Johnson Health Tech: EMG Sensor Holder for Heels and Center of Mass Approximation

Biomedical Engineering Design 400

University of Wisconsin-Madison

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Preliminary Design Report

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Abstract

Johnson Health Tech uses Delsys Trigno sensors to collect data on a runner's center of mass and step force. To do so, they use the sensor's inertial measurement unit to collect acceleration data and convert it into force using the subject's mass. The current method of attaching the sensors to the back of the shoe with athletic tape often causes the sensor to move and the tape to roll up. This is less than ideal since the sensor movement adds excess noise to the data making it harder to process and uncomfortable for the runner. They do not currently have a device to hold the third sensor to the user's chest and are looking for a design to do so. Two different chest strap designs will be tested and compared to determine which one is the most stable, while three heel holders will be tested to also determine stability. Based on the results, the most stable design will be chosen and modified to improve comfort and further improve stability if need be.

Table of Contents

I. Introduction

A. Motivation

The use of accelerometers to determine the forces on and velocities of different body segments eliminates the need for a force plate to be used to measure reaction forces. This allows for the collection of movement and force data in situations when using a force plate is not possible or not ideal. The vertical ground reaction forces calculated from the accelerometers on the user's shoe, coupled with the step rate estimated from data collected by the sensor at the user's center of mass, can be used to assess the risk of injury for runners and other athletes on a variety of surfaces [1]. Johnson Health Tech currently implements this idea of using accelerometers for some of their research, but the method they use to attach the accelerometer sensors to the user's shoe causes issues that can affect their data collected. There is a need to create easily applied sensor holders that will remain stable and not impede the user's natural gait cycle throughout use. This will result in increased accuracy of movement, acceleration, and force values collected. This data can then be extrapolated to better assess the conditions and stresses the runner's body undergoes.

B. Existing Models

Multiple commercial systems currently exist for strapping different motion sensors to the chest and the heel/ankle region of the user. Johnson Health Tech also has an existing model that they use, but the current models used have issues that they want to be addressed.

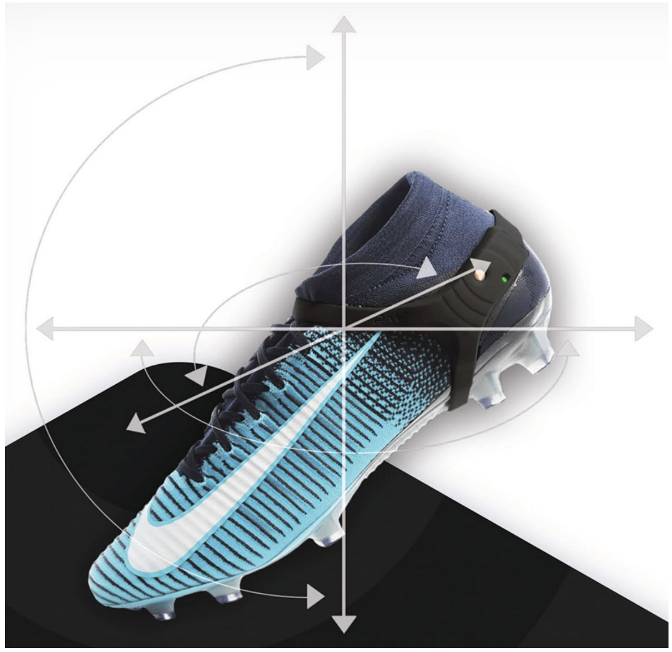

Figure 1: The Playmaker motion sensor shown on a cleat [2].

Playermaker, an athlete performance tracking platform, fabricates a smart motion sensor with a strap system to attach it to the user's cleat. The sensor system is usually used while playing soccer, and it gives the user insights on many different variables such as load and gait analysis [2]. The strap system uses a rubber material that wraps around the top and bottom of the cleat while securing the motion sensor to the outer heel of the user as seen in Figure 1. The placement of these straps works well for cleats but not for regular running shoes. It uses the cleat to secure the sensor in place, so on normal running shoes, it would slide off. Since this design is made of a rubber material there is some adjustability.

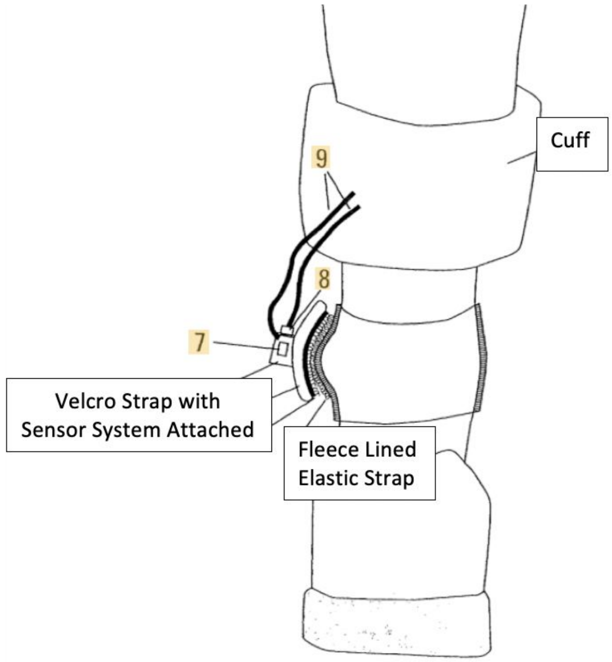

Fig. 2

Figure 2: A view of the Xybermind sensor and cuff from the back of the shoe. The device is attached to the outside of the ankle using velcro straps [3].

