Delsys Trigno Sensor Holder for Center of Mass and Shoe Acceleration

Cassidy Geddes, Quinton Heney, Emily Johnson, Ian Schirtzinger, Kiley Smith

Abstract

Delsys Trigno sensors can be utilized to collect data on the center of mass and step force of a runner, by converting the inertial measurement unit of the sensor into force using the mass of the subject. The sensors provide reliable data; although, noise is prevalent due to the lack of devices that can securely hold the sensor in place. The purpose of this study is to create reliable sensor holders for the shoe and chest so accurate gait-based data is obtained. Overall, the outcome from the study is not attributed to a specific population. The design of the study is a descriptive laboratory study describing the kinesiology of the gait of a runner. Our group executed three 30 second trials at speeds of 7 mph and 10 mph on a treadmill for each design. The sensor is attached to the shoe with athletic tape for the control, the experimental attachments are a metal wire design that uses the body weight of the runner to maintain the sensor position and a straps design that uses compressive forces to maintain the position. Additionally, information is extrapolated for a center of mass or chest securement. From the trials, the auxiliary movement from a respective trial is then compared to that of the others.

Include results and conclusions based on the data gathered at Johnson Health Tech

Clinically, the study will provide more accurate collection for future studies over a variety of terrain and equipment.

Key Terms: Gait, Accelerometer, Securement, Sensor

Introduction

The objective of this design was to create two Delsys Trigno™ sensor (Delsys Incorporated) holders that secure the sensors in place, one at the heel of both shoes and one just below the sternum. Ideally these sensor holders will be comfortable and easily implemented.

The use of accelerometers to determine the forces on and velocities of different body segments eliminates the need for a force plate to measure reaction forces. This allows for the collection of movement and force data in situations when using a force plate is not possible nor ideal. Development of reliable sensor holders ensures that accurate data can be acquired in a variety of different environments. This data can then be extrapolated to better assess the conditions and stresses the runner's body undergoes. This information can then be used to develop better exercise equipment and optimize running technique to reduce risk of injury (D. Kiernan et al.).

Multiple commercial systems currently exist for strapping different motion sensors to the chest and the heel/ankle region of the user. Playermaker, an athlete performance tracking platform, fabricates a smart motion sensor with a strap system to attach it to the user's cleat (Playermaker). This design is catered specifically to soccer cleats and relies on the presence of studs beneath the shoes to hold the straps in place. 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 (R. Feichtinger et al.). 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 that is just above the ankle of the user. 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. 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 (Polar Global). One of their chest strap designs uses a soft textile material with silicone dots on the inside to prevent slipping and it is secured with a buckle. This design has most of the important elements needed in our design however it is intended for use directly on the skin, whereas our chest strap design will go over the users clothing.

We have developed two separate designs for the sensor holder at the heel. The first consists of secure straps made of rubber with varying tensions that run beneath the bridge of the user's shoe and over the laces. The other is an 18 gauge stainless steel wire “clip” that is held in place by the user’s body weight beneath the sole of their shoe. Preliminary testing showed that these two designs succeed in eliminating opposite directions of sensor movement; the Clip design restricted horizontal displacement, and the Straps design restricted vertical displacement. Preliminary testing was promising for the chest strap holder as well. Further testing and data analyses needs to be conducted before concrete conclusions about these designs can be made.

Methodology

Designs

The chest strap was constructed by sewing a spandex pouch onto an elastic strap. The strap was adjustable to fit different chest sizes and designed to sit at the base of the sternum. The clip shoe sensor holder was made by bending wire to pinch the heel of the shoe and was made with 18 gauge copper wire, 16 gauge galvanized steel wire, and 18 gauge stainless steel wire. The different metals and gauges were picked to test the strength and comfort of different designs. The final shoe holder consisted of rubber athletic bands wrapped around the shoe to hold the sensor in place.

