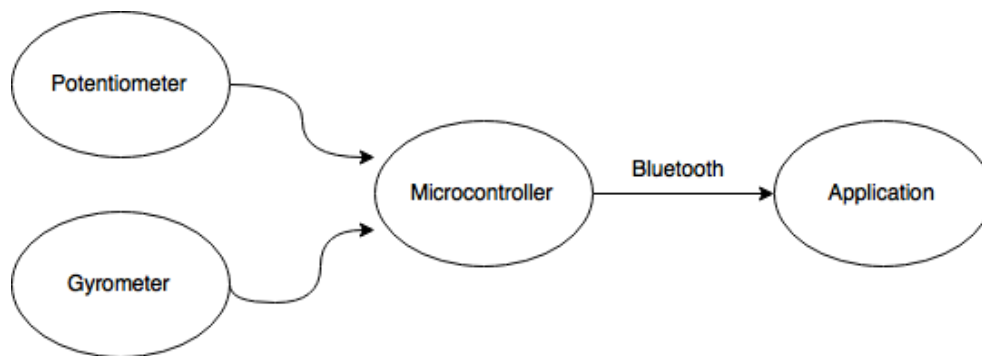


Figure 3: Model of overall project

Since the system is being attached to an existing knee brace, there must be constraints on dimensions. The potentiometer, gyrometer, and microcontroller all have to be small enough to fit on the knee brace, and not interfere with the user's movements. After measuring the dimensions of the knee brace, the components

should be no more than 50mm x 30mm (1.97" x 1.18"). In addition, there must be restrictions on the weights of the equipment. The weights must be negligible, so the user cannot feel the added weight to the knee brace. A good value to strive for is for each component to weigh less than 5 grams.

Battery life, number of samples per second, and memory are three more requirements that need to be quantified. A daily rehab session takes about an hour to complete. In this hour, a user typically completes 15 exercises. Each one of these exercises consists of the patient bending and straightening their knee for 3-5 sets of 10-15 repetitions. Each exercise takes approximately 2 minutes to complete. In between sets, a person usually rests for a couple of minutes. Since the total rehab exercises take roughly an hour, the battery power source must provide enough current to support at least one hour of continuous use. In addition, the number of samples taken per second need to be quantified. The angle of the knee joint and angular velocity of the user's knee will constantly be changing. As a result, the number of samples taken per second has to be great enough to ensure that no values are missed. After much thought, I decided 100 samples per second would ensure this. Furthermore, the memory of the microcontroller has to be quantified as well. The microcontroller has to have enough memory to capture and store the data before it sends it to the smartphone. 2 KB of SRAM memory would be sufficient.

Furthermore, the desired values for range of motion is a design requirement as well. The range of motion of a knee is up to 135 degrees (14). Therefore, the desired values should be between 0 and 135 degrees. Also, the range accuracy should be within 1 degree. Since a patient will be tracking their results on a day-to-

day basis, any slight increase or decrease in their range of motion needs to accurately be recorded.

Similar to range of motion, the desired values for angular velocity is a necessary design requirement. The maximum knee angle velocity in a normal gait is roughly 380 degrees per second (15). Thus, the desired values should be between -380 and 380 degrees per second. In addition, the range accuracy should be within 1 degree. This is for the same reason that the range accuracy of the range of motion should be within 1 degree.

Another design requirement is the user interface. On the smartphone, the user needs to see the current max values for angle of rotation of their knee, as well as the angular velocity. Also, it would be extremely helpful for them to see all the values throughout every exercise. Furthermore, they need a way to see results from prior days, so they can track their progress during the rehabilitation program.

The Smart Brace also must be affordable. Even if the product is extremely functional and useful, it must be cheap enough for a consumer to buy it. As stated earlier, the knee brace that is commonly prescribed to patients is the Breg Fusion Knee Brace. The retail price of it is \$530. As a result, the Smart Brace must be priced at an amount where the cost of buying it does not outweigh the usefulness of it.

Table 1 below summarizes all the design requirements.

