Augmented Knee Protection through Fall detection and Impact Reduction with comfort provided by Alleviation Design

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ABSTRACT

There are many knee pad products on the market today, the traditional knee pads provide passive protection for users such as sports players, or people need knee protections from injury in various movements. Still, security protection is not effective in some aspects. Among these, we see low durability, low flexibility, tightness, and comfort are the most important features we want to improve without limiting the user's athletic ability.

In this paper, we will review SoftBreak, a new knee pad design that utilizes soft robotics technologies through utilizing piezoresistive strain sensors for physical impact detection. By combining physical impact sensors, auto inflatable technology, parametric designs, and comfort adjustment, a superior environment for the knee is realized. We will show how new knee brace design provides enhancements in two main aspects of knee braces: safety and flexibility.

The introduction section will discuss knee pad design history, traditional knee brace drawbacks, and the motivations of our design. In the methodology section, we will illustrate design overview and detail subsystems designs of inflation control systems, physical impact detection, falling prediction, straps, adjusting for comfort, etc. We will also discuss what sensors are used in our design, the reasons behind how we choose materials, and how this design realizes the features we need. In the result and analysis, we will show the data we collected from the fall detection system simulation and the final 3D model. Finally, we will provide a conclusion of the functions of this new design and the advantages of how it improves from the traditional knee pad, potential applications, and possible future improvements for this design.

I. INTRODUCTION

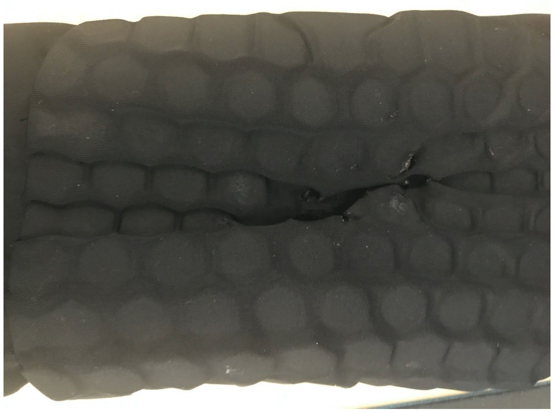

FIG. 1. This is an example of a knee pad tearing due to its weak and vulnerable material.

FIG. 2. This is an example of a current knee pad which is popular among athletes with the HEX design

In general, the knee is one of the most affected parts of the body as far as injury and irritation. Knee pads are used to protect the user's knee from any potential injury and reinjury. Current knee pads, as seen in

FIG. 2., have several problems which limit them from having a greater, beneficial effect on the user. For example, knee pads aren't very comfortable and at times slide off the user's knee due to the "one size fits all" concept. Additionally, knee pads rip and tear very easily therefore exposing the knee and being useless after it's ripped. This happens very often due to its ailing material and design. FIG. 1 shows a sample of how a torn knee pad would look like. If someone were to use this ripped knee pad, their knee would be very prone to injury therefore making the knee pad useless. Knee pads can also limit one's athletic ability due to being very tightly wrapped around one's knees. This can either make an athlete not run as fast or jump as high even though they aren't injured. Knee pads are definitely in need for enhancements to further increase the comfortability, protectiveness, and impact on the user.

Protective knee wear is a fairly new concept. The first lateral knee brace was made by physiologist Dr. Robert F McDavid in 1967 . Its main purpose was to prevent knee injuries and reinjuries. This knee brace quickly turned into a common item for athletes in sports such as basketball and football and it was modified into the kneepad we all know today. Today Dr. Robert F McDavid owns one of the biggest if not the biggest sport knee pad arsenals in the world. FIG. 2 shows one of his knee pads with the famous HEX parametric design.

II. METHODOLOGY

Device Overview

Our design serves the same purpose as other knee pads: to protect the user's knee. However, instead of the traditional route of implementing a single layer of protection that will be teared easily, we are implementing two layers of protection. The first and outer layer being the protection against minor bruises and contact with other objects or people, and the second layer being an inflatable membrane that will expand to protect a user's knee when they fall. Furthermore, we offer two ways of detection if the user is falling. The first way is to predict if the user is falling through a program, and the second way is to use physical impact detection to check if the user's knee came in contact with the ground. Additionally, we also provide the user with adjustable knee straps that will automatically tighten upon landing.

Control System

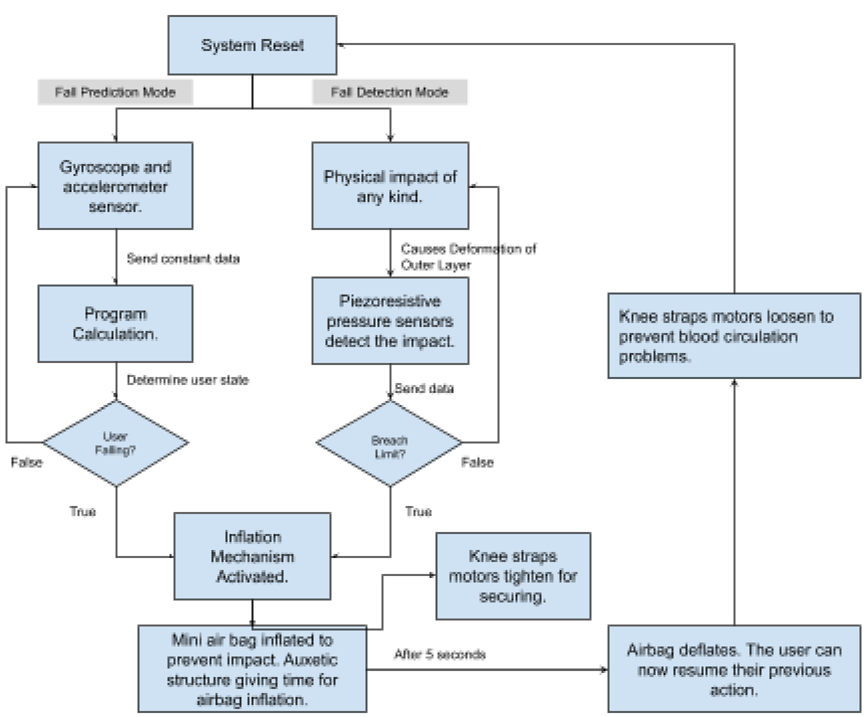

FIG. 3. This is the inflation control system of our final design of the device.

The device itself has two modes, fall detection and fall prediction. Fall detection mode is using the pressure sensors to detect the fall and inflate the air membrane. So if an input from the sensors is detected, hence a physical impact, the sensor determines if a threshold was breached. If not breached, the impact is ignored. If breached, the sensors signal the inflation mechanism to inflate the membrane and the knee straps will tighten to secure the device. Fall prediction mode constantly checks if the user is in a falling motion; if the user is in a falling motion, then the air membrane will inflate. The knee straps will also tighten automatically if the user was detected to have fell or falling under both cases. The mini air bag made of nylon is inflated to prevent impact. Auxetic structure also gives time for airbag inflation. After 5 seconds, the airbag deflates, and the user can now resume their previous action. The system resets.

Outer Layer Design

For the knee pad to function under normal circumstances where there are no significant, an outer layer is added in order to prevent accidental triggering of the inflation mechanism. A common flaw in traditional knee protection gear is that the material tears easily. Thus, we came to the conclusion that the outer layer should be an auxetic design, consisting of polyurethane foam that has a low Poisson's ratio. To summarize, Poisson's ratio is a ratio of a proportional decrease in lateral measurement to the proportional increase in length in the sample of material that is elastically stretched. Conventional material tends to increase in length but it decreases in width when pulled, while low Poisson's ratio material increases in both length and width when pulled; making it an ideal material for our design since the outer layer must expand in proportion with the inflatable membrane.

