SRSA Project Overview 2017-2019: Biomechatronics' Patient Scanner

Project: Designed and implemented a patient Scanner and Indenter to capture the time-varying 3D shape and mechanical properties of a residual limb.

Project Impact: This work aims to replace the current manual socket design process that is expensive and often leads to poor fitting sockets. Painful sockets can result in negative health outcomes: weight gain, depression, even further amputation.

Research Impact:

Scanner performed data collection for n=18 NIH funded clinical trial.

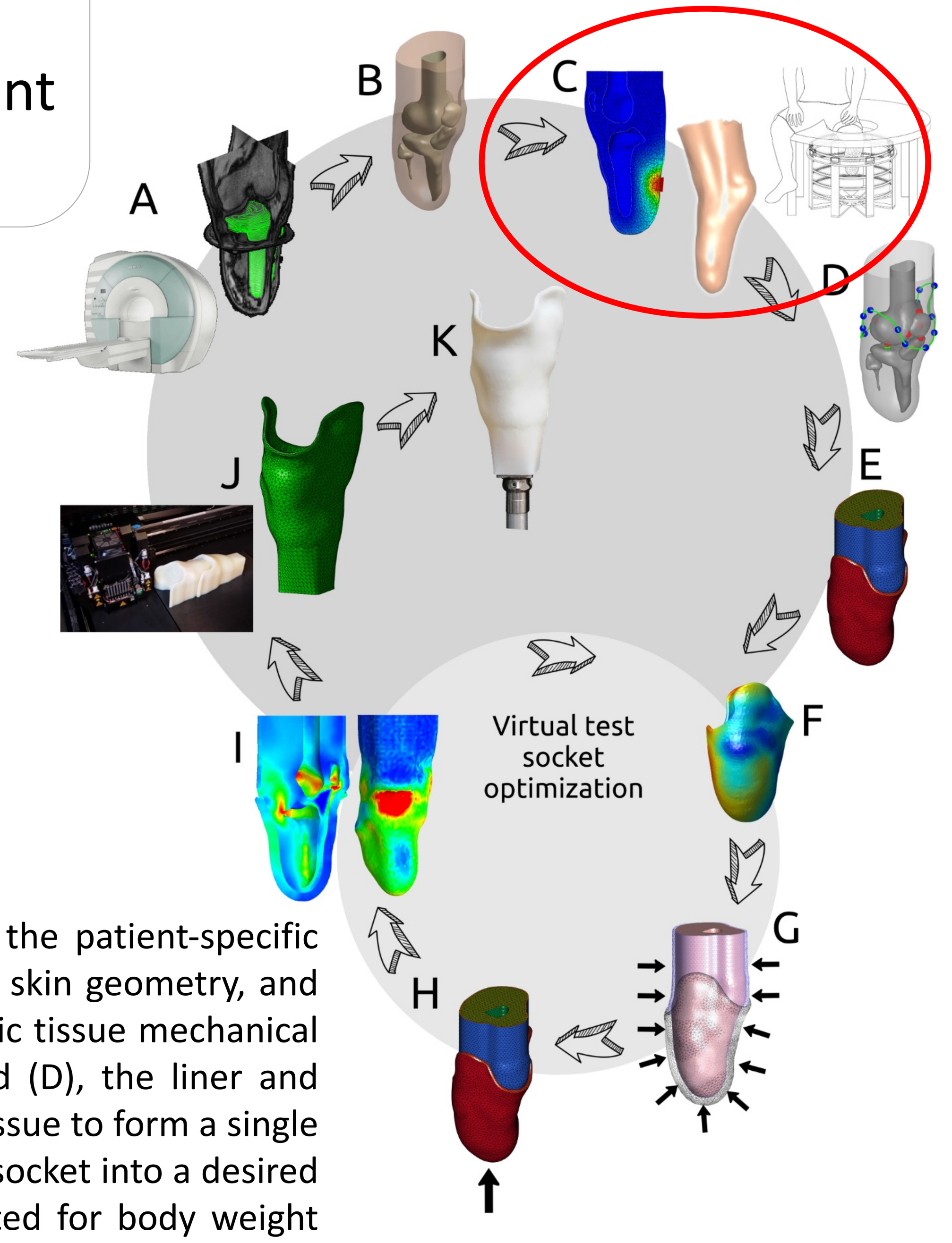
Data from this scanner is included in two peer reviewed publications (cited on next page)

Data assisted three research scientists in advancing their careers to professorship.

Two additional Master's students depended scanner data for thesis work.

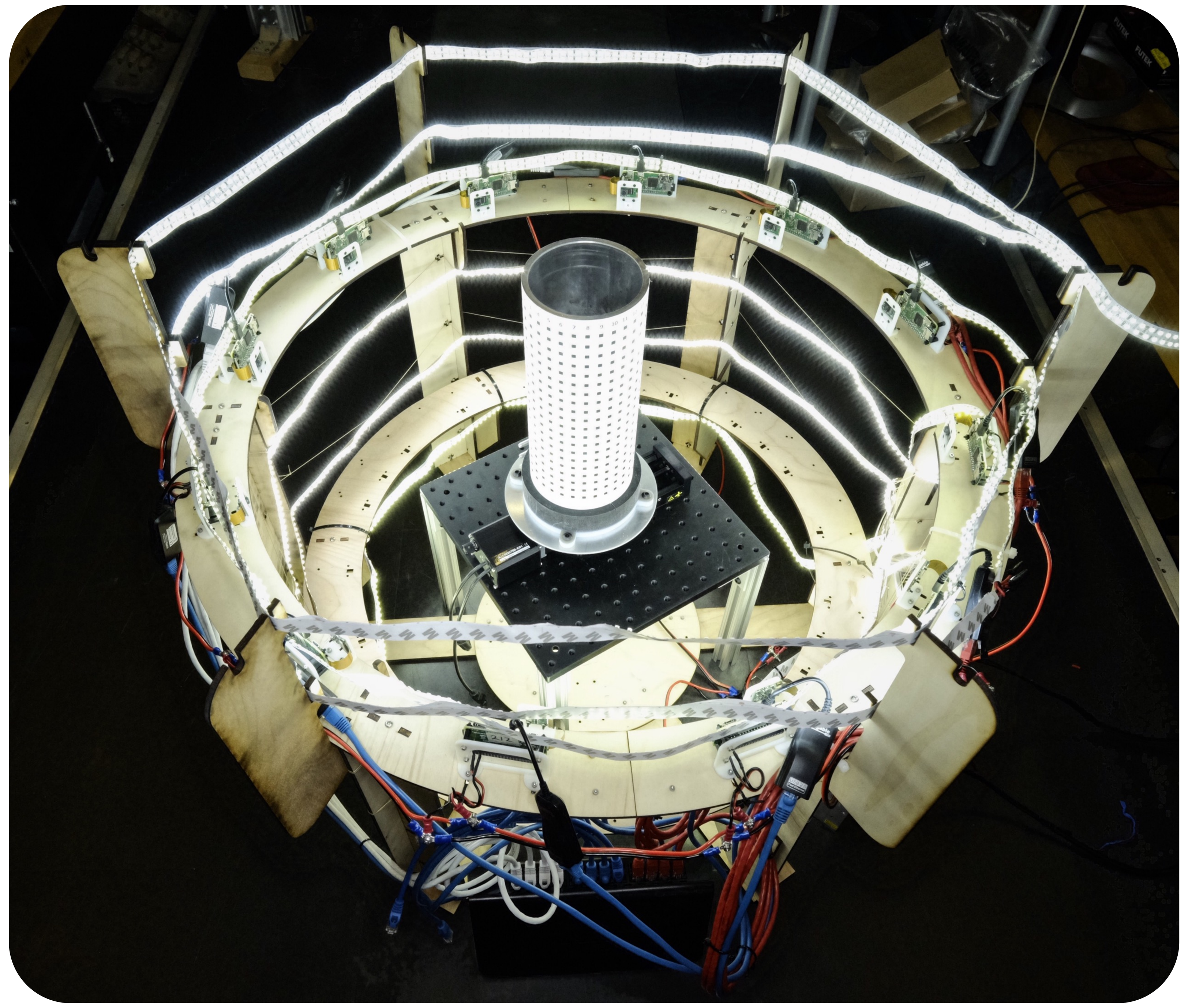
The scanner is included in Biomech's Socket Design Patent (Cited next page)

Project Role: The work for the clinical trial was done by a small group of researchers. I was responsible for the entire data acquisition system. I was supervised by Research Scientists and developed the system to meet their data needs. Throughout the project I mentored undergraduate students working for Biomech.



