GRADO EN INGENIERÍA INDUSTRIAL

TRABAJO FIN DE GRADO

WEREABLE, REAL-TIME IMPACT FORCE MONITORING

Autor: Paula Faura García

Director: Enrique Gutierrez-Wing

Madrid

Junio de 2020

Declaro, bajo mi responsabilidad, que el Proyecto presentado con el título

WEREABLE, REAL-TIME IMPACT FORCE MONITORING

…………………………………………………………………………………

en la ETS de Ingeniería - ICAI de la Universidad Pontificia Comillas en el

curso académico **2019/2020** es de mi autoría, original e inédito y

no ha sido presentado con anterioridad a otros efectos. El Proyecto no es

plagio de otro, ni total ni parcialmente y la información que ha sido tomada

de otros documentos está debidamente referenciada.

Fdo.: Fecha: 12/ 6 / 2020

Autorizada la entrega del proyecto

EL DIRECTOR DEL PROYECTO

Fdo.: Fecha: 17 / 06 / 2020

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Resumen

Este proyecto llamado ‘’Wereable, real-time impact force monitoring’’ fue propuesto y dirigido por el profesor Enrique Gutierrez-Wing, ingeniero mecánico de la Universidad de Boston University. El objetivo de este trabajo consiste en diseñar y construir un prototipo que permita a corredores obtener información relevante mientras realizan este deporte para así evitar lesiones encontrando la manera óptima de correr.

El primer paso fue realizar una investigación sobre los principales motivos que puedan causar lesiones para así poder centrar el diseño del dispositivo en ellas. En esta investigación se descubrió que la mayoría de corredores principiantes no apoyan correctamente el pie al correr. Esto debe a que existen tres tipos distintos de pisada según la anatomía del pie. La primera es la pisada ‘’pronada’’ por la cual el impacto de la pisada suele centrarse en la parte interna del pie, los corredores que tienen esta pisada son más propensos a sufrir lesiones. La segunda es la pisada ‘’neutra’’ siendo esta la correcta y la que se debe intentar alcanzar debido a que el impacto se reparte a lo largo de la planta del pie y con ella alcanzamos la postura óptima para evitar lesiones. La tercera es la pisada ‘’supinada’’ en la que el esfuerzo de centra en la parte exterior del pie siento esta la menos común de las pisadas pero la que peor lesiones puede causar. Con el fin de corregir la pisada de pronadores y supinadores existen numerosas zapatillas de deporte en el mercado especializadas para corregir ambos casos para mantener una posición neutra, sin embargo son muchos los expertos que afirman que el uso de estas mismas zapatillas pueden no ser beneficiosas sino perjudiciales ya que cada pie tiene una anatomía distinta y el uso de estas zapatillas podrían resultar en graves lesiones para el corredor. Lo que está claro es que la postura y la forma en la que el pie impacta con el suelo son claves en la aparición de lesiones. Por ello este proyecto se focalizó en el diseño de un dispositivo que permitiese ser introducido en la suela del zapato y obtener información sobre la fuerza de impacto a lo largo del pie. Esto beneficiaría al usuario ya que de este modo podría probar distinto tipo de calzado y con ayuda de un especialista poder corregir su pisada reduciendo así la probabilidad de sufrir lesiones.

Imagen 1: Tipos de pisada.

Los problemas de rodilla son también lesiones muy comunes entre los corredores por lo que se también se diseñó el dispositivo con el objetivo de encontrar correlación entre la pisada del usuario y la fuerza de impacto en la rodilla. Tras esto se llevó a cabo el esbozo del dispositivo mostrado a continuación:

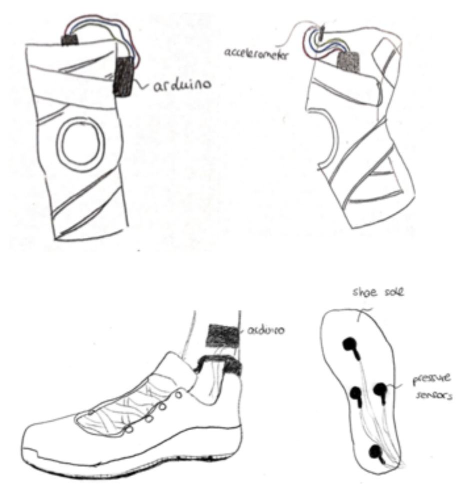

Imagen 2: Diseño inicial del dispositivo.

El primer diseño consistía en la combinación de dos dispositivos inalámbricos que puedan ser llevados con facilidad. El primero consiste un una suela en la cual hay situados diversos sensores de presión que permitan conocer la distribución de las fuerzas de impacto en el pie al correr, el circuito será programado con arduino. El segundo consiste en un acelerómetro situado en la rodilla programado a su vez con arduino y se fijará con ayuda de una rodillera. Tras esto se llevó a cabo la programación de ambos códigos y la construcción de ambos prototipos. El primero de ellos se hizo utilizando placas de Arduino Uno conectadas directamente al ordenador por los que el test se realizó corriendo sobre un mismo punto sin desplazamiento. Con esto se pretendía llevar a cabo la calibración del sensor de presión y del acelerómetro para comprobar su correcto funcionamiento. Este primer prototipo se muestra en la imagen siguiente:

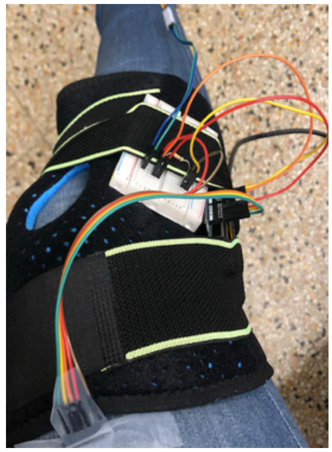

Imagen 3: Foto del primer prototipo.

Tras esto se llevó a cabo la búsqueda de una placa de menor tamaño a la de de Arduino Uno que permitiese además la transmisión de la información inalámbrica entre el dispositivo y el ordenador. Durante la construcción del dispositivo se adquirieron distintos modelos de placas, la primera que se intentó integrar fue la placa Arduino Nano 33 BLE la cual supuestamente permitía la transmisión vía Bluetooth entre el circuito y el ordenador siendo además de un tamaño mucho menor a la Arduino Uno. El uso de esta placa no tuvo sin embargo los resultados esperados ya que a pesar de funcionar correctamente cuando se utilizaba conectada al ordenador, cuando se utilizaba de forma ''inalámbrica'' alimentándola a través de una batería externa no se conseguía la transmisión de la información al ordenador. Se estudió usar aplicaciones externas de Bluetooth que pudieran comunicarse con la placa Nano pero no se obtuvo buenos resultados por lo que se decidió usar otro tipo de placa para conseguir esta comunicación inalámbrica. Tras esto se estudió el uso de dos dispositivos Xbee que integrados a dos placas de Arduino Uno permitían conseguir comunicación inalámbrica dejando para más adelante el problema de las dimensiones y peso de la placas. Los Xbee fueron programados para que se comunicaran entre ellos usando el software XCTU, de este modo uno estaba integrado a la placa Arduino del circuito y el otro a otra placa conectada al ordenador. Usando la librería ''Software Serial'' de Arduino el resultado de la implementación de los dispositivos Xbee fue exitoso. El esquema de estas conexiones se muestra a continuación:

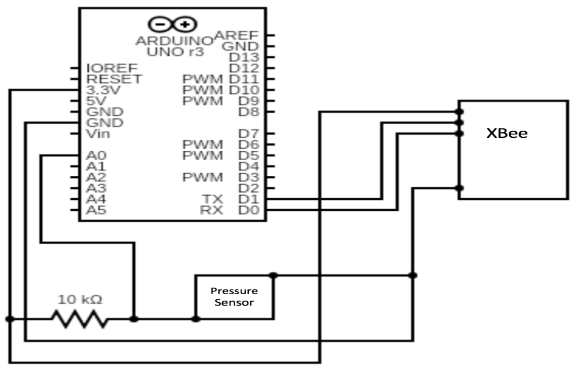

Imagen 4: Circuito con el Xbee integrado.

El siguiente paso fue encontrar otra placa de menores dimensiones para el circuito, se adquirió por tanto la placa Adafruit Feather Huzzah para la cual se tuvieron que realizar significativos cambios en el código para que funcionara correctamente. Sin embargo a pesar de que los sensores podían producir un valor de output cada 50 milisegundos, al usar esta placa SoftwareSerial solo permitía el traspaso de información entre Xbees cada 1000 milisegundos, es decir cada segundo se obtenía en el ordenador el valor obtenido por los sensores. Este rango de tiempo no era aceptable para el objetivo de este proyecto por lo que se buscaron otras alternativas como el uso de otras placas como el ArduinoMega. Debido a la falta de tiempo no se pudo encontrar otra alternativa a este problema por lo que se volvió al diseño anterior compuesto por las placas de Arduino Uno combinadas con los dispositivos Xbee.

Finalmente se trabajó en el desarrollo de un modelo de una pierna humana usando el programa de SolidWorks y su librería de ‘’motion analysis’’ con el objetivo de comparar en el futuro datos experimentales obtenidos con el dispositivo y datos computacionales obtenidos con este modelo. Atribuyendo a este modelo cualidades físicas podemos obtener información sobre fuerzas de impacto en distintas partes del cuerpo como articulaciones y planta del pie. De este modo podemos obtener un rango aproximado de valores de fuerzas de impacto con los que comparar los datos obtenidos experimentalmente.

En el futuro se espera poder comprobar la eficacia del prototipo diseñado para este proyecto, para ello se seleccionarán un grupo variado de personas para probar este dispositivo comparando entonces los resultados obtenidos experimentalmente con los obtenidos a partir del modelo tras modificar sus cualidades físicas adaptándolas a cada persona.

Summary

This project, called ‘’Wereable, real-time impact force monitoring’’, was proposed and directed by Professor Enrique Gutierrez-Wing, a mechanical engineer at Boston University. The objective of this work is to design and build a prototype that allows runners to obtain relevant information while performing this sport in order to avoid injuries by finding the optimal way to run for each individual.

The first step was to conduct a research focusing in main causes of injury before developing the disign. In this research it was discovered that most novice runners do not properly support the foot when running. This is because there are three different types of tread depending on the anatomy of the foot. The first is the pronator tread by which the impact of the tread usually focuses on the inside of the foot, runners who have this tread are more likely to suffer from injuries. The second one is the neutral tread being this the correct one and the one that should be achieved because the impact is distributed along the sole of the foot and the optimal posture is obtain to avoid injuries. The third one is the supinator tread in which the stress centers on the outside of the foot feel this the least common of the footprints but the worst injuries can cause. In order to correct the tread of pronators and supinators there are numerous sports shoes on the market specialized to improve both cases to maintain a neutral position, however there are many experts who claim that the use of these same shoes may not be beneficial but harmful as different people have different foot anatomy so the use of trainers could result in serious injuries to the runner. What is clear is that the posture and the way the foot impacts the ground are key to the appearance of injuries. This project therefore focused on the design of a device that could be inserted into the sole of the shoe to obtain information about the impact force along the foot. This would benefit the user as this would enable him to test different types of footwear and, with the help of a specialist, correct his tread, thereby reducing the likelihood of injury.

Image 1: Types of tread.

Knee problems are also very common injuries among runners so the device was also designed with the aim of finding correlation between the tread of the user and the impact force on the knee. The the preliminary design of the device was sketched as it is shown below:

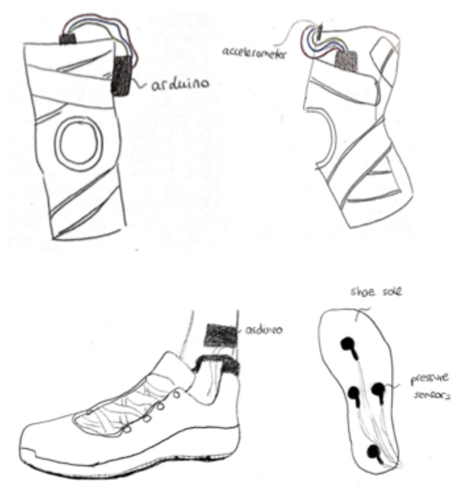

Image 2: Preliminary design of the device.

The first design consisted of the combination of two wireless circuits that needed to be comfortable enough to be worn while running. The first one consists of a sole in which there are placed various pressure sensors that allow to know the distribution of the impact forces in the foot when running, the circuit will be programmed using arduino. The second one consists of an accelerometer located in the knee fixed with the help of a knee brace and programmed using Arduino too. After this, the programming of both codes and the construction of both prototypes were developed. The first one was made using Arduino One plates connected directly to the computer so the test was carried out running on the same point without displacement. The aim was to calibrate the pressure sensor and the accelerometer to check their correct functioning. This first prototype is shown in the following image:

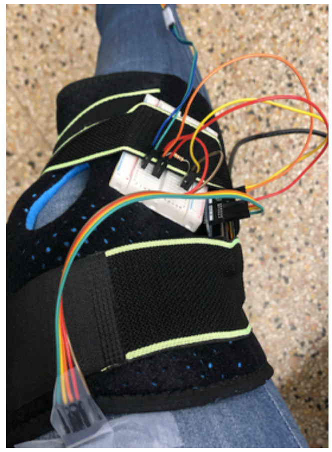

Image 3: Photo of the first prototype.

This was followed by the search for a smaller board than that of Arduino Uno that would also allow the transmission of wireless information between the device and the computer. During the construction of the device different models of plates were acquired. The first attempt was made using the Arduino Nano 33 BLE board, which supposedly allowed transmission via Bluetooth between the circuit and the computer and was much smaller than the Arduino One. The use of this plate did not however have the expected results because despite working correctly when used connected to the computer, when it was used in a wireless way, feeding it through an external battery, the transmission of the information to the computer was not possible. It was studied to use external Bluetooth applications that could communicate with the Nano board but no good results were obtain using this method so it was decided to use another type of board to achieve this wireless communication. Then the use of two Xbee were tried in order to make the device wireless, leaving for later the problem of the dimensions and weight of the plates. The Xbees were programmed to communicate with each other using the XCTU software, so one was integrated into the Arduino circuit board and the other into another board connected to the computer. Using Arduino's 'Serial Software' library the result of the implementation of Xbee devices was successful. The diagram of these connections is shown below:

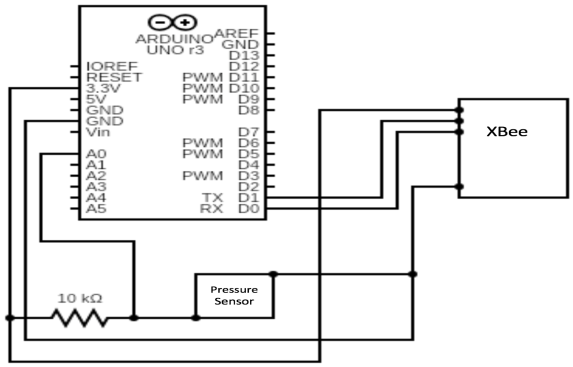

Imagen 4: Sketch of the circuit integrating the Xbee module.

The next step was to find another smaller plate for the circuit, so the Adafruit Feather Huzzah board was acquired for which significant changes in the code had to be made to make it work properly. However, even though the sensors could produce a output value every 50 milliseconds, using the SoftwareSerial library with this board only allowed the transfer of information between Xbees every 1000 milliseconds, every second the value obtained by the sensors was obtained in the computer. This time range was not acceptable for the purpose of this project so other alternatives were sought such as the use of other plates such as the Arduino Mega. Due to lack of time it was not possible to find another alternative to this problem so it was returned to the previous design composed of Arduino One plates combined with Xbee devices.