FIG. 4. Simple Hexagonal Design inflated by an air membrane.

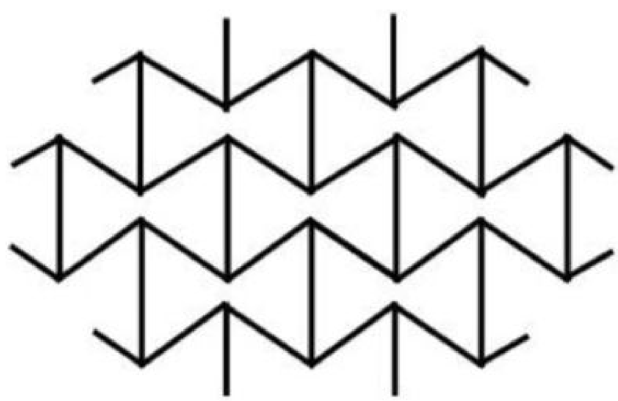

FIG. 5. Re-entrant Hexagonal Design.

The first design is a simple hexagonal design. At first, it seems to work fine since the hexagons will inflate in accordance with the airbag. However, one crucial flaw in the design is the thickness of the hexagons. The design's thickness must be thin, around 5mm for the inflation to occur smoothly. The thickness does not offer enough time for the inflation of the membrane to prevent the impact entirely. The second design is the re-entrant hexagonal design. This design can be designed with a much longer thickness, thus increasing the amount of time before physical impact. It can also be folded into a much thinner shape, offering more space for the user to bring the knee pad to events.

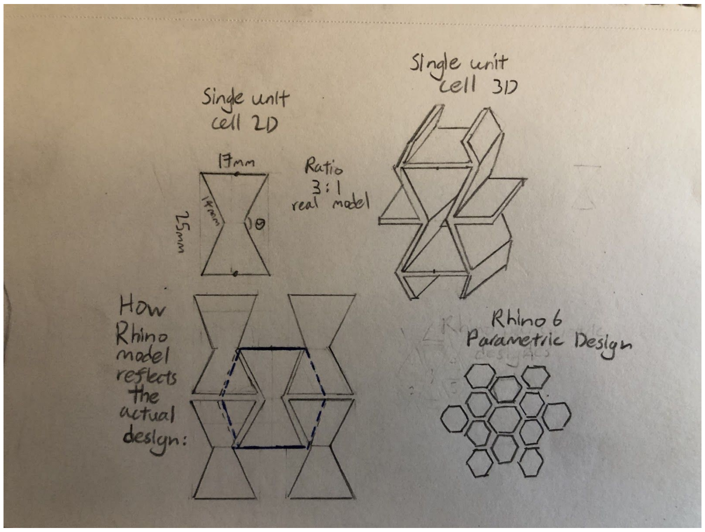

FIG. 6a. The parametric design of the outer layer. The first sketch (to the top left) presents a single unit cell in 2D, the second sketch (to the top right) is a single unit cell in 3D. The third sketch (to the bottom right) is the parametric design displayed in Rhino. The fourth sketch (to the top left) is how the Rhino model reflects the actual design.

We also drew a sketch for what the en-entrant hexagonal cell will look like in the 3D model.

Finally, the third design is the voronoi pattern shown in the figure below. It's the design we propose for our device due to it being more versatile than the re-entrant hexagon pattern in the process of 3D printing, which is how we're creating the outer layer if we had the accessible hardware. Voronoi pattern structures can be created using a technique known as additive manufacturing, which allows intricate structures to be created with ease.

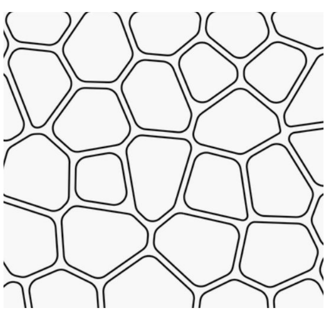

FIG. 6b. The voronoi pattern in 2D.

Physical Impact Detection

For detecting the physical impact, we propose using the piezoresistive strain gauge sensor. The piezoresistive strain gauge sensor uses a strain gauge made from a conductive material that changes its electrical resistance when it is stretched. Then the strain gauge can be attached to a diaphragm that recognizes a change in resistance when the sensor element is deformed. This change in resistance is converted to an output signal. Three separate effects contribute to the change in resistance, being 1) The resistance of a conductor is proportional to its length so stretching increases the resistance, 2) When a conductor is stretched its cross-sectional area is reduced, which also increases the resistance, 3) The inherent resistivity of some materials increases when it is stretched. We choose to use silicon for strain gauge elements since it’s an easily accessible semiconductor, and it provides a large output signal, making it effective under both low and high -pressure applications. The change in resistance is measured using a Wheatstone bridge circuit, which allows small changes in resistance of the sensor to be converted to an output voltage. Additionally, an excitation voltage must be provided to the bridge. The output voltage is measured by the equation $V_0 = [\frac{R_3}{R_3+R_4} - \frac{R_2}{R_1+R_2}] * V_{ex}$ The reason we choose to use the piezoresistance strain gauge sensor is that its performance and calibration is stable over time, which is needed for our design since we must ensure stable performance under any condition with the user.

FIG. 7a. This is the SensorTile microchip.

FIG. 7b. The SensorTile is mounted on the waist using velcro straps.

Falling Prediction

For predicting a fall, we decided to test with a gyroscope sensor due to its ability to detect changes in angles and an accelerometer due to its ability to detect changes in acceleration. We are carrying out physical simulation to ensure our fall prediction aspect is as accurate as possible. To carry out this research we are using the SensorTile microchip by STMicroelectronics. This microchip contains an array of different attributes including a humidity sensor, gyroscope, accelerometer, microphone, temperature sensor, and several others. The sensors will be placed on the waist since it dramatically changes position when you are falling. The microchip contains bluetooth as well as a rechargeable battery so it can be used multiple times and it can function wirelessly.

In order to carry out the simulation we will first connect the SensorTile microchip to the SensorTile BLE application on a smart mobile device. From the app we can get raw data from each of the sensors for any given time frame. Within this time frame, we will simulate a falling motion and based on which axis returns the biggest spike in the data, we will end up coding with that axis. We will do the falling simulation several times and come up with a common average to ensure accuracy. Also, if one sensor demonstrates a more dramatic change than another sensor, then we are going to use that sensor in the program. After we get the raw values and the specific threshold necessary for the program, we will then connect the app to the cloud so our data is accessible on the coding platform. From there, we will connect the coding platform to our device and write the code from there. The coding platform is Node Red which is a flow based editor written in JavaScript and using it we were able to connect to our values which were stored in the cloud.

Initially, our wearable SenorTile microchip connects to the SensorTile BLE app. From the app, we are able to connect to IBM which can store all of the live data values in the cloud. This makes it so that the data is accessible to us from anywhere. From IBM, we are able to open the Node Red coding platform which gets fed all the live data. Once the threshold-based program is executed, the number of falls as well as a notification for every fall is displayed on a dashboard. The architecture for our data flow can be seen in Fig. 8.