Objective	Requirement
Size	< 50mm x 30mm (1.97" x 1.18")
Weight	< 5 grams per component
Battery Life	> 1 Hour of use
Samples Per Second	~100 samples per second
Memory	>= 2 KB
Range of Motion	0-135 degrees
Range of Motion Accuracy	Within 1 degree
Angular Velocity	-380 to 380 degrees per second
Angular Velocity Accuracy	Within 1 degree
User Interface	Display max values Results from prior exercises/days
Price	Not a lot greater than \$530

Table 1: Table summarizing design requirements

4. Design Alternatives

4.1 Microcontroller Alternatives

When choosing what microcontroller to use, there were several options. After much consideration, I decided to settle on the Arduino family of microcontrollers. This is because Arduino prides themselves on being an open source platform used for building electronic projects. Unlike many other microcontrollers, the Arduino does not need a separate piece of hardware to load code onto the board. A USB cable is all it needs. Furthermore, the piece of software that the microcontrollers uses is called the Integrated Development Environment. The Integrated Development Environment uses a basic version on C++, making it easier to program (16).

The first microcontroller in the Arduino family that we considered using is called the Arduino Uno. The Uno consists of 14 Digital I/O pins, and has 2 KB of SRAM memory. Also, it can be powered by a 9V external power supply, making it portable so it could be attached to the knee brace. However, one of the main design requirements was that the microcontroller had to be small enough to fit on the knee brace. With a length of 68.6mm and a width of 53.4mm, the Arduino Uno is too large to be placed on the knee brace, without interfering with the user's movements. In addition, another major design requirement was the user could not feel the weight of the microcontroller added to the knee brace. The Uno has a weight of 25 grams. Ideally, we were looking for microcontroller weighing much less than that (17).

The next microcontroller that was considered using was the LilyPad Arduino USB. According to the Arduino website, “The LilyPad Arduino USB is the perfect board for e-textiles and wearable projects” (18). With only a 50mm diameter, and a weight of 0.8 grams, the LilyPad Arduino USB would pass the size requirements for the microcontroller. However, similar to the Arduino Uno, the LilyPad presented one big problem. It is be powered with a 3.7V battery (18). This battery would not have enough power to support all the devices for an hour of continuous use. As a result, the decision was made to not use either the Arduino Uno or LilyPad Arduino USB for this product.

4.2 Sensor Alternatives

In addition to the microcontroller, there were also design alternatives for the sensors. At first, I planned on using an accelerometer instead of a gyrometer. The accelerometer I thought about using was the SparkFun Triple Axis Accelerometer Breakout – LIS331 (19). Just like every accelerometer, this accelerometer measures proper acceleration (“g-force”) in m/s^2 . After much consideration, it was decided that measuring the proper acceleration when the user bends their knee would not be beneficial to the user. An increase in the acceleration while a user is bending their knee does not guarantee that a user is progressing. For example, a user can accelerate while bending their knee quickly at first, but then can barley continue bending their knee after that point. As a result, an accelerometer is not the best sensor in this case. It is better to use a gyrometer to measure the angular velocity

when a user bends their knee, since the user will be able to track the angular velocity throughout the whole rotation of their knee.

In the beginning of the design process, a rotary encoder was thought to be the best way to measure range of motion. However, one of the design requirements for the Smart Brace is that the price cannot be way higher than that of the Breg Fusion Knee Brace. In order to keep the final cost in an acceptable range, the components cannot cost a lot of money. However, the cost of a rotary encoder tends to be moderate to high compared to other devices. Consequently, it was decided to use a different device that was much cheaper (20).

4.3 Software Alternatives

Originally, the decision was made to use Swift to program the smartphone app. This was due to the fact that Swift is the programming language created by Apple for iOS application development. I own an iPhone, so I believed that Swift would be the most beneficial programming language to use. This way, I could test the device on my iPhone. However, at 41.3%, Apple is the second leading smartphone platform. Android ranks as the top platform at 53.2% (21). In addition, the official language for Android development is Java (22). At Union, the majority of Computer Sciences classes are taught in Java. This means that I am more familiar with this programming language than any other.