Xybermind, a German company that develops small devices for the sport and fitness markets, has a patented device used to evaluate displacement angles using three different sensors [3]. The sensors are secured to the ankle region of the user using a velcro strap over a fleece elastic strap in conjunction with a cuff higher up on the ankle of the user as seen in Figure 2. While this strap mechanism has proven to work in the company's studies, this design does not secure any of the sensors used onto the heel of the user. Having the sensors centered on the back of the user’s heel is important to Johnson Health Tech since this location of the sensor is most representative of the ground reaction force that is being experienced and it allows them to make generalizations about total body movement.

Figure 3: The Polar H10 heart rate sensor modeled on a user [4].

Many different companies create chest straps to secure different types of sensors to the user's chest. One example is Polar, a company that specializes in a wide range of sports training computers. They have multiple heart rate monitors that utilize a chest strap to be secured to the user. One of their strap designs uses a soft textile material with silicone dots on the inside to prevent slipping and it is secured with a buckle [4]. The strap is made to go around the chest of the user and is in direct contact with their skin as seen above in Figure 3. The chest sensor used by Johnson Health Tech does not need to be in direct contact with the user's skin, but it is important for the sensor to have minimal movement from its starting position during physical activity.

Figure 4: An image of the existing design used by Johnson Health Tech. Shown is the athletic tape that wraps around the sensor at the heel. Additional tape is used that is not depicted [5].

In the current method used by Johnson Health Tech, the shoe sensor is secured to the back of the user's shoe using athletic tape, as seen above in Figure 4. It is further wrapped in tape that goes across the laces and under the sole. This method is time-consuming to set up and the sensor often slips. The tape can also roll up, causing the runner to feel changes in their steps affecting the results collected by the sensor. Currently, Johnson Health Tech is not incorporating a center of mass chest sensor into their design. However, it is something they would like to incorporate into their testing going forward. Johnson Health Tech has reached out to determine other devices that can hold the Delsys Trigno Avanti sensors that they use to the back of the user's shoe and chest, allowing for different data to be collected during testing.

C. Problem Statement

The current methods used by Johnson Health Tech do not do a sufficient job in holding the center of mass and force sensors steady and in place. They use electromyography sensors that also function as accelerometers to collect data. The shoe holders are currently secured to the user with athletic tape that often slips and rolls up. The slippage causes less accurate data and the rolling can affect the user's gait and possibly cause them to trip. This project's goal is to create a safer and more stable sensor holder to collect more accurate data.

II. Background

A. Background Research

The Delsys Trigno Avanti sensor is an electromyography and accelerometer device. To collect the data it has a nine-axis inertial measurement unit so it can measure movement in any direction. It measures three degrees of rotational data and three degrees of linear movements. It can communicate wirelessly with a phone or a computer. The sensors use their own program to process data, however, raw data can be extracted to be processed on other platforms [6].

The acceleration data collected by the sensors can be converted into steps per minute and force per step. By looking at the changes in acceleration and counting the number of zeros for acceleration moving parallel to the sagittal plane, the number of steps can be obtained. This is because with each step the foot will switch directions causing it to have no acceleration. By calculating the derivative of the acceleration data, which is treated as a function of time, the velocity can be obtained. Using the acceleration and velocity in the vertical direction, the time of the shoe's impact can be determined. When looking at the velocity over time, the subject will have their foot on the ground when the vertical velocity hits zero. The acceleration value can then be found for that same time. Using Newton's second law, force equals mass times acceleration, the force of the step can be determined. The sensor located at the center of mass is used in addition to this data, allowing for generalizations of total body movement and a more accurate estimation of step rate.

The forces subject to the runner are another useful variable to track as they can relate to injury and running technique. Typical forces analyzed in a runner's gait include peak vertical ground reaction force, peak brake ground reaction force, and peak force along the tibia. These variables are obtained by taking the maximums of the acceleration data collected by the Delsys Trigno Avanti sensor at corresponding time intervals and relating them to the runner's weight in kilograms [7]. Additionally, these ground reaction forces can be used along with joint angle and loading rate, which is the speed at which forces are applied to the body, to characterize the running technique of the user. Because this typically requires the use of force plates and motion capture systems, the possibility of characterizing a runner's kinetics with only a few sensors is highly attractive [8]. With optimized algorithms for relating acceleration data to such variables, Johnson Health Tech would be capable of characterizing a runner's gait as well as detecting the risk of injury in a number of different environments.

B. Client Information

Arrington Pollmann is an intern and Staci Quam is a project engineer at Johnson Health Tech. They have used Delsys Trigno® sensors in the past to estimate the force and velocity of the limbs and center of mass data and has noticed issues with their current method of securing the sensors to the user and hopes to make the testing process more comfortable for users and lower the chances of greatly extraneous data.

C. Design Specifications

The client wants two sets of sensor holders consisting of two shoe holders, one for each shoe, and one chest holder. The holders need to securely hold the 26.85 mm by 37.00 mm by 14.75 mm Delsys Trigno Sensor. Each shoe holder should be compatible with running shoes women’s size 5 to men’s size 12, specifically 21.6 cm to 28.6 cm [9], and each chest holder should fit a chest circumference from 80 to 150 cm [10][11]. The shoe holders should also be durable enough to withstand forces of, at least, 2.28 to 2.64 kN [10][12]; to adjust for the majority of users, the sensor holders should be able to withstand up to 4 kN of force. Both types of sensors should also hold the sensor vertically to allow for proper data collection.

The shoe holder should not cause any slipping or tripping to the user and should not contain any hard parts that would be in contact to, or rub against the skin. The holders should also be minimally burdensome to the user and barely noticeable during usage. All of the holders should also have, at most, aminimal alteration to the gait of the user; the shoe holder should have a sensor displacement of less than 0.5 cm in any direction relative to the placement of the device on the heel, and the chest holder should not displace more than 2.0 cm in any direction relative to the placement on the chest. The sensor must be placed on the back of the heel with the indicator arrow facing upwards.

The sensors should either be reusable or inexpensive enough to be a one time use device. A reusable device is the preferred method. The holders should be easily washed and sterilized for maintaining a sanitary environment for the users.