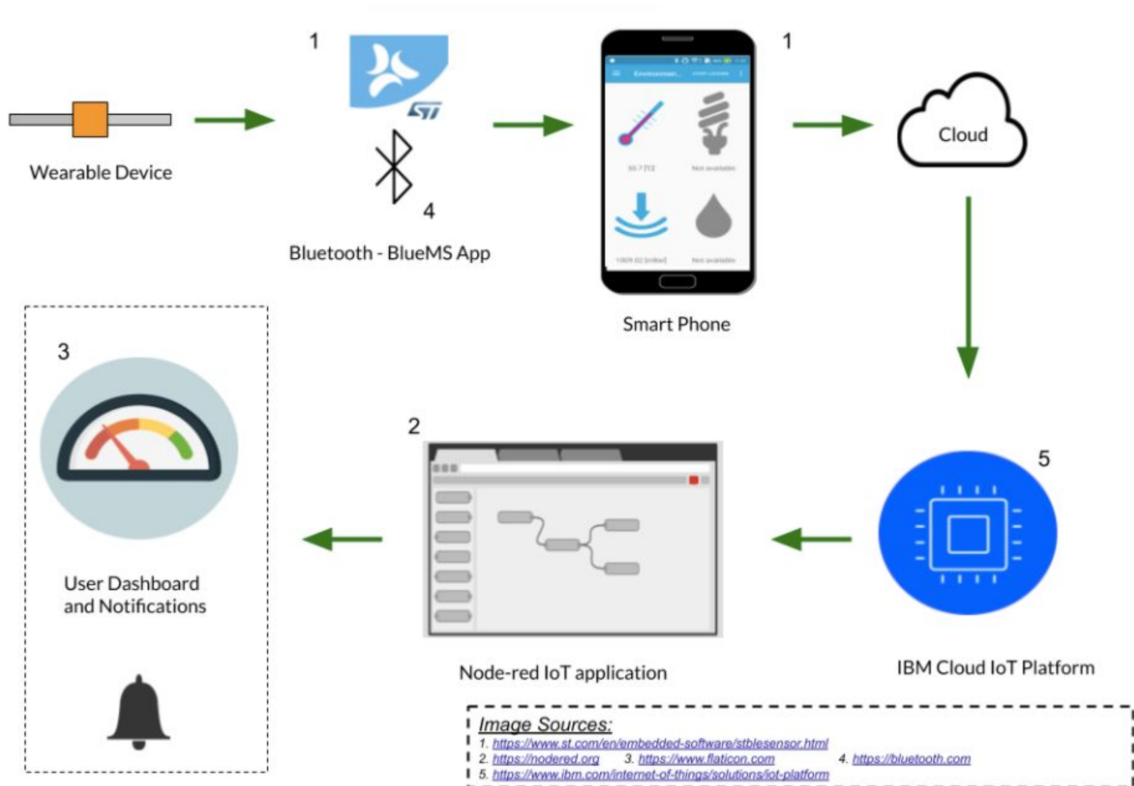

FIG. 8. General architecture of Fall Prediction System.

Inflation Mechanism

The inflation mechanism is actually a biomimicry of how a Puffer fish inflates. The pufferfish are known for inflating like a balloon and using their spikes as a form of self-defense. They inflate by absorbing water or air, and their stomachs can stretch to enormous sizes. Another form of inspiration we have taken a look at are the airbags put in cars. Airbags have been effective at preventing harm to users if used correctly. Thus, all of these inspirations lead us to coming up with the idea of using an inflatable membrane to break a user's fall. However, one of the first challenges we faced is how to inflate the membrane. Normal automatically inflation devices such as the ones used to inflate balloons can take up to several seconds to completely inflate a 5 inch balloon. We need time much faster.

As shown in the two figures above below, we propose using an ignitor that can trigger a chemical reaction, in which stored cells of sodium azide are decomposed into nitrogen gas, then the gas is used to inflate the membrane. The system is the same as the inflation mechanism used in car airbags. One of the significant improvements in this method is the speed at which the inflation is done. The same system can inflate an average car airbag under 0.03 seconds, thus we believe that our airbag, much smaller in comparison, will inflate fast enough to protect a user's knees from fall.

Our previous design, Fig. 9a, consisted of four mini airbags so the time for the reset process is reduced. But then a problem we encountered is that individually inflated airbags might cause imbalance in impact reduction, causing the knee to get hurt in other uncovered parts. So we switched to using one, giant airbag that is able to cover the entire knee shown in Fig. 9b.

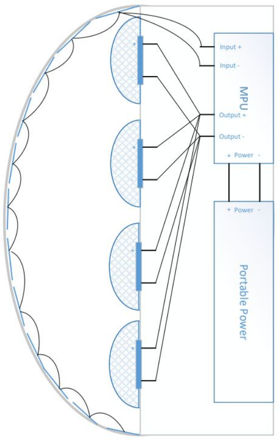

FIG. 9a. The previous sideways diagram of our device.

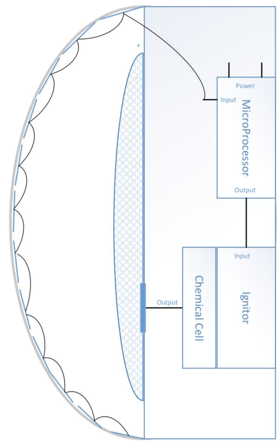

FIG. 9b. The current sideways diagram of our device.

Straps vs. Leggings

When figuring out how to keep the knee pad secure, we came across two options: straps (Fig. 10a) or an all-covering legging like approach (Fig. 10b). The main difference between our options was surface area. Both are sturdy choices, but we wanted to adhere to what is most comfortable for the user. We knew that surface area was the only changing variable, so we decided to look towards manipulating equations. The formula for pressure (P) is $P = F/A$, where F is force and A is surface area. When a perpendicular force is applied to a surface, a pressure is exerted. For instance, somebody wants to slice a wooden board with their hand. There will be a difference in the pressure applied to the board if the palm of the hand hits it versus a perpendicular hand hitting the board with equal force. In the first case, the wooden board will most likely not break because of the large surface area. A perpendicular slice has a better chance of splitting the board because of a smaller surface area, making the pressure greater than that from the palm. This concept can be applied to the knee pad. With force remaining constant, the straps (having a smaller surface area) will drive the pressure exerted on the knee area up. This pressure does not aid in our comfort initiative, and therefore will not benefit our knee pad. Based on this conclusion, we decided to continue the design process based on the legging-like approach.

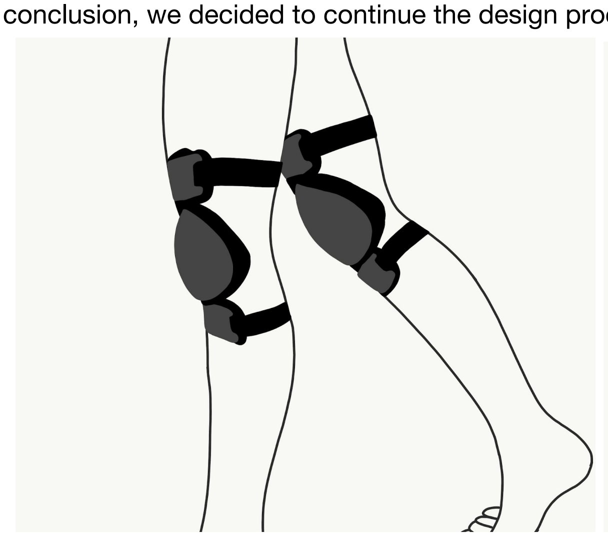

FIG. 10a. Example of knee pads with straps.