Finally, we worked on the development of a model of a human leg using the program of Solidworks and its library of motion analysis' in order to compare in the future experimental data obtained with the device and computational data obtained with this model. By attributing physical qualities to this model we can obtain information about impact forces in different parts of the body such as the joints (ankle and knee) and sole of the foot. In this way we can obtain an approximate range of impact force values in order to compare the data obtained experimentally.

In the future it is hoped to be able to verify the effectiveness of the prototype designed for this project. For this purpose, a varied group of people will be selected to test this device, then comparing the results obtained experimentally with those obtained from the model after modifying its physical qualities and adapting them to each person.

Table of Contents

DOCUMENT 1

MEMORY

Problem Definition

Technical Areas

Running, exercise, sports science, injuries, correct running form, impact force, novice runner

Problem Summary

Running is a great form of exercise to promote cardiovascular health, however there are so many ways it can lead to injuries. From incorrect form to the running gear worn, the correct way in which a person should run is very subjective. All research done has led to inconclusive results, with experts measuring different parameters and claiming different hypotheses. For beginners, running with an inadequate form only becomes apparent after an injury, not allowing any preventative measures. The purpose of this project is to formulate a prototype device that allows a novice runner to track the impact force being absorbed by their knee in real time, so that they can adjust their form and observe immediate results.

During the research it was discovered that there are various devices already on the market tracking fitness statistics, however, none allow the user to track real-time data for a useful statistic such as impact force. Additionally, it was found that the type of shoes a runner should wear depends on their natural foot arch and the way they apply pressure to their soles. Using this as a benchmark, it was decided to compare the total impact force on the body with each step, detected at the foot, with the impact force being absorbed at the knee, to specifically prevent knee injuries. This was done using two wearable devices; smart socks that contain a foot insole with pressure sensors, and a knee brace containing an accelerometer. Using force measurements from the two devices and referencing a prerecorded database, the user is informed about their form and are given recommendations for footwear. The prototype uses Xbees for wireless communication between the sensors and a receiving interface, ideally a smartphone app for the final product.

Project Goal

The project goal is to provide the customer with a prototype of a wearable device that allows the user to observe the ratio of force being absorbed by their knee in comparison to the force on their foot when in contact with the ground.

Specific Aims

1. Search for and summarize all research that has already been done on injuries related to running form and current solutions
2. Form own design that allows some measurement to provide information
3. Build prototype design
4. Test prototype on a runner to collect data and determine if goals are fulfilled

Deliverables

1. Force results at foot and knee
2. Code for pressure sensor and accelerometer
3. Design sketches and prototype
4. Final report and presentation

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ISSUE No.	Date of Issue	Reason for (Re)Issue
1.1	10/30/19	Original Paper
1.2	11/25/19	Formatting for submission
1.3	02/17/20	Updated after midterm feedback
1.4	04/30/20	Formatting and revision before final submission

Introduction

Running is a great form of exercise to promote cardiovascular health; however, there are so many ways running can lead to injuries. From incorrect form to the running gear worn, the correct way in which a person should run is very subjective. All research done on the correct form of shoes that should be worn have led to inconclusive results, with experts measuring different parameters and claiming different hypotheses. This makes it hard for a novice runner to get into the activity long-term without having to worry about injuries. For beginners, running with an inadequate form only becomes apparent after an injury, not allowing any preventative measures.

In order to help people overcome and identify the reason or reasons of injuries a device will be designed. To achieve this a research of the different motives of why a runner can be injured while running is developed, and it will be discovered that there are anatomy factors and equipment factors. As it will be explained next, there are many types of foot shapes that determine the posture of a person while walking or running as well as how the weight is distributed over the foot and for these different shapes there are multiple shoe types. Having this in mind the first idea that arose was to create a device that could be worn in the foot and that would be able to measure in real time forces. This would allow the user to use it with different running shoes and with specialized help be able to find the prefect match.

After this initial research another one was developed in this time studying the devices that were already in the market and helped people with injury problems. As it will be explained below there are different models in the market that go from shoe pads that measure distribution of forces to ear plugs that measures the tilt of the head in order to get more detailed information about body posture. This researched help to get ideas for the design of the prototype developed for this project.

For the initial prototype it was decided to integrate a force sensor with an accelerometer. The force sensor is located in the shoe sole and will measures impact forces in real time while the accelerometer will be located in the knee in order to get information about acceleration in the horizontal and vertical direction. This acceleration will be used to calculate forces in the knee, body part where most runners suffer injuries, using a two mass model of the body. The device must be small and light enough to be able to wear and it will have to send data wirelessly. The coding for this devices is developed using Arduino. During the designing process several changed had to be done in order to achieve these characteristics as it will be explained in detain in the preliminary design section. The circuitry and parts of the prototype were bought using a budget provided by the mechanical engineering department of $300.

A model of a human leg was designed using SolidWorks, physical properties such as mass, damping and stiffness were integrated into this model to get computational data that would be used to compare it with the experimental data. In the future to prove the efficacy and accuracy of the device and the model, a group of 16 to 20 participants consisting of an equal number of men and women will be tested using the prototype. This group of people will include novice runners, sport athletes, track and field athletes, and avid runners.

The last part of the report is the cost analysis in which the costing of the materials used to build the prototype are listed and an approximation of the final cost of the device is presented.

Project

The project was introduced by Professor Gutierrez who proposed to formulate a device that allows novice runners to track their running form in comparison to a standard. After interviews with the professor, the following objectives were established: to make the device wearable by measuring dimensions and weight, minimize the cost of the device by adding the cost of components and manual labor, and provide a data display for the device. In undertaking this project, there were two major parts to execute. First, it was needed to obtain data from the sensors at both the knee and foot of a test subject. Second, organize the data collected and prepare a display of the quantitative data to our client. This project also has major requirements that include the code for pressure sensor and accelerometer and the prototype.

The proposed device will compare the impulse force on the user's foot when in contact with the ground with the impact force absorbed by the knee. [1]This allows direct correlation with the correct form, as a majority of the force absorbed should be spread over the entire body and not focused on just the knees. The impulse forces will also be compared to a set of pre-recorded data to allow the user to compare themselves to a benchmark and adjust themselves accordingly.

Customer

The client for this project is Professor Enrique Gutierrez Wing, a mechanical engineering professor at Boston University. The customer plans on using the device as he continues to gain a better running form that restrains from injuries while running.

Acknowledgements

I would like to show our deepest appreciation to Professor William Hauser and Professor Enrique Gutierrez Wing for their guidance and advice during the process of this project. Their constant encouragement and assistance helped us tackle the toughest parts of this project and successfully deliver a well-done project. I would also like to thank the ME department for their support of funding materials needed for this project. Special Thanks to Professor Enrique for providing with this project, providing necessary material, and helping with the circuitry of the project.

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[1] Clark, Kenneth P., Laurence J. Ryan, and Peter G. Weyand. "A General Relationship Links Gait Mechanics and Running Ground Reaction Forces." The Journal of Experimental Biology 220, no. 2 (March 2016): 247–58. https://doi.org/10.1242/jeb.138057.

Background and Benchmarking

Findings

There are many principles that affect the step of a novice runner such as: posture, body tilt, anatomy of the foot, and type of shoe. Naturally, novice runners are not completely aware of their form of running and are more exposed to injuries such as knee injuries, stress fracture, shin splint, achilles tendinopathy, muscle pull: hamstring, ankle sprain, plantar fasciitis, IT (iliotibial) band syndrome and blister. These injuries are determined by a runner's movement of foot and their soft touch. A runner's heel strike could also cause higher impacts than landing near the middle or front of the foot, possibly contributing to an increase in risk of injuries. This is related with pronation, which is the natural movement that the foot takes while walking or running. There are three different foot types: neutral foot, which need an equal balance between cushioning and support, pronated foot or overpronators, which needs extra support because the foot tends to roll in due to the flat arch form, and last supinators that need extra cushioning due to the natural high arch of the foot that causes it to roll out.

The force that it is created when striking the ground has to do with weight distribution, which will determine the stability of a runner and could affect a runner's tread and this is related with the foot anatomy, therefore a correct type of running shoe must be selected in order to prevent injuries.

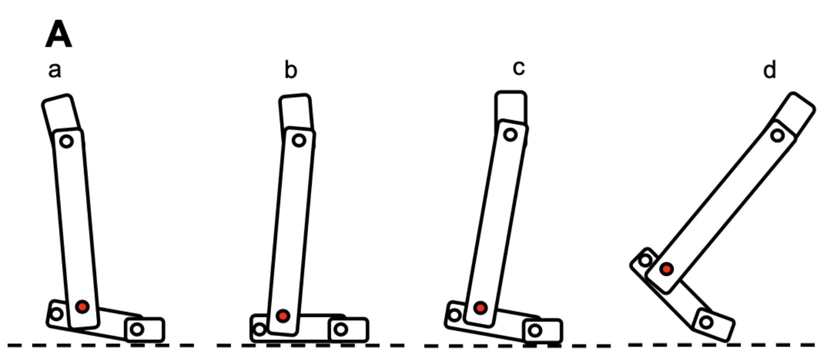


__Figure 1:__ Stick Figure Illustration of Mass Segment

Different types of shoes are made to solve problems such as a runner's stability and impact force. It was found that there are five common types of shoes used by runners: maximal shoes, stability shoes, motion control shoes, cushion shoes and minimal shoes.

Maximal shoes are padded shoes that elevate the heel as a result realigning the foot, keeping it more stable and reducing the impact of each step.

Stability shoes are best for runners with normal arches and only mild control problems. The extra stability these shoes offer comes from extra arch-side supports and high-density foam and are typically built with a gentle arch from front to back that provides rear-foot stability and forefoot flexibility.

Motion control shoes are great for flat-footed and heavy runners who tend to overpronate. These shoes typically have rigid devices made out of plastic, fiberglass, or high density foam. The arch area on motion control shoes is filled in for increased stability which is why there is a different color at the midsole. The extra rigidity in these shoes prevents the heel from turning out and the foot from overpronation.

Cushion shoes support people with high arches and rigid feet who tend to underpronate. This highly flexible shoe is built on a curve and made of lightweight materials that provide minimal rigidity with optimal cushioning.

Minimal shoes are defined to have less cushion and stability than traditional running shoes. While minimal shoes are often considered a new trend in running footwear, they have been around for a very long time. It is only in the past 50 years that footwear has progressively evolved into the modern-day, elevated cushioned-heel, motion-control shoe. While such changes were purported to assist in reducing running injuries, these injuries have persisted at a high rate. It has been suggested that this modern-day footwear has significantly changed the way we run and may contribute, in part, to the high rate of running injuries.

There have been many studies on the fact that the use of these shoes make a difference when it comes to causing injuries; however, the evidence is very dispersed and there are no conclusive results. Researchers do not agree when called for a conclusion.

Similar/Contrasting Solutions

There are existing products and research on gait mechanics. A research was found by Clark et al [1] studied the relationship between gait mechanics and ground reaction forces. [2]They used a two-mass model by using body mass and three stride-specific measures: contact time, aerial time and lower limb vertical acceleration during impact. Prior to discovering the research study on the relationship between gait mechanics and ground reaction forces, it was thought of creating a wearable device that would link the spine to the knee and foot. This approach would have been difficult to carry out. This project is different from the research study because the research study compares other parts of the body, while this project focuses on the knee and knee related injuries.

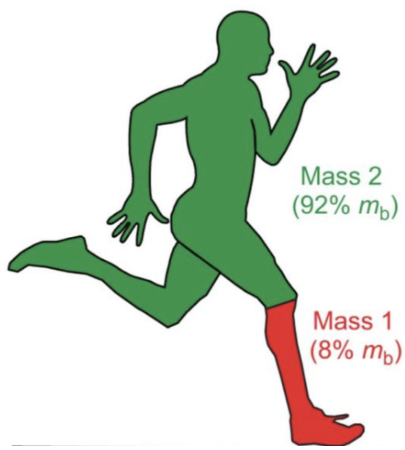


Figure 2: *Two-Mass Model*

It was also found similar products and ideas to our device, namely, RunScribe Pods and Lechal Pods. RunScribe is a wearable gait analysis system that provides a comprehensive gait analysis for running, walking, and hiking. RunScribe makes use of its new ShoeRide visualization, which allows its customers to see ground contact. It has 500Hz IMU foot pods that record each step and is connected to an app that shows in real time data. Any user is able to view and compare their runs through analytic tools provided by RunScribe.

[2] Clark, Kenneth P., Laurence J. Ryan, and Peter G. Weyand. "A General Relationship Links Gait Mechanics and Running Ground Reaction Forces." The Journal of Experimental Biology 220, no. 2 (March 2016): 247–58. https://doi.org/10.1242/jeb.138057.

Figure 3: *RunScribe Pods*

Lechal Pods is a smart navigation and fitness tracking insoles produced by Sensoria. Lechal can be inserted in your insole or clipped to your shoelace. Most importantly, it provides analytical data on steps, calories, and distance traveled. Although the use of this wearable device is not similar to that of this project, our team implemented their idea of a insole from this device.

Figure 4: *Lechal Pods*

Models

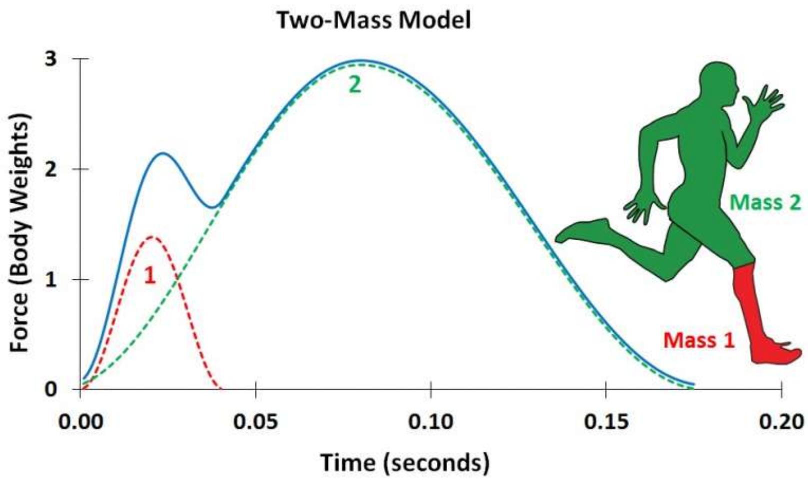


Figure 5: *Two-Mass Model*

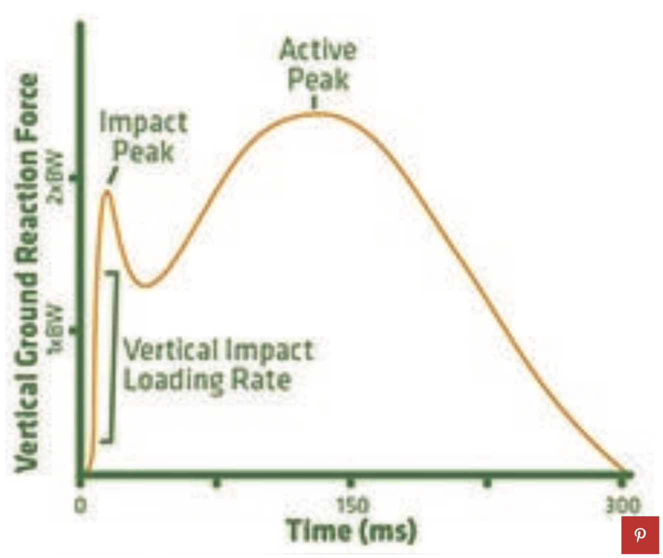


Figure 6: *Active Peak and Impact Peak for Two-Mass Model*

Conceptual Design

Various different approaches were explored for possible data collection methods with our prototype device. These approaches were based on the benchmarking research done regarding products already existing on the market and the fitness statistics used for measurement. As it was still unsure about which measurements they would collect and how, different designs explored different statistics and possible sensors.

