DESIGN OF A MECHANICAL CLUTCH SYSTEM FOR A PROGRAMMABLE SURFACE

by Caydn White

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DESIGN OF A MECHANICAL CLUTCH SYSTEM FOR A PROGRAMMABLE SURFACE

Project Approved:

Supervising Professor: Stephen Weis, Ph. D.
Department of Engineering

Curtis E. Larsen, Ph. D.
Department of Engineering

Yuri Strzhemechny, Ph. D.
Department of Physics and Astronomy

ABSTRACT

Flatfoot and cavus foot are postural issues that affect approximately 40% of people and can be corrected by means of orthotic inserts for shoes. A programmable surface is being developed as a tool for orthotists to visualize and fabricate orthotic inserts. The surface will be formed by an array of solenoid actuators controlled by the orthotist. The patient will stand on the programmable surface while the orthotist evaluates the patient's needs by manipulating the surface. Once the orthotist is satisfied with the array, the surface position will be held by a clutch system, so the patient can step off the surface and the surface positions can be recorded. This work describes my development of a prototype mechanical clutch for the programmable surface. The result of this project is a proof-of-concept design of an array of twenty-five physical clutch points which may be individually addressed by means of servo motors controlled by an Arduino microcontroller. With the development of this prototype, it is believed that such a control interface could be implemented on a system large enough for an adult human to stand on. This proof-of-concept is a small step in a larger project of developing a full-scale reconfigurable surface by which an orthotist could create posture correcting devices.

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I. Introduction and Motivation

This paper details the research and design of part of a larger project to create a programmable surface that will be used for the creation of custom orthotic inserts for posture creation. My part of this project has been to create a mechanical clutch subsystem for the programmable surface. The extent of my work was to brainstorm, design, and build a proof-of-concept for this clutch system that could eventually be scaled up and used in a full-sized programmable surface. Programmable surfaces are an emerging technology that are currently being researched by a group of major engineering research organizations, MIT and NASA being among them. The point of a programmable surface is that a two-dimensional surface could be controlled digitally to produce any desired shape on the surface. This will provide additional levels of usefulness to common tasks as well as open more possibilities for humans to learn, create, and design things using such a surface. Further details regarding what a programmable surface is will be detailed in one of the following sections, as will the design approach and the design of the final prototype.

The significance of this project is that the development of this prototype is an advancement in the understanding of how programmable surface technology can be applied. The core motivation for creating this surface is to provide a new means by which professional orthotics makers, called orthotists, can create posture correcting devices. This prototype also represents a potential change in how orthotics makers are educated, as this is a difficulty in their field. The basics of posture correction through orthotic insoles, as well as how they are made, will be explained in more detail later in this paper.

This project is a continuation of work done by several previous students on the project. Their work will be referenced throughout this paper where appropriate.

II. Programmable Surface Technology

A programmable surface is a three-dimensional surface that can be commanded to take different shapes based on a digital input, usually from a computer or some other device capable of digital control. The simplest way to explain such a surface is using Pin Art, the children's toy. Pin Art is a surface composed of pins that can move up and down based on what is pressed into the pins and the other side of the pins recreate what is being pressed. The idea behind a programmable surface is that you take a surface like the pins in the Pin Art and make each element of the surface controlled digitally. This would give the ability to set each pin to whatever height the user wants to create, and the elements would together make up the shape of the entire surface.

Figure 1: A common Pin Art toy
Credit: Google Images

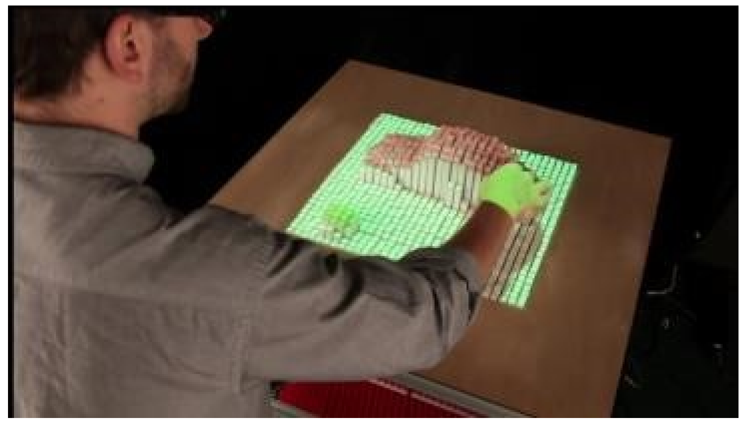

Figure 2: inForm surface being used to alter the design of a car
Credit: MIT Tangible Media Lab