4.4 Communication Alternatives

When selecting a way to transmit the data to the smartphone, I decided on using Wi-Fi. At first, it seemed like the perfect method. However, the cost of Wi-Fi is high. In addition, it has a range of 32 meters indoors and 95 meters outdoors. For the application of the Smart Brace, this long range is unnecessary and impractical. When performing rehab exercises, the smartphone will not be a more than a couple meters away from the user. Other reasons why Wi-Fi wasn't the best method is because it has high power consumption and is not easy to use. It is extremely complex and requires both configuration of the hardware and software. Ultimately, it was decided that Wi-Fi was not the greatest way to transmit the data to the smartphone (23).

5. Preliminary Proposed Design

The goal of this project is to make a prototype where a microcontroller correctly obtains data from a potentiometer and gyrometer, and sends it to a smartphone app. As the data comes in, the smartphone will update the angle of the knee joint and angular velocity, and display it to the user.

A diagram of the system is shown below in Figure 4. In this section, each component of the system will be discussed, as well as a timeline schedule for the Winter Term.

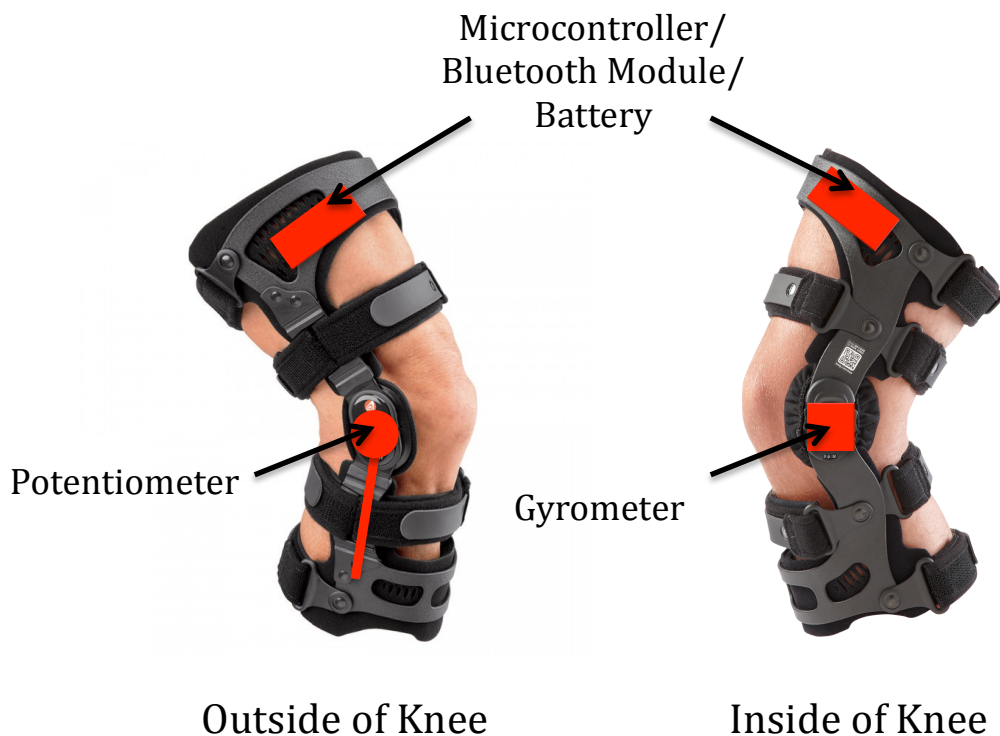


Figure 4: Diagram locating location of the parts

5.1 Microcontroller

Ultimately, I decided to use the Arduino Nano 3.0 (24). The specifications are given below in Table 1.

Input Voltage	7-12 Volts
Operating Voltage	5 Volts
Digital I/O Pins	14
DC Current per I/O Pin	40 mA
SRAM	2 KB
Dimensions	45 mm x 18 mm
Weight	5 grams

Table 2: Specifications of the Arduino Nano used in the Smart Brace

The Arduino Uno was chosen because there is more than enough I/O pins to support the other devices in this product. The components of the Smart Brace only need to use 5 pins, so 14 pins are enough. Also, unlike the Arduino Uno, the Arduino Nano is small enough to fit on the brace without impacting the user's performance. With dimensions 23.6 mm x 35.4 mm smaller than that of the Arduino Uno, the microcontroller is small enough for the Smart Brace. Furthermore, the Arduino Nano weighs a very light 5 grams, 20 grams less than the Arduino Uno. Even though

the user may still feel this added weight on the knee brace, it is nowhere near extra weight that the Uno provided. Finally, this microcontroller was chosen because the input voltage is between 7-12 Volts. Unlike the 3.7 Volts used to power the LilyPad Arduino USB, a battery of 9 Volts could provide enough current to power the Smart Brace for more than an hour. This calculation will be shown in section 5.5.