III. Preliminary Designs

A. Center of Mass Sensor Holders

1. Fanny Pack

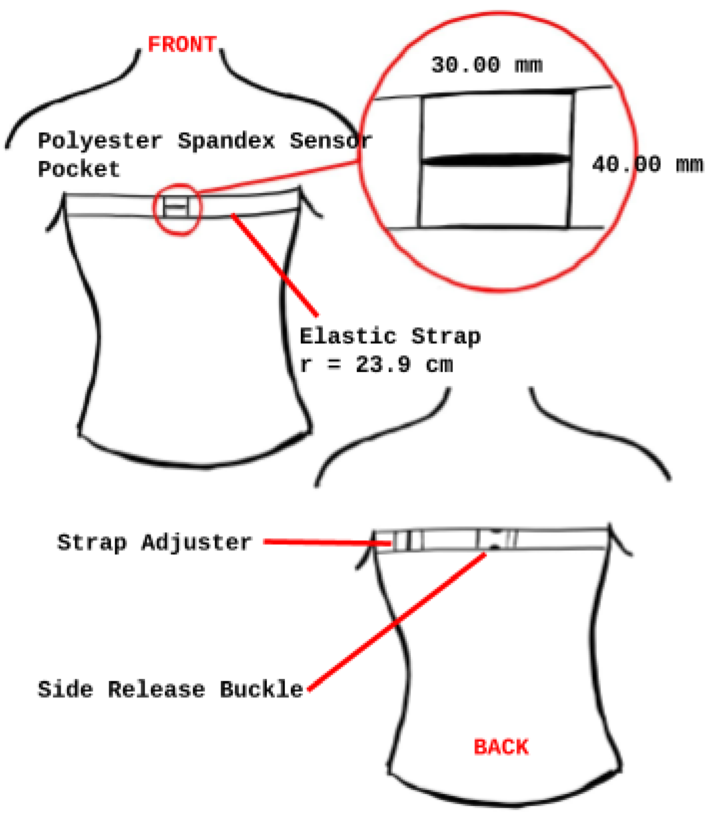

Figure 5: The Fanny Pack design for the center of mass sensor which is a singular strap with a fitted-pocket.

The "Fanny Pack," Figure 5, encompasses a singular elastic strap with a polyester-spandex pocket that is 30 mm by 40 mm. This will allow the 28.85 mm by 37.00 mm by 14.75 mm sensor to be stable during activity, as the elastic characteristic of the polyester spandex material will stretch around the thickness to maintain a tight junction with the body. The singular strap with the side release buckle for attachment and strap adjuster for the fit is simple and is similar to other active accessories such as a running fanny pack as the name implies. This resemblance allows for the assumption of comfort during activity. In terms of size, the circumference of the band without any adjustments will be approximately 150 cm or a radius of 23.9 cm. The average circumference of an adult male in the United States is approximately 100 cm according to the Centers for Disease Control [10]. The additional 50 cm of material accounts for larger subjects and, if necessary, the stretch property or a nylon expander can allow for larger subjects still. To account for smaller, particularly female, subjects it may be necessary to include an additional strap adjuster or shift the placement of the side release buckle. One possible obstacle of the fanny pack design is the movement in the vertical direction as the subject center of mass moves during the running gait. Proper, secure adjustment of the band is expected to minimize the potential bounce of the sensor. The sensor bounce could also arise from the deformation of the elastic material due to fatigue over time. The simplicity and low cost of the design would allow the user to replace the model when this occurs within reason.

2. Mounted Harness

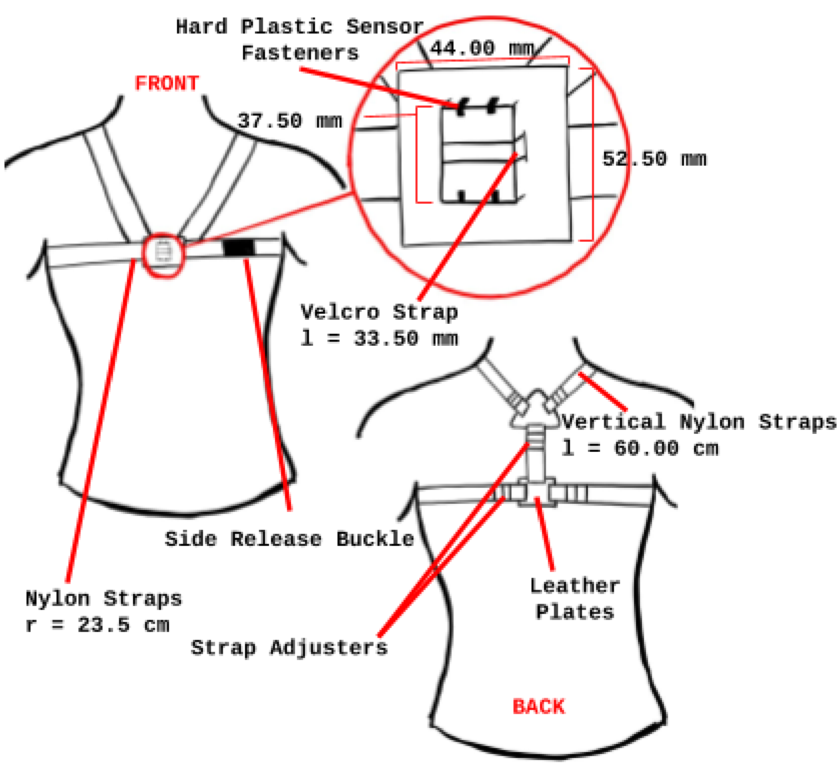

Figure 6: The Mounted Harness chest holder design that has vertical straps for stabilization and multiple adjustment points for subjects of various sizes.