The surface that inspired this project is a programmable surface called inFORM that was created by the MIT Tangible Media Lab several years ago. It achieves the goal of being a surface that can be reconfigured based on a user input or other digital command. It captures spatial images from a Kinect camera and translates that to the surface. Three-dimensional CAD drawings can also be translated onto the surface allowing inventors to see visual representations of their designs (Figure 2). Its main purpose is for digital media and to introduce a new way for people to learn and interact with said media. It has been used to create many different types of three-dimensional surfaces, including cityscapes, mountain ranges, mathematical surfaces, and representations of human hands. Current iterations of this surface allow for some types of video games to be played and the Tangible Media Lab is constantly exploring ways to develop and mature this technology.

As demonstrated by the team at MIT, this technology could have many potential uses and they have only begun to scratch the surface of its implications. While this programmable surface currently only exists in research environments, I believe that as the technology matures, it could begin to appear in more environments, such as classrooms, manufacturing and design facilities, and as we are about to explore, in doctor's offices.

III. Orthotic Posture Correction

The problem that our proposed programmable surface is intended to solve is the issue of correcting the posture of people that have fallen arches, also known as flatfoot, or high arches, also known as cavus foot. Fallen arches are a chronic condition present in about 20% of the population and occur when the ligaments in the foot are not strong enough to form a normal arch in the foot. As a result, the arches "fall", causing the foot to become flat when supporting the person's weight while standing or performing physical activity. This condition can either be genetic or can be caused by injury to the foot. High arches are also a chronic condition affecting another 20% of the population and occur when the ligaments in the foot are especially tight, drawing the foot into an unnaturally high arch. Both conditions can cause unnecessary pain to the people affected by them when uncorrected. Without some sort of correction to the arch, people with fallen arches or high arches can experience pain in the ankles, knees, and lower back when performing normal physical activities, such as walking, running, or playing sports. [2] Figure 3 shows a comparison of what high arches and fallen arches look like compared to a normal, properly formed arch.

Figure 3: Comparison of flat arch and high arch to a normal arch
Credit: www.runsociety.com

Sometimes these conditions can be corrected by using over-the-counter arch supports, with the hope of providing relief from the pain caused by flat feet or high arches. However, not all cases can be corrected with over-the-counter supports. These cases require custom made orthotic inserts that are molded to the contours of an individual's foot. These devices must be made by specially trained orthotics makers, called orthotists. These orthotic specialists have unique skills and training that give them the knowledge and ability to make orthotic inserts that match the individual's foot well, provide the proper correction, and that will last the user a long time under daily use.

Orthotists have a specific method that they follow when creating these inserts. The first step is to examine the patient's feet and begin evaluating the needs for their feet to be corrected properly. Oftentimes, their training allows them to "see" these corrections in their mind first based on how the patient's knees and hips align when he or she stands and walks. The orthotist is then able to take a non-weight bearing corrective impression of the patient's feet in impression foam resulting in a negative impression of the foot. Figure 4 shows an example of what the foam and this corrective impression look like. Using this negative impression, the orthotist then pours plaster into the foam and creates a positive impression of the foot, which is then used as a model for which to create the orthotic inserts. [3]

Figure 4: An example of a negative impression in a foam mold.
Credit: orthomedics.com

The proposition presented in this paper is that if a programmable surface is specially developed for creating orthotic inserts, it could replace the current method of creating them. A programmable surface would be used in place of the foam molds. The new process would start with the patient standing on the programmable surface while it is completely flat. The orthotist would then use a digital control interface such as a laptop or a tablet to change the shape of the programmable surface to match the feet of the patient. The orthotist would be able to see in real time what the adjustments in the surface are doing to the patient's posture. Once the orthotist is satisfied with the shape of the surface and the correction it is providing the patient, the orthotist would lock the position of the surface elements in place and ask the patient to step off the surface. The orthotist would then perform a 3D scan of the surface, providing them a cloud of 3D data points that could then be used to create the orthotic insert by means of a 3D printer.