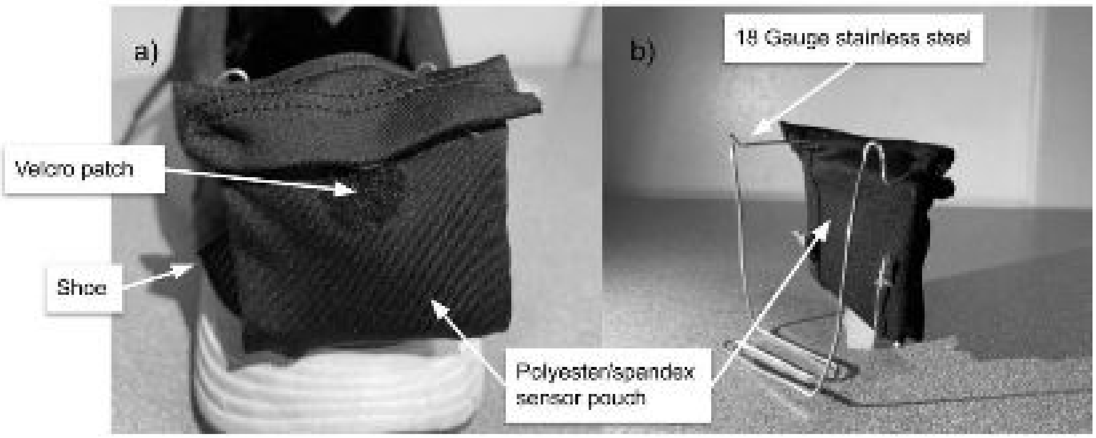


Figure 1: The clip design showing the 18 gauge stainless steel wire. The same shape is used for all wire designs. Figure A shows the design on the shoe and figure B shows it stand alone.

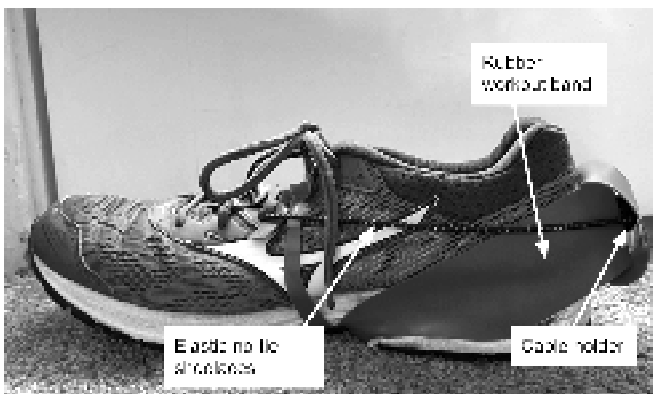


Figure 2: The straps design shown from the side. The rubber workout band wraps over the sensor holder and under the shoe while the shoe lace holds the sensor against the shoe.

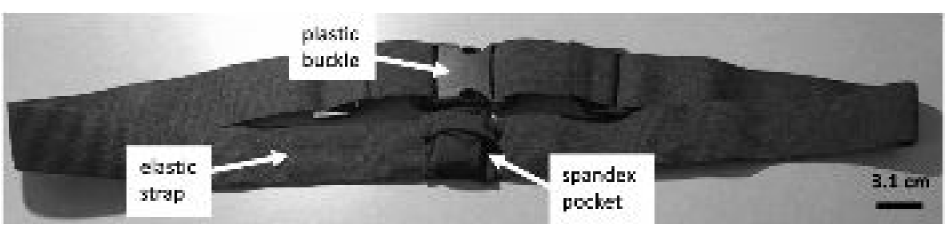


Figure 3: The chest strap design with the sensor holder centered in the middle.

Delsys Trigno Sensor Recordings

The first stage of testing was conducted by recording the acceleration data from the Delsys Trigno Sensor. We conducted trials on four different users with a total of five different attachment methods: athletic tape (control method), 18 gauge copper wire, 16 gauge galvanized steel wire, 18 gauge stainless steel wire, and athletic workout bands (straps). Please note all of the wire materials have the same structure. The chestband was worn during every trial and tested over different materials such as a sweatshirt, t-shirt, and a tight fitting shirt. The designs were tested through a minimum of six trials. The user first ran at a 10 minute mile pace for 30 seconds and then rested for 45 seconds for a total of three trials. This process was repeated at a pace of seven minute mile.

The data was exported to MATLAB and the acceleration data resulting directly from stepping was filtered out and the leftover data was noise or extra movement of the sensor. The noise would be compared to that collected from the control method. The designs were considered to be more accurate than the current method if the amount of noise was less than the control method.

Kinovea Motion Capture

In order to use Kinovea, we placed dots on the shoe and on the sensor holder in order to measure the movement. From the back view, a dot was placed on the center of the sensor holder, 2 cm to the right, and 2 cm below. From the side view the dots were placed on the center of the sensor holder, 2 cm down, and 3 cm towards the toe. To capture the back view an X was placed on the ground and the camera was placed 75 cm away and 30 cm above the ground. The user ran for 30 seconds for three trials and the process is repeated on another user. To capture the side view the same camera setup was used. Each model was tested a total of six times.