Figure 6 is the “Mounted Harness” design which has both vertical and horizontal straps for supplementary stabilization of the sensor at the center of mass. The design has four separate nylon straps, one horizontal, and two halters connecting to a short vertical one on the back. The sensor is secured to a 44.00 millimeter by 52.50 millimeter plastic plate by L-shaped, plastic fasteners, and a velcro strap that measures 33.50 millimeters. Discomfort for the crisp edges of the plastic plate could arise; albeit, the sensor is anchored firmly in position. The horizontal strap is identical in design to the ‘Fanny Pack” in terms of the radius and width. The major differences are the anterior and posterior plates that create a disconnect in the nylon strap. To account for the various sizes of subjects, there are also strap adjusters flanking the posterior plate of the 150 centimeter band. The two identical vertical straps measure 60 centimeters and the one connecting the leather plates on the back is 12 centimeters. The harness needs to be compatible with all subject sizes, but if made too big it can create an excess of materials on the petite subjects which is not ideal. Furthermore, there is a possibility of irritation from the straps near the neck. Proper calculations of the strap angles would diminish the possibility of itch. The intricate design of the “Mounted Harness” provides securement of the sensor in all directions during activity but creates more chances of discomfort with the increase in design aspects.

3. Lederhosen

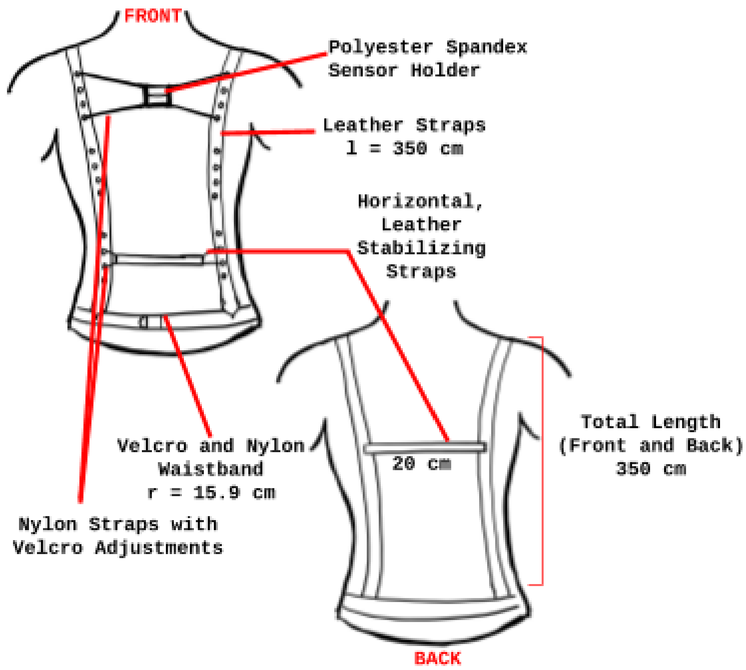

Figure 7: The Lederhosen center of mass holder that is based on the German Suspenders with two vertical straps supporting the sensor holder.

The "Lederhosen," as depicted in Figure 7, is inspired by German suspenders. The design incorporates two leather straps measuring 350 centimeters each that attach to a nylon waistband that would measure 100 centimeters. The dimensions of this design are based on the average adult male in the United States. The suspenders' length was calculated from the average height of men, 175 centimeters, then doubling the approximate waist-length determined from anthropometric data [10]. The major flaw with this design is the lack of adjustability. It is perfect for the average man but would be ill-fitting for everybody else. Adjustments could be made to the design to better fit more subjects; although, other dilemmas are also present, such as the leather material and maintaining the waistband position. The leather material is necessary for the holes on the suspenders portion of the design as it is flexible, but also durable enough to maintain the proper hole dimensions. The holes are utilized in the mobility of the sensor position. The polyester spandex sensor pocket with velcro straps can be vertically relocated on this device for other applications. The sensor pocket is the same dimensions as the "Fanny Pack" at 30 millimeters by 40 millimeters and it has four velcro straps attached to it for secure positioning of the sensor. Although there is a possibility of the sensor being askew from the centerline as the adjustments to the velcro are man-made thus leaving room for human error. In addition to the sensor holder on the front, there is a horizontal leather stabilizing strap that also has velcro on either end. The strap is used to keep the suspenders relatively parallel. There is also another horizontal strap, this time fixed in width, on the back. This again creates a few issues with adjustability between users. Ultimately the "Lederhosen" is a unique interpretation of a center of mass sensor holder with some major design flaws that would need to be addressed before continuing.

B. Shoe Sensor Holders

1. The Clip

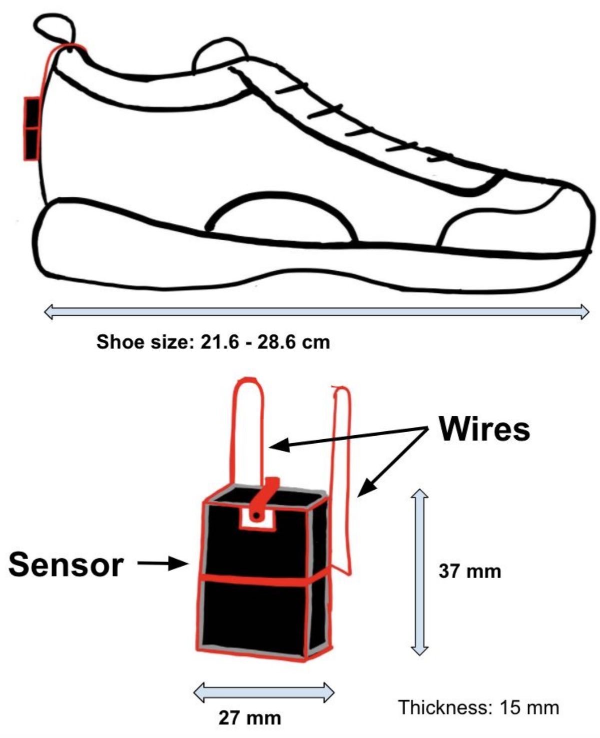

Figure 8: Shown here is "The Clip" design which uses wires that attach at the sensor holder and extend over the heel of the shoe and run down along the insides of the shoe.