The usefulness of a programmable surface in this process comes largely in the education of new orthotists. The skills required to make these inserts require years of training to acquire, and the most difficult skill for them to obtain is being able to "see" what the patient needs as far as corrections in the foot. This is often a frustration with experienced orthotists when they are training a new apprentice, as there is no easy way to transfer this knowledge and it is currently only acquired through years of observation and practice. The programmable surface would accelerate this process as an experienced orthotist would be able to show an apprentice exactly how a certain correction would affect a patient's feet and posture in real time using the digitally control mechanisms in the surface. The apprentice would be able to move more quickly through the phase of watching to the phase of doing and practicing, as they would be able to start attempting their own corrections under the watchful eye of their tutor as soon as they are trained in how the digital interface works. The programmable surface is also more forgiving than the foam mold, as the surface is reconfigurable if there is a mistake, unlike the permanence of the foam mold.

The design of a programmable surface for posture correction has been underway for several years at Texas Christian University and the remainder of this paper will document my contributions to the development of the surface.

IV. Design Approach

My portion of the design work for this project began in January of 2018 and started with addressing the necessary deliverables for the proof-of-concept prototype to be a success. Two of the students that worked on this project previously met with Alan Hood, a licensed Orthotist and the owner of the Center for Postural Correction in Fort Worth, TX to determine many of the parameters that would make this theorized programmable surface useful for orthotopic posture correction. The surface that we are seeking to create would need to be able to support the weight of a 250-pound person while still allowing the free movement of the pin elements of the surface. It would also need to be configured such that individual elements of the pins could be moved by themselves, or entire groups of pins could be moved together. Another parameter is that the ideal pin density is 9 pins per square inch to allow for enough to control to accurately create the surface necessary for a person's foot. The surface would also need to be controlled digitally through a user-friendly interface. [1]

The design of the programmable surface can be broken down into four major components: the system that moves the surface elements up and down, the system that locks the elements into position and unlocks them when they need to move, the 3D scanner, and the digital control interface. Stephen Culver, a student that previously worked on this project, successfully created the 3D scanner using an Xbox Kinect [4]. Two previous students that have worked on the project, Nathan Loewen and Parker Wise, were able to create a surface using linear motors that satisfied the need to have a system to hold surface elements in place as well as the means to move them up and down simultaneously. However, due to the size of the motors, the surface elements were far too bulky to be useful and would have been difficult to scale down to increase surface resolution [1]. My assignment on the project was initially to revamp their system, creating a new version of the mechanical parts of the surface. Because their design could not be scaled down and seemed to have reached its developmental conclusion, my work had to start with a clean sheet design to address the issue of creating the surface prototype. My original design meetings with my advisor, Dr. Stephen Weis, outlined that my contribution to the project would be to explore alternative methods of these two major functions performed by the programmable surface: the movement of pin elements and the locking of these elements in place when they do not need to move.

Early Prototyping

Our first step was to brainstorm ideas of how this system could be created. We began focusing mainly on the movement of the surface elements and developing ideas as to how we could push and pull the pins of the surface up and down. Some of our original ideas were to use pneumatic cylinders, hydraulics, a ratcheting system, and a revisit of linear motors. To get a better understanding of the usability of the various systems, we started prototyping what we believed were some of the more promising ones. One that we saw as a viable option was the use of pneumatics. I spent some time investigating the design of pneumatic cylinders and ended up making some simple pneumatics cylinders in the lab. After testing these cylinders, it became clear that they would not suffice as a solution because as soon as the surface is formed, and the patient steps off, the air inside the cylinder would expand and the pin would move, causing the surface to be distorted and unusable. There would also be an issue of how to get the air inside the cylinder as adding an air compressor would make the system usually bulky and the compressor itself would be loud while in use. We deduced that a hydraulic system would also be bulky and would come with the added complexity and mess of introducing hydraulic fluid.

Upon investigating some of our brainstorming options and developing the simple prototypes, it became clear that the best way to address the movement issue and the locking issue was to treat them as separate subsystems instead of trying to solve both issues with one system. This led to a separation of responsibilities for the development of the surface prototype. Another student began working solely on the mechanism for moving the surface elements up and down. My responsibility became purely to construct the system which would lock and unlock the surface elements. We began calling my system a clutch, borrowing the name from the clutch on a car.