After the recordings were completed, the videos were uploaded into kinovea and the markers were selected. To ensure accuracy the videos were checked frame by frame to make sure the markers were accurately followed. This data was then exported to MATLAB to determine the overall movement of the sensor in the X and Y directions.

Results

Outline of an outline possibility

- Chest Strap Holder
    - List the results of the chest strap holder
    - Discuss it on different clothing type
    - Quantify comfort / ease of use
    - Figure X: The average noise observed for the chest holder over the various clothing type per trial.
- Shoe Holders
    - State the results for both
    - Describe the experimental variations with shoe types
    - Compare them to the control data
    - Quantify comfort / ease of use
    - Figure X+1: The average noise observed for the shoe holder for both the clip and straps design at 7 mph and 10 mph for each.

By looking at the raw data with professionals it was observed that when using the clip designs the sensor bounced when the user's foot hit the ground. When using the straps design it was observed that slight horizontal translations occurred during use. The data of the chest strap showed that the chest strap had an overall vertical? displacement during use. This can be fixed by making the chest strap so that it can be adjusted to a smaller circumference and by adding silicone grip to the inside. Based on the data for the shoe sensor holders, ideas for future improvements to the design include combining the two design ideas to limit movement even more. Compared to the control the specialists observed that both the clip and the strap design improved the stability of the sensors during use.

Discussion

- Compute statistical analysis for the two designs
    - Discuss statistical significance
        - Chest strap compared to value in PDS
        - Shoe sensor holders to control and value in PDS
- Discuss what design for the shoe is the best
- Prove that the chest strap fulfill the requirements

Conclusion

We have examined two sensor holder designs that are fixed on the shoe and one that is strapped to the user's chest and determined that all of the methods still allow for movement of the sensor; however, this movement has been significantly diminished compared to the control designs. Further testing needs to be done to determine which of the shoe sensor strap designs hold the sensor in the most stable position. The data for lateral movement while wearing the sensors should be collected as well. Further analysis of the data collected needs to be done using

MATLAB to determine exact movement of the sensors during use. This will allow for better understanding of the designs and will lead to more improvements.

References

Delsys Incorporated, “Trigno® Wireless Biofeedback System User's Guide,” Trigno Wireless Biofeedback System User's Guide, Feb-2020. [Online]. Available: https://delsys.com/downloads/USERSGUIDE/trigno/wireless-biofeedback-system.pdf. [Accessed: 06-Oct-2020].

D. Kiernan, D. A. Hawkins, M. A. Manoukian, M. Mckallip, L. Oelsner, C. F. Caskey, and C. L. Coolbaugh, “Accelerometer-based prediction of running injury in National Collegiate Athletic Association track athletes,” *Journal of Biomechanics*, vol. 73, pp. 201–209, May 2018.

Playermaker, “Play Smart. Connect Your Game. ,” *Playermaker*. [Online]. Available: https://playermaker.com/. [Accessed: 17-Sep-2020].

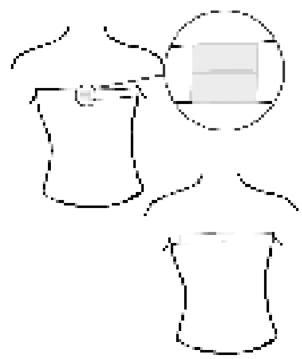
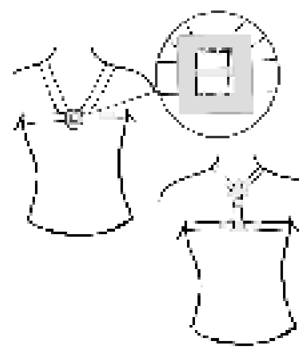
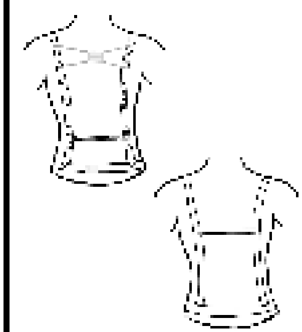
Polar Global, “Heart Rate Sensors,” 2020. [Online]. Available: https://www.polar.com/en/products/heart-rate-sensors. [Accessed: 05-Oct-2020].

R. Feichtinger and J. Löschinger, “Method and Device for Evaluating Displacement Signals,” U.S. Patent 7912672B2, Mar. 22, 2011.