Overview of the data-driven computational design framework. By segmenting MRI data (A), the patient-specific geometry is obtained (B). Digital Image Correlation (DIC) is employed to obtain more accurate skin geometry, and indentation tests and inverse FEA informed by DIC can be used to determine the patient-specific tissue mechanical properties (C). Using anatomical landmarks the socket cut-lines can be automatically created (D), the liner and socket source geometries can be offset from the skin surface and can be meshed with the soft tissue to form a single FEA model (E), spatially varying fitting pressures is defined (F), allowing for the morphing of the socket into a desired shape, while also pre-loading the tissue due to donning (G), the designs can now be evaluated for body weight loading (H), enabling skin surface pressure and internal strain analysis (I). The process F-I can be iteratively repeated and optimal designs can be exported for 3D printing based manufacturing (J) of final socket (K). Figure and description: Kevin Moerman, Dana Solav

First Prototype of Scanner System

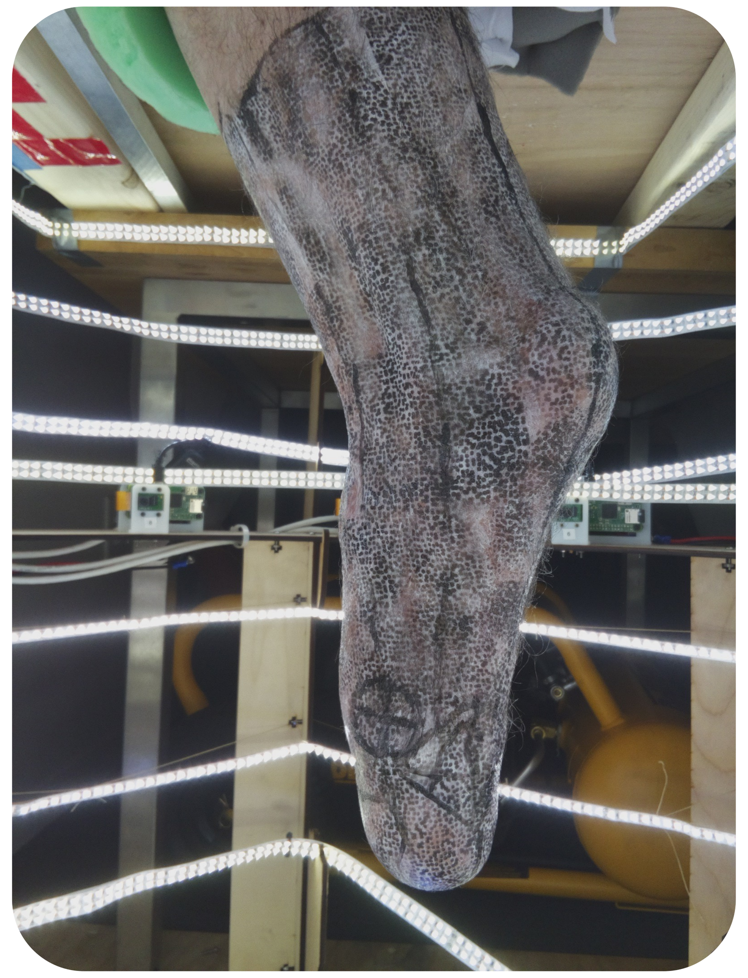


I built this first prototype from discarded materials during my first month in Biomech. It was iterated upon for a year as our research team figured trial protocol.

Camera Calibration Object

The calibration object allows for simultaneous stereo calibration for each camera. It features 700 black rectangular planar faces on a white background. The 3D coordinates of the centroids of black dots used to obtain the stereo triangulation parameters

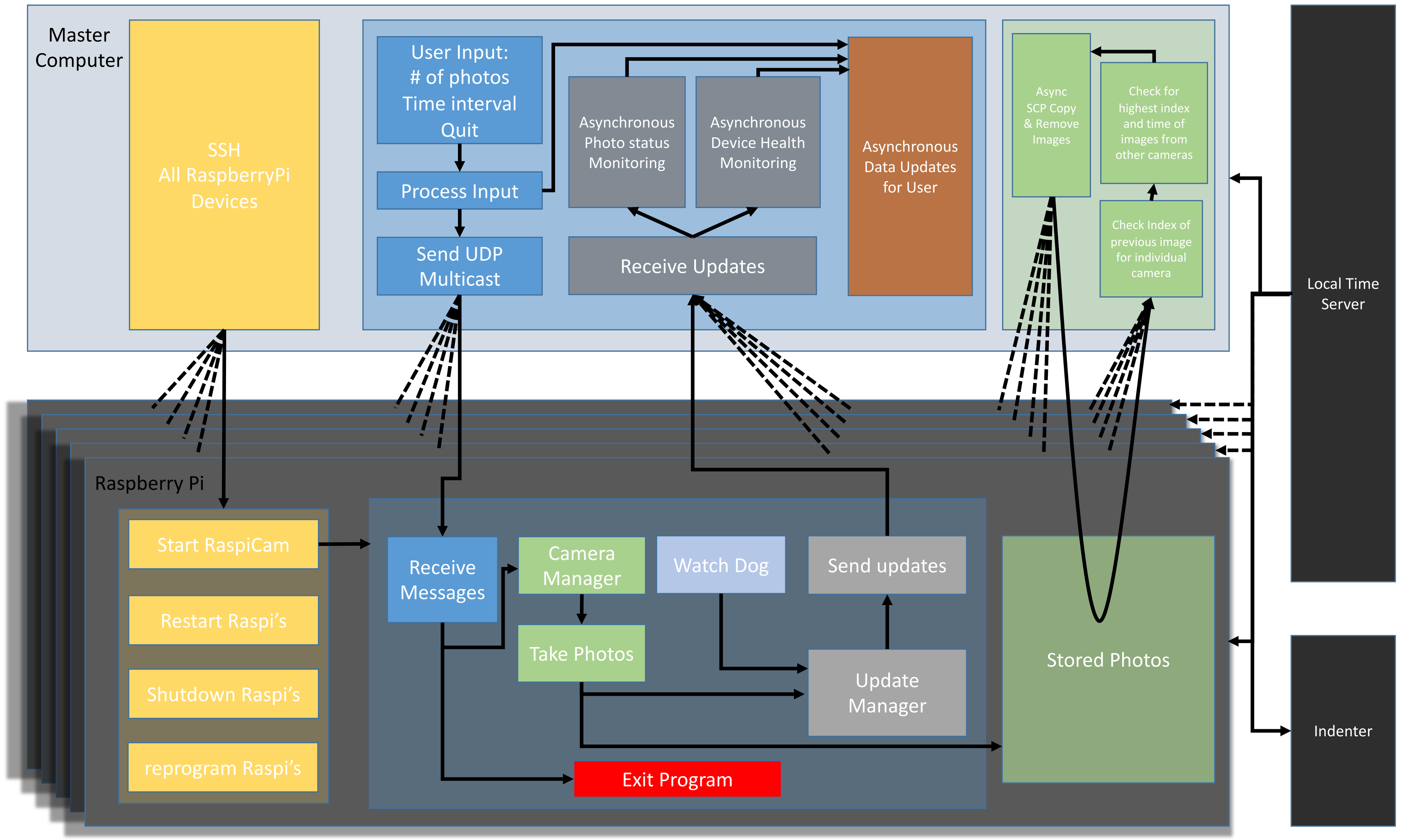
Photo Credit: Jerry Jaeger



Speckled Residuum during scanning. Additional markings noting sensitive regions and anatomical locations

3D reconstructions of residuum. Figure Credit: Dana Solav

The designed socket model can be 3D printed using rigid Vero material, and get the rigid socket which can be connected to the foot/ankle system



High Level Scanner System Software Overview

I had to account for the four following factors when implementing the scanner's software architecture. First, there are a lot of cameras, and the number of cameras continues to increase as our research needs progress, therefore the cameras must be independent units and the system be scaleable. Second, the devices are unreliable and prone to crashing, we can't spend an hour with a test subject only to find out the next day that we failed to collect data. Third, the cameras need to capture images simultaneously, however they are not running an RTOS and therefore operate asynchronously. The cameras need to function in parallel but cannot block other devices from operation. Finally, due to the number of cameras, and time sensitivity of every operation, every task must be automated.

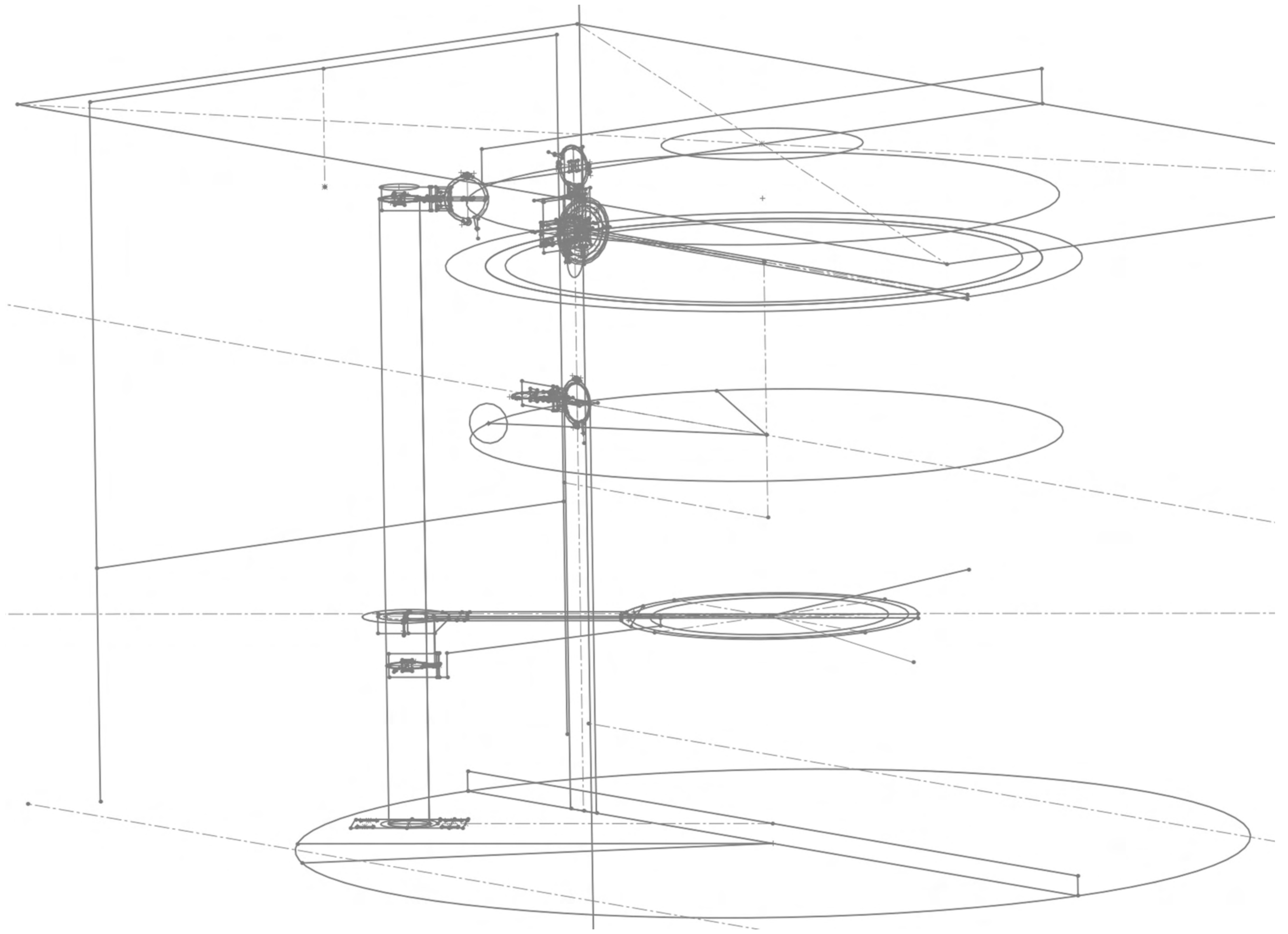
Biomechatronics Patient Scanner: Scanner Hardware V2