Initial Clutch Design

My first design of the clutch was rather simple and consisted of multiple bars laid across each other to form an array that would be able to move to address any point in the array. Each position for a pin had holes drilled with a larger hole slightly overlapping a smaller hole. The pins were manufactured to have grooves cut into one inch of their length for the smaller hole to lock into when the pin needed to be held in place. When the pin was to be moved, the bars would shift so the center of the pin was aligned with the larger hole, unlocking it and allowing it to be moved by the driving mechanism below it. A prototype version of this clutch system, what we ended up calling the sliding bar clutch, was manufactured and mounted on a frame made of aluminum T-slot bars. Figures 5-9 show the various components of the sliding bar clutch prototype as well as the assembly of the clutch on the T-slot frame.

Figure 5: Single pin element with grooves cut for clutch

Figure 6: Single clutch bar with holes for pins

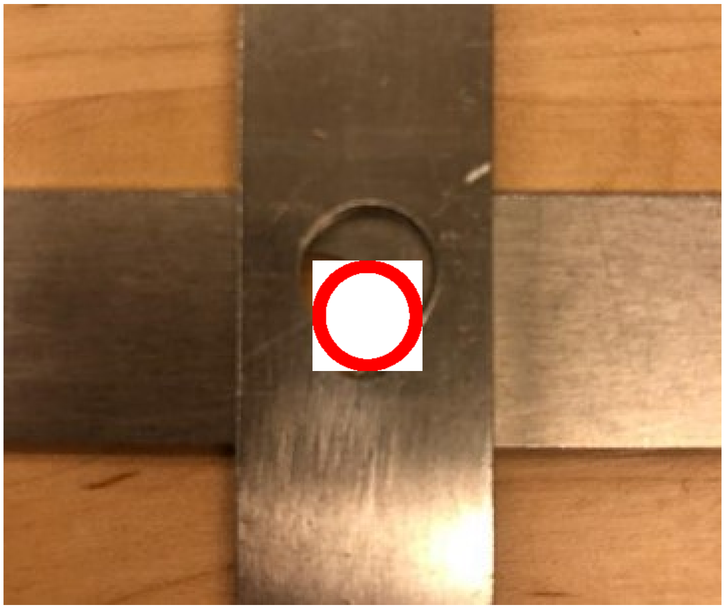

Figure 7: Clutch point in closed position. The red circle represents the location of a pin.

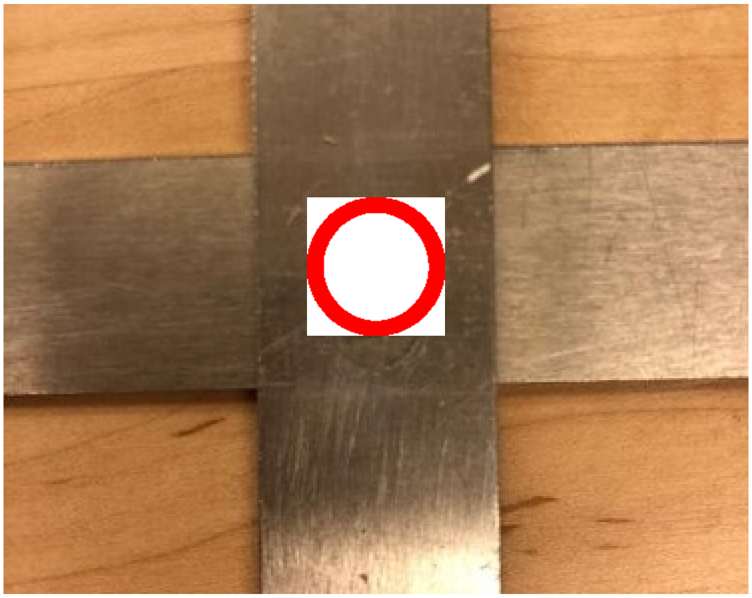

Figure 8: Clutch point in open position. The red circle represents the location of a pin.