<u>**Appendix**</u>

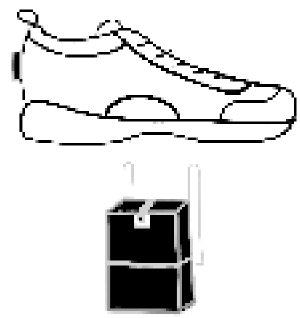
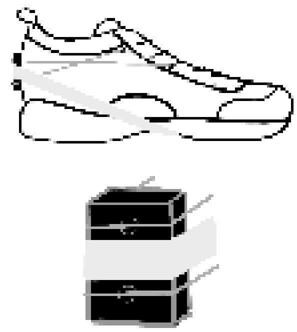
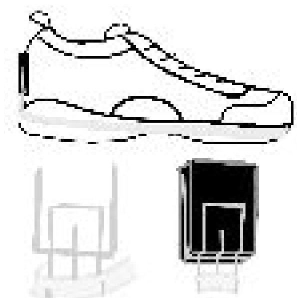
Design Process

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

	The Fanny Pack		**The Mounted Harness**		**Lederhosen**	
						
Criteria	**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 (/100)		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 due to the design's simplicity with a single strap. The one strap will not impede the user as much compared to the other designs since it is similar to many existing heart rate monitors that are already in use. The strap has additional functionality to be made to fit many body sizes by using a design similar to a belt or other sort of buckle; it does not have the highest predicted stability among the designs, since nothing would prevent it from moving up or down other than the forces of friction. The high scores in the other categories gave the "Fanny Pack" design the highest overall score.

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

	The Clip		The Straps		The Goal Post	
						
Criteria	**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

Overall, the sensor holders all scored within four points of each other, with “The Goal Post” scoring the highest at 68.75 out of 100. The “Clip” scored the highest in predicted stability and ease of use. The “Clip” scored highest in predicted stability since it is the only design that can guarantee that the sensor will not slip downward on the shoe and can also pinch tighter to resist lateral movement. There are no size adjustments necessary to fit the “Clip” design to different shoes, which allows for a greater ease of use.

“The Straps” scored the highest in ease of fabrication and cost. Partly because only the sensor holder would need to be constructed while the straps themselves would just need to be cut to size; this contributes to a lowered fabrication 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 on the straps could also cause the sensor to slip down the shoe.

Testing Design

Multiple phases of testing were conducted, all of which to attempt to quantify the amount of extraneous movement. The rounds of testing were conducted with the motion capture software, Kinovea. Testing with Kinovea involves placing multiple markers on the user and filming them during the activity, followed by processing the data from the markers. The filmed activity can be used to measure movement, acceleration, and joint angles. Markers that were bright and contrasting were placed on the sensor and on the shoe or chest. The recordings were then opened in Kinovea where the markers were selected for the software to track frame-by-frame movement and to generate data for the position of the markers throughout the trial; if the movement was tracked inaccurately, the marker was then adjusted. After Kinovea, the data was processed in MATLAB to calculate the change in distance between the markers during the testing period and also calculate the change in x and y distance from each other. The average movement was then calculated for each trial. The chest strap had two trials recorded from the front of the user and the markers being placed on the sensor and the user's sternum. Each heel sensor holder went through four trials, with two measured from the side and two measured from the back, to gain data on both vertical and lateral movement of the sensor during use; each trial lasted for 15 seconds.

Testing Results

For the first round of testing, the method was not completely accurate, but the results still helped analyze the effectiveness of each prototype and gave information to help with making design decisions.

For the chest strap testing, the average total displacement was calculated. In this trial, there was a large disparity in total movement. This could be due to movement closer or farther away from the camera. The average movement was less than 0.42 cm but could reach over 2.5 cm. This lead to a large margin of error and standard deviation of 0.74 as seen in figure 4 below.

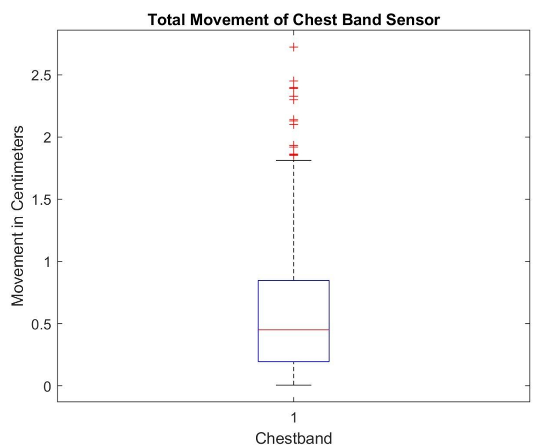


Figure 4: The average change in movement for the chest band sensor prototype.