The first design explored was earphones that a user could wear to measure their orientation, acceleration, and impact force. This was based off of the product that informed users about their head tilt and how that could affect their running form. Using an accelerometer and gyroscope, the way that the user's head moved mid-run could be determined, and whether any danger was posed to their spine. Additionally, the impact force measured could also lead to some investigation regarding whether the user is distributing force across their foot evenly when coming into contact with the ground.

The second design consisted of a knee brace slip on to measure the acceleration of the runner. The accelerometer in the device could provide data on acceleration in all 3 axes, therefore providing useful information on how the user's knee moved vertically as well as horizontally. This would be another method of observing the running form of a user, where pre-recorded data could be used for comparison.

The third design was a shoe sole insert that could be used to measure impact force and pressure distribution across the foot. This design was based off of the shoe sole found on the market that was able to produce a live pressure map visualization. This design consists of pressure sensors placed along the sole to capture the vertical movement of the user's foot when coming into contact with the ground, as well as the horizontal movement of their foot arch. This data would provide useful recommendations to what shoes a user should wear depending on the stability and control of their foot arch.

The last design explored was a device that could clip onto a user's belt to measure their impact force and acceleration. In benchmarking research, many pod-like devices were found that could be hooked to various surfaces such as a belt or the exterior of a shoe. This design plays off that concept, making it an easy gadget that requires minimal customization. The device would contain an accelerometer that could translate acceleration into impact force using the user's mass.

Before moving on to concept selection, it was decided it was best to combine designs in order to get more useful data for a user, as the individual designs were not optimal. It was decided that design three would be combined with each of the other designs instead of being its own design. The combination of the shoe sole with the other designs allowed the collection of data from two locations of the body, therefore allowing comparison of impact force at two locations and more parameters to be measured. The data could then be cross-referenced with existing data to determine the extent of danger.

In order to further explore the feasibility of the three initial conceptual designs, a Pugh Chart was formed to compare the designs based on criterias that were selected as important to the project. These criteria included safety, the weight and comfort of the device for a user, estimated costs to produce the prototype as well as the final product, the accuracy of the device in measuring the specific statistics it needed to measure, and lastly, the ease of implementation for the team to accurately produce the prototype.

Criteria	**Weight**	**Option 1**	**Option 2**	**Option 3**
		Soles + Earphones	Shoe Sole + Knee Brace	Soles + Belt
Safety	3	++	++	++
Weight/Comfort	2	0	+	+
Cost	1	-	0	0
Accuracy of measurement	3	-	0	-
Ease of Implementation	3	--	+	+
+		6	11	11
0		2	4	1
-		10	0	3
Net Score		**- 4**	**11**	**8**

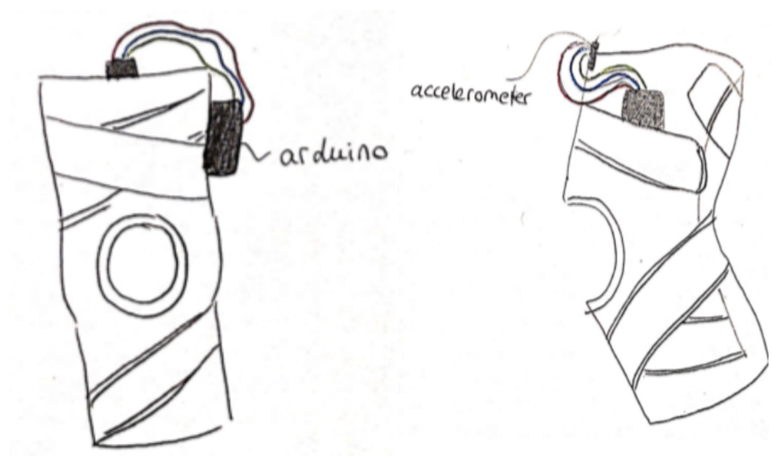
Table 1: *Pugh Chart Evaluation*

It can be seen from Table 1 that the criterias outlined above were given weightings based on their importance to the team. The criteria most important included safety, accuracy of measurement, and ease of implementation. Apart from safety, the other two criteria were deemed important as they were most necessary in ensuring that the prototype would fulfill its objective. If the device were unable to measure the statistics it needed to to provide useful information, or if the team was unable to properly build the prototype due to difficulty in implementation, the prototype would be rendered ineffective. The next most important factor was the weight and comfort for the user. This was decided to be more of an aesthetic preference in order to ensure user satisfaction with the product. The last criteria for the team was cost. This was because the team already had an estimated budget of $300 to produce the prototype, and based on benchmarking research, products that contained one or two sensors were priced between $25-200. It was therefore predicted that the prototype would not exceed the budget no matter which design was chosen.

The chart demonstrates how each design fares against the criteria selected, and it is clear that the design consisting of the shoe sole and the knee brace comes out the highest net score. It was therefore decided to continue with this design moving on into the project.

Preliminary Design

The next part of the project consisted in the preliminary designing process which was started by drawing out rough sketches of how the multi-part product would look, seen in Figure 7.



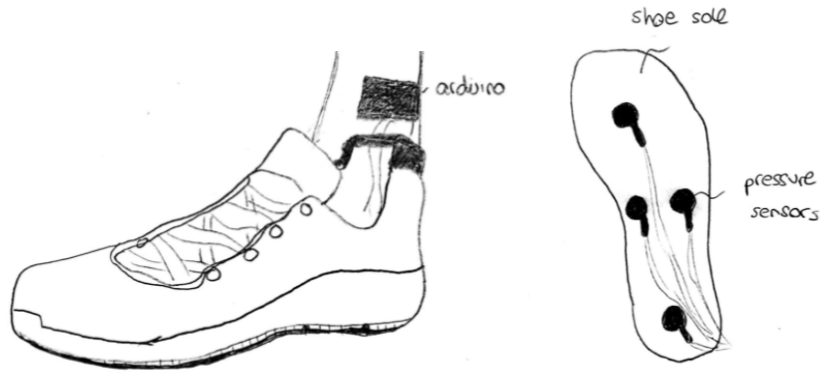


***Figure** 7: Preliminary Sketches of Two-Component Prototype Design*

The first part of the device is the knee brace, in which an accelerometer is housed in order to measure the impact force across the knee of the user. With the accelerometer, the force could be calculated using the body mass of the runner excluding the lower leg area between the foot and knee. These calculations are based on the two-mass model discussed in the Models section. The second part of the device is the shoe sole that can be inserted into any runner's shoe. The shoe sole contains multiple pressure sensors placed across the sole in order to collect useful data for both vertical and horizontal movement of the foot when coming into contact with the ground. The pressure sensors are connected to electronics that can be housed at the user's ankle. The pressure sensor would allow data collection of force per unit area.

As stated earlier, the impact force at the two locations of the user's body can be compared to one another to determine the percentage of impact force absorbed by the knee from the total impact force. The impact force would be collected at the foot when it came into contact with the ground, while the knee would output the impact force midst run. This percentage can then be referenced to a database of pre-recorded data by runners with both the right and wrong form to determine if the value is too large and dangerous for the user. The team decided this would be a suitable solution to the problem provided by the client as the client faced many problems with knee injuries, and knee injuries were found to be the most common for runners.

The data collected from the multiple pressure sensors can be used to determine whether the user has a neutral, underpronated, or overpronated arch as it was explained in the research . Based on these results, the device could recommend to a user whether they should be using maximal or minimal shoes in order to gain the additional cushioning and stability they need.

Preliminary Testing

After designing the preliminary model the work centered in the coding of the device. First the coding for a simple circuit using an accelerometer and an Arduino board was developed, then a circuit that consisted of a pressure sensor, a resistor and another Arduino board was built, coded and calibrated for a person of approximately 53 Kg. The circuitry, coding and calibration are explained below. This first prototype needed to be connected to a computer in order to get data.

Calibrations

In order to calibrate the pressure sensor to the correct output, objects with known weights were put onto the sensor. Using a linear calibration method, an equation was constructed to adjust the output of the pressure sensor, however, after further testing, this equation was found to be incorrect. Although the maximum and minimum values were correct, all intermediate output had inconsistent values with what was expected. It was later found that the pressure sensor displayed output in a logarithmic manner, represented by Equation 1 below;

force = -15185 * log(float(pressure)) + 105239.56

Equation 1:

In a similar manner, linear calibration was also used for the accelerometer, however, we were just able to have two known values for this method. Using an acceleration of zero, and the acceleration of gravity, an equation was constructed for the accelerometer. As the accelerometer measured in 3 axes, the same procedure was followed for all axes, making it point in the direction of gravity for calibration, represented by Equations 2-4;

a_x = 0.1463 * float(x) - 48.95;

a_y = 0.1465 * float(y) - 48.75;

a_z = 0.1595 * float(z) - 53.95;

Equations 2-4:

Circuitry and Code

To utilize the sensors properly and collect data, the electronics were wired in the following way, seen in Figure 8;

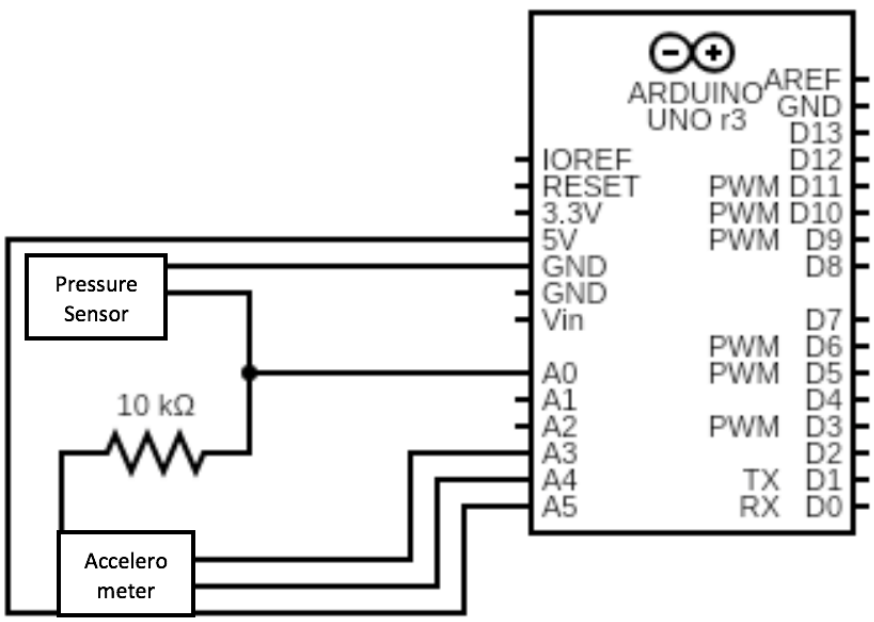


Figure 8: *Circuit Diagram for Sensor Testing*

In this configuration, both sensors were connected to the same Arduino in order to collect and output data simultaneously. The team used the code outlined in Appendix A in order to test the sensors output.

Data

Data collected from the preliminary tests are summarized below in Figures 9 and 10, differentiating between the accelerometer and the pressure sensor.

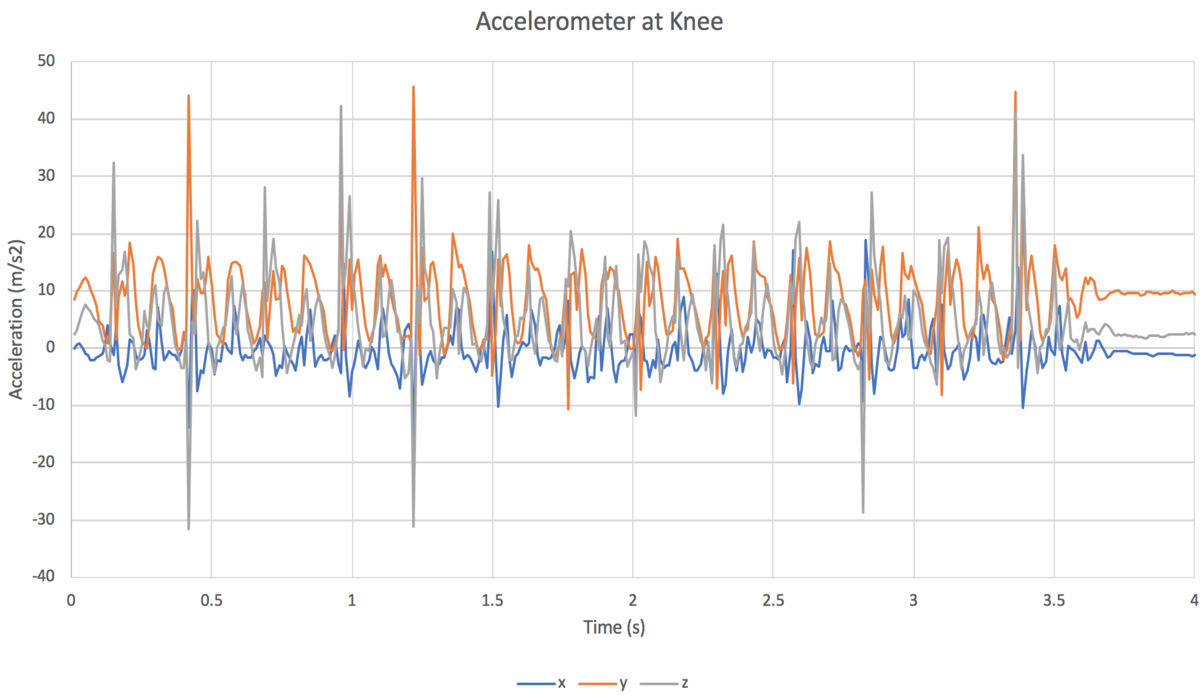


Figure 9: *Recorded Acceleration in x, y, z axes at the knee, mid-run*

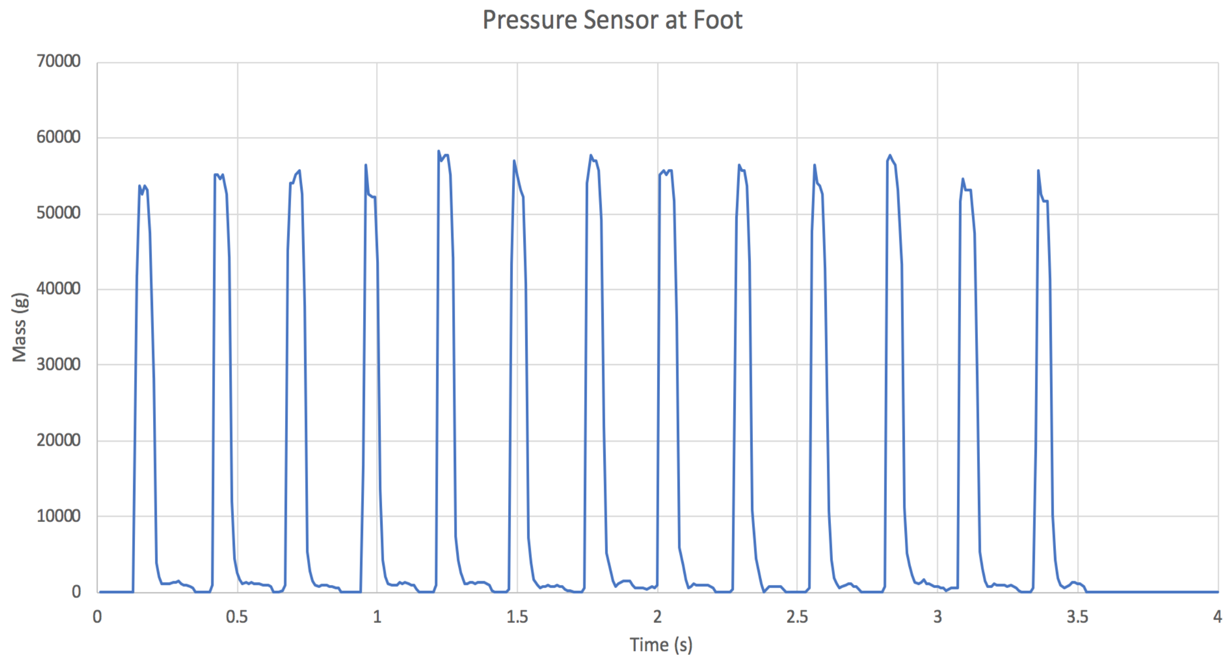


Figure 10: *Recorded Mass on Pressure Sensor, mid-run*

It can be seen that the biggest peaks in acceleration are in the X and Y axes of the accelerometer. This correlates with up and down movement, and forward and backward movement of the knee. It was decided that simulating just the movement in these two axes may provide useful information, however, this would be done towards the end of project completion if time allowed.