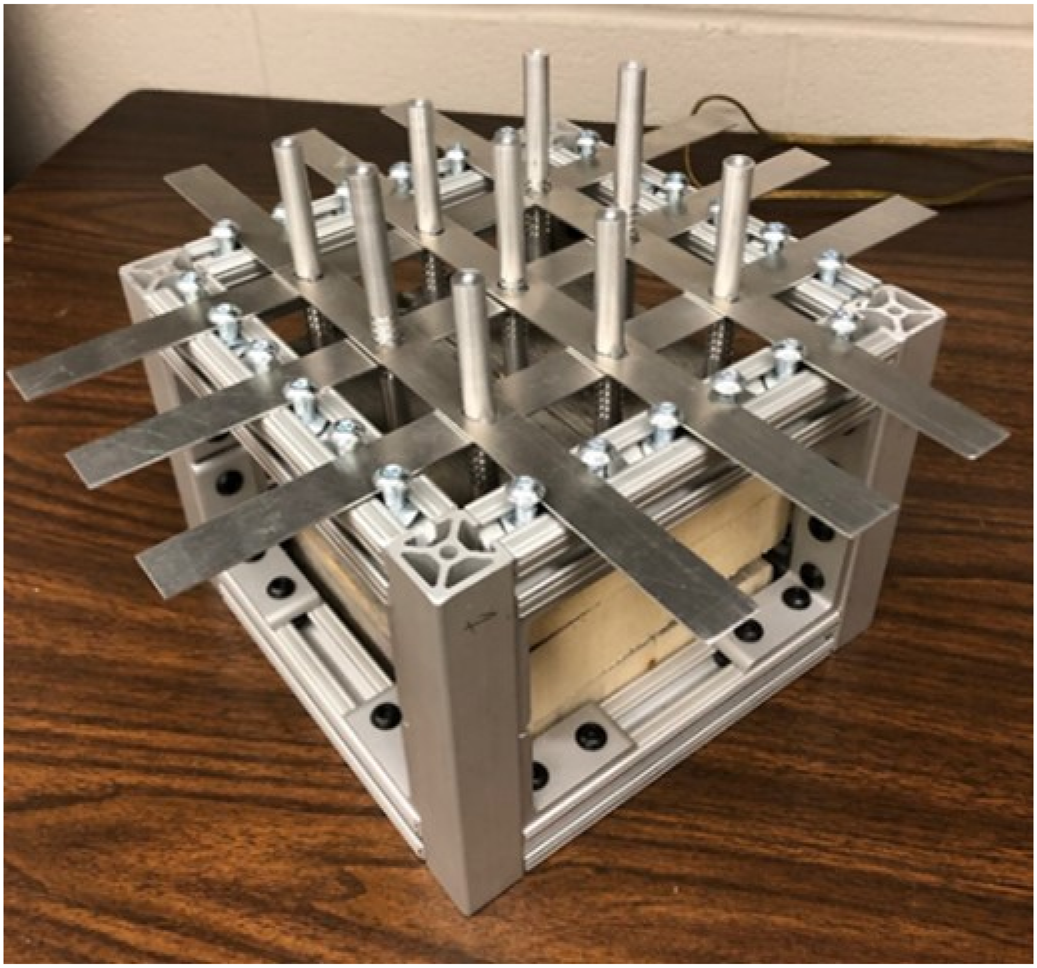

Figure 9: Sliding bar clutch with pins mounted on T-slot frame.

The design of the sliding bar clutch accomplished the goal of creating a mechanism to hold and release the pin elements upon command. However, we discovered that while the pins would be held and released properly, the grooves in the pins would often snag on the edges of the holes that the pins were in, impeding their free movement. We attempted to increase the diameter of the holes, but this did not solve the issue.

V. Current Clutch Prototype

The issues with the sliding bar clutch lead to the creation of our current clutch prototype, what we have called the clamshell clutch. To solve the problem of getting the pins caught on the edges of the holes, I designed a clutch that has the bars split in half. When closed, the split bars are together, and the pins are held between them in semicircles cut out on the sides of the bars. When open, the bars move away from each other and away from the pin, allowing the pin to move freely with no chance of getting caught on the edges of the bars. This design is called the clamshell clutch because the bars give the image of the opening and closing of a clamshell. Figures 10-12 show the bars and how they look when they are open and closed.