The first design is "The Clip." It consists of a 3D printed sensor holder connected to wires as shown in Figure 8. The wire is bent into a clip shape that goes over the back of the shoe and inside adjacent to the sides of the heel of the user. The wires should be approximately 2 mm thick to minimize their effect on the user's gait while providing enough support so the clip does not easily lose its shape. Stainless steel wire is the most likely material that will be chosen for this design because of its accessibility, malleability, and strong mechanical properties.

A perk of this design is that it is easy to apply and will fit all shoe sizes. It is not dependent on the width or length of the shoe so it can easily be clipped on from user to user without any adjusting. The plastic and wire are also easy to clean with any disinfecting spray or wipe. Additionally, it uses minimal material, making it lightweight, decreasing the chances that it affects the user's natural gait. One concern is that the user might find the wires inside the shoe uncomfortable to run or walk with. The strength of the stainless steel wires will also need to be tested to ensure that they can remain in shape during normal running stresses.

2. The Straps

Figure 9: Shown above is one strap beneath the arch of the shoe and two smaller straps run through shoe lace holes all connected to the 3D printed sensor holder located on the outside heel of the shoe. An XYZ coordinate is given to aid in conceptualizing the direction of forces.

This design incorporates the use of three different "straps" all attached to the 3D printed sensor holder at the back of the shoe as shown in Figure 9. Each of these straps exerts a force in the x-direction, preventing the sensor holder from falling off the back of the shoe. The larger strap depicted above runs beneath the sole of the shoe to provide a force downward in the y-direction on the sensor holder, while the two smaller straps provide counter-forces in the positive y-direction. Forces in the z-direction are equal and opposite because there are three straps on either side of the shoe.

Some advantages of this design include that it is lightweight, adjustable, and secure. The straps will be made of athletic band material (bottom strap) and nylon (two upper straps). This will make it lightweight and not be cumbersome for the user. The straps will also be adjustable and capable of fitting shoe sizes 6 in women's to 12 in men's. Because of the balancing forces in the x, y, and z directions, this design will likely be secure, however, testing will need to confirm this. Possible downsides to this design include the stability of the bottom strap and the need to occupy two laces holes. In runners with high arches, and thus shoes with high arches, the athletic band strap will likely be secure. However, the concern is that the athletic band strap may slip when applied to runners with relatively flat shoes, possibly causing discomfort, injury, and loss of data. The other possible complication is that because this design requires the use of the top two laces holes of the user's shoe, there may not be room for both the nylon straps and the runner's laces. If this is the case, the runner would have a slightly different gait than normal, causing inaccuracies in the collected data.

3. <u>The Goalpost</u>

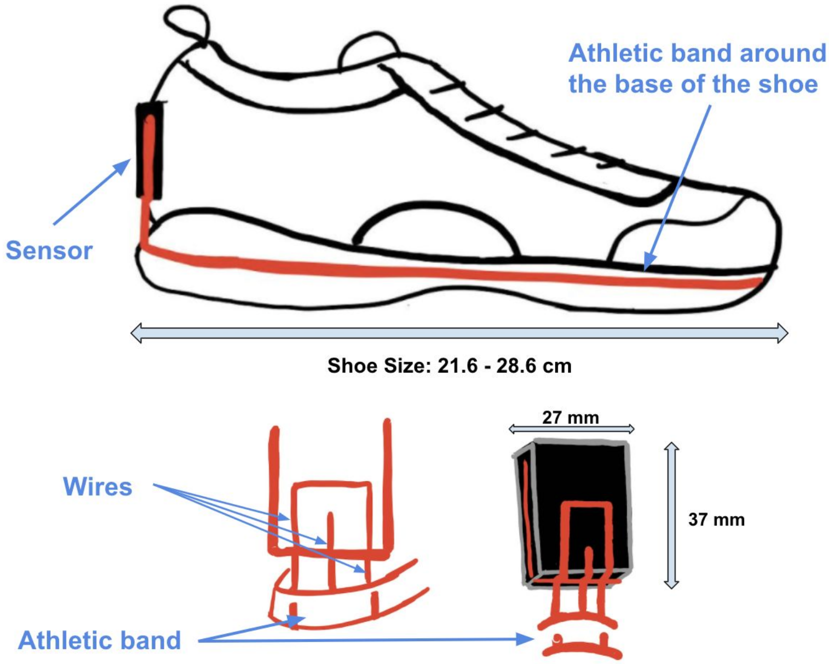

Figure 10: This image shows "The Goalpost" design in which an athletic band is wrapped around the base of the shoe. This band is connected to the 3D printed sensor holder via stainless steel wires.

This design utilizes an athletic wrap around the base of the shoe, avoiding any contact with the user as shown in Figure 10. Stainless steel wires adhered to the athletic band, either by glue or tape, will be connected to the 3D printed holder located at the back of the heel. The main advantage of this design is that its location is below where the user's foot would be placed. This means that the user will not be able to feel when the apparatus is attached and will therefore undergo their natural gait cycle. Although this is a very important characteristic, there are some drawbacks to this design as well. Because this design uses a fixed athletic band, it is not adjustable for multiple shoe sizes. It would be possible however to fabricate different sized models (small, medium, large) that could cover the specified requirements of 21.6 to 28.6 centimeters. Another negative of this design is that the elastic band surrounding the base of the shoe may slip off while the user is running. The stability of the band would have to be tested experimentally to accurately assess its function. Lastly, the stainless steel wires used to connect the elastic band to the 3D printed sensor holder need to be tested to ensure that they can withstand the stresses associated with a runner's movement over a prolonged period of about 20 hours.