Hardware Revision Goals:
Upgrade the patient scanner based on learnings from first prototype.

Design the system to be a robust and upgradable platform that can support future subject measurement projects.

Gain experience working with outside manufacturers and vendors.

Scanner Master Model Sketch

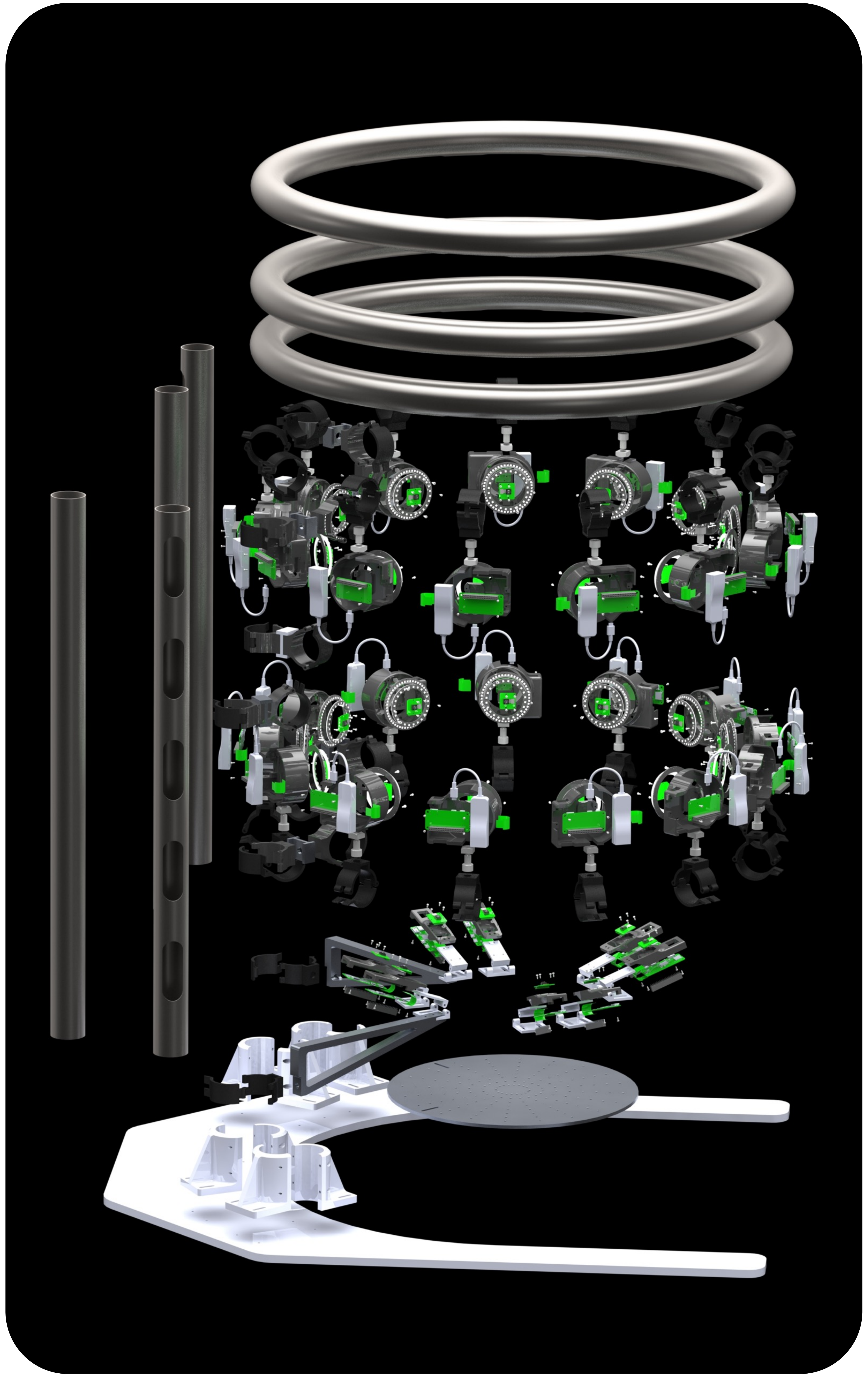


Publications supported by the two scanners:

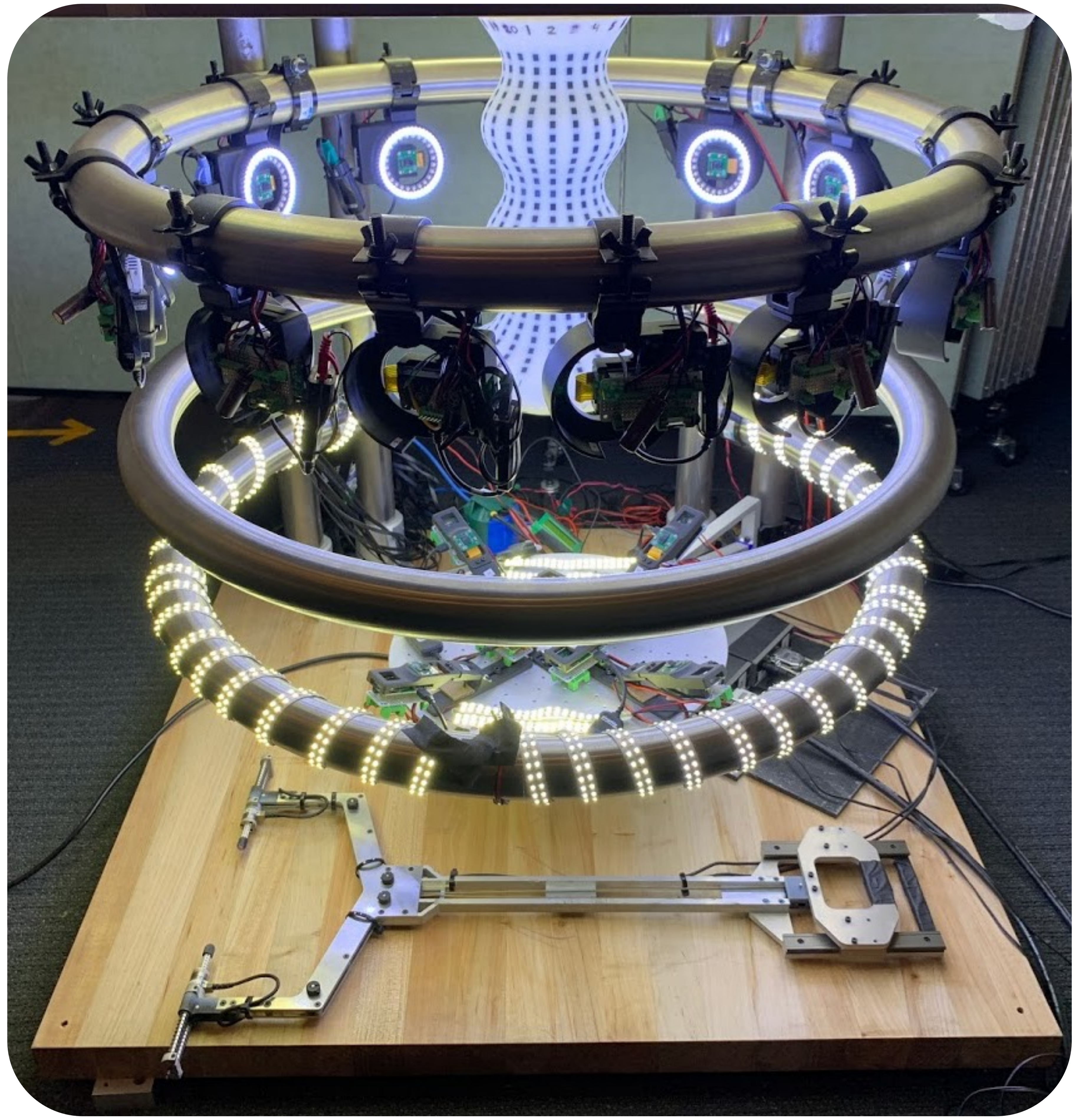
D. Solav, K. M. Moerman, A. M. Jaeger, K. Genovese and H. M. Herr, "MultiDIC: An Open-Source Toolbox for Multi-View 3D Digital Image Correlation," in *IEEE Access*, vol. 6, pp. 30520-30535, 2018, doi: 10.1109/ACCESS.2018.2843725.