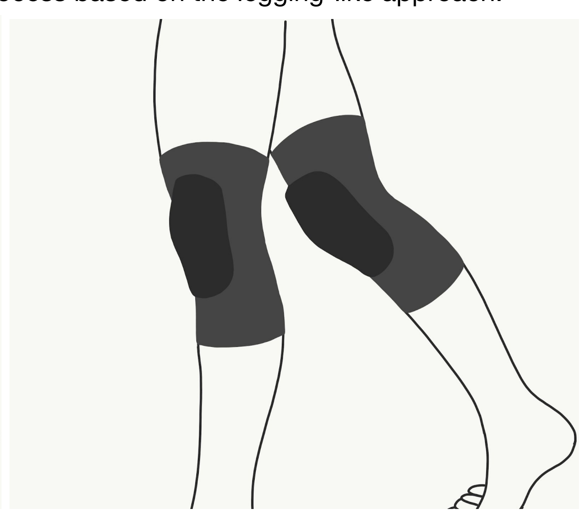

FIG. 10b. Example of legging knee pads.

Adjusting for Comfort

To enhance the user’s experience, we propose an adjustable knee pad. Our preliminary research helped us find out that a current issue with knee pads is tightness. The adjustment aspect of our design is inspired by a related product: the Double-O Kneepad. This product attaches a knee pad directly to pants to reduce poor blood circulation and discomfort. Knee pads in general cause a loss in blood circulation (shown through the need to develop the Double-O Kneepad), simultaneously increasing the risk for future knee damage.

Our initial proposal was to use a blood circulation sensor to evaluate if the circulation is at a good level. The knee pad would adjust according to the data received by the sensor. For example, if circulation is not ideal, the knee pad will loosen to allow the blood to flow at a better level.

The other aspect to consider is how this adjustable idea will work with our airbag mechanism (Fig. 12b). To prevent the issue of problems with airbag inflation because of the straps being too loose, we had fall detection data be sent to the adjustment controls. Essentially, if there is an expected fall based on sensory data, the knee pad will tighten to ensure the inflatable mechanism will be secure for the fall.

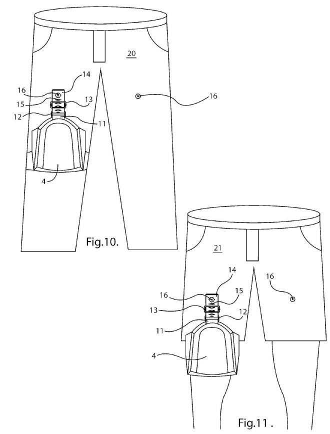

FIG. 11. 2D model of the Double-O Kneepad.

https://patents.google.com/patent/US20070150993A1/en

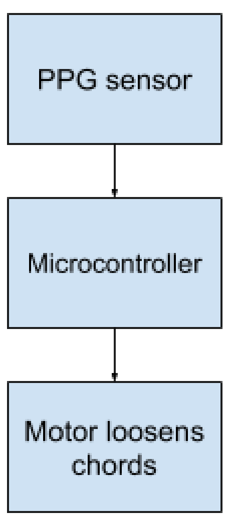

FIG. 12a. Overview of the adjustment aspect of the knee pad control system. Input data comes from the PPG sensor. Output is loosening the knee pad to increase comfort.

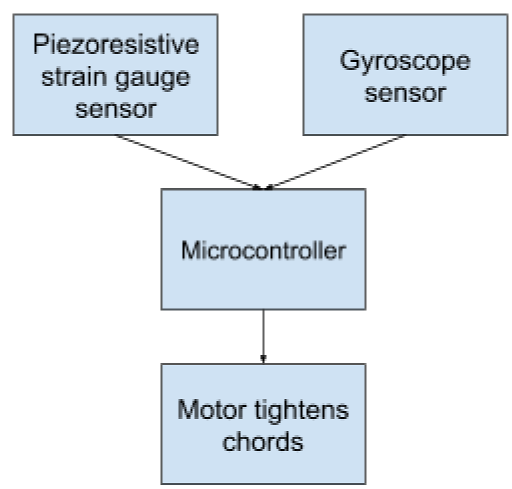

FIG. 12b. Overview of the adjustment control interaction with the knee pad fall/impact detection control system. Input data comes from both the piezoresistive gauge sensor and gyroscope sensor. Output is tightening the knee pad to increase safety.

Detecting Discomfort:

Going off of our original idea, a blood circulation sensor would be needed. A photoplethysmogram, also known as a PPG, uses a light source and photodetector to detect the volumetric variations in blood circulation. The heart pumps blood into the arteries of the body which causes them to expand to a slight extent. The arteries then restore to their former state. Depending how the light refracts and passes through the artery tissue sample the PPG interacts with, how much blood is present can be determined. A knee pad that is too tight will change the pulse pressure, which also creates a difference in how much light is refracted back into the light sensor on the PPG. This signal's amplitude is directly proportional to the pulse pressure, so the lower the peak on a graph, the weaker the pulse is.

There is research done on a flexible and organic photoplethysmogram. It is proven through research to be more reliable than the commercially available PPG sensors, with the added benefit of being less power consuming. This PPG sensor has a very thin encapsulation structure, making it also very flexible. Flexibility was what we needed for our knee pad. Harder materials are generally not as comfortable, so this PPG sensor greatly helped for physical ease.

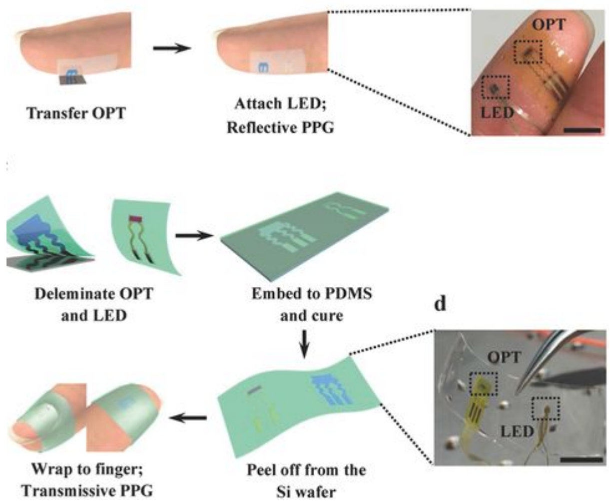

FIG. 13. Images of flexible PPG sensor. https://doi-org.proxy.library.ucsb.edu:9443/10.1002/adma.201700975

Tightening/Loosening Mechanism:

The data from the PPG will allow the knee pad to know when to adjust. The next step was to figure out *how* the knee pad will adjust. One way is through expanding and contracting straps. We looked to other adjustable technology to figure out how to do this. Currently, there is a self tying shoe made by Nike: HyperAdapt (Figure 14). We studied how this system works to see if there is a practical application for our knee pad since we want a similar mechanism.

The hyperadapt shoes work by the press of a button to tighten and loosen the shoelace part of the shoe. They have channels on each side of the laces that are connected to a motor which tightens them. A main difference between our mechanism and the shoe's is that the input of ours is not from a button, but

FIG. 14. Picture of the Nike HyperAdapt shoe. https://mindtribe.com/2017/02/nike-hyperadapt-teardown/

from the PPG sensor. We implemented many of the shoes ideas, as they are in a readily available product, and do in fact work.