Figure 10: One clamshell bar pair

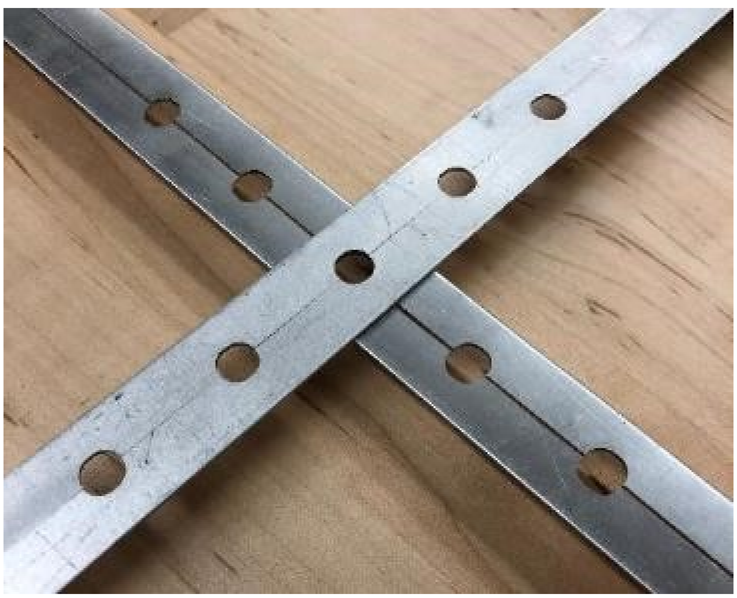

Figure 11: Clamshell bars in closed position

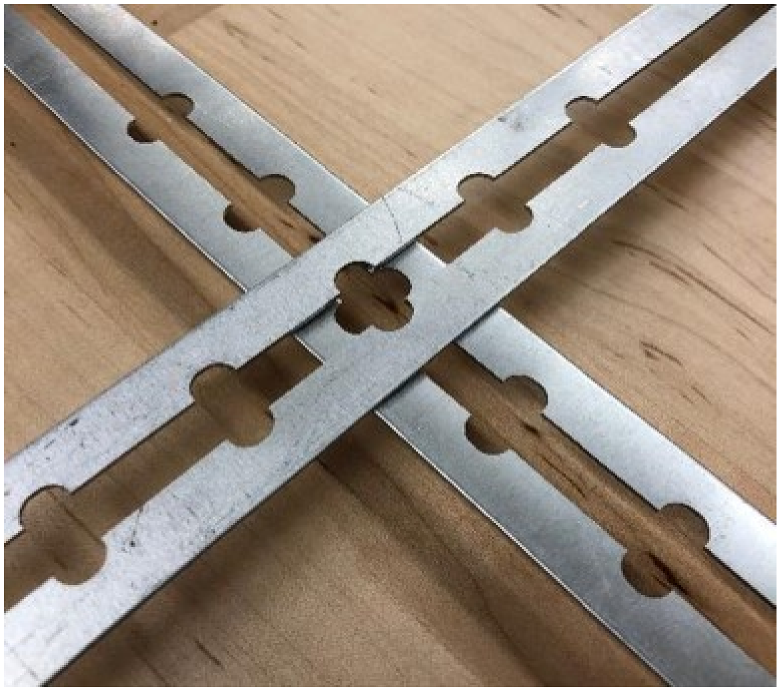

Figure 12: Clamshell bars in open position

The bars are opened and closed using servos mounted to the frame of the prototype. Each pair of bars have a servo head attached to their ends that serve to translate the rotational motion of the servos into linear motion that will push the bars away from each other when the servos are rotated to the open position and pull the bars together when the servos are rotated to the closed position. Figure 13 shows the servo head attachments and Figure 14 shows the servos mounted on the frame without the bars attached. Figure 15 shows the full prototype with all bars attached.