D. Solav, K. M. Moerman, A. M. Jaeger and H. M. Herr, "A Framework for Measuring the Time-Varying Shape and Full-Field Deformation of Residual Limbs Using 3-D Digital Image Correlation," in *IEEE Transactions on Biomedical Engineering*, vol. 66, no. 10, pp. 2740-2752, Oct. 2019, doi: 10.1109/TBME.2019.2895283.

Scanner Assembly Exploded



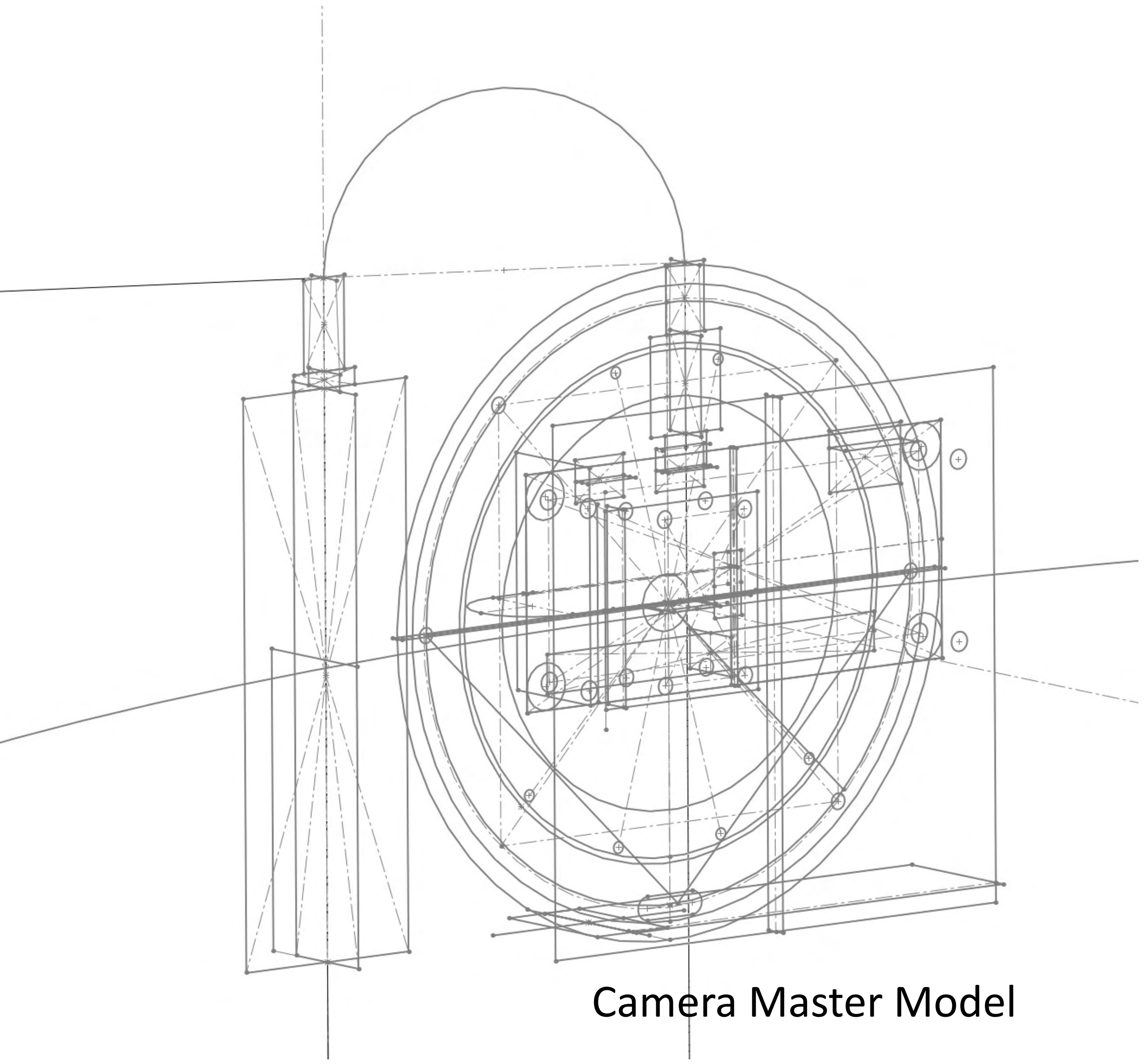
Scanner System



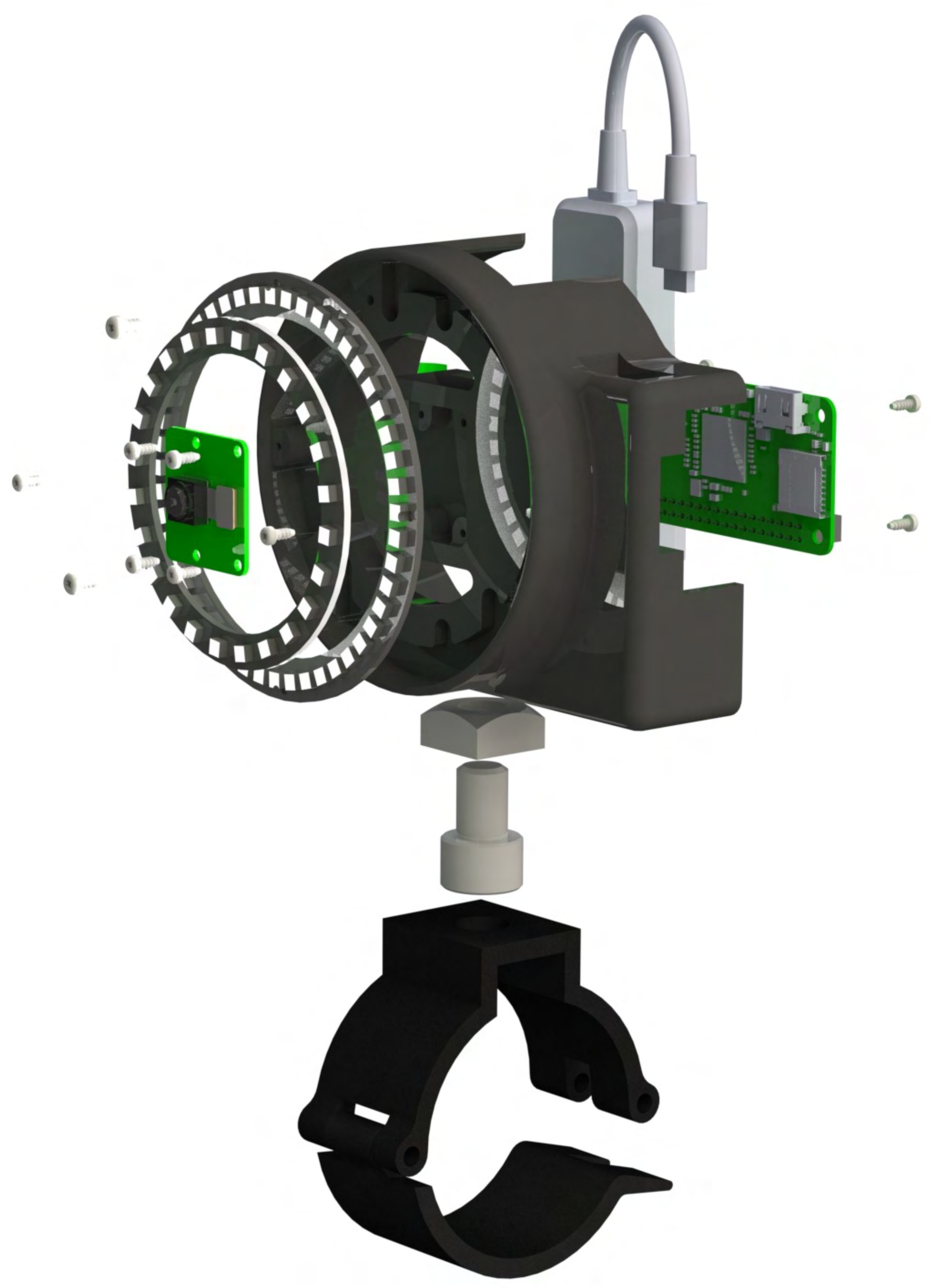
Design Considerations

- Scanner frame and components designed to be rigid, and prevent camera calibration issues from accidental contact
- Slotted Rings and legs allow for cleaner internal wiring
- Design allows greater adjustability for repositioning camera location, height, and orientation
- Better wiring, and position adjustment also accommodates adding extra cameras when necessary
- Dual camera rings expand capture volume
- Has large opening and support railing for Indenter
- Components are easily accessible
- Attractive design