5.2 Potentiometer

The potentiometer being used is a 1 W 5K Ohms 5% precision potentiometer manufactured by ETI Systems (25). Table 2 gives the specifications of the potentiometer.

Resistance	5K Ohms
Linearity	+/- 0.25%
Tolerance	5%
Number of Turns	3
Weight	0.8 oz
Size	1.57" x 0.88"

Table 3: Specifications of the Potentiometer used in the Smart Brace

As you can see, the potentiometer has a resistance of 5K Ohms. Using the 5V supplied from the Arduino Nano, the power dissipation is calculated below in Figure 5.

$$P = I^2 R$$

$$R_{\text{pot}} = 5000 \Omega$$

$$I = \frac{V}{R}$$

$$I = \frac{5V}{5000\Omega} = 0.001 A = 1 \text{ mA}$$

$$P = (0.001A)^2(5000\Omega) = 0.005 W = 5 \text{ mW}$$

Figure 5: Calculations for Power Dissipation across the Potentiometer

As the calculations show, a resistance of 5K Ohms is not too low where the potentiometer will get warm and blow out. This is due to the fact that not a lot of Watts are dissipated. Also, the resistance is not too high where it would load down the signal, causing the voltage to drop. Thus, a potentiometer with a resistance of 5K Ohms is sufficient to use.

Another reason why this potentiometer was chosen was because it is called a precision potentiometer. This is due to the fact that its linearity was +/- 0.25%. Linearity is the relationship between the output voltage and rotation of the shaft. In this case, the output voltage will be within 0.25% of the correct amount, based on the rotation of the shaft. Since the angle of rotation of the user's knee needs to be as accurate as possible, this potentiometer ensures that the readings will be very accurate.

Ideally, the number of turns needed for the potentiometer is one. Since the range of motion of a knee is up to 135 degrees, the potentiometer does not need to rotate more than one turn. However, there is no potentiometer that had one turn, with a resistance of 5K Ohms, and a linearity of $\pm 0.25\%$. Both the resistance and linearity are more important in obtaining accurate data, so I chose the number of turns to be the next smallest number. This value happened to be 3.

Finally, the weight and size of the potentiometer fit under our restrictions, so I decided to use it.

5.3 Gyrometer

The gyrometer used is a SparkFun Tri-Axis Gyro Breakout L3G4200D.

Similar to the previous parts, the specifications are listed in Table 3 below.

Measurement Scales	± 250 , ± 500 , ± 2000
Sensitivity	17.50 mdps/digit
Supply Voltage	2.4V-3.6V
Supply Current	6.1 mA
Sleep Mode Current	1.5 mA
Power-Down Current	5 μ A
Size	23mm x 17.5mm

Table 4: Specifications for the Gyrometer used in the Smart Brace

This gyro was chosen because of its small size. With the dimensions of 23mm x 17.5cm, the L3G4200D gyro will be able to be attached easily to the knee brace. In addition, the maximum knee angle velocity in a normal gait is roughly 380 degrees per second (26). As a result, a gyro had to be chosen that could measure this range of data. This gyro has user selectable scales of +/-250, +/-500, and +/-2000 degrees per second. Thus, the +/-500 degrees per second scale can be used to accurately obtain all the data. Another reason why this gyro was chosen is because it has a sensitivity of 17.50 mdps/digit. This value is up to ten times better than equivalent products on the market. This is important because it ensures the data will be extremely accurate. Finally, the L3G4200D gyro has high shock survivability. Therefore, if the gyroscope accidentally gets hit during the rehab exercise, there is less of a chance that it will be destroyed.

5.4 Bluetooth Modem

After contemplating between using Wi-Fi or Bluetooth, Bluetooth was ultimately chosen. This is because Bluetooth has shorter range, low power consumption, and is much easier to use than Wi-Fi. The Bluetooth modem that was chosen is called the SparkFun Bluetooth Modem - BlueSMiRF Gold (27). I chose this modem, because all the specifications support the application of the Smart Brace. Also, it is known for being easy to use with Arduino microcontrollers. Table 4 includes the specifications for this device.