IV. Preliminary Design Evaluation

The two components of this device each received their own design matrix. Both matrices have the same categories except for safety, which is only in the shoe design. The highest score in each category is highlighted. Each design is given a score out of five. Then using the weight is converted into a total score out of one hundred.

Predicted stability: How stable the predicted design is based on forces acting on and created by the design. It is an estimate of how well the design is predicted to resist slippage due to gravity and excess movement due to jostling and momentum. The importance of reliable data earned it the highest weighted score.

Comfort: Takes into account the user's ability to notice the device and any pain it will cause. The goal is to have the device be unnoticeable by the user or, at a minimum, cause the least amount of discomfort. If the user is comfortable using/wearing the design, it should allow them to run more naturally. This is why it is weighted as the second highest.

Lack of Hindrance: A gauge of how the device impacts the runner's natural gait. A higher score represents less hindrance. If the runner does not experience hindrance, then the data will be the most representative of their actual run, so it is also weighted the second highest.

Safety: Category only for the shoe holder designs. Since the design is on the shoe, the design must not pose a tripping hazard.

Ease of Fabrication: How easy the device is to make. If something were to happen to the designs, it should be easy to replicate, so testing can continue. This earned it the third lowest weight.

Cost: A higher score represents a lower cost. Since the materials needed for each design are relatively low and equal-cost was weighted the lowest along with ease of use.

Ease of Use: How easy the device is to put on each user and clean after each use. Each design does not require any special skills or training to use and there are no predicted complications from using the designs, so it is also weighted the lowest.

Table 1: The chest holder design matrix utilized to rate the three preliminary models.

		The Fanny Pack		The Mounted Harness		Lederhosen	
	Weight	**Score Out of 5**	**Weighted Score**	**Score Out of 5**	**Weighted Score**	**Score Out of 5**	**Weighted Score**
Predicted Stability	25	3.5	17.5	4.5	22.5	4.5	22.5
Comfort	20	4.5	18	4	16	3.5	14
Lack of Hinderance	20	5	20	3.5	14	3.5	14
Ease of Fabrication	15	5	15	4	12	2.5	7.5
Cost	10	4.5	9	4.5	9	3.5	7
Ease of Use	10	5	10	4.5	9	3	6
Total			89.5		82.5		71

The “Fanny Pack” design scored the highest for comfort, lack of hindrance, ease of fabrication, cost, and ease of use. This is largely due to its simplicity in only having a single strap. The one strap will not impede the runner as much since it is similar to many existing heart rate monitors used by runners. It could be made to fit many sizes with a design similar to a belt or other sort of buckle. It does not have the highest predicted stability though since nothing would prevent it from moving up or down other than the forces of friction. The high scores in the other categories gave it the highest overall score.

The “Mounted Harness” scored the next highest overall tying with the “Fanny Pack” for cost and scoring highest in stability. The added straps over the shoulder are predicted to help counteract any jostling in the vertical direction which would add stability. However, these straps may be less comfortable to the runner and impede their natural arm movements while running. These factors caused it to score lower than the first design. They also would be more time-consuming to produce, decreasing the ease of fabrication.

Finally, the "Lederhosen" scored the lowest overall. It tied with the "Mounted Harness" for predicted stability since the large number of straps would prevent movement in all directions, but scored lower in the other categories. The large design covering most of the torso would be uncomfortable for running and the inelasticity of the leather straps would impede movement. It would also be the hardest to fabricate and use. There would be many different components to adjust, including the waist strap, and the sensor height. Other portions do not have an adjustable component such as the shoulder straps. All of which accounts for the much lower score.

Table 2: The design matrix for the three shoes sensor holder designs.

		The Clip		The Straps		The Goal Post	
	Weight	Score Out of 5	Weighted Score	Score Out of 5	Weighted Score	Score Out of 5	Weighted Score
Predicted Stability	20	4	16	2.5	10	1	4
Comfort	15	2.5	7.5	3.5	10.5	5	15
Lack of Hinderance	15	4	12	4	12	4.5	13.5
Ease of Fabrication	12.5	3.5	8.75	4	10	4	10
Safety	12.5	4	10	3	7.5	4.5	11.25
Cost	10	2	4	4.5	9	4.5	9
Ease of Use	10	4.5	9	3	6	3	6
Total			67.25		65		68.75

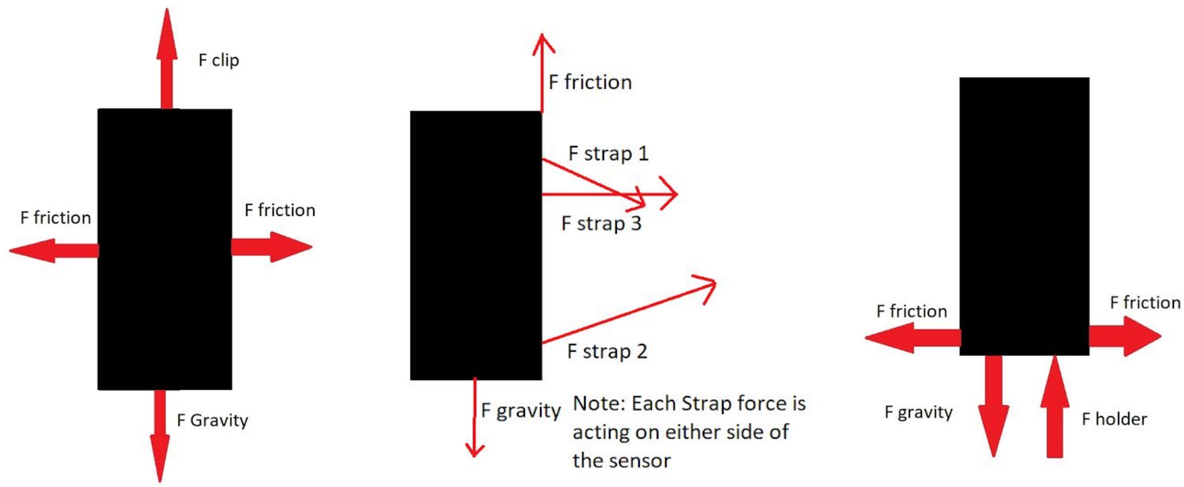

Figure 11: Force Body Diagrams of each shoe holder design. From left to right it is "The Clip," "The Straps," and "The Goal Post." "The Straps" View is from the side while the other two are from behind. Placement of the arrows is to indicate approximately where each force would be acting on the design.