Biomechatronics Patient Scanner:
Camera Assembly V2

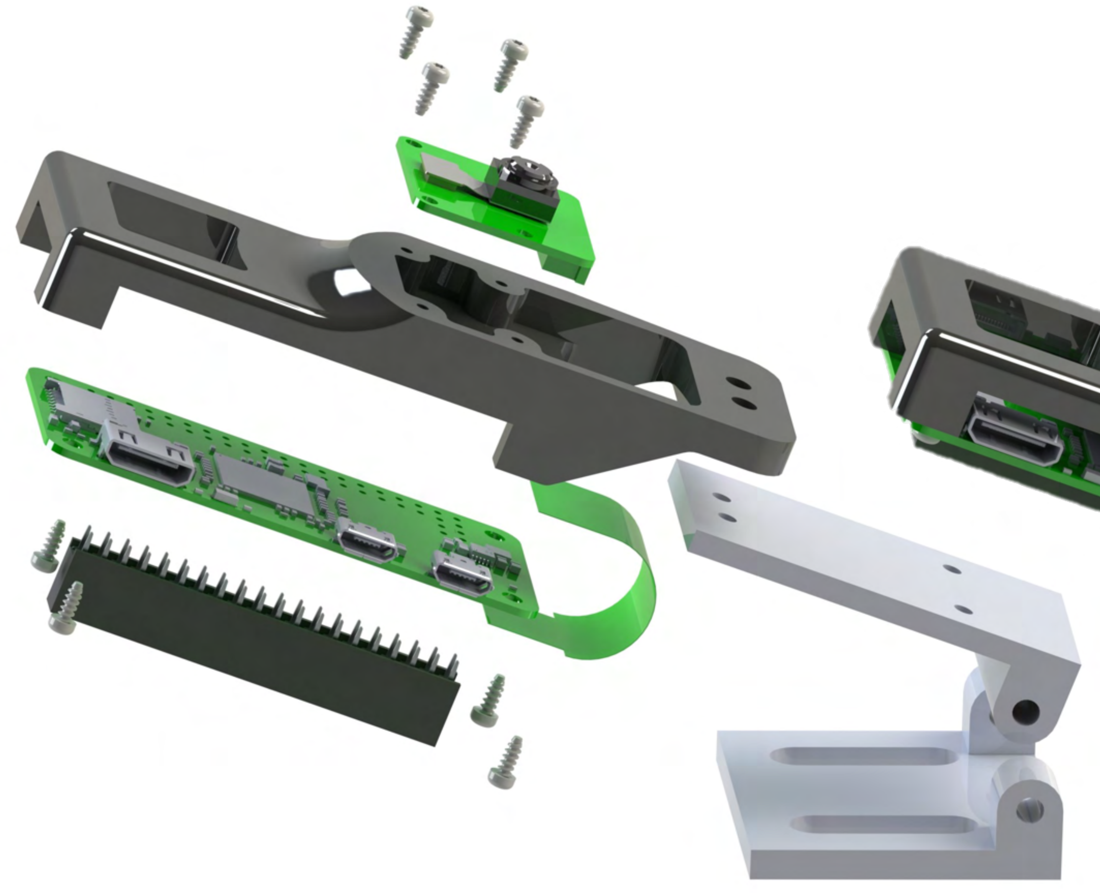


Camera Master Model

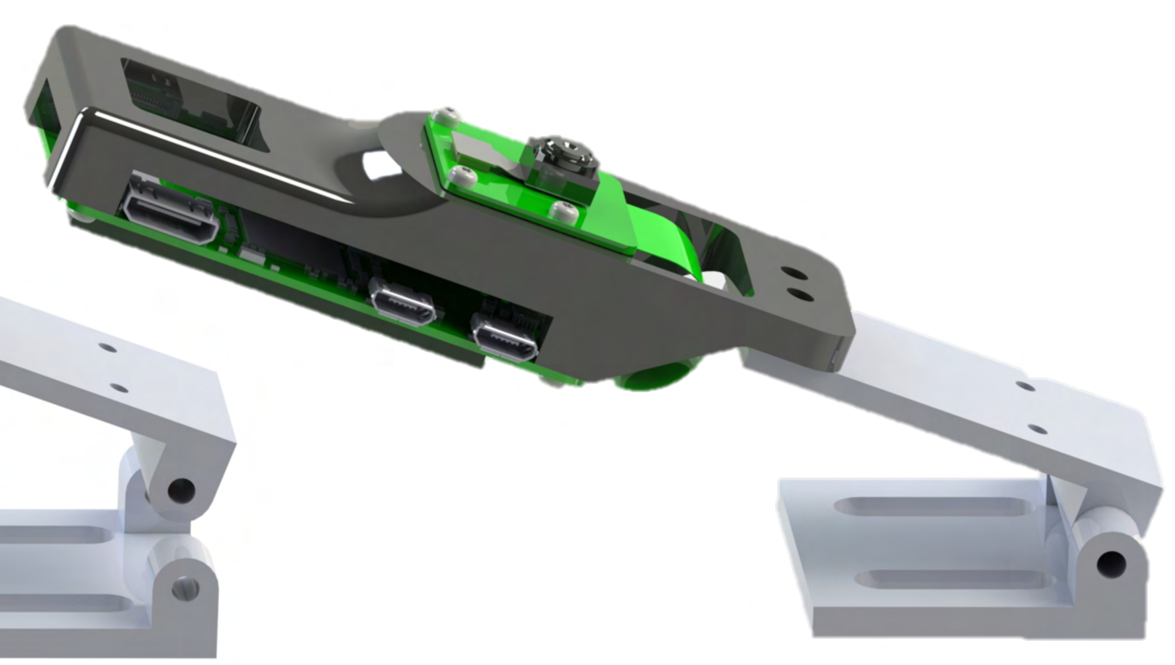


Exploded Camera Assembly

Camera Master Model



Exploded Bottom Camera



Bottom Camera

Camera Design Considerations

- The new scanner was intended to have 34 cameras
- The unibody case is designed so all parts only require screws to be attached
- Manufactured with vacuum casting process
- No standoffs, spacers, nuts, washers
- Self tap screws reduce manufacturing cost
- Reduced parts simplify assembly, and reduces costs
- Outer LED ring lights up camera field of view, and reduces clutter over previous light
- Inner ring of RGBW lights provide test subject and clinician feedback
    - Scanner currently requires operator to sit behind screen separate from test subject, a light feedback interface was intended to remove the separation