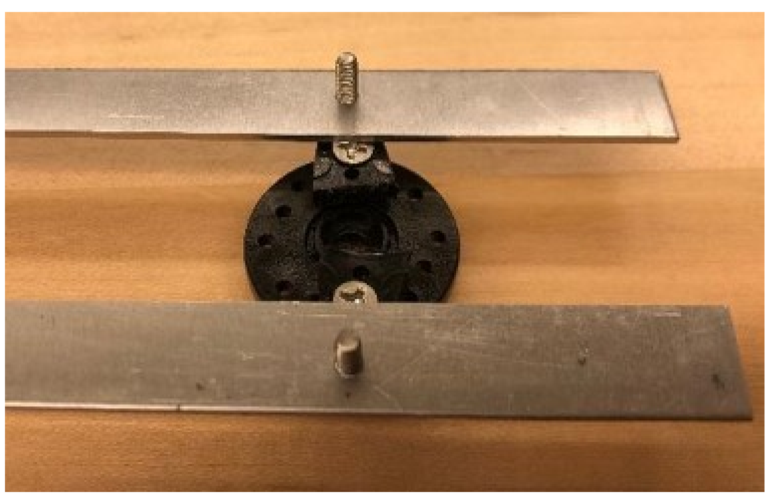

Figure 13: Servo head attachments

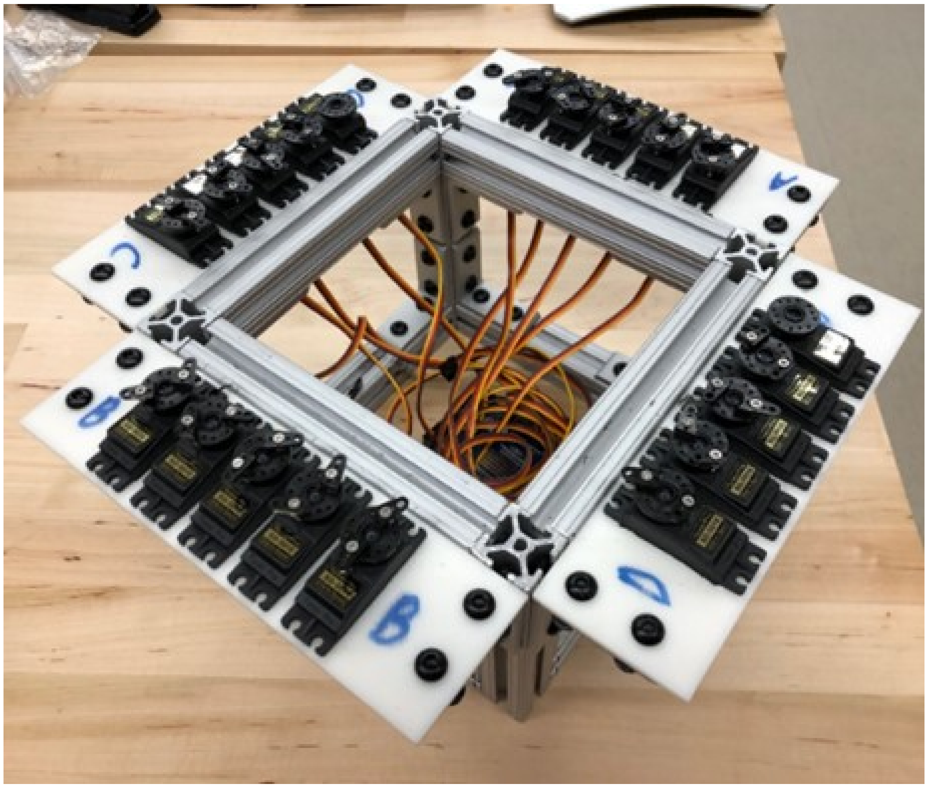

Figure 14: Frame and servos with no bars

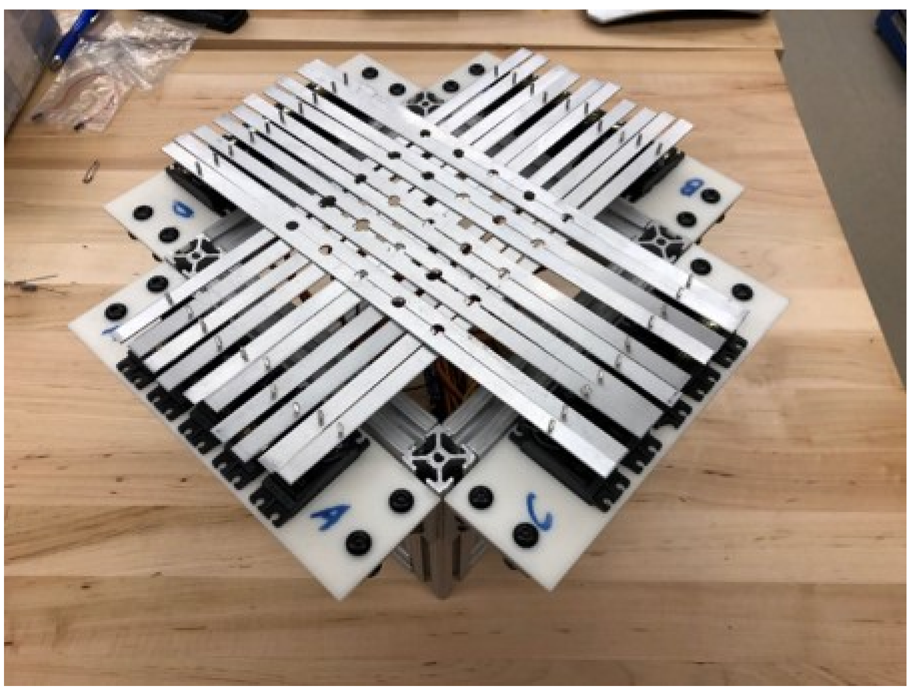

Figure 15: Full prototype

The full prototype consists of ten pairs of bars that together make up a 5x5 array of addressable points. A total of twenty servos control the motion of the bars. All the servos are connected to an Arduino Mega microcontroller using two servo shields to address all twenty servos. The Arduino will eventually be controlled by the yet-to-be-developed digital user interface.

VI. Future Improvements

The completion of this proof-of-concept prototype represents a small step in the development of the overall programmable surface system. The system is far from complete, however, and the intent of this section is to outline the next steps that need to be taken to bring this to a mature design that could be used practically. The first and most obvious step is to take the concept of the mechanical clutch system and scale it up so that the matrix of addressable elements would be large enough to accommodate a person's foot. This would require a matrix that is approximately 6 inches wide and 15 inches long. The mechanism of how the bars open and close would remain fundamentally the same, but there would be an increasing tendency for the bars to deflect under a bending load as they get longer. The solution here would be to either make the bars out of a stiffer material such as stainless steel or even a carbon fiber composite, or to provide reinforcement underneath the bar matrix, or a combination of both.

Another necessary step in the maturation of this prototype would be to reduce the size of the bars in the matrix so that the pin elements that make up the surface can be packed more closely together. This increase in pin density would allow for finer control by the operator and create a surface that will more reliably create a surface that will correct posture and produce a usable orthotic device. It is currently undetermined how densely the pins could be packed, but theoretically there could be as many as 9 or 16 pins per square inch. This improvement is limited in the same ways as the previous, as the bars would need to shrink and get stronger. That means the same solutions could solve this issue.