This first prototype is shown in the image below:

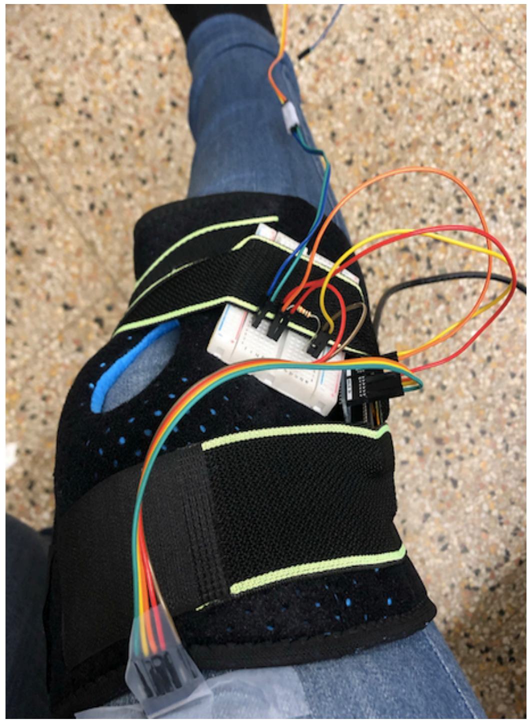


Image 1: *Photo of the circuitry of the first prototype*

Detailed Design

Communications

In order to further sophisticate our prototype and proceed from a preliminary design into a more detailed design, it was decided that proper testing capabilities were needed. In order to effectively do this, the sensors would need to work wirelessly to relay the data collected back to a user. For the initial testing, the Arduino was directly connected to a laptop in order to transfer results for pressure and acceleration, however, for a prototype product, the data must be able to be sent wirelessly to a user's phone.

To begin the process of wireless communication, it was started with attempting to use the Bluetooth feature on an Arduino Nano (Version 1). Not only was this version of the Arduino smaller and more fitting for the product, it also had several wireless capabilities. After uploading the code onto the Arduino and disconnecting it, it was found that the program could not run as the Arduino still needed a power supply. Despite using batteries as a power supply, the Nano needed to be connected to the laptop to work. After further research, it was found that the Bluetooth capabilities worked with other connections from a phone or different device, but the board would still need to be connected to a laptop. As this did not fit with the requirements, it was needed to turn to an alternative solution.

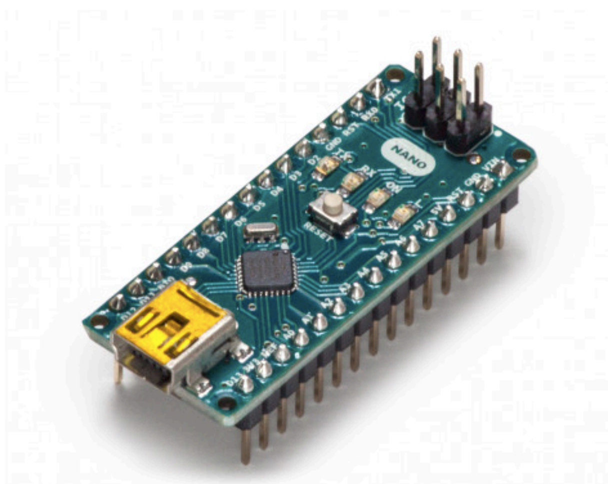


Image 2: *Photo of an Arduino nano.*

Next, it was attempted to use Xbee modules for communication. The Xbees could be set up to send and receive data from one another using XCTU software, as long as each were being powered. One Xbee was connected to an Arduino Uno with the pressure sensor/accelerometer that was powered using a battery, while the other Xbee was connected to another Arduino Uno that was directly attached to a laptop (Version 2). This set-up utilized the Software Serial library in the Arduino IDE, which allows communication between two programs without direct connection of RX and TX pins. It was found that the Xbees were able to properly communicate with one another, however, received data was slightly different than what was being sent. After significant troubleshooting, the team was able to use type casting and specific serial monitor command functions to produce the correct output.

Image 3: *Photo of a xbee module.*

To make the prototype more feasible for testing, the board was further adjusted to an Adafruit Feather Huzzah, a smaller board with similar capabilities (Version 3). Similar to when testing with the Arduino Nanos, the output had to be adjusted for correct values but the connection worked smoothly with Software Serial and similar code. When it was attempted to start collecting data, a significant issue arose; it was found that although the sensors could produce an output value once per 50 milliseconds, Software Serial could only communicate values once per 1000 milliseconds, or once per second. This became a big problem for the project, as in order to truly see the peaks and troughs of the impact force as the user stepped on each foot, one value per second would not be fast enough to see any change in data; the time it takes for a runner to take a step while mid-run is less than a second.

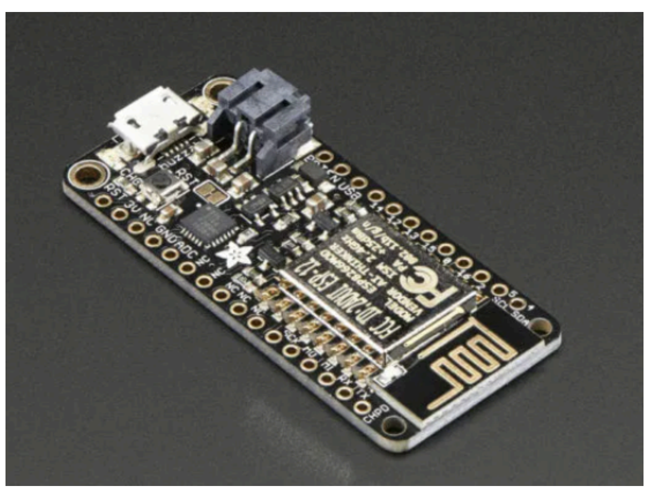


Image 4: *Photo of an Adafruit Feather Huzzah.*

To fix this problem, an alternative to Software Serial was needed for remote transmission of data. After thorough online research, it was found that the Adafruit board was configured with the ability to send data wirelessly to an Adafruit Online IDE, eliminating the need for Xbees and a second board connected to a laptop (Version 4). The online environment had various capabilities and methods to display data which would be very useful for the project, however, after further research and testing, it was found that this method of transmission was even slower than Software Serial, sending data every two seconds.

It was then tried using an Arduino Mega instead of an Arduino Uno for the receiving end of communication, as the Mega had multiple serial port connections and could therefore receive information directly while still being able to send the information back to the computer (Version 5). However, even with the direct RX and TX connections, the data being transmitted was incorrect. It was also later decided that trying to get this alternative to work would not fit with the project requirements as well, as there would be a direct connection between the two boards, defeating the purpose of wireless communication. Not only would a runner not be able to properly run with these connections, testing for the prototype device would also not work.

In terms of the prototype's electronics design, it was decided that the solution with the two Xbees connected to an Adafruit Feather on the sending side and an Arduino Uno on the receiving side, Version 3, was the best option. For further work, it would be needed to find a way to improve the transmission speed, as the current speed with Software Serial is too slow.

Circuitry and Code

As Versions 2 and 3, the only configurations which produced successful and useful results were identical except the board used to send data, a single circuit diagram is represented below. These diagrams illustrate an Arduino Uno Board (Version 2), while Version 3 contains an Adafruit Feather Huzzah Board instead.
The circuitry and code for the two sending components of the device (Shoe Sole and Knee Brace) will be individually represented in Figures 12 and 13, however, the circuitry of the receiving end Arduino were identical, represented in Figure 11.

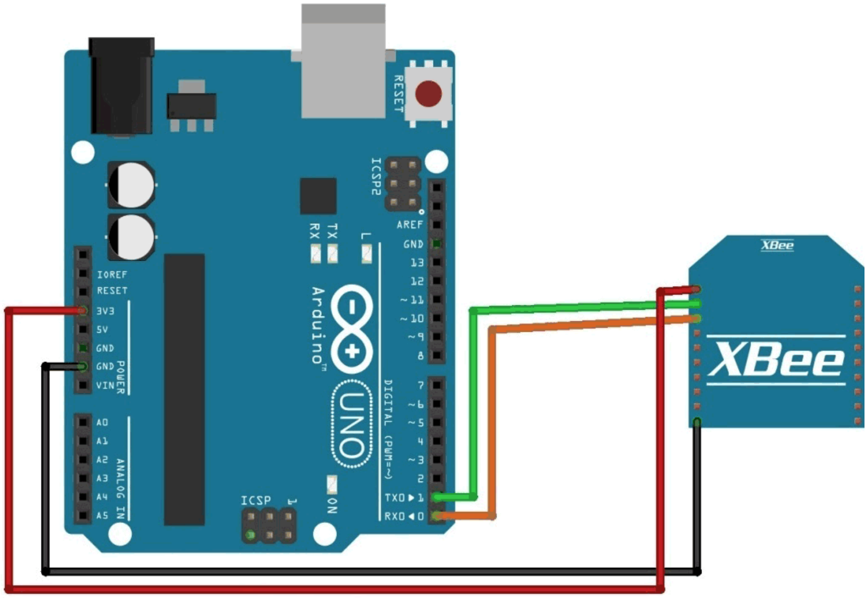


Figure 11: *Circuitry for Xbee Communications with Shoe Sole + Knee Brace (Receiving Side, XBee pins 1,2,3,10)*

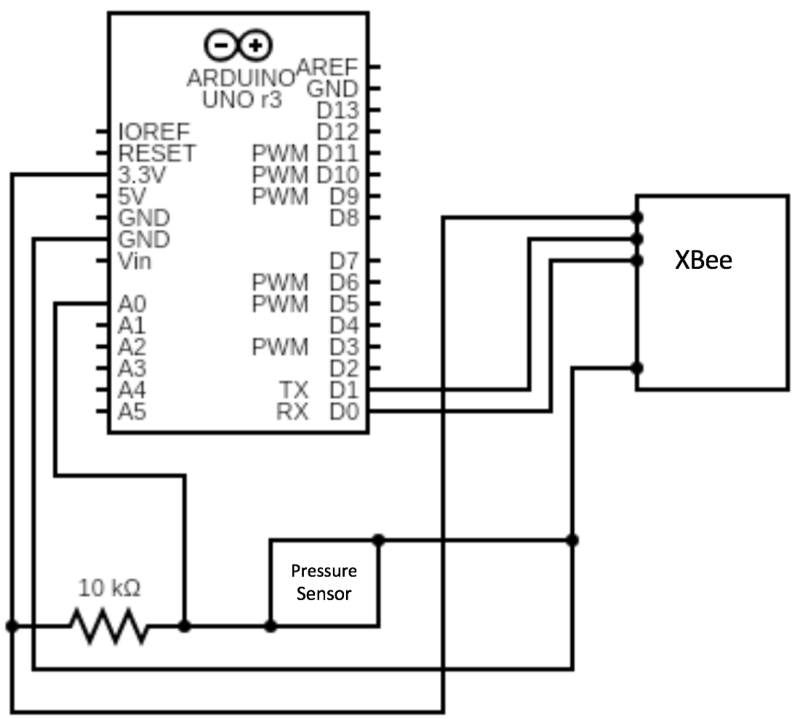


Figure 12: *Circuitry for Xbee Communications with Shoe Sole (Sending Side, XBee pins 1,2,3,10)*

The code referenced in Appendix B was used for testing the pressure sensors on the Shoe Sole, with minor differences between the two versions of the communication design.

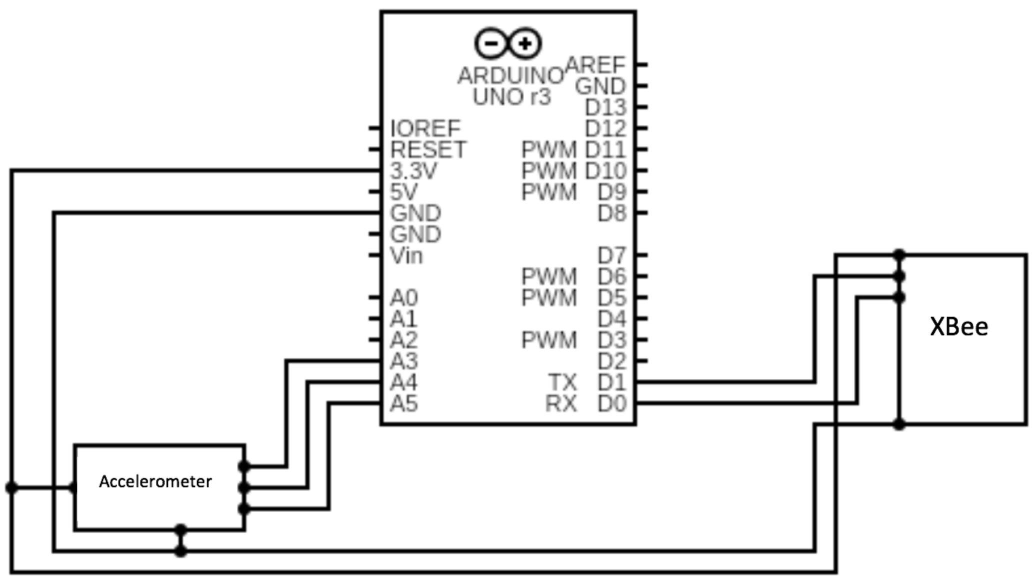


Figure 13: *Circuitry for Xbee Communications with Knee Brace (Sending Side, XBee pins 1,2,3,10)*

The code referenced in Appendix C was used for testing the accelerometer placed at the Knee Brace. It was decided that data from all 3 axes would be collected, and could be further isolated into the X and Y axes if needed.

Simulations

As it was not possible to collect testing data, in order to evaluate the accuracy of our detailed design, a simulation was constructed to mimic the movement of a leg during a run.

In order to have a reference of the quantities we want to measure with our device, a 3D simulation was made using the SolidWorks program. This will allow to make a comparison between experimental measurements and theoretical data that is estimated using this model. With this, in the future of our work the team wants to compare different simulations, changing attributes such as speed, length of step, mass… according to the different experimental test that we will perform using our prototype. The model and simulation method will be presented and explained below.

Our model includes the parts of the foot, the lower leg, including ankle and knee joints, and the upper leg. Physical attributes have been programmed to make the simulation as precise as possible, these attributes are mass, gravity, damping and stiffness. The joints have been modeled as bushings and the parameters used are shown in the appendix. The model of the leg used for the simulation is shown below:

Figure 14: *Lateral view of the leg model*

Figure 15: *Exploded view of the leg model*

In order to calculate impact forces on both ankle and knee, critical areas most affected when running, it is necessary to perform a simulation with movement, so that in order to find the displacement of the ankle and knee a study was carried out through the follow-up of these joints when taking a step. To achieve a simulation in which the movement and displacement of the leg is in accordance with reality, an algorithm was used to identify this trajectory. The algorithm was coded using Matlab. This code can read a video and identify a specific color throughout the video and follow the path of that color. Our team has chosen to use bright green stickers located in the knee and ankle joints as it is shown in the images below:

Figure 16: *Images from the video of a person running wearing a green sticker in the ankle.*

Figure 17: *Images from the video of a person running wearing a green sticker in the knee.*

Using a camera, a video of the person running was recorded. The video only shows one step movement wearing first the sticker on the ankle and then in the knee. The algorithm was able to follow and collect the coordinates of the trajectory of this movement. To achieve this it is necessary to change the colors of the video to black and white, the algorithm identifies the color chosen by the user to track its trajectory, as said before our team chose rounded green stickers, the code changed the colors of the video to black excepting this sticker that is changed to white.