Camera Case Front

Photo Credit: Jerry Jaeger

Camera Case Front

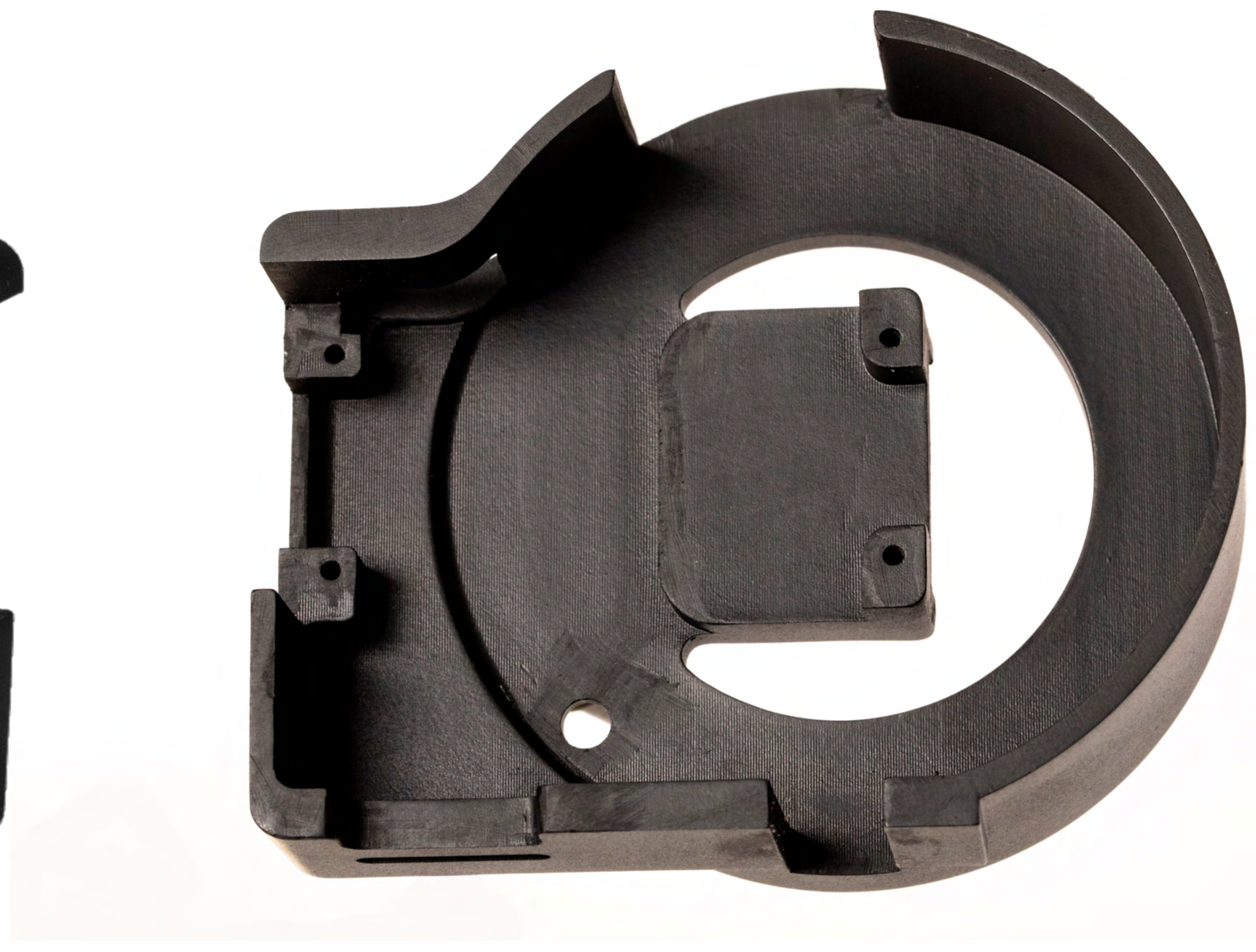


Photo Credit: Jerry Jaeger

Unibody Case Front

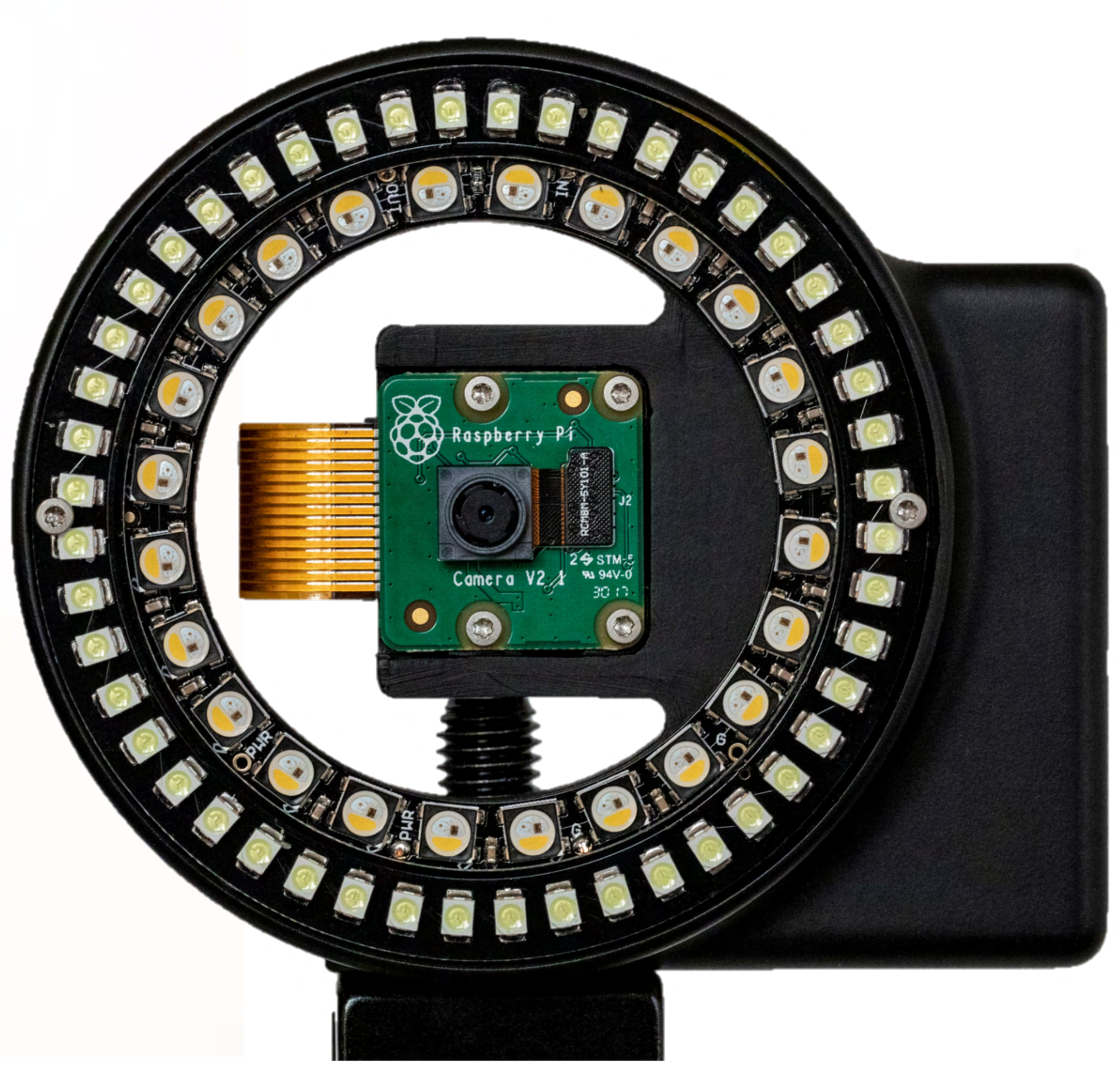


Photo Credit: Jerry Jaeger

Biomechatronics Patient Scanner: Indenter

Project Goals:

Tool used with patient scanner to determine residual limb soft tissue properties.

Deform tissue and measure force in 6 DOFs

Avoid:

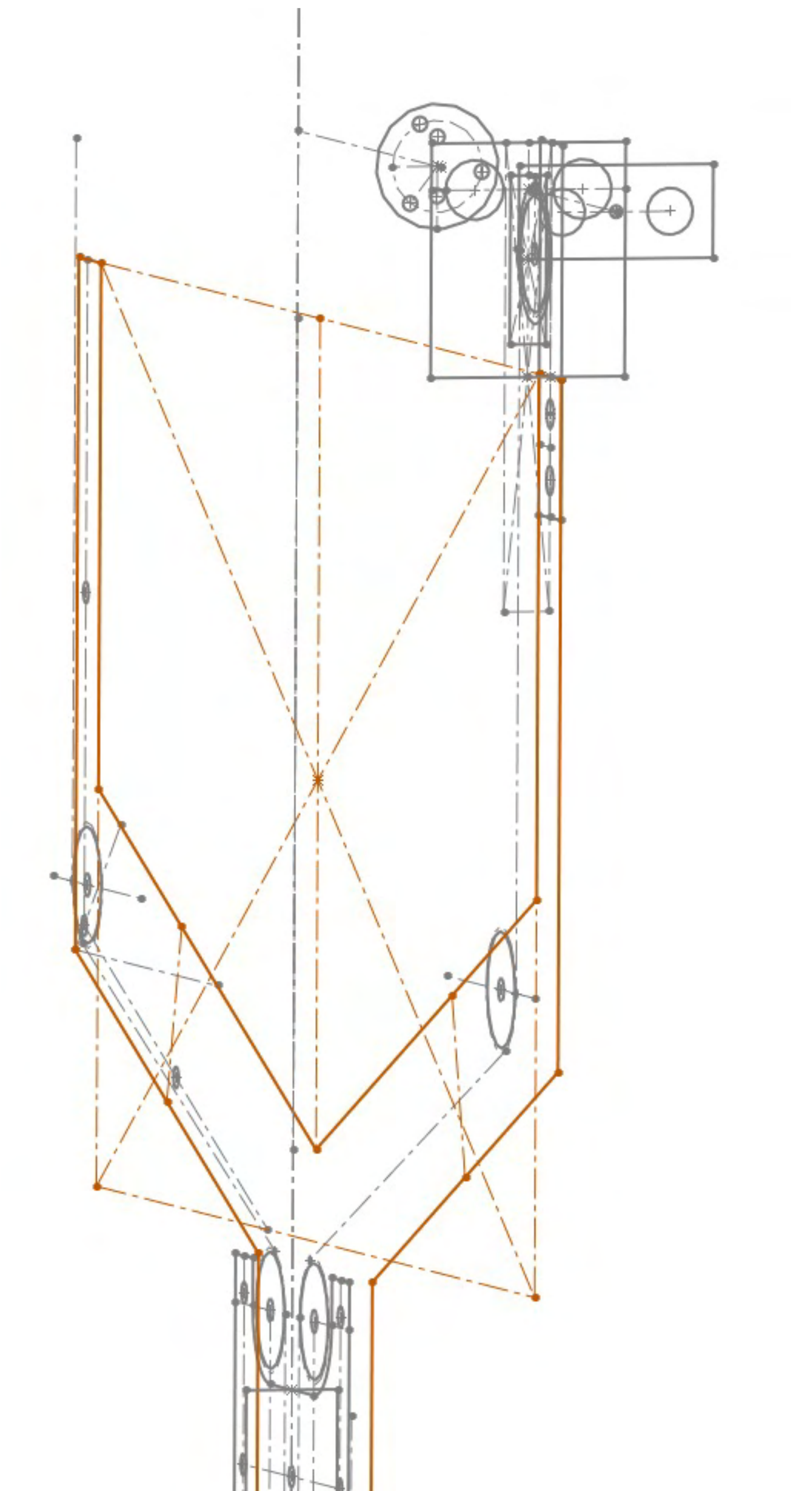
Hurting the test subject

Blocking the cameras

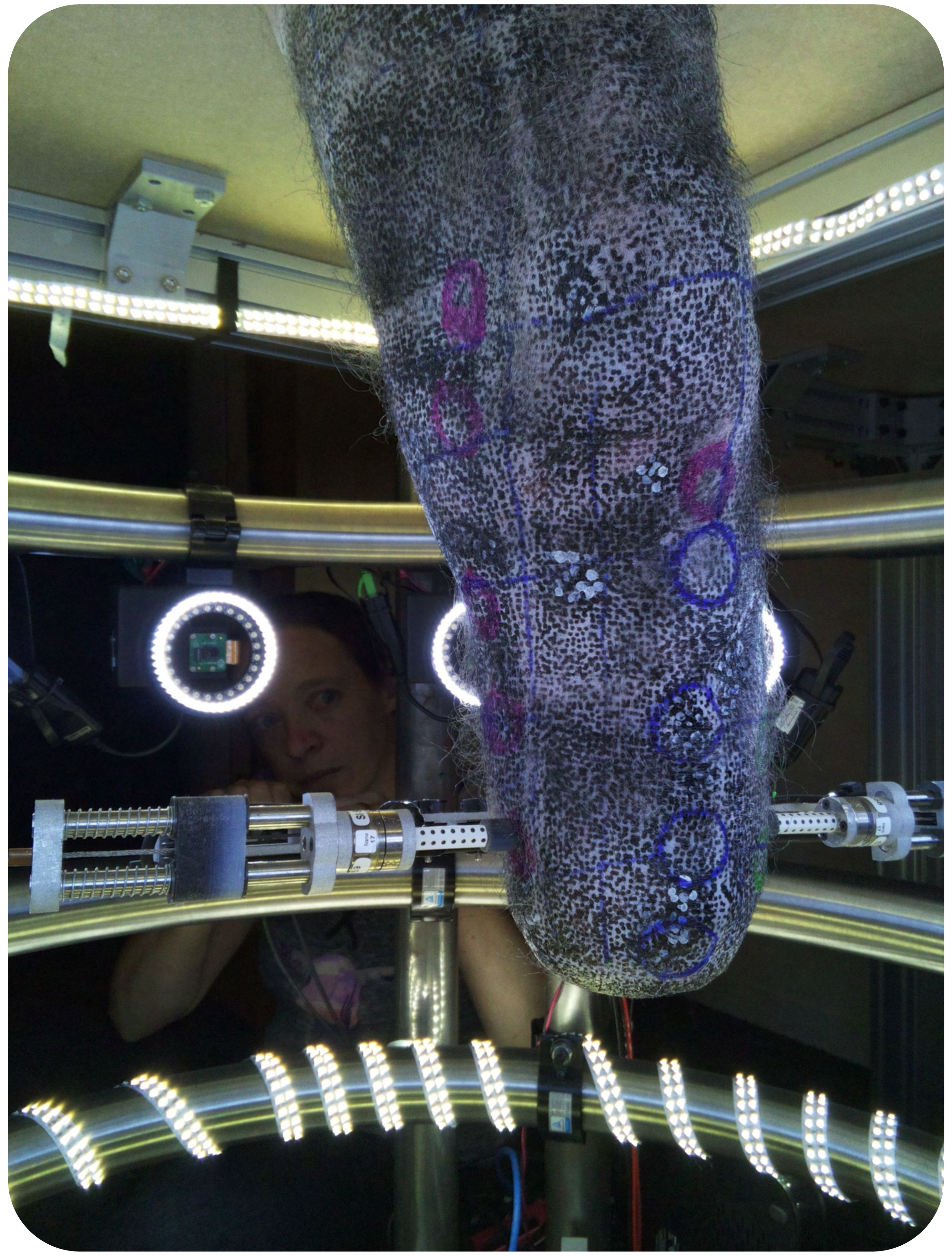
Moving the patient's leg

Design considerations:

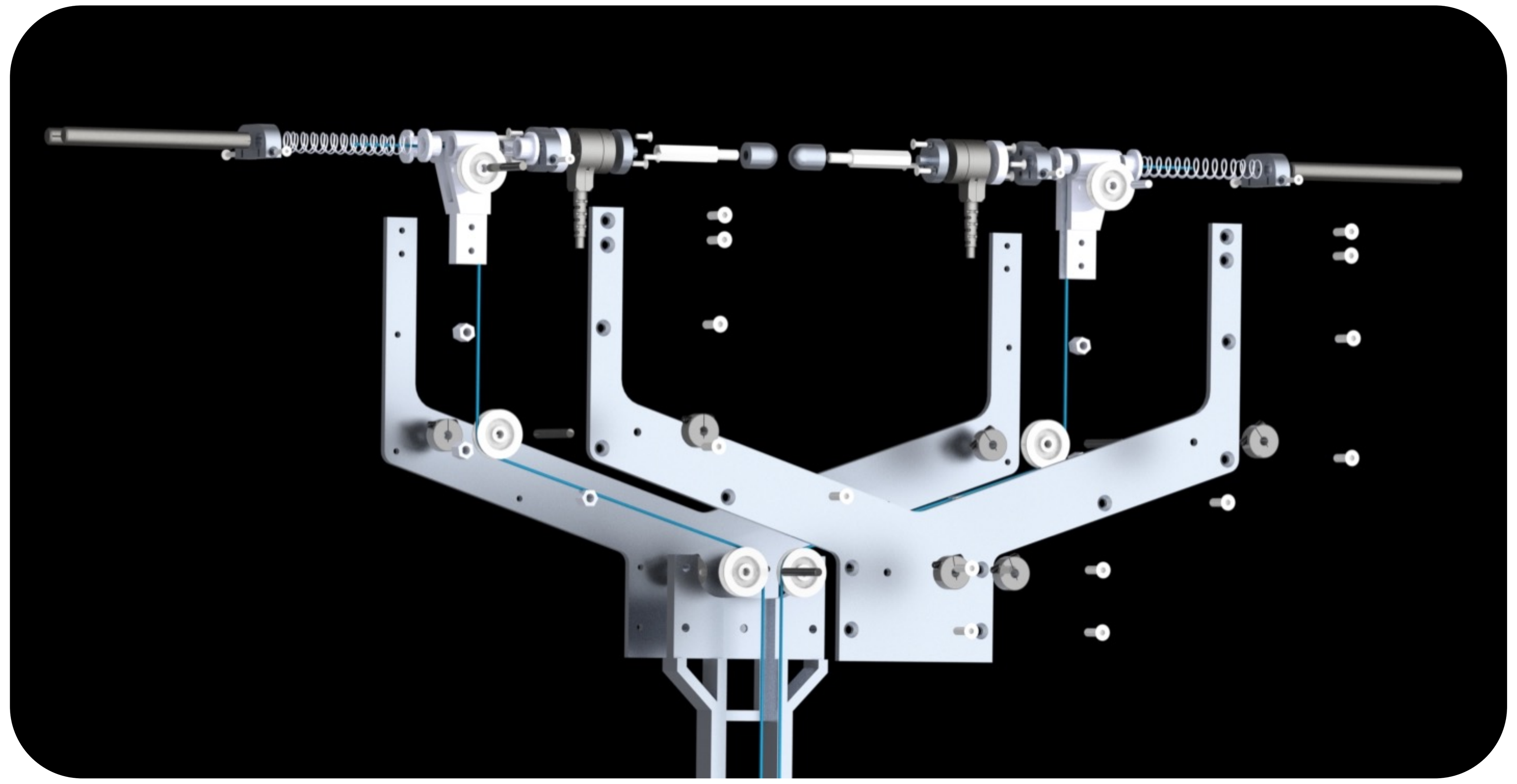
Parts design influenced by available manufacturing method capabilities. It was designed so I could easily machine the parts with a combination of the water jet, and manual mill.