Supply Voltage	3.0V – 3.3V
Serial Communication	2400 – 115200 bps
Frequency	2.402 ~ 2.480 GHz
Power Consumption:	
Standby/Idle	25 mA
Connected (Normal Mode)	30 mA
Connected (Low Power)	8 mA
Size	42mm x 16.5 mm x 5.6mm

Table 5: Specifications for the Bluetooth Modem used in the Smart Brace

5.5 Battery and Battery Life

The battery I decided on is an Energizer LA522 9V Lithium Battery (28). By using the currents used by the Arduino Nano, potentiometer, gyrometer, and Bluetooth modem, as well as the data sheet for the battery, it will take roughly 2.95 hours to discharge the battery from 9V to 5.4V. This calculation is shown below in Figure 6. On top of this, the battery will be stored in a battery holder case (29). The case includes an on/off switch for the battery. A user can extend the battery life if they turn the battery off in between exercises. As stated earlier, a normal rehab session takes about an hour to complete. Therefore, the LA522 9V Battery is able to support the Smart Brace without having to worry about it dying during a rehab exercise.

Arduino Nano: 40 mA x 5 pins = 200 mA (Shown in Table 1)

Potentiometer: 1 mA (Calculated in Figure 5)

Gyrometer: 6.1 mA (Shown in Table 3)

Bluetooth Modem: 30 mA (Shown in Table 4)

$$\begin{array}{r}
 200 \text{ mA} \\
 1 \text{ mA} \\
 6.1 \text{ mA} \\
 + 30 \text{ mA} \\
 \hline
 \end{array}$$

237.1 mA being discharged

Using data sheet, $237.1 \text{ mA} \approx 700 \text{ mA} \cdot \text{Hr}$

$$700 \text{ mA} \cdot \text{Hr} \circ \frac{1}{200 \text{ mA}} = 2.95 \text{ Hours to Discharge to 5.4 Volts}$$

Figure 6: Calculations to find battery life of Lithium LA522

5.6 Memory and Data Transferring

After much thought, I decided that 100 samples would be taken every second. This guarantees that no major values and results will be missed. Since both the angle of rotation and angular velocity of the user's knee will include decimals, the data will be stored as floats. According to Arduino, a float takes up 4 Bytes of information (30). Using 100 samples per second, 4 bytes per float, 15 exercises per workout session, and 2 minutes per exercise, the data will take up a total of 720,000 Bytes. As stated in Table 1, the Arduino Nano has 2 KB of SRAM memory. As a result, the data cannot be transferred over Bluetooth to the smartphone one byte at

a time. Instead, the data must be packaged, and then sent over. I decided that 20 Bytes of data should be packaged and sent at a time. To figure out if the delivery time is acceptable for this project, the transmission time was first calculated. The transmission time is the amount of time from the beginning until the end of a message transmission. It was concluded that the transmission time is 0.049 ms. Next, the propagation delay was calculated, which is the time it takes for the first bit to travel from the sender to the receiver. For this calculation, it was assumed the smartphone is 2 meters away from the actual knee brace. Since people usually have their phone on them at all times, this was a safe assumption. I ended up getting 0.0067 for this value. Finally, both the transmission time and propagation delay were used to determine the time the first bit leaves the transmitter until the last is received. For the packet delivery time, it would take 0.0557 ms. This value is acceptable for the application of the project. The calculations are shown in Figure 7.