Figure 5 depicts the average change of overall distance per frame for two trials of the two "Clip" designs - copper wire and steel wire - and the "Straps" design. The first "Straps" design trial had both a shoe with a flat bottom and one with a groove in the center of the shoe. The average movement from the back was much greater than from the side due to the changing perspective. Although the side profile for the straps design appears to result in a much greater movement than the other two designs, we believe that it is because of a change in the distance from the camera resulting in a perceived difference rather than an actual change of up to six cm.

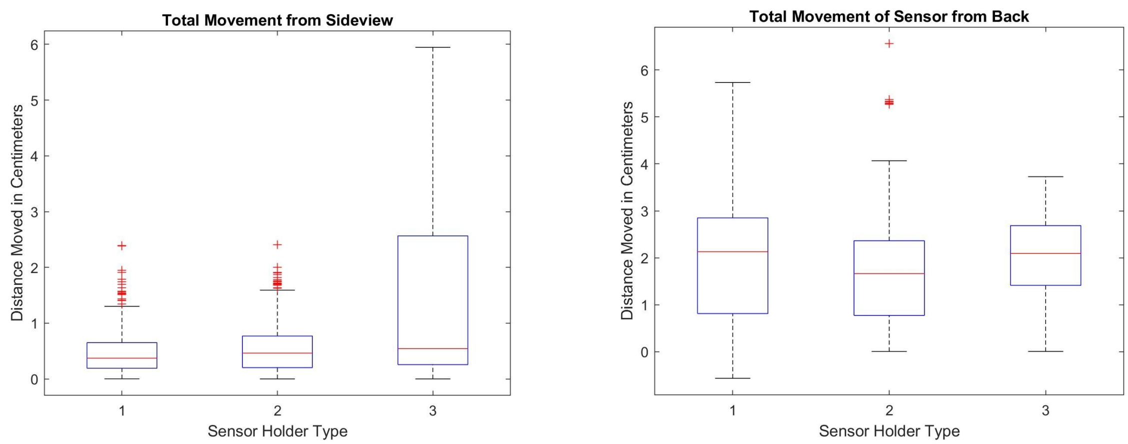


Figure 5a and b: The average change in distance per frame of the shoe sensor holder prototypes. 1 is the clip design with copper wire, 2 is the clip design with steel wire, and 3 is the straps design.

All of the preliminary tests conducted indicate that both of the current shoe holder designs are capable of securely affixing the sensors to the shoe. The average of each is 1 cm for the side view and under 2 centimeters for the back view. It is currently not feasible to conclude which design is the most stable, since the number of trials and subjects are insufficient.

The data provides a good starting point for the evaluation of the sensor holder prototypes, but there are several sources of error that make definitive conclusions difficult to make. First, results from the test subject moving closer to or further from the camera during the trial. Kinovea is not able to take the perspective into account and it registers this change in distance of the subject as a change in distance of the markers. If the user moves further away, the distance will appear to shrink which could cause any movement of the sensor to appear as normal such that the sensor was held in place and the opposite can be said for when the user gets closer to the camera. For tests that are looking at the angles of joints this would not be an issue, but since this test relies on the initial distance between the sensors compared to that distance over time, it can cause discrepancy in the data. It is hypothesized that this is what happened during trial two of the

“Straps” design, based on the high movement average. To prevent this issue going forward, the user could mark the ground with an X as a target to step on.

Another source of error could be due to low camera quality and poor lighting, which can cause the frames to be blurry, as shown in figure fv. Kinovea often lost track of the markers and the traces needed to be manually adjusted to lie on the marker; in this case, the markers often appeared as a blur so the trace placement itself needed to be estimated. Higher quality video cameras, that record more frames per second, will reduce blur and make the videos easier to map.

Lastly, the back perspective could inaccurately measure the vertical distance between the two markers due to the change in foot angle. This is evident in the data seeing that the change in distance from behind was three times greater than the side view in many of the trials. As the foot rotates, the plane that the markers are on becomes more horizontal which causes the camera to register the change in perspective as a change in distance. To eliminate this going forward, the back view could be used to measure only the lateral movement of the sensor. If the two markers are placed co-linearly, the overall distance between the two markers will not matter only the difference between the X coordinates of the two markers.

As for the chest holder trials, a source of error is that sometimes the subject’s hand moved in front of the markers. In future trials, it will be important to ensure that the test subject is cognizant of where their hands are; if they swing their arms more parallel to their body, there should be no obstruction of the markers and minimal disruption to their gait.