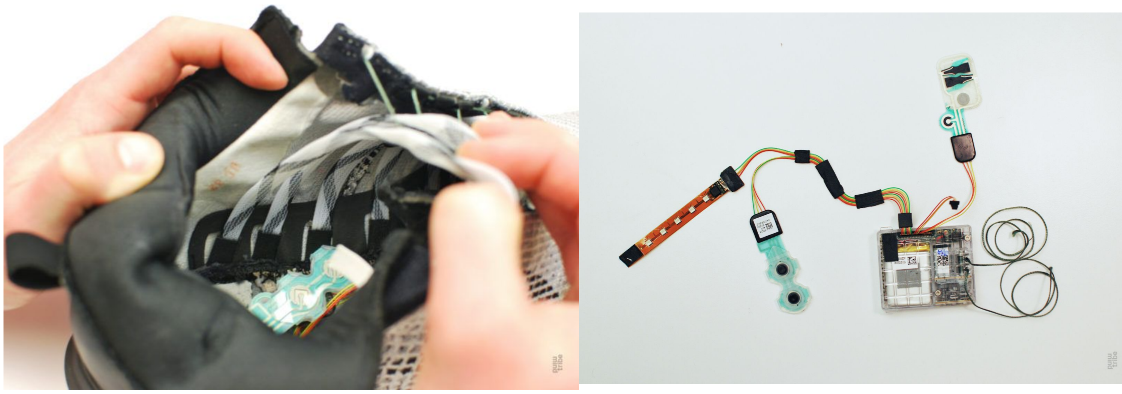

FIG. 15. (left) Can see part of the lacing mechanism on the shoe. (right) Shows the wires and gearbox of the shoe.
https://mindtribe.com/2017/02/nike-hyperadapt-teardown/

Implementing Design:

These side by side pictures (Figures 16a and 16b) make it easier to see how this shoe design will be implemented. On the right there is a sketch of the back of the knee pad with two chords labeled. These chords are analogous to the adjustable laces on the HyperAdapt shoe. Similarly, the shoe's tongue is comparable to the lighter area behind the two chords, so they don't rub up against the skin. A technical fiber, which Nike calls Flywire, runs along the lace channels. This flywire is strong, it's made of vectran thread and a spun liquid polymer. The fibers of the thread are said to have a similar strength to Kevlar, which is also known for being very strong. We wanted our knee pad to be very durable so we used the same materials in order to achieve this. The laces of the shoe are made out of polyethylene cable sheathing. They have a good resistance to oils, water, and chemicals. We used this same material for our chords. Polyethylene is good for our knee pad, especially the water resistance aspect because of our sports focus. A notable feature of the shoe is the motor. It outputs an impressive amount of pull (around 30 pounds) for something that can fit in the size of your hand. We were looking for something small enough to put inside of a knee pad, and through our research we found that this type of motor does exist (as seen in the Nike HyperAdapt). We used the same sized motor with the same strength for our knee pad. Our gearbox casing is made out of polycarbonate. This material can take a beating which makes it good for resistance to impact, something we were looking for. It only makes sense to use a material with this soundness since knee pads are designed to combat impact.

FIG. 16a. Birds eye view of typical shoe.

https://www.kicksonfire.com/the-nike-air-max-lunar-line-has-given-in-to-another-bw-design/

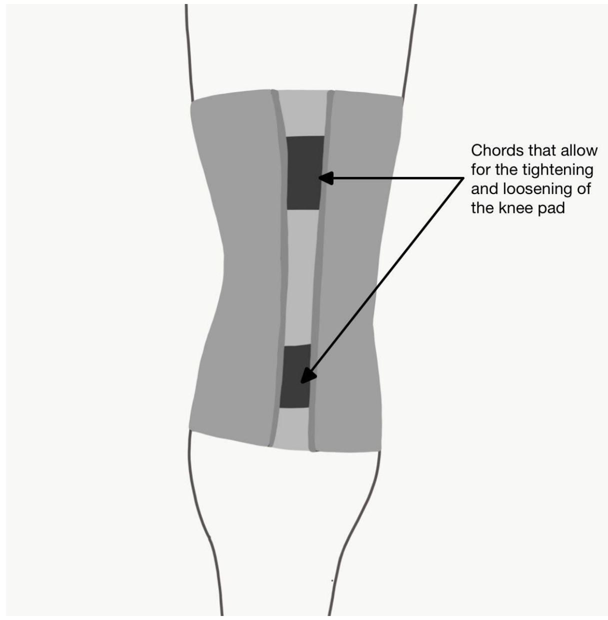

FIG. 16b. Sketch of the back of the knee pad. Shows the adjustable mechanism.

Battery

Lastly, to power all the functions we described above, a power source is needed. We first looked into three different kinds of batteries: Alkaline, Silver-oxide, and Lithium ion. We first consider Alkaline batteries because they're the most commonly used batteries; usually in the shape of a cylinder and in various different sizes. Alkaline batteries also come in both non-rechargeable form and rechargeable form. They are prone to leaking potassium hydroxide, which can cause respiratory, eye and skin irritation, if used incorrectly. Alkaline batteries gradually self-discharge overtime over 3-10 years (depending on the performance of the device) and will eventually leak. Secondly, we take a look at silver-oxide batteries, a one-usage battery that has a very high energy-to-weight ratio. They are available in small sizes as button cells, which are used in watches and small devices. The advantages of silver-oxide batteries is the production cost, since the amount of silver used is minimal. However, silver-oxide batteries become hazardous if it leaks, but generally takes 5 years from the time they are put into use. Lastly, we consider the Lithium-ion battery, a kind of rechargeable battery used in portable electronics and electric vehicles. Lithium-ion batteries can be wary in performance and depending on the performance of the device, can get increasingly dangerous to use. For our device, we propose to use the silver oxide battery that has a nominal cell voltage of 1.55 V due to the minimal amount of material it uses, the low cost, and small size.

FIG. 17a. Image of a silver-oxide battery as button cells.

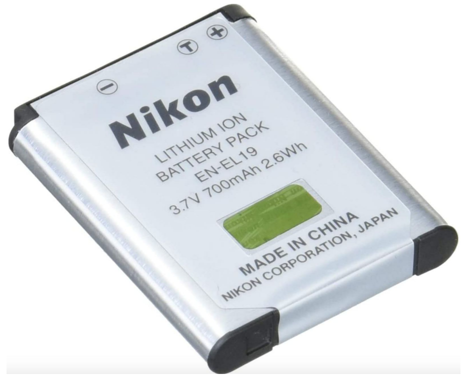

FIG. 17b. Image of a lithium ion batteries used in electronic devices.

FIG. 17c. Image of Alkaline batteries.

III. RESULTS / ANALYSIS

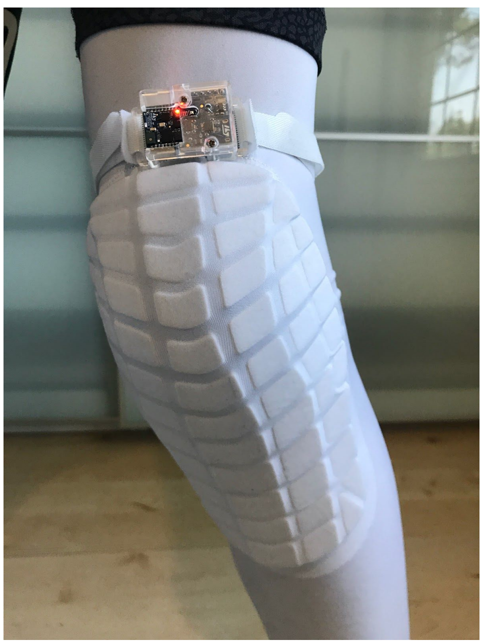

FIG. 18 Example of the first Fall Detecting Prototype

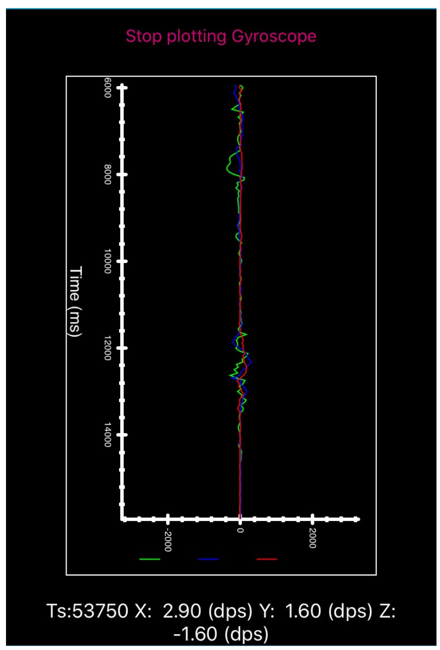

FIG. 19 Raw Data received from a fall through the gyroscope with sensor on kneepad.