Indenter in Use

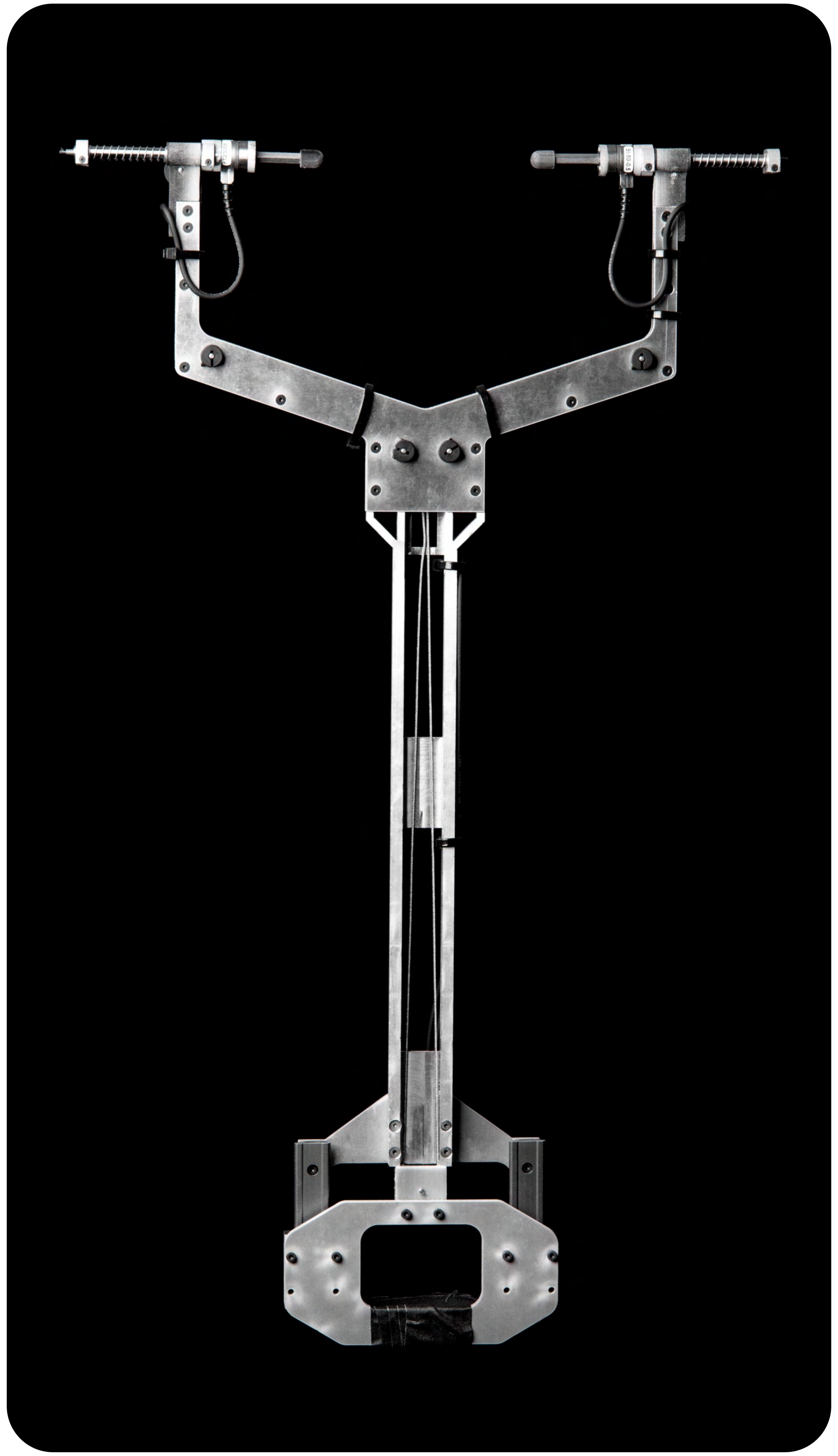


Indenter Exploded



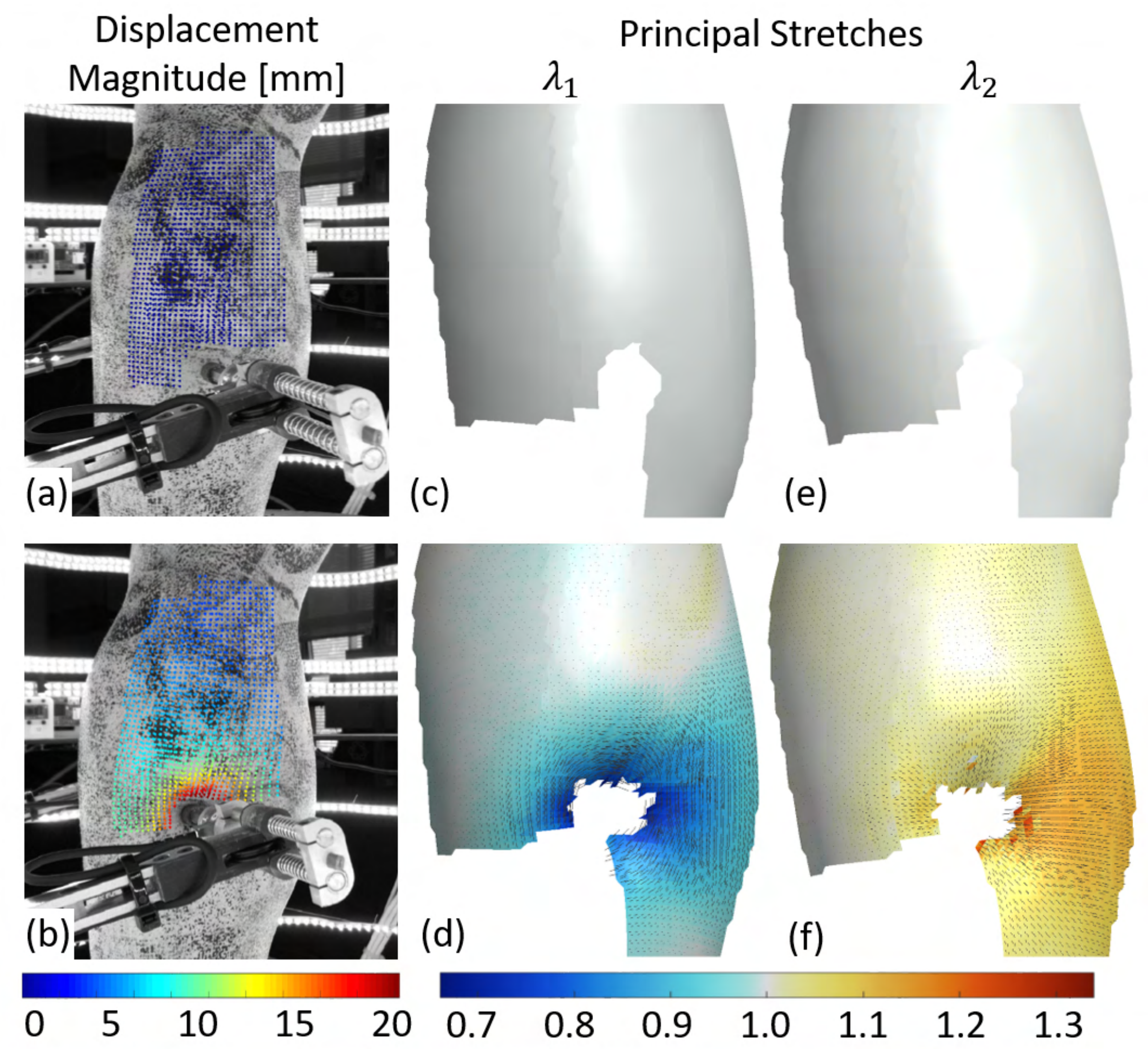
Indenter

Photo Credit: Jerry Jaeger



The data from the indenter and scanner are combined to determine the mechanical properties of the limb's soft tissue. A simulated indenter using the real indenter's measurements presses on simulated soft tissue, defined by best guess Ogden parameters. If the behavior of the simulated soft tissue matches the behavior of the real soft tissue, as measured by the scanner, then the Ogden parameters are correct. If the behavior does not match, the parameters are changed, and the simulation is run again.

Professor Hugh Herr presenting the Indenter at Media Lab Member Meeting Fall 2018



Preliminary testing with the Indenter

Figure Credit: Dana Solav

SRSA Project: Socket Validation

Project Goals:

Compare pressure from the socket on residual limb between the traditional socket and the digitally designed socket.

Compare actual pressure in socket to pressure expected from simulation.

Design Considerations:

A limited development timeline meant focusing on creating best practices for using commonly used, but unreliable pressure sensors.

Easy to use UI as this subject trial was especially stressful. Data collection had to happen without user error.

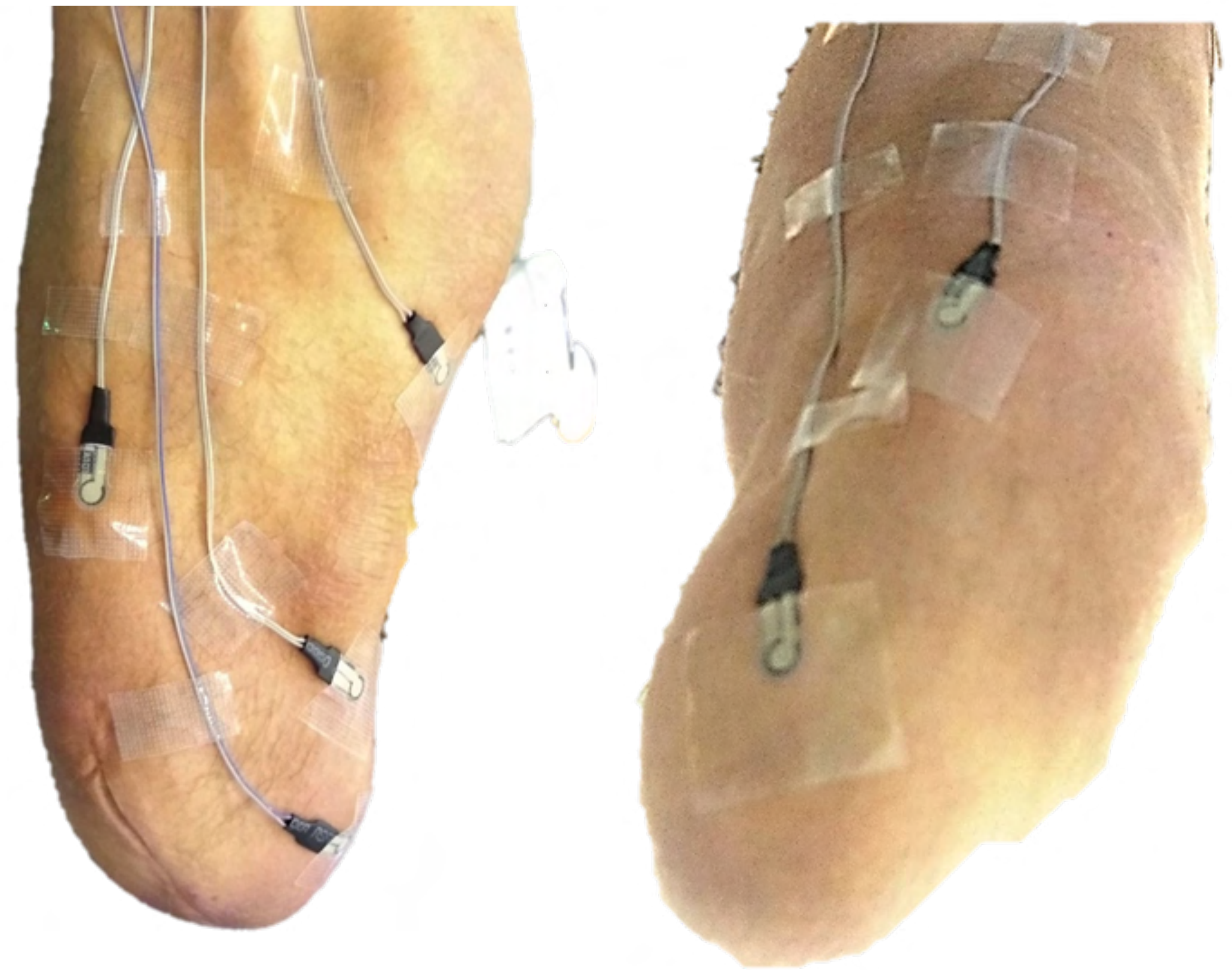
Research Outcome:

Relative pressure comparison between digitally designed socket and traditional socket.