Figure 17: *Green sticker is turned to white to follow its trajectory*

This step is necessary because in order to get this path a Matlab function was used. This function is called ‘’regionprops’’ and can identify the centroid of a white element in a black colored background. In a loop the video was divided into numerous images and the centroid of the sticker was saved as coordinates in a matrix. These coordinates were used to make the displacement graphs. Thanks to this we were able to understand the movement and thus introduce it in the program Solidworks to produce a simulation as accurate as possible. The code used to achieve this is shown in the Appendix D and the graphs of the ankle and knee trajectories are shown below:

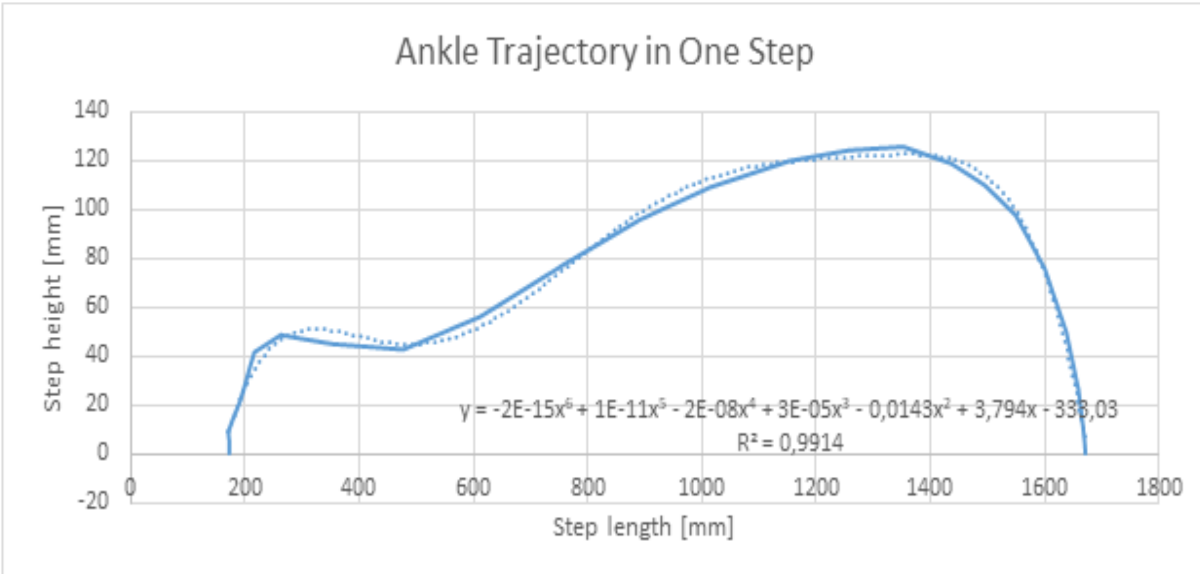


Figure 18: *Ankle trajectory in one step*

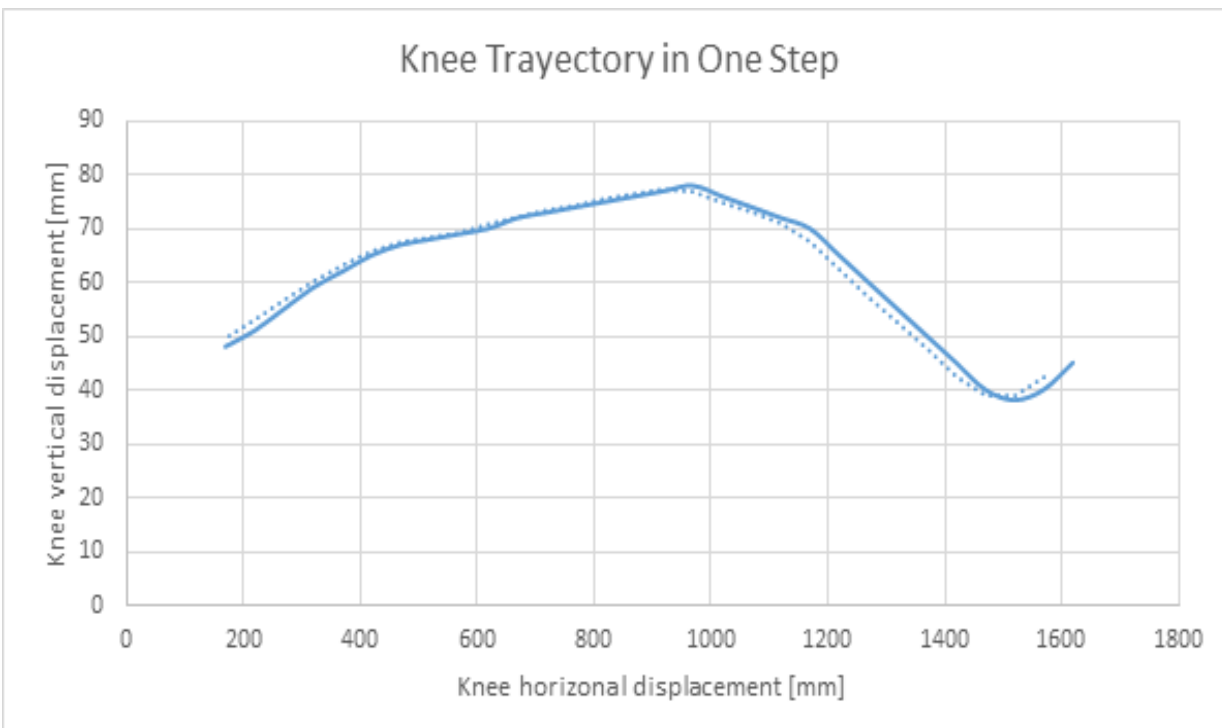


Figure 19: *Knee trajectory in one step*

Once we got the desired trajectory, we introduced this data into the SolidWorks model in order to perform a motion analysis. As it is said before, physical attributes have been programmed to make the simulation as precise as possible and the joints have been modeled as bushings with the following characteristics:

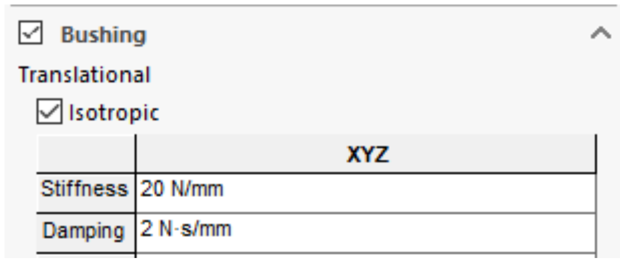


Figure 20: *Stiffness and damping values used in the model joints*

Using these approximations and the Motion Analysis Tool from Solidworks we were able to get values of the reaction force in different parts of the leg throughout time. For this simulation we used the measurements of an average man, 1.75m and 80kg. As it was explained previously in the report the parts of interest are the joints (knee and ankle), using this program we were able to get data of the reaction force in the vertical direction in both articulations as well as the reaction force in the shoe sole as it impacts the floor. The data obtained will be explained below:

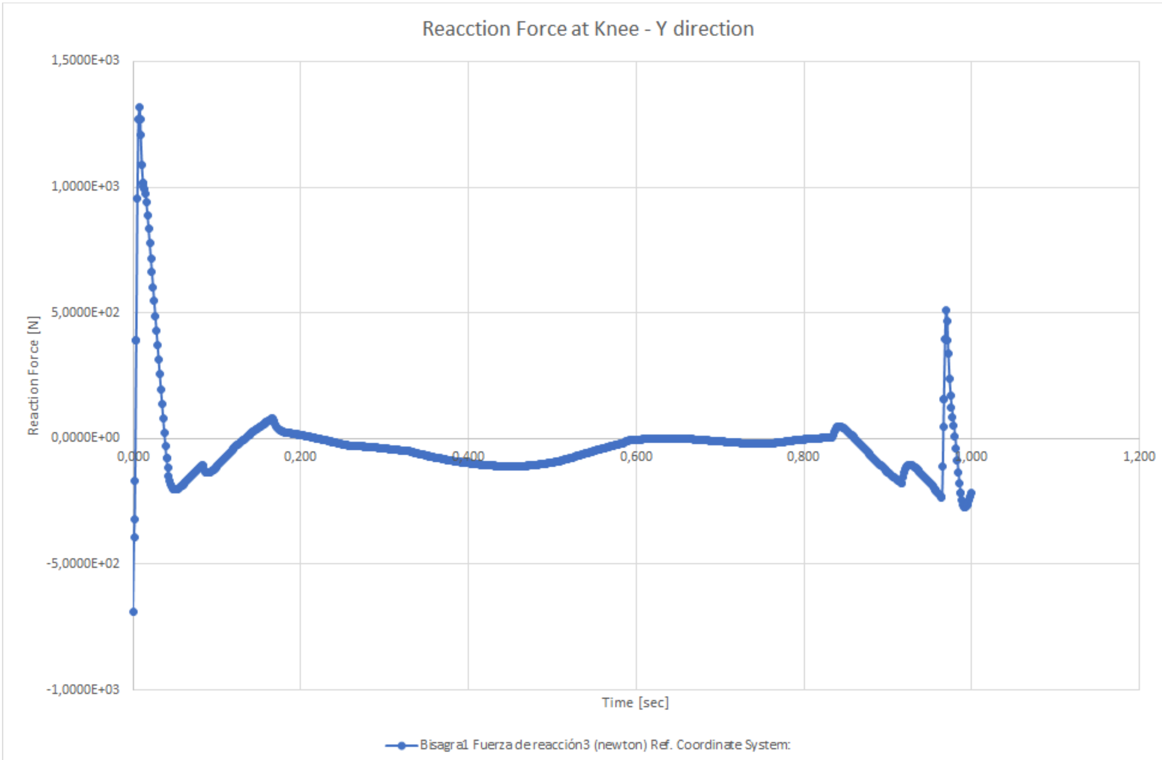


Figure 21*: Graph of the reaction force at the knee in the vertical direction*

The simulations starts with the person at rest, in the graph above it can be observed that the first peak is the highest, this may be because the person starts with a speed of 0m/s and the momentum generated to separate the foot from the ground and push it forward when starting to run should be high. The second peak corresponds to the first impact when running, this contact with the ground is instantaneous so the peak is very inclined at a very sharp angle. The reaction force at the knee is the lowest of the forces we estimated with this model.

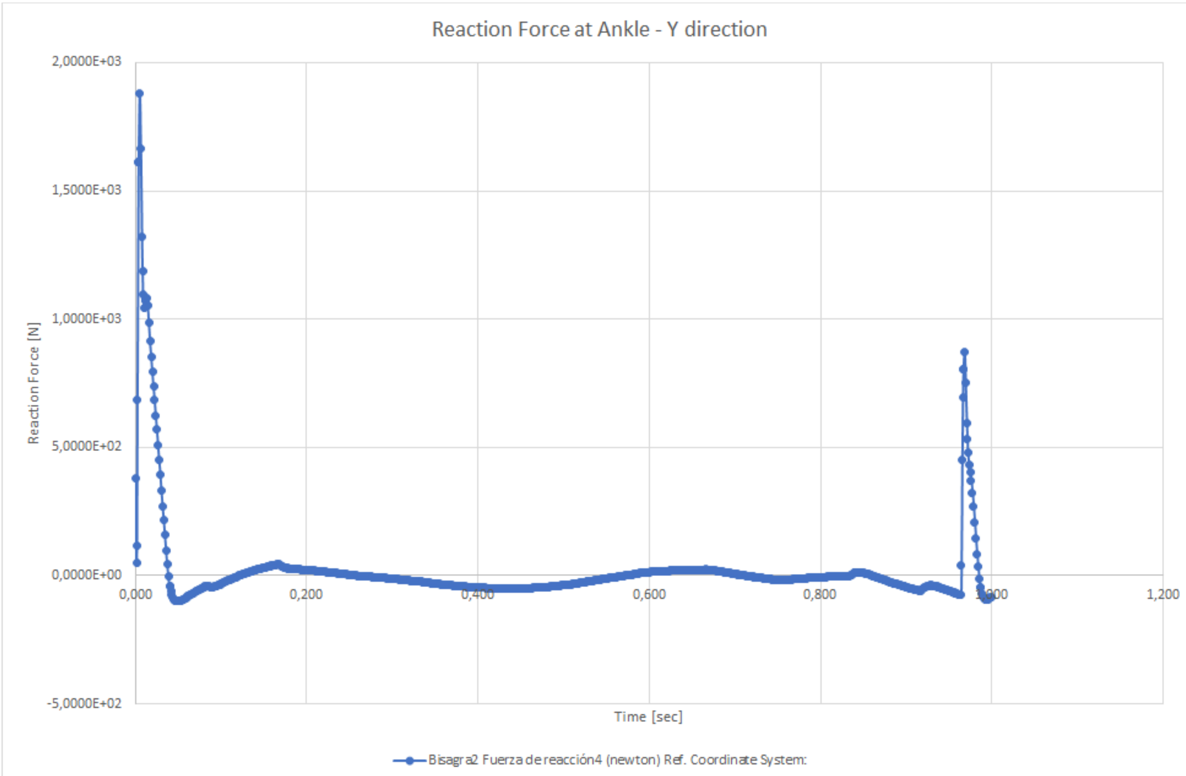


Figure 22: *Graph of the reaction force at the ankle in the vertical direction*

In this case it is observed that the shape of the graph corresponding to the reaction in the ankle shown above is very similar to that of the knee but the values are slightly higher, this may be due to the weight that the ankle supports is higher than the one the knee supports.

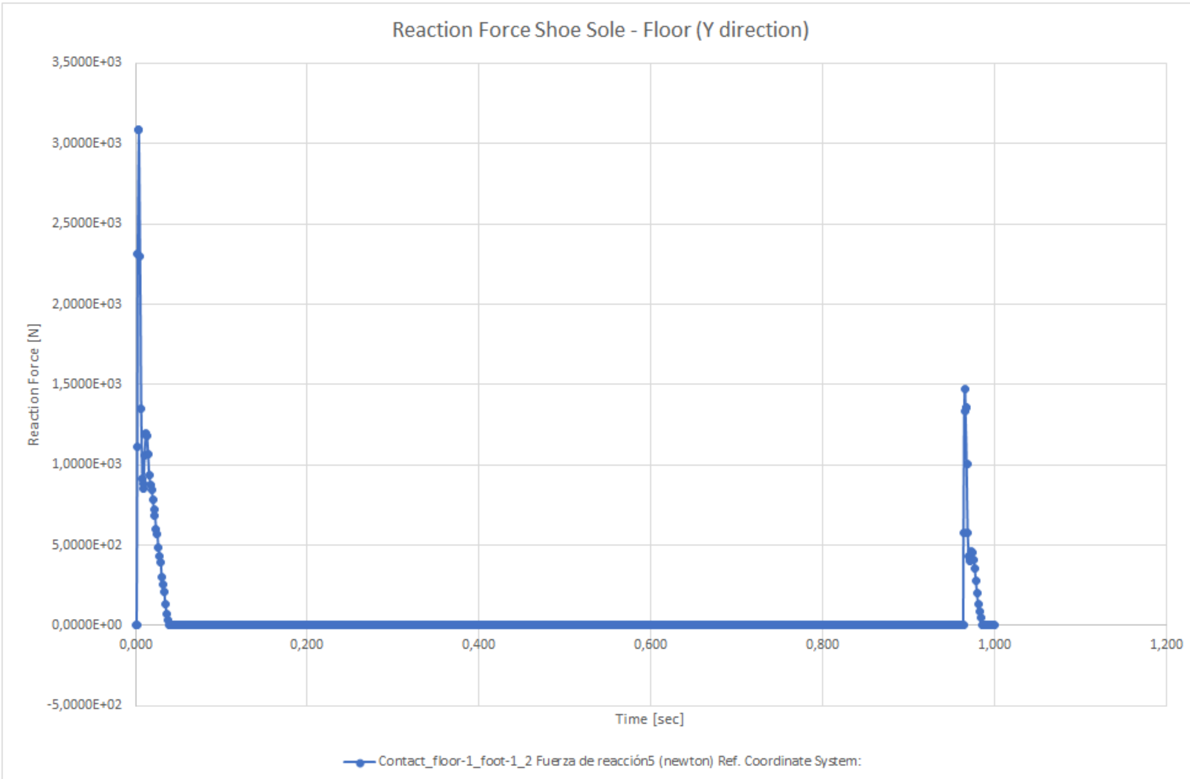


Figure 23: *Graph of the reaction force between the shoe sole and the floor*

This graph is the one we will compare to the data obtained with the pressure sensor located at the sole of the foot. It can be noticed that this is the highest force of the three, and that the force is equal to 0 N when the foot is not in contact with the ground.