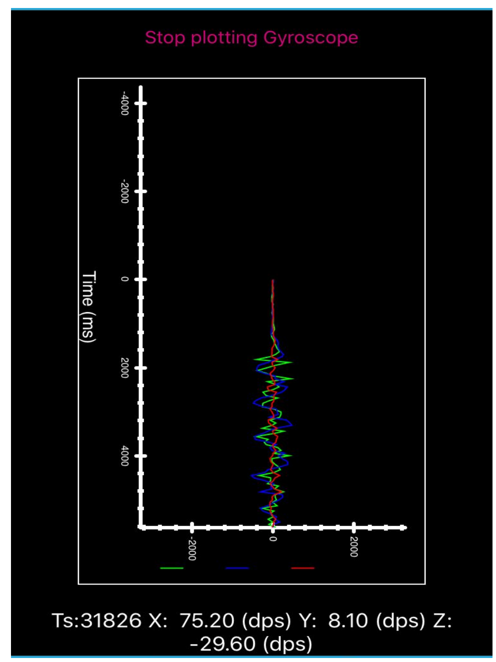

FIG. 20 Raw Data received from a running through the gyroscope with sensor on kneepad.

A. Fall Prediction Simulation Results

When testing for the fall detection aspect of the knee pad, both a gyroscope and an accelerometer sensor were used. In the tests, we simulated a falling motion in order to get specific values needed for creating threshold values. Additionally, we compared these values to running, which is the most common motion in sports, because we didn't want the run to count as a fall when the product was finished.

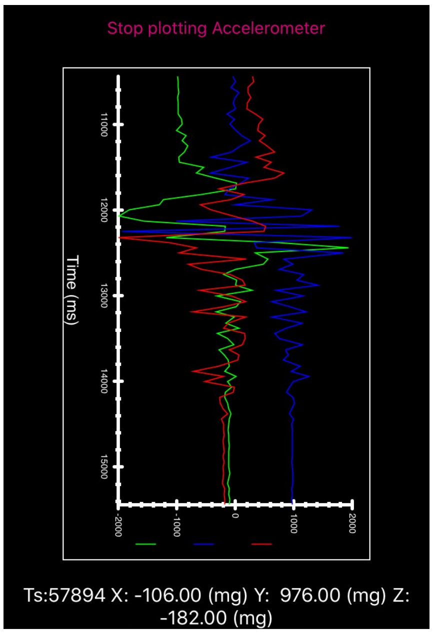

FIG. 21 Raw Data received from a fall through the accelerometer with sensor on knee pad.

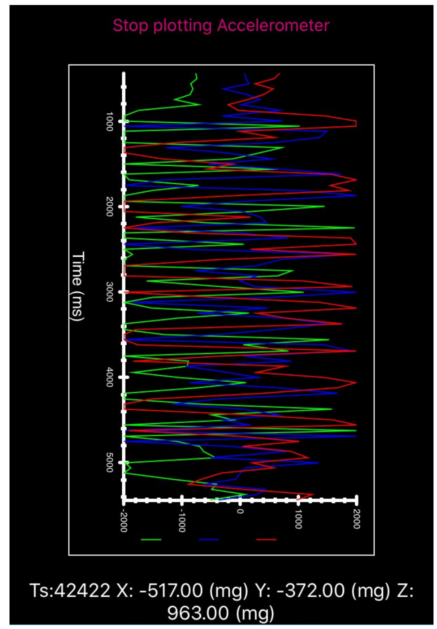

FIG. 22 Raw Data received from a fall through the accelerometer with sensor on knee pad.

Initially, the sensor was placed on the upper part of the knee pad as shown in Fig. 18. The raw data from the gyroscope gave back similar values for both falling and running as seen in Fig 19 and Fig. 20. Using this sensor and setup would end up with runs being counted as counts. The accelerometer had the same pattern that can be seen in Fig. 21 and Fig. 22. This orientation, the microchip being on the kneepad, did not work out, so we altered it in order to find a good relationship between the running and falling outputs.

Since none of the motion-related sensors met the requirements in the initial setup, we decided to move the sensor to the waist. The reason it was moved is because while running, the waist is somewhat still, but when you run, the waist completely changes direction and its angle. When simulating using this configuration, the gyroscope gave back decent changes in the axis. Although there was a notable difference between running and falling, the difference wasn't large enough and there was a chance of the actions overlapping. After testing with the accelerometer, there was an immense difference between running and falling. As seen in Fig. 23 and Fig. 24, it can be seen that there is a difference in the x-axis (red line) by around 1000 units. This enabled us to code with the accelerometer in the x-axis and create the necessary thresholds as well. As far as our program, we used a sliding window technique which enabled our program to analyze data over a second long window. For every new sample of data, which comes around every 0.1 of a second, the oldest value in that second will be thrown out. Within this second long window, there is a minimum and maximum value. If these values surpass the thresholds, then the action will count as a fall. Additionally, the program only allows one fall action per second since it's very unlikely someone will fall twice in a second. The program can be seen in Fig. 25.

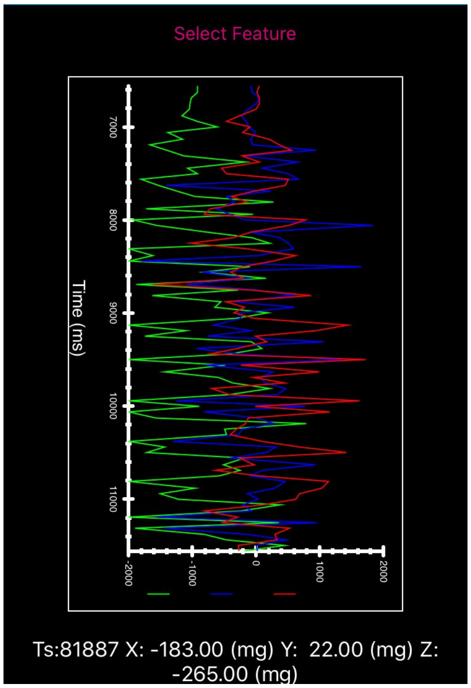

FIG. 23 Raw Data received from running through the accelerometer with sensor on waist.