Overall, the sensor holders all scored within four points of each other with "The Goal Post" scoring the highest with 68.75 out of 100. The "Clip" scored the highest in predicted stability and ease of use. It has the highest predicted stability since it is the only design that can guarantee that the sensor will not slip downward on the shoe. It can also pinch tighter to resist side to side movements. The free-body diagrams of the "Clip" and the other two shoe sensor holders can be seen in Figure 11. It is also very easy to use because no size adjustments are needed to fit different shoes.

"The Straps" scored the highest in ease of fabrication and cost. Only the sensor holder would need to be constructed. The straps themselves would just need to be cut to size. This also lowers the estimated cost. Although the straps would be easy to adjust for any shoe size, it also has the potential to roll up like the tape and be time-consuming to put on and position correctly. The downward forces of the straps could also cause the sensor to slip down the shoe.

"The Goal Post" design scored the highest in all categories except cost and ease of use. The strap going around the shoe could be very difficult to position in order to make sure it doesn't slip off while in use. The base of the holder is also far from the sensor, allowing it to potentially act like an inverted pendulum. Assuming that everything is positioned correctly and the strap does not come loose, it should be the most comfortable and hinder the runner the least since it does not go inside the shoe or wrap around the bottom.

V. Proposed Fabrication and Testing

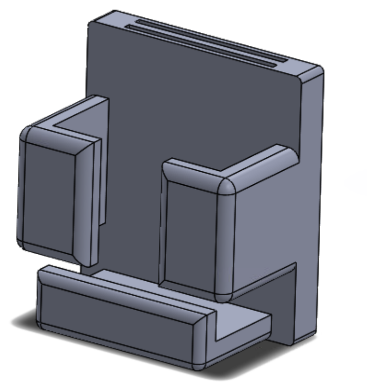

Figure 12: A base design for the various sensor holders that will be adjusted for the different designs. It currently shows two strap slots running through the design vertically.

Despite some designs scoring higher than others, every design besides “The Lederhosen” will be created and tested. The component, Figure 12, that holds the sensor will be 3D printed using PLA. This is the case for both the shoe holders and chest straps, excluding “The Fanny Pack”. For each sensor holder, the 3D printed component will need to be modified to fit the design. For example, “The Clip” will either have holes for the wire to feed through or be printed into the clip itself, and “The Goalpost” will include a base to wrap around the heel of the shoe.

After the fabrication has been completed, testing can begin. Each design will be tested three times per subject on at least three different subjects. The ultimate goal would be to use motion capture of the runner to determine the optimal data. Then the subject will run with the sensors attached by the current method of athletic tape. This will act as the baseline that the new methods will need to improve upon. To compare the comfort and hindrance of the design, the test subjects will rate each category on a scale of one to ten.

To determine if the sensor moved at all during the trial, it will first be outlined in chalk or another easy to remove substance. Any movement will be measured and recorded. The raw data will also be looked at to see if any excess noise from the sensor shifting has been picked up.

After all models have been tested, the most stable and comfortable design will be picked. From there it will be determined what, if any, adjustments need to be made to the design. Possible alterations to the designs include creating a combination of two of them such as adding straps to “The Clip” design. Another option is creating an insole component that attaches to the clip.

VI. Conclusion

The ultimate goal of the project is to develop two sets of the three sensor holders that provide higher accuracy during the collection of force and velocity data on a running subject. Fabrication of multiple models, especially the highly variable shoe holders, initiates a testing cycle of fabrication and modification in order to produce the most stable design. In terms of the chest holder, only the “Fanny Pack” and “Mounted Harness” will be fabricated and tested. The impracticality of the “Lederhosen” in terms of material and adjustability are the two major reasons why it will not be used going forward. In order to establish the baseline for accurate force and acceleration data, motion capture technology will be attempted to be utilized. The acquired data will be compared both to the motion capture and the data from the current method of Johnson Health Tech. Modifications to the design will be made according to results and feedback from Johnson Health Tech and aspects of various designs may be combined.

Future work of this project will mainly focus on the shoe sensor holder as there are little advancements necessary for the center of mass holder. After the completion of the basic running shoe design, the goal is to make it adjustable to other athletic applications. This will allow for expansion of the technology beyond the more focused, current study at Johnson Health Tech. Additionally, adjustability of the location of the sensor on the foot and the sensor dimensions it can hold would provide an opportunity to gather more data with the same device. Ultimately, the initial focus of the project is designing a running shoe and center of mass sensor holder for the Johnson Health Tech application, but then standardizing the design to fit a variety of sensors in a variety of locations on a variety of shoes.

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Appendix

Product Design Specifications

Function: The current methods used by Johnson Health Tech do not do a sufficient job in holding the center of mass and force sensors steady and in place. They use electromyography sensors that also function as accelerometers to collect data. The shoe holders are currently taped to the user with athletic tape that often slips and rolls up. The slippage causes less accurate data while the rolling can cause the user to trip. This project's goal is to create a safer and more stable sensor holder in order to collect more accurate data.