With this our team has achieved the purpose of developing a model in order to compare computational data with experimental data.

Cost Analysis

One of the main objectives of our project is to minimize the cost of the device. For this prototype economic components have been used but our team wants to point out that for more accurate results the implementation of more expensive and advanced components will be required in the future.

As it was shown in previous sections, our final prototype consists of an electrical circuit composed of two Arduino Uno that can communicate and transfer data from one to another wireless thanks to the implementation of two xBee modules. The components used to gather the significant data are a pressure sensor and an accelerometer. The list of the components and their cost used for the final prototype are listed in this section.

Components	Amount	Unit price ($)	Total Price ($)
Arduino Uno	2	20,7	41,4
XBee modules	2	18,92	37,84
Pressure sensor	1	9,7	9,7
Accelerometer	1	8,8	8,8
Wiring + resistors	1	2	2
Knee brace	1	18,99	18,99
Battery pack	1	2	2
TOTAL			120,73

Table 2: *Total Cost*

These are the cost of the components our team used to build the prototype, many of these parts were provided by the Mechanical Engineering Department while the others were bought using the team budget.

Conclusion

In conclusion, this project was challenging since the design of a prototype had to be done form scratch, the circuitry had to be designed with the uncertainty of how it would later work had as a result the need to do multiple changes in the design throughout the developing of the project. In order to achieve the goals presented at the beginning of the project, which are get data from the impact force at the foot and the acceleration and force at the knee both in real time from multiple runners and compare it to the simulation data, the prototype will need to be improved. The lack of time made it not possible to continue developing the prototype.

To sum up the development of this project can be summarized in the following parts: first the problem was presented which was injuries in runners and how to avoid them. Before sketching a device multiple researches were done, the main ones were the reasons why people get injuries and the devices that are already in the market that are related with the problem description. From these is was discovered that there are so many ways running can lead to injuries : there are many types of foot shapes (pronator, supinator or neutral foot) that determine the posture of a person while walking or running as well as how the weight is distributed over the foot and for these different shapes there are multiple shoe types (maximal shoes, minimal shies, stability shoes, cushion shoes ets…). Having this in mind the first idea that arose was to create a device that could be worn in the foot and that would be able to measure in real time forces. In the market there are several devices that were studied such as RunScribe Pods and Lechal Pods. Some of this devices were used as an inspiration to develop the prototype.

During the development of the prototypes multiple changes were done, first Arduino Uno boards connected to a computer were used but this prototype did no satisfy the wireless communication so an Arduino Nano with Bluetooth integrated was bought but it was not possible to make it work with the existing circuit. After this two xbee modules were programmed and succeeded in making communication between the device and the computer wireless. In order to make the device smaller so it was more lightweight and easy to wear, an Adafruit Feather Huzzah was used as a substitute to the Arduino Uno Board. This board could have been the optimal one if the Software Serial library used in the coding would not need a delay of at least one second in order to send data to the computer. The lack of time made it not possible to solve this problem, so in the future it will be expected to reduce significantly this delay since one second is not acceptable for the purpose of this project.

The simulation developed using SolidWords will be used in future works to contrast experimental data with computational data.

Regarding the final cost of the prototype it can be concluded that the cost was high and in order to develop a better prototype a bigger budget will be needed.

The last part of the report is the cost analysis in which the costing of the materials used to build the prototype are listed and an approximation of the final cost of the device is presented.

It is expected that in the future, it will able to provide the customer with a prototype of a wearable device that allows the user to observe the ratio of force being absorbed by their knee in comparison to the force on their foot when in contact with the ground. When structuring the project, our main consideration was the timeline of data collection due to our several hardware issues. The hardwares handles the processing and communication. The receiving hardware had an issue of displaying the exact information from the sender, so we became weary of being able to meet up with the deadline. After prioritizing the project, more time was allocated to solve and successfully accomplish this problem.

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Appendix

Appendix A: Code for Preliminary Design Testing

```
void setup() {
 Serial.begin(9600);
}

int pressure;
int x, y, z;
float f, ax, ay, az;

void loop() {
  pressure = analogRead(0);
  f = -15185*log(float(pressure))+105239.56;

  x=analogRead(5);
  y=analogRead(4);
  z=analogRead(3);

  ax=0.1463*float(x)-48.95;
  ay=0.1465*float(y)-48.75;
  az=0.1595*float(z)-53.95;

  Serial.println(f)
  Serial.print('\n');

  Serial.print(ax);
  Serial.print(" ");
  Serial.print(ay);
  Serial.print(", ");
  Serial.println(az);

  delay(50);
}
```

Appendix B: Code for Detailed Design Testing (Shoe Sole)

//on the sender side

```
#include <SoftwareSerial.h>
SoftwareSerial airSerial(2, 3); // RX, TX

void setup() {
  Serial.begin(9600);
  airSerial.begin(9600);
}

int pressure;
String strPressure = "";

void loop() {
   pressure = analogRead(0);
   f = -15185*log(float(pressure))+105239.56;
   strPressure = String(f); // type cast to work with serial.read
   Serial.println(strPressure); // to check output
   airSerial.println(strPressure); // to send output
   delay(50);
}
```

//on the receiver side

```
#include <SoftwareSerial.h>
SoftwareSerial airSerial(2, 3); // RX, TX

int received;

void setup() {
  Serial.begin(9600); //matches the serial speed configured for XBee
  airSerial.begin(9600);
}

void loop() {
  if (airSerial.available() ) {
    received = airSerial.read()-'0'; // converts to correct output

    delay(50);
    Serial.println(received); // prints received output
```

```
  }
}
```

Appendix C: Code for Detailed Design Testing (Knee Brace)

//on the sender side

```
#include <SoftwareSerial.h>
SoftwareSerial airSerial(2, 3); // RX, TX

void setup() {
  Serial.begin(9600);
  airSerial.begin(9600);
}

int x, y, z;
float ax, ay, az;
String strX = "";
String strY = "";
String strZ = "";

void loop() {
   x=analogRead(5);
   y=analogRead(4);
   z=analogRead(3);

   ax=0.1463*float(x)-48.95;
   ay=0.1465*float(y)-48.75;
   az=0.1595*float(z)-53.95;

   strX = String(ax); // type cast to work with serial.read
   strY = String(ay); // type cast to work with serial.read
   strZ = String(az); // type cast to work with serial.read

   // to check output
   Serial.print(strX);
   Serial.print(" ");
   Serial.print(strY);
   Serial.print(", ");
```

```
  Serial.println(strZ);

  // to send output
  airSerial.print(strX);
  airSerial.print(" ");
  airSerial.print(strY);
  airSerial.print(", ");
  airSerial.println(strZ);

  delay(50);
}
```

//on the receiver side

```
#include <SoftwareSerial.h>
SoftwareSerial airSerial(2, 3); // RX, TX

int received;

void setup() {
 Serial.begin(9600); //matches the serial speed configured for XBee
 airSerial.begin(9600);
}

void loop() {
  if (airSerial.available() ) {
    if (airSerial.read() == ",”){
      received = airSerial.read(); // does not alter comma
    }
    else {
      received = airSerial.read()-'0'; // converts to correct output
    }

    Serial.println(received); // prints received output
  }
}
```

Appendix D: Matlab Code to Calculate the Knee and Ankle Trajectory

```
% Read a video file and play it.
   videoFReader = vision.VideoFileReader('tobilliluli.mov');
   videoPlayer = vision.VideoPlayer;

   ct=0;
   pts=[];

   while ~isDone(videoFReader)

       videoFrame = step(videoFReader);

      step(videoPlayer, videoFrame);

       r=videoFrame(:,:,1);

       g=videoFrame(:,:,2);

       b=videoFrame(:,:,3);

       p=(g-r)*255;                    % Difference between colours green and red

       [r,c]=size(p);

       th=50;                          % Umbral

       pvec=p(:);                      % Turns a matrix into a vector

       pvec_bn=double(pvec>th)*255;   % Detects vector positions where values > th

       p1=double(reshape(pvec_bn,r,c));    % Puts together the matrix again

       figure(1),image(p1)

       pause(0.1)

     % In order to calculate the centroid, first we have to turn the video to black and white

     umbral = graythresh(p1);
     imag_bw = im2bw(p1, umbral);
     imshow(imag_bw);
     imag_bw_label= bwlabel(imag_bw);             % Identifies objects in the image
```

```
    s=regionprops(imag_bw_label,'Centroid'); % Caculates the centroid of the object

    cent= struct2cell(s);
    cent2 = cent{1};

    ct=ct+1;

     % A is the matrix where the centroid of the object during the video is saved as coordinates
    A(ct,1)=cent2(1,1);
    A(ct,2)=cent2(1,2);



  end

  [fila,columna]=size(A);


 X=A(:,1);            % x direction coordinates
 Y=A(:,2);            % y direction coordinales
 ymaximo=max(Y);
 Ym= ymaximo -Y;

 plot(X,Ym)           % plots the graph
 axis auto
 title('Movement of the ankle in one step');
 xlabel('mm')
 ylabel('mm')

 release(videoPlayer);

release(videoFReader);
```

Appendix E: Gantt Chart

Task	Start Date	End Date	Duration	01/20/20	01/27/20	02/03/20	02/10/20	02/17/20	02/24/20	03/02/20	03/09/20	03/16/20	03/23/20	03/30/20	04/06/20	04/13/20	04/20/20
Planning																	
Semester Schedule/Final Research Approach	01/22/20	01/24/20	3														
Sticker Simulation	01/27/20	01/28/20	2														
Bluetooth Devicing	01/29/20	01/31/20	3														
Data Collection	01/27/20	02/06/20	11														
CAD Final Design	02/06/20	02/07/20	2														
Order Final Materials	02/10/20	02/12/20	3														
Final Internal Circuit Test	02/10/20	02/14/20	5														
Building																	
Prototype	02/17/20	02/19/20	3														
Weld/assemble outside parts	02/21/20	02/26/20	6														
Test movement	02/28/20	02/28/20	1														
Assemble final	03/02/20	03/06/20	5														

product/Test product/Make adjustments																	
Product																	
Alternative Customer App	03/10/20	03/20/20	11														
App Draft Review	03/22/20	03/25/20	4														
Final Review	03/27/20	03/31/20	5														
Written Report																	
Meet with Customer	03/02/20	04/05/20	35														
Excutive Summary Update	04/06/20	04/19/20	14														
Engineering Specification Updated	04/06/20	04/19/20	14														
Bill of Materials Created	04/06/20	04/19/20	14														
Benchmarking Reviwed	04/06/20	04/19/20	14														
Design Description Updated	04/06/20	04/19/20	14														
Market/Cost Analysis Written	04/06/20	04/19/20	14														

Report Draft Review	04/20/20	04/20/20	1														
Final Report Review	04/21/20	04/25/20	5														

Appendix F: Integrating The Sustainable Development Goals:

The Sustainable Development Goals (SDGs) are a collection of 17 global goals designed to be a "blueprint to achieve a better and more sustainable future for all."

This Project will approach two goals that are part of the SDGs, these are ``good health and well being´´ and ``partnership for development´´.

The project is aimed at helping people with problems related to injuries caused by playing sports, in particular running. Nowadays running is one of the most popular and practiced sports, that is why the number of people whose health is affected by this sport is increasing. Being a fashionable sport, there exists in the market numerous footwear designs and a lot of accessories for running. This is why it can be difficult for the consumer to find the right footwear or mechanics to run. In addition, there is a lot of information on the internet that can be contradictory since there are many theories about which aspects affect the runner and which errors cause injuries, you can find opinions on the above mentioned topic of footwear and also about posture or the floor material on which the sport is performed, etc.

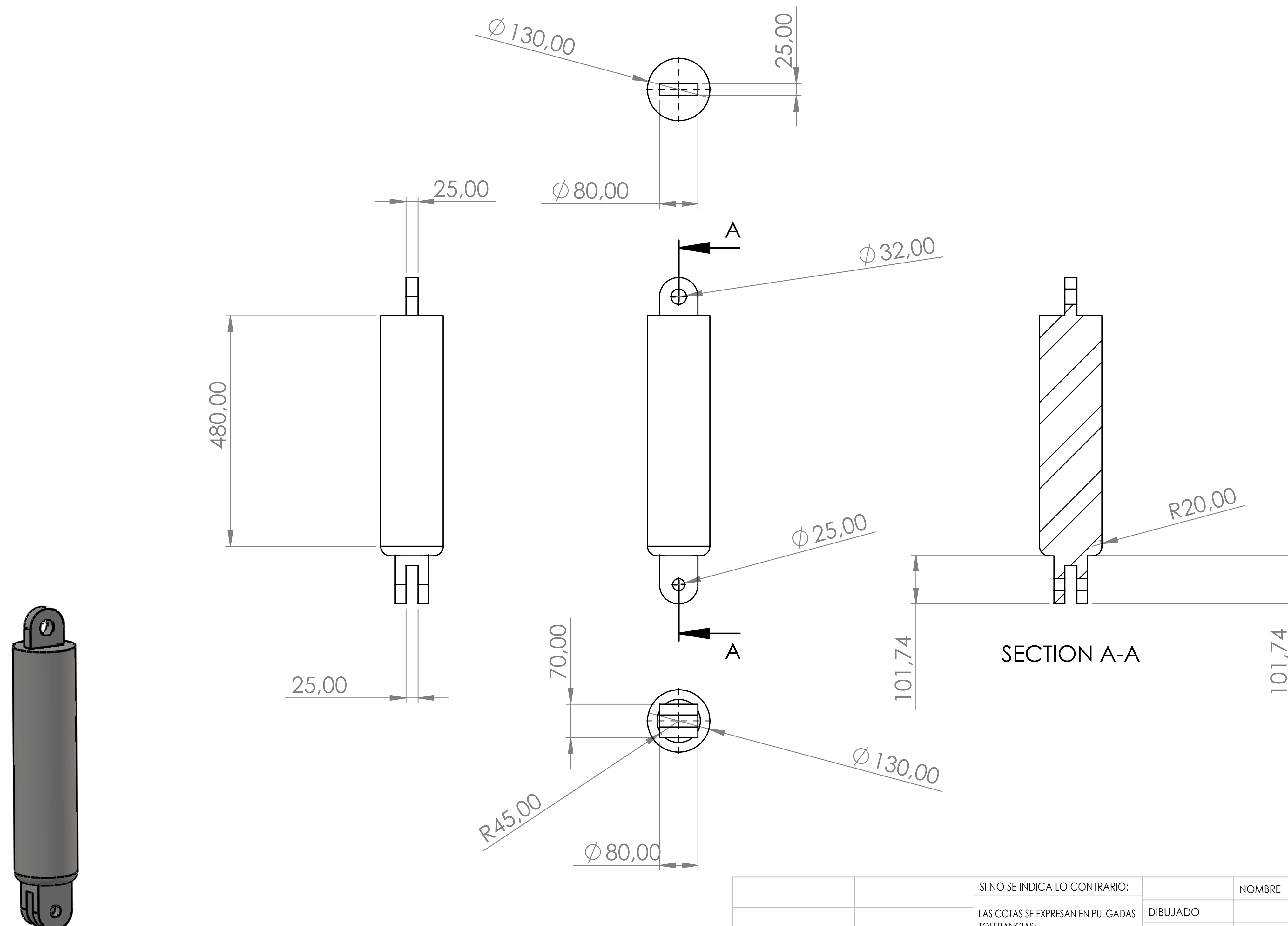
This is why the project will help people to know and understand better their dynamics when running, helping the health of the runner as they will be able to get data in real time about the impact force when running, and will be able to compare it when using different types of shoes and different postures while running. In addition, since a platform will be developed in which this information will be recorded, the consumer will be able to call upon professional, such as doctors and physiotherapists, for help and advice. In this way professionals will be able to have information that will help to create a true platform with data and analysis of these professionals, thus creating a community that helps athletes find useful information.