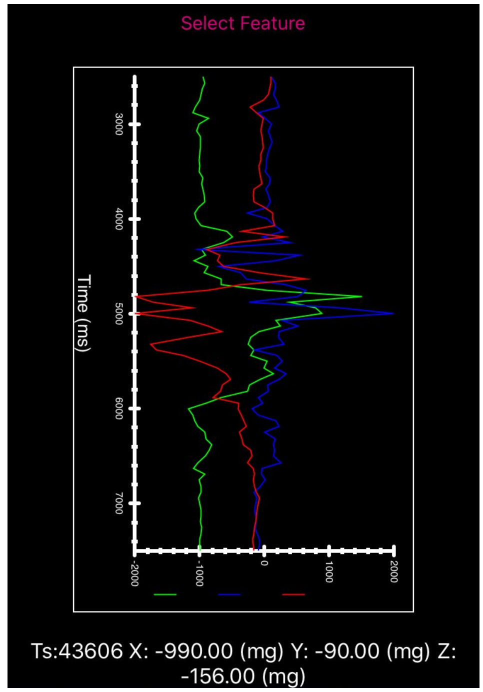

FIG. 24 Raw Data received from a fall through the accelerometer with sensor on waist.

```javascript
// determines the average of all payload values passed in
// over the specified time range
// https://discourse.nodered.org/t/nodes-suggestion-for-timed-rolling-average-and-desynchronised-sum/4933
const range = 20;   // window time millisecs
let buffer = context.get('buffer') || [];
let falls = context.get('falls') || 0;   // the accumulated total so far
//use the gyroscope Y values
let value = Number(msg.payload.AX);
// remove any samples that are too old
var states = global.get( "statecount")||0;
while (buffer.length >= range-1)
{
    // remove oldest sample from array and total
    //node.warn(`removing oldest ${buffer[0].value}`);
    buffer.shift();
}
// add the new sample to the end
buffer.push({value: value});
context.set('buffer', buffer);

if (buffer.length > 10)//looks at a full second of data
{
    var min = 5000;
    var max = -5000;
    for (i = 0; i < buffer.length; i++)
    {
        if (buffer[i].value < min)//for all the data in the half-second, the max and min value are initzialized
        {
            min = buffer[i].value;
        }
        if (buffer[i].value > max)
        {
            max = buffer[i].value;
        }
    }
    if (min < -1000 && max > -500)//if the min and max in within the thresholds, it counts as a shot
    {
        falls++;
        context.set('buffer', []);
        states = 1
```

FIG. 25 Main Algorithm in Javascript (sliding window technique)

B. Actuator Simulation

The actuators in the device are the airbag that can be inflated to protect the user's knee. In order to ensure the user's knee to protect safely, we have a design for the airbag. This is designed in Rhinoceros 6, a 3D modeling software, using grasshopper, a visual programming language and environment, with the Kangaroo 2 plugin. The grasshopper code for the design is included in the Appendix.

As shown in Fig. 25 below, the airbag is flat when uninflated, in the shape of a square. When the airbag is being inflated, the air gathers in the center and inflates a hump-like shape. This is due to the four points anchored to the surface, thus all the air must gather up in the center. We connected the mesh surface to a gravity function and added a movement factor in the z-axis.

Other designs to consider is changing the surface into the shape of a circle or use a 3d shape, like a cube, to create the inflation. However, the problem with inflating in the cube shape is that the air will be distributed evenly among all the surfaces, so the knee might not be fully covered.

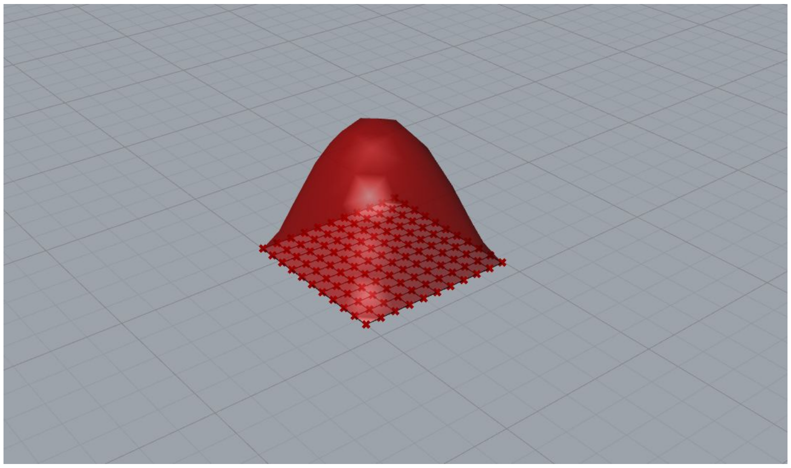

FIG. 25 The Rhino model of the airbag belonging to the actuation subsystem. The airbag is inflated, with the air gathering in the middle, forming a hump.

C. Initial to Final Design

For modeling our product in 3D, we went through two designs. The first design, as shown below in Fig. 26a, consisted of a legging wrapped around the human's model knee. There are also two straps that secure the outer layer in place, which has a re-entrant hexagonal pattern. The second design, as shown below in Fig. 26b and Fig. 26c is our final model in 3D. The legging structure is modified so it better fits the knee and recoloring is applied so it's more complete. The pattern on the outer layer has also been changed from the re-entrant hexagonal design to the voronoi pattern. Fig. 26d and Fig. 26e are the rendered final model.

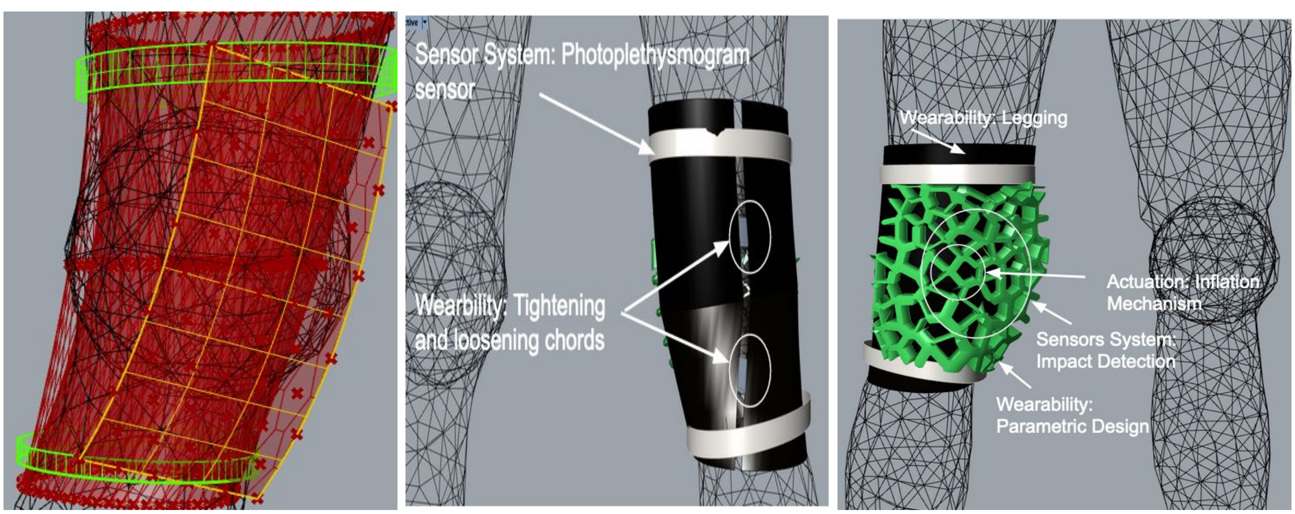

FIG. 26a The initial Rhino model of the device.

FIG. 26b SoftBreak Wireframe back view in 3D model.

FIG. 22c SoftBreak Wireframe front view in 3D model.