Client requirements (itemize what you have learned from the client about his / her needs):

- Two sets of sensor holders
- Each set contains two shoe holders and one chest strap
- The holders should hold the sensors vertically on the back of the shoe
- The chest holder should hold the sensor towards the bottom of the sternum
- The sensor holders should fit the Delsys Trigno EMG and accelerometer sensor
- The shoe holders should hold the sensors with minimal alteration to the gait of the runner
- The sensor holders should be reusable or inexpensive enough to discard them after each use.

Design requirements:

- Total cost should be less than $500

1. Physical and Operational Characteristics

a. *Performance requirements*: The device should be able to be used once a week and withstand being used by multiple runners or be built for a single use. It should be able to take the force of someone stepping. According to a Harvard study, the impact during running can be as much as three times the body weight which would translate on average to 2.28 kN for women and 2.64 kN for men [1] [2]. To allow most people to utilize the device, the sensor holder should be able to withstand 4 kN of force. The center of mass holder must be able to securely hold the sensor in place on the abdomen during running. There is no direct load on the device, but should be able to maintain position while undergoing vertical momentum. Both holders should be barely noticeable by the user as if they are running normally. They should be easily cleaned/sterilized, so they can be used by multiple users.

b. *Safety*: The shoe holders should not cause any slipping or tripping. If it wraps around the bottom of the shoe it should be able to grip the ground like a shoe, to avoid loss of traction and injury [3]. The device should not incorporate any hard materials that could rub against the user's skin. There are no real liabilities when it comes to the safety of the chest holder.

c. *Accuracy and Reliability*: The shoe holder should limit movement of the sensor to +/- 0.5 cm in any direction. The chest band should limit movement to +/- 2 cm in any direction. The device should also minimally change the runner's gait.

d. *Life in Service*: The devices should last at least a year, being used on average about once a week for several hours.

e. *Shelf Life*: It is not anticipated that there will be any particular storage conditions needed for this device.

f. *Operating Environment*: The devices will need to be able to be used in various environments both inside on a treadmill and outside on pavement during different weather/temperature conditions ranging from 0-32° Celsius during dry and rainy days. The shoe device will need to be compatible with up to 100 different users who have different shoe sizes (women's 5 through men's 13) and different running shoe brands/styles. Since the device will be attached to the user's shoe during physical activity, it will experience a variety of different loads (1-4 kN). The chest holder must be able to fit around the abdomen of a large variety of subjects in different amounts of shape.

g. *Ergonomics*: These devices must be as lightweight and minimally invasive as possible. Each component should not weigh more than 0.25 kg. The user should not experience much discomfort while wearing the device. This will be dependent on the material and the design. Additionally, the shoe device should not extend to the calf of the user.

h. *Size*: These devices should be adjustable to fit most users. One set of holders will be designed to fit women's shoes ranging from a women's size five to size eleven. This constitutes shoe lengths between 21.6 and 26.7 centimeters [4]. The other size will be for men's shoes ranging from a men's size eight to a size twelve. Thus, the sensor holder needs to be adjustable between 25.4 and 28.6 centimeters in length [4]. The part that secures the sensor should be able to fit the 26.85 mm x 37.00 mm x 14.75 mm sensor. The chest holder must have a circumference exceeding 100 cm, the average circumference of the abdomen of an American male [2]. To better fit a wide range of subjects, the design should be able to tightly fit an abdomen in the range 80 centimeters to 150 centimeters.

i. *Weight*: The goal is to make this product as light as possible so the user does not feel that they are running with weights on their feet. The average running shoe weighs 9 oz or 270 grams [5]. To keep interference at a minimum we want to keep each sensor under 45 grams. The weight of the chest sensor should be restricted to a similar weight as to not apply additional stress on the body as a subject runs.

j. *Materials*: Important material properties for this design are that it is lightweight, durable, and adjustable for different shoe sizes. Hard materials such as metals and plastics should be avoided as they could cause discomfort or injury to the user. Depending on the design, it may be preferable to use multiple materials. The chest strap should be washable or able to be wiped down with disinfectant like the shoe holders.

k. *Aesthetics*, *Appearance, and Finish*: The holders should be designed with the least amount of material that can reliably secure the 26.85 mm x 37.00 mm x 14.75 mm sensor to the heel of a shoe or to the center of mass. Excess material may cause the user to modify their natural gait. The color should be neutral so that it goes well with multiple different shoe types; although this is not an essential component of the design.

2. Production Characteristics

a. *Quantity*: Two sets of sensor holders. Each set includes a chest band and two shoe holders.

b. *Target Product Cost*: The total budget for this project is $500, but the product should be less than $50.

3. Miscellaneus

a. *Standards and Specifications*: The additive of the device to running shoes does not follow the standards for competitive athletic shoes as it gives an unfair advantage and information the shoe itself cannot provide [6]. Taking this into consideration, there are no specific standards that the design has to meet.

b. *Customer*: The sensor hold should be able to better stabilize the sensor than the current use of tape. It should be able to accurately measure the force and velocity of the lower limb and the center of mass. Although it is necessary for it to function properly during running trials, adaptability to other athletic endeavors is a welcomed bonus.

c. *Patient-related concerns*: The sensor holder should be able to be sterilized between use. They should be able to withstand being wiped down with a disinfecting wipe or spray.

d. *Competition*: There are similar designs for strapping different types of sensors to the user's shoe during different physical activities. One design that is similar is by PlayerMaker. Their product is a smart motion sensor with a strap system that is intended to be strapped to the user's cleat while playing soccer. It uses AI and machine learning algorithms to give insight on the player's performance and collects data such as stride length, acceleration/deceleration zones, cadence, and release velocity zones [7]. The strap goes around the heel and both above and below the cleat, and the sensor is held on the inside of the heel. US Patent (US7912672B2) attaches a sensor to the back of the heel by rubber bands on the heel cap [8]. The design has a smaller sensor that obtains data on vertical acceleration and an ankle cuff to which the sensor is attached.

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