SRAM Value = 2 KB

Memory Used:

$$15 \text{ exercises} \times \frac{2 \text{ minutes}}{1 \text{ exercise}} \times \frac{60 \text{ seconds}}{1 \text{ minute}} \times \frac{100 \text{ floats}}{1 \text{ second}} \times \frac{4 \text{ Bytes}}{1 \text{ float}} = 720,000 \text{ Bytes}$$

Transmission Time:

Bit Rate = 3.1 Mbps

$$\text{Transmission Time} = \frac{\text{Packet Size}}{\text{Bit Rate}}$$

$$\frac{20 \text{ Bytes}}{3.1 \text{ Mbps}} = 0.049 \text{ ms}$$

Propagation Delay:

Propagation Speed = 3×10^8 m/s (Speed of Light)

$$\text{Propagation Delay} = \frac{\text{Distance}}{\text{Propagation Speed}}$$

$$\frac{2 \text{ meters}}{3 \times 10^8 \text{ m/s}} = 0.0067 \text{ ms}$$

Packet Delivery Time:

Packet Delivery Time = Transmission Time + Propagation Delay

$$0.049 \text{ ms} + 0.0067 \text{ ms} = 0.0557 \text{ ms}$$

Figure 7: Calculations for Transferring Data

5.7 User Interface

The phone that will be used to test the app will be a Samsung Galaxy 4S. The app will be designed to have a button on the smartphone screen saying “Start”. The user will press this when they start their exercise. Once a packet of data is transferred to the smartphone, the app will update the max value for angle of the knee joint and angular velocity. Once these max values are updated, they will be displayed for the user to see. In addition, the smartphone will display a graph of the results for the exercise. This will be similar to a stock market ticker. When the exercise is over, the user will press a “Stop” button, and the data will be stored.

5.8 Ordered Parts

Table 6 below shows the parts ordered to complete the Smart Brace.

QTY	ITEM(S) ORDERED	UNIT PRICE	TOTAL
	Robotshop.com		
1	Arduino Nano USB Microcontroller v3 Product Code: RB-Gra-01 http://www.robotshop.com/en/arduino-nan-v-3.html	\$34.99	\$34.99
1	USB to Mini B Cable 1.3m Product Code: RB-All-33 http://www.robotshop.com/en/usb-mini-b-cable-1-3m.html	\$2.40	\$2.40
	Sparkfun.com		
1	SparkFun Bluetooth Modem-BlueSMiRF Gold Part Number: WRL-12582 https://www.sparkfun.com/products/12582	\$34.95	\$34.95
1	Break Away Headers – Straight Part Number: PRT-00116 https://www.sparkfun.com/products/116?_ga=1.42913389.993224844.1447628979	\$1.50	\$1.50
1	SparkFun Tri-Axis Gyro Breakout L3G4200D Part Number: SEN-10612 https://www.sparkfun.com/products/10612	\$49.95	\$45.95
	Amazon.com		
4	Lithium LA522 9V Battery ASIN Number: B0046TV5VO http://www.amazon.com/Energizer-LA522-Industrial-Lithium-Detectors/dp/B0046TV5VO	\$9.15	\$36.60
1	Pair 9V Battery Holder Storage Case On/Off Switch With Cap 2 Pcs ASIN Number: B00FHJTOVU http://www.amazon.com/Pair-Battery-Holder-Storage-Switch/dp/B00FHJTOVU/ref=sr_1_6?ie=UTF8&qid=1447705000&sr=8-6&keywords=9V+battery+pack	\$2.58	\$2.58
	Mouser.com		
1	Potentiometer Mouser Part Number: 882-MW22B-3-5K Manufacturer Part Number: MW22B-3-5K Manufacturer: ETI Systems http://www.mouser.com/ProductDetail/ETI-Systems/MW22B-3-5K/?qs=sGAEpiMZZMvygUB3GLcD7ngsAX7l9Vbcje%2fGy1c6G2Q%3d	\$17.35	\$17.35

Table 6: Parts ordered and their price

5.9 Winter Term Schedule

The schedule for next term is should below in Table 7.

Week 1	Set up potentiometer and use laboratory equipment to obtain data
Week 2	Attach potentiometer to knee brace, and read data into microcontroller
Week 3	Set up gyrometer and use laboratory equipment to obtain data
Week 4	Attach gyrometer to knee brace, and read data into microcontroller
Week 5	Set up Bluetooth module, and send data to computer (easier to see data and make necessary changes to how data is being transmitted)
Week 6	Adjust code to make sure data is being presented correctly
Week 7	Work on sending data to smartphone
Week 8	Prepare for Presentations
Week 9	Make last minute changes and write Final Report
Week 10	Make last minute changes and write Final Report

Table 7: Timeline for Winter Term

Throughout the term, I will be developing the smartphone application, since this will take the most amount of time.

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