The device designed in this project could also be used by stores that are specialized in selling sneakers. Many runners who suffer from injuries go to specialists for advice and on many occasions they are recommended a particular type of shoe depending on whether their tread is neutral, pronator or supinator as it was explained previously in this report. However there are many contradictory opinions about the use of these sneakers as each person has a different foot anatomy that may not be suitable for the foot model for which the shoe was designed. A runner can then often purchase a running shoe that does not fit his or her foot properly and will therefore prevent him or her from ceasing to be injured. This can cause the individual to end up purchasing several pairs of shoes before finding the right one for his type of foot. With this in mind, different brands of running shoes could implement these devices in some of their sneakers in stores, so the consumer could check before buying the slipper which is the most suitable for his foot. To ensure this, in the store there must be a specialist to help and advise the consumer.

In conclusion the The Sustainable Development Goals can be integrated in this project by approaching two goals that are part of the SDGs, these are ``good health and well being´´ as the prototype developed in this project could help many people who suffer form running injuries and would like to find the reasons for there injuries and ``partnership for development´´ as the information and data recorded could help specialist to come together and share their thoughts on this theme.

DOCUMENT 2

DRAWINGS
APPENDIX G



SI NO SE INDICA LO CONTRARIO:
LAS COTAS SE EXPRESAN EN PULGADAS
TOLERANCIAS:
FRACCIONAL ±
ANGULAR: MÁQUINA ± PLIEGUE ±
2 LUGARES DECIMALES ±
3 LUGARES DECIMALES ±

INTERPRETAR TOLERANCIA GEOMÉTRICA POR:
MATERIAL
ACABADO
NO CAMBIE LA ESCALA

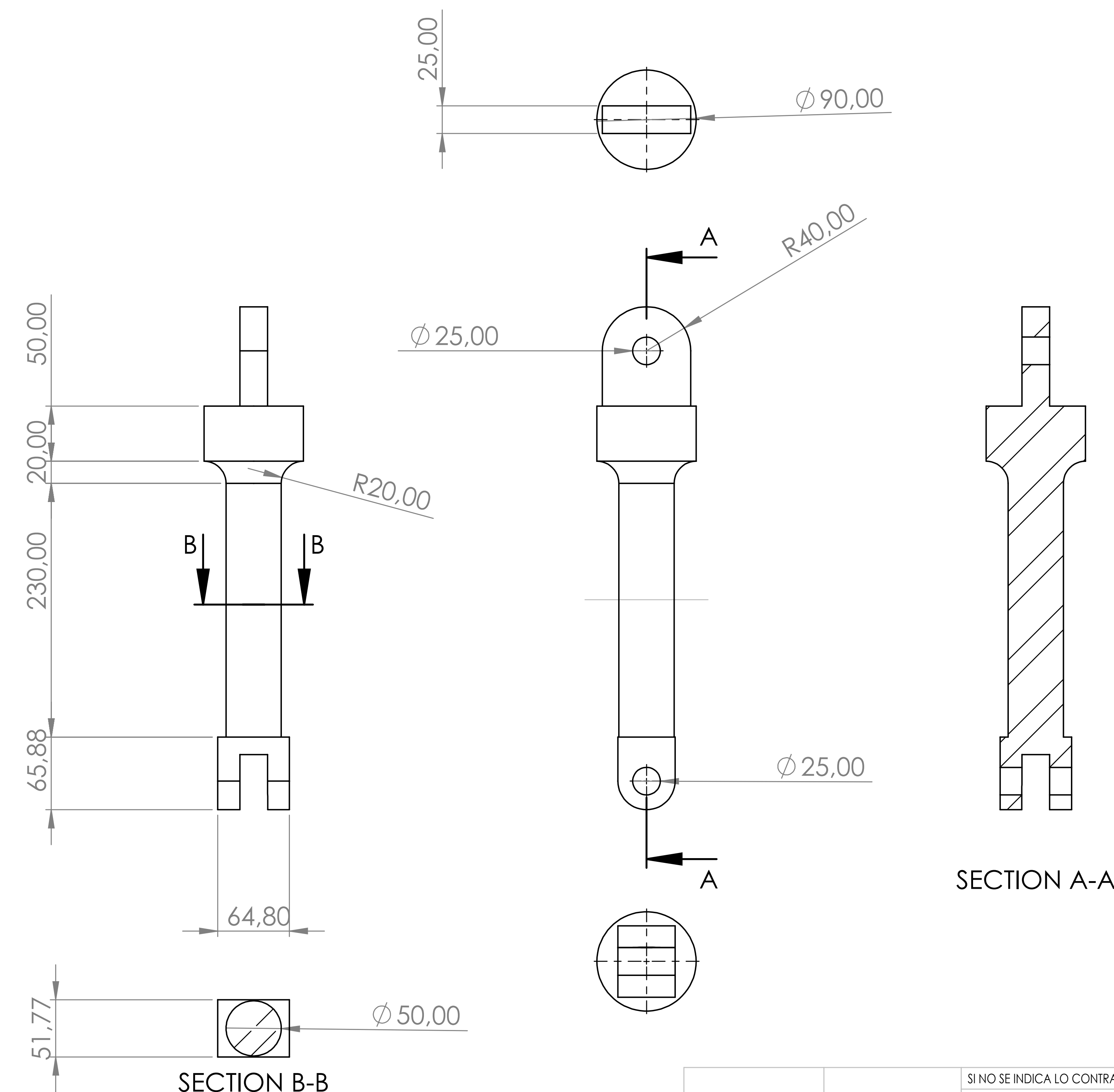
SIGUIENTE ENSAMBLAJE | UTILIZADO EN
APLICACIÓN

	NOMBRE	FECHA
DIBUJADO		
VERIFICADO		
INGENIERÍA		
FABRICACIÓN		
CALIDAD		

COMENTARIOS:
BOSTON UNIVERSITY

TÍTULO:
UPPER LEG

TAMAÑO **B** | N.º DE DIBUJO 1 | REV
ESCALA: 1:10 PESO: | HOJA 1 DE 1



INFORMACIÓN CONFIDENCIAL Y DE MARCA

LA INFORMACIÓN INCLUIDA EN ESTE DIBUJO PERTENECE EXCLUSIVAMENTE A PAULA FAURA GARCIA. QUEDA PROHIBIDA LA REPRODUCCIÓN TOTAL O PARCIAL SIN EL PREVIO CONSENTIMIENTO POR ESCRITO DE <NOMBRE DE LA COMPAÑÍA>.

SIGUIENTE ENSAMBLAJE | UTILIZADO EN

APLICACIÓN

SI NO SE INDICA LO CONTRARIO:
LAS COTAS SE EXPRESAN EN PULGADAS
TOLERANCIAS:
FRACCIONAL ±
ANGULAR: MÁQUINA ± PLIEGUE ±
2 LUGARES DECIMALES ±
3 LUGARES DECIMALES ±

INTERPRETAR TOLERANCIA GEOMÉTRICA POR:

MATERIAL

ACABADO

NO CAMBIE LA ESCALA

	NOMBRE	FECHA
DIBUJADO		
VERIFICADO		
INGENIERÍA		
FABRICACIÓN		
CALIDAD		

COMENTARIOS:

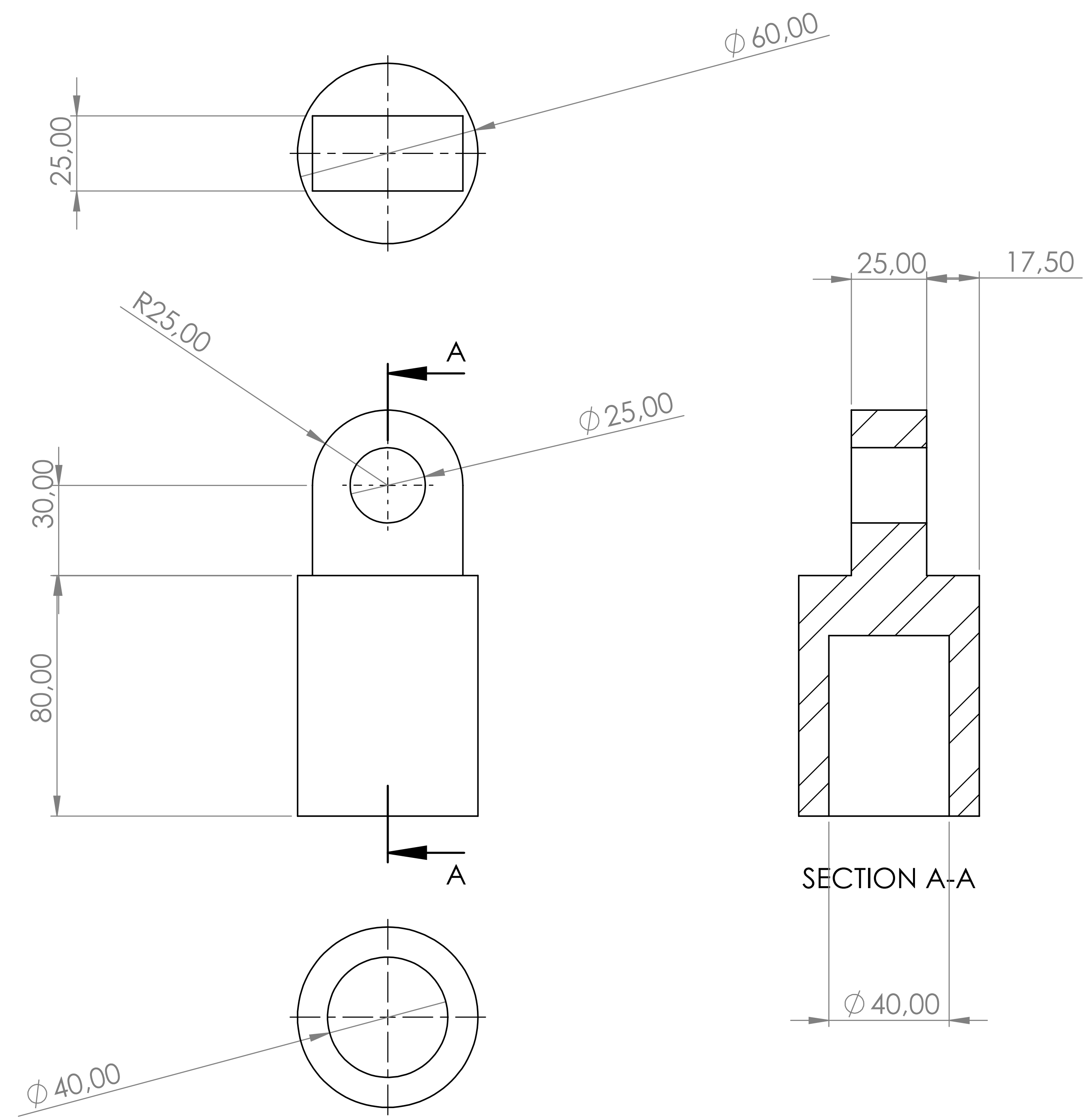
BOSTON UNIVERSITY

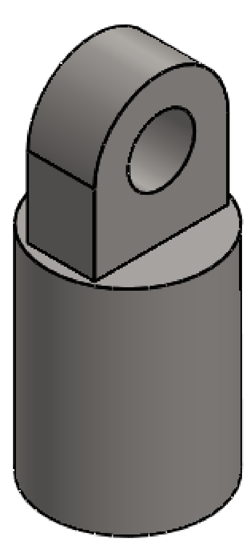
TÍTULO:

LOWER LEG

TAMAÑO **B** | N.º DE DIBUJO 2 | REV

ESCALA: 1:5 | PESO: | HOJA 1 DE 1





INFORMACIÓN CONFIDENCIAL Y DE MARCA

LA INFORMACIÓN INCLUIDA EN ESTE DIBUJO PERTENECE EXCLUSIVAMENTE A PAULA FAURA GARCIA. QUEDA PROHIBIDA LA REPRODUCCIÓN TOTAL O PARCIAL SIN EL PREVIO CONSENTIMIENTO POR ESCRITO DE <NOMBRE DE LA COMPAÑÍA>.

SIGUIENTE ENSAMBLAJE	UTILIZADO EN
APLICACIÓN	

SI NO SE INDICA LO CONTRARIO:
LAS COTAS SE EXPRESAN EN PULGADAS
TOLERANCIAS:
FRACCIONAL ±
ANGULAR: MÁQUINA ± PLIEGUE ±
2 LUGARES DECIMALES ±
3 LUGARES DECIMALES ±

INTERPRETAR TOLERANCIA GEOMÉTRICA POR:

MATERIAL

ACABADO

NO CAMBIE LA ESCALA

	NOMBRE	FECHA
DIBUJADO		
VERIFICADO		
INGENIERÍA		
FABRICACIÓN		
CALIDAD		

COMENTARIOS:

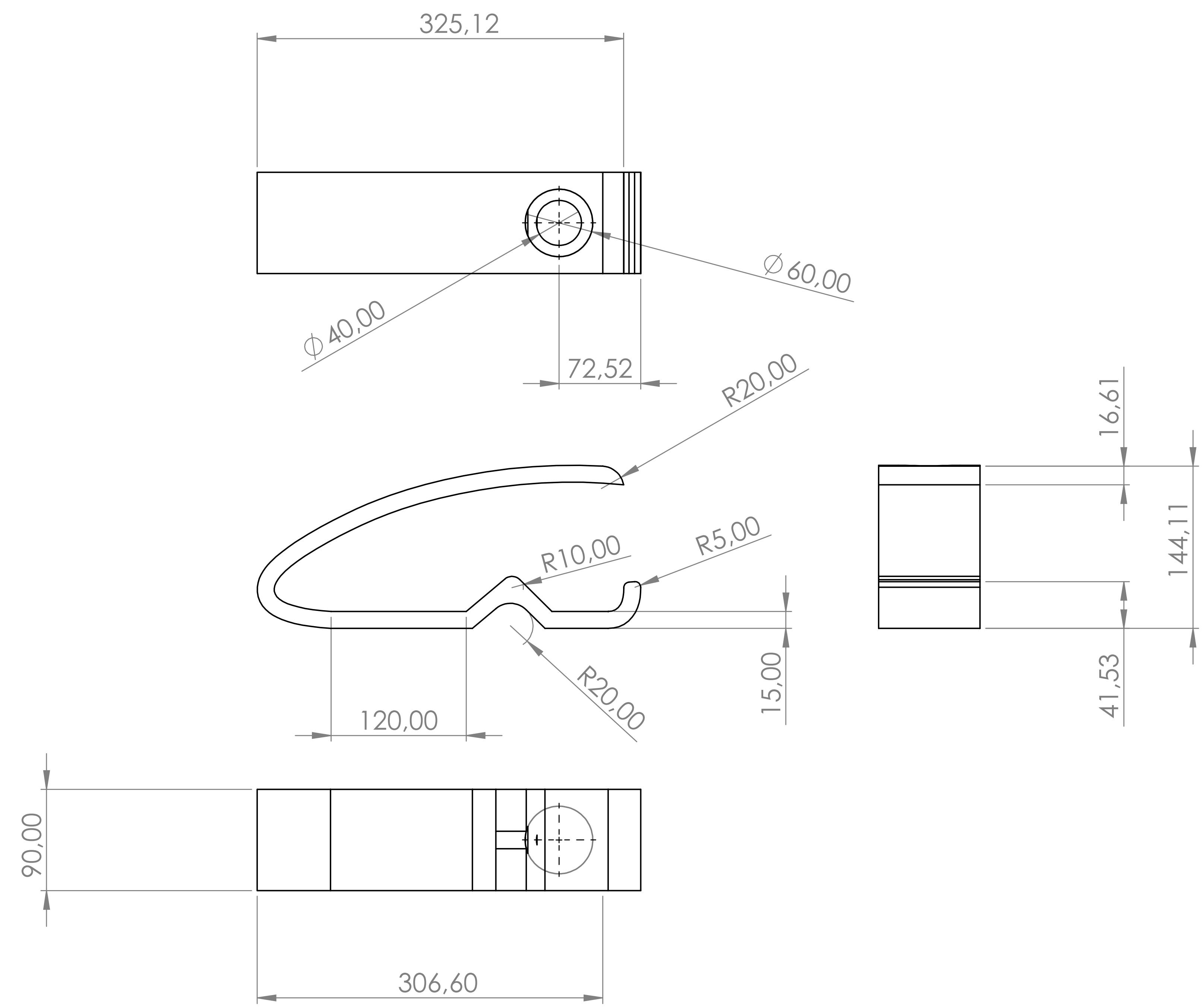
BOSTON UNIVERSITY

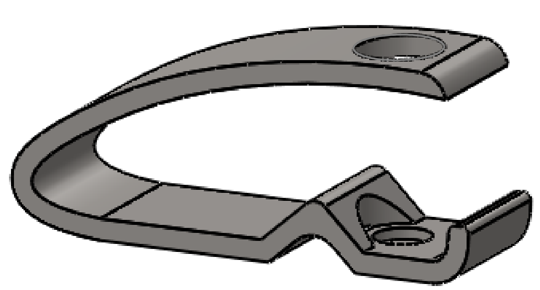
TÍTULO:

ANKLE

TAMAÑO	N.º DE DIBUJO	REV
B	3	

ESCALA: 1:2	PESO:	HOJA 1 DE 1





INFORMACIÓN CONFIDENCIAL Y DE MARCA

LA INFORMACIÓN INCLUIDA EN ESTE DIBUJO PERTENECE EXCLUSIVAMENTE A PAULA FAURA GARCIA. QUEDA PROHIBIDA LA REPRODUCCIÓN TOTAL O PARCIAL SIN EL PREVIO CONSENTIMIENTO POR ESCRITO DE <NOMBRE DE LA COMPAÑÍA>.

SIGUIENTE ENSAMBLAJE	UTILIZADO EN
APLICACIÓN	

SI NO SE INDICA LO CONTRARIO:
LAS COTAS SE EXPRESAN EN PULGADAS
TOLERANCIAS:
FRACCIONAL ±
ANGULAR: MÁQUINA ± PLIEGUE ±
2 LUGARES DECIMALES ±
3 LUGARES DECIMALES ±

INTERPRETAR TOLERANCIA GEOMÉTRICA POR:

MATERIAL

ACABADO

NO CAMBIE LA ESCALA

	NOMBRE	FECHA
DIBUJADO		
VERIFICADO		
INGENIERÍA		
FABRICACIÓN		
CALIDAD		

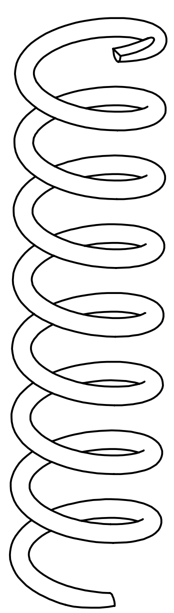
COMENTARIOS:

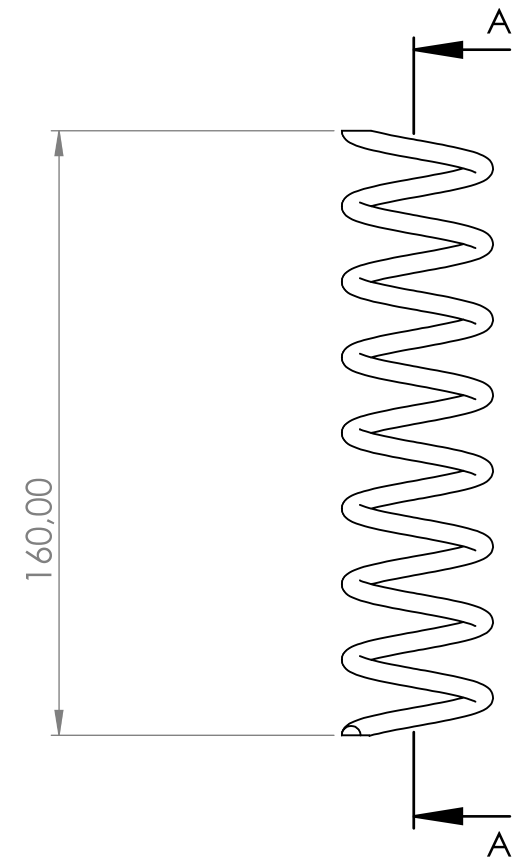
BOSTON UNIVERSITY

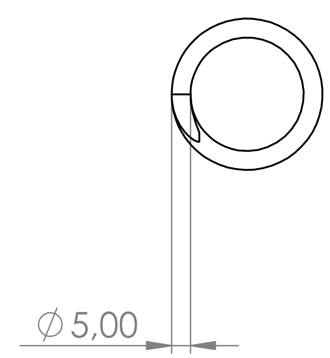
TÍTULO: FOOT

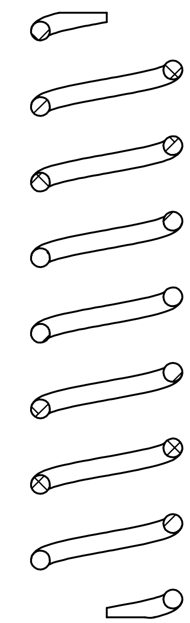
TAMAÑO	N.º DE DIBUJO	REV
B	4	

ESCALA: 1:5 PESO: HOJA 1 DE 1









SECTION A-A

INFORMACIÓN CONFIDENCIAL Y DE MARCA		
LA INFORMACIÓN INCLUIDA EN ESTE DIBUJO PERTENECE EXCLUSIVAMENTE A PAULA FAURA GARCIA. QUEDA PROHIBIDA LA REPRODUCCIÓN TOTAL O PARCIAL SIN EL PREVIO CONSENTIMIENTO POR ESCRITO DE <NOMBRE DE LA COMPAÑÍA>.		
SIGUIENTE ENSAMBLAJE	UTILIZADO EN	
APLICACIÓN		

SI NO SE INDICA LO CONTRARIO:
LAS COTAS SE EXPRESAN EN PULGADAS
TOLERANCIAS:
FRACCIONAL ±
ANGULAR: MÁQUINA ± PLIEGUE ±
2 LUGARES DECIMALES ±
3 LUGARES DECIMALES ±
INTERPRETAR TOLERANCIA GEOMÉTRICA POR:
MATERIAL
ACABADO
NO CAMBIE LA ESCALA

	NOMBRE	FECHA
DIBUJADO		
VERIFICADO		
INGENIERÍA		
FABRICACIÓN		
CALIDAD		

COMENTARIOS:

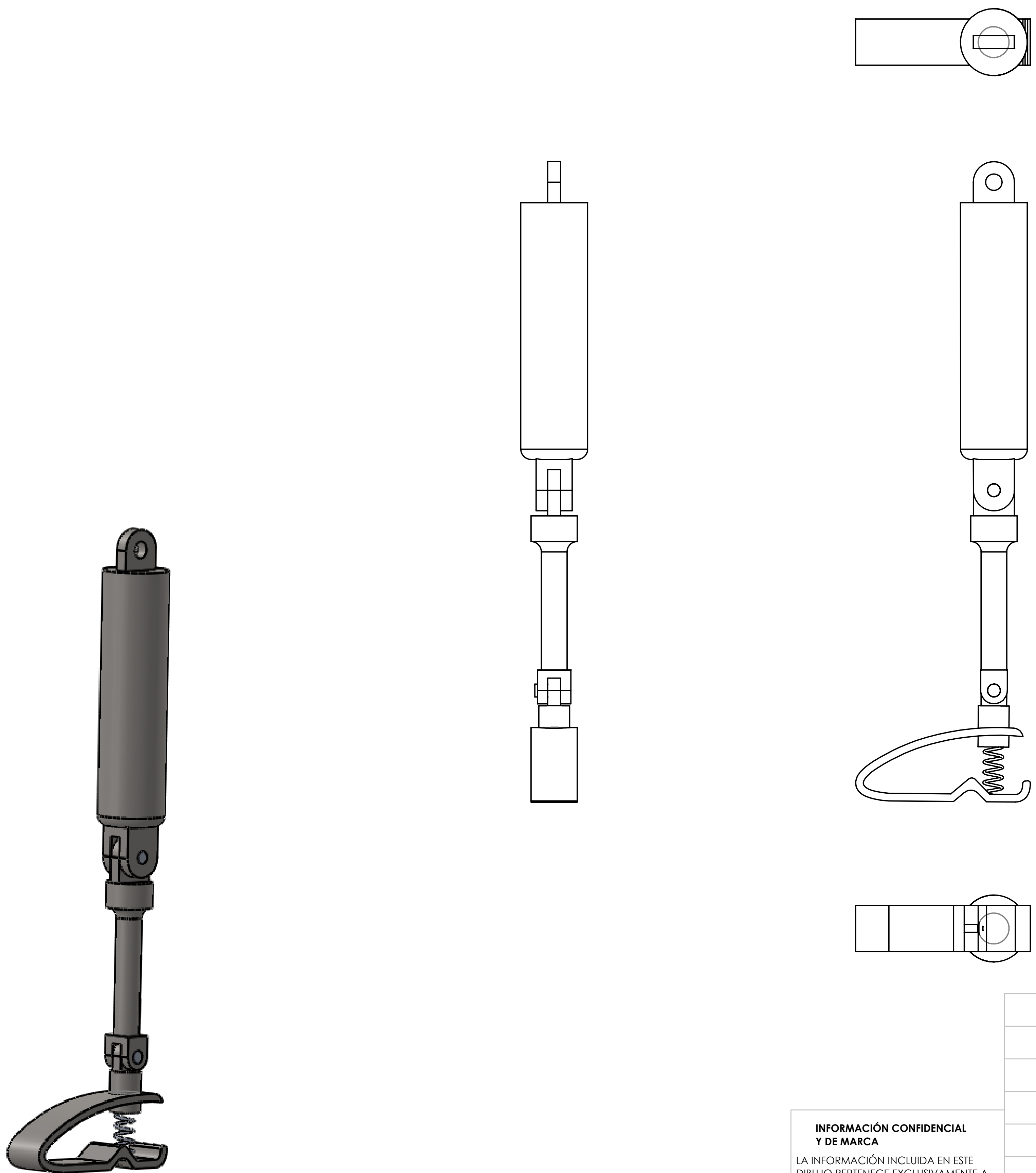
BOSTON UNIVERSITY

TÍTULO:

DAMPING SPRING

TAMAÑO	N.º DE DIBUJO	REV
B	5	

ESCALA: 1:2 PESO: HOJA 1 DE 1



INFORMACIÓN CONFIDENCIAL
Y DE MARCA

LA INFORMACIÓN INCLUIDA EN ESTE DIBUJO PERTENECE EXCLUSIVAMENTE A PAULA FAURA GARCIA. QUEDA PROHIBIDA LA REPRODUCCIÓN TOTAL O PARCIAL SIN EL PREVIO CONSENTIMIENTO POR ESCRITO DE <NOMBRE DE LA COMPAÑÍA>.

SIGUIENTE ENSAMBLAJE | UTILIZADO EN
APLICACIÓN

SI NO SE INDICA LO CONTRARIO:
LAS COTAS SE EXPRESAN EN PULGADAS
TOLERANCIAS:
FRACCIONAL ±
ANGULAR: MÁQUINA ± PLIEGUE ±
2 LUGARES DECIMALES ±
3 LUGARES DECIMALES ±
INTERPRETAR TOLERANCIA GEOMÉTRICA POR:
MATERIAL
ACABADO
NO CAMBIE LA ESCALA

	NOMBRE	FECHA
DIBUJADO		
VERIFICADO		
INGENIERÍA		
FABRICACIÓN		
CALIDAD		

COMENTARIOS:

BOSTON UNIVERSITY

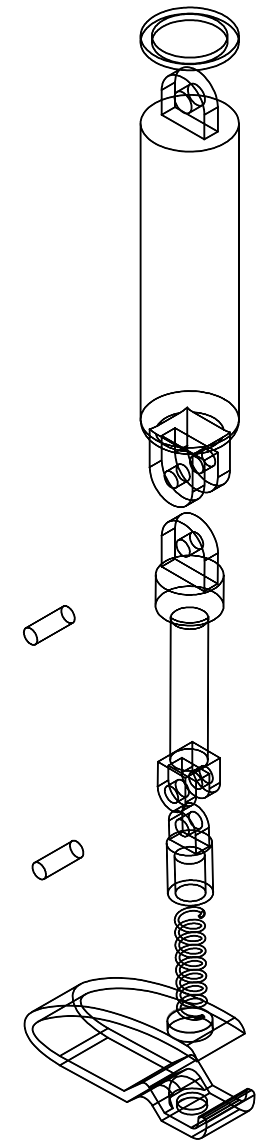
TÍTULO:
LEG ASSEMBLY

TAMAÑO B | N.º DE DIBUJO 6 | REV

ESCALA: 1:10 | PESO: | HOJA 1 DE 1

4 3 2 1

B B



A A

INFORMACIÓN CONFIDENCIAL Y DE MARCA

LA INFORMACIÓN INCLUIDA EN ESTE DIBUJO PERTENECE EXCLUSIVAMENTE A PAULA FAURA GARCIA. QUEDA PROHIBIDA LA REPRODUCCIÓN TOTAL O PARCIAL SIN EL PREVIO CONSENTIMIENTO POR ESCRITO DE <NOMBRE DE LA COMPAÑÍA>.

SIGUIENTE ENSAMBLAJE	UTILIZADO EN
APLICACIÓN	

SI NO SE INDICA LO CONTRARIO:

LAS COTAS SE EXPRESAN EN PULGADAS
TOLERANCIAS:
FRACCIONAL ±
ANGULAR: MÁQUINA ± PLIEGUE ±
2 LUGARES DECIMALES ±
3 LUGARES DECIMALES ±

INTERPRETAR TOLERANCIA GEOMÉTRICA POR:

MATERIAL

ACABADO

NO CAMBIE LA ESCALA

	NOMBRE	FECHA
DIBUJADO		
VERIFICADO		
INGENIERÍA		
FABRICACIÓN		
CALIDAD		

COMENTARIOS:

BOSTON UNIVERSITY

TÍTULO:

EXPLODED VIEW

TAMAÑO	N.º DE DIBUJO	REV
B	7	

ESCALA: 1:20 PESO: HOJA 1 DE 1

4 3 2 1