The next issue is to develop the system by which the pin elements are moved up and down. There is currently another student working to develop such a system by using solenoids. The idea is that the magnetic force of the solenoids could push or pull the pin elements to their required height. It remains to be seen whether this solution will be implemented into the final programmable surface design, but the current results look promising.

The final component of the system before it becomes something usable by an orthotist is the digital control interface. The prototype clutch uses a Arduino for the means of controlling the servos that move the clutch bars and this Arduino may be of use for the next person on the project as a basis to build the user interface. The vision of the final interface is an application on a tablet or a laptop that would allow the user of the system to unlock and move a single pin at a time or to be able to unlock and move whole sections at a time. There is not currently a student working on this part of the final design.

VII. Conclusion

The goal of this research and design project was to create the proof-of-concept for a mechanical clutch prototype for a programmable surface and that goal was accomplished. The project was presented at the TCU College of Science and Engineering Honors Research Symposium as well as the Michael and Sally McCracken Student Research Symposium at TCU and received interest and positive feedback at both events. It shows that the vision of creating a programmable surface at TCU is possible and can be accomplished by the future students that work on this project under the direction of Dr. Weis.

VIII. References

[1] N. Loewen, P. Wise, “Design and Development of a Reconfigurable Surface Prototype for Orthotics Posture Correction.”

[2] “Flatfeet – Symptoms and causes”, *mayoclinic.com,* Available: https://www.mayoclinic.org/diseases-conditions/flatfeet/symptoms-causes/syc-20372604. [Accessed: Feb- 2019]

[3] “Custom Foot Orthotics”, *Orthomedix.com,* Available: http://orthomedix.com/custom-foot-orthotics/. [Accessed: April- 2019]

[4] S. Culver, “Use of An Xbox Kinect as a 3D Scanner for the Manufacturing of Custom Orthotic Insole.”