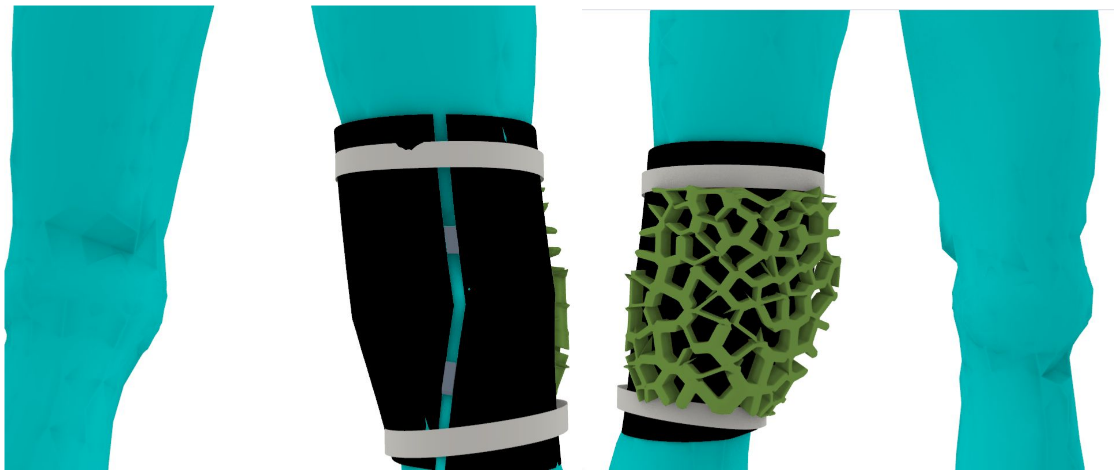

FIG. 22d Rhino 3D design of SoftBreak front view.

FIG. 22e Rhino 3D design of SoftBreak front view.

IV. DISCUSSION / CONCLUSION

Although many details of the knee pad design have been figured out, there is always room for improvement. In the future we hope to add the ability to account for the change in the coefficient of friction due to sweat. As shown in Figure 27, the coefficient changes based on how lubricant the skin is. The wet skin (in grey) had the highest coefficient each time, with vaseline in second, and natural skin in last. Sweat makes skin more slippery which reduces the friction between the knee pad and the body. This means that the knee pad will be looser and could possibly slide off. One way to combat this issue is through the use of a sensor that can detect the coefficient of static friction between two surfaces. This sensor works by using piezoresistive beams. By adding this sensor, the adjustable mechanism will be greatly improved.

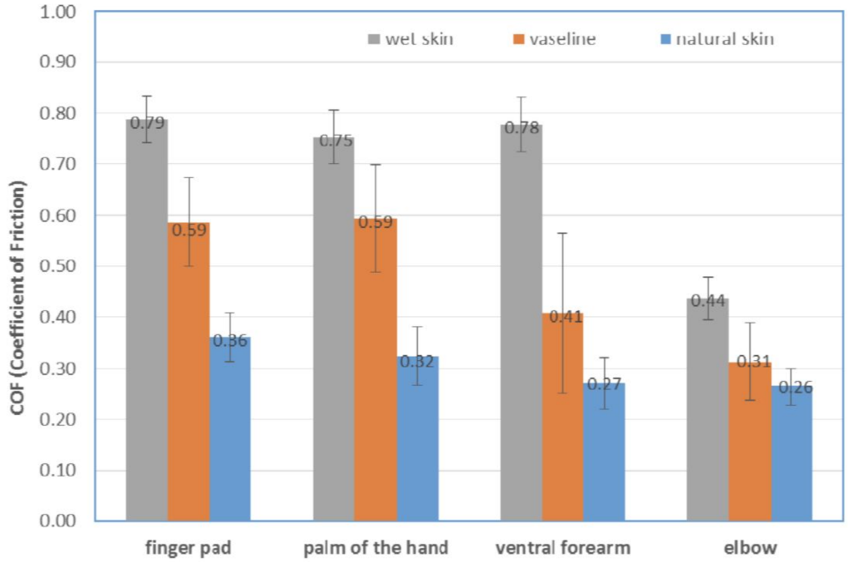

FIG. 27. Shows the difference in coefficient of friction based on how lubricant the skin is. https://www.mdpi.com/2075-4442/4/1/6/pdf

Something we must implement for future purposes is having a more efficient way of harnessing the velcro straps on the waist for the fall prediction. In the simulation we used jeans to fasten the strap to the belt loops. An athlete would definitely not play in jeans so we would need a better mechanism to keep the microchip steady on the waist. Additionally, we need better material than velcro which is durable and also able to bend so that it is breathable for the user and so that it won't break or rip.

We definitely also need a safer inflation mechanism considering we're using a chemical reaction to achieve the inflation process. We also considered other methods such as using compressed air contained in a metal canister, but the two main problems that always reside are weight and energy efficiency. So we will keep looking for an inflation method.

Another point to address is the device's ability to handle rough contact surfaces. Knee pads weren't designed to handle rough surfaces like the sharp edges of a pebble or small rock can tear apart the fabric easily, so this is a problem that we can also improve in the future.

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VI. APPENDIX

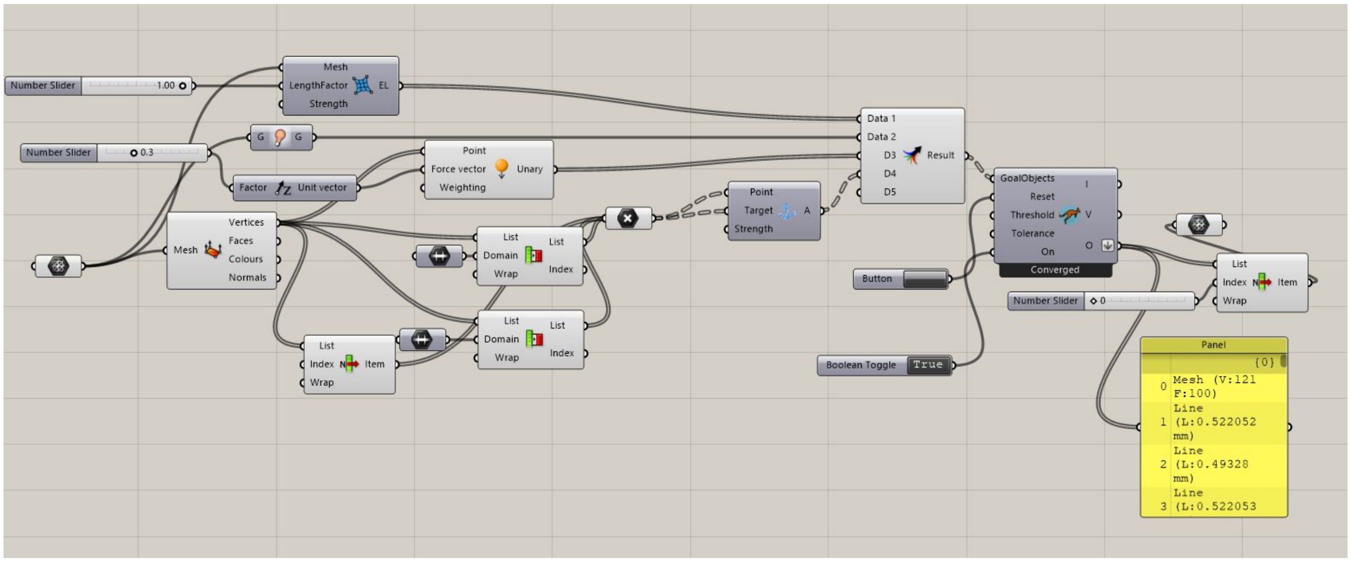

FIG. 28. Grasshopper code for the airbag actuation.

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VIII. AUTHOR CONTRIBUTION STATEMENT

(10pt) Must include all authors, identified by initials, for example: A.A. conceived the experiment(s), A.A. and B.A. conducted the experiment(s), C.A. and D.A. analysed the results. All authors reviewed the manuscript.

J.Z. designed the digital prototype of the device, inflatable simulations. J.Z. and A.P. analysed the results. A.P. Tested the fall detection. I.M. developed the adjustable mechanism. All authors reviewed the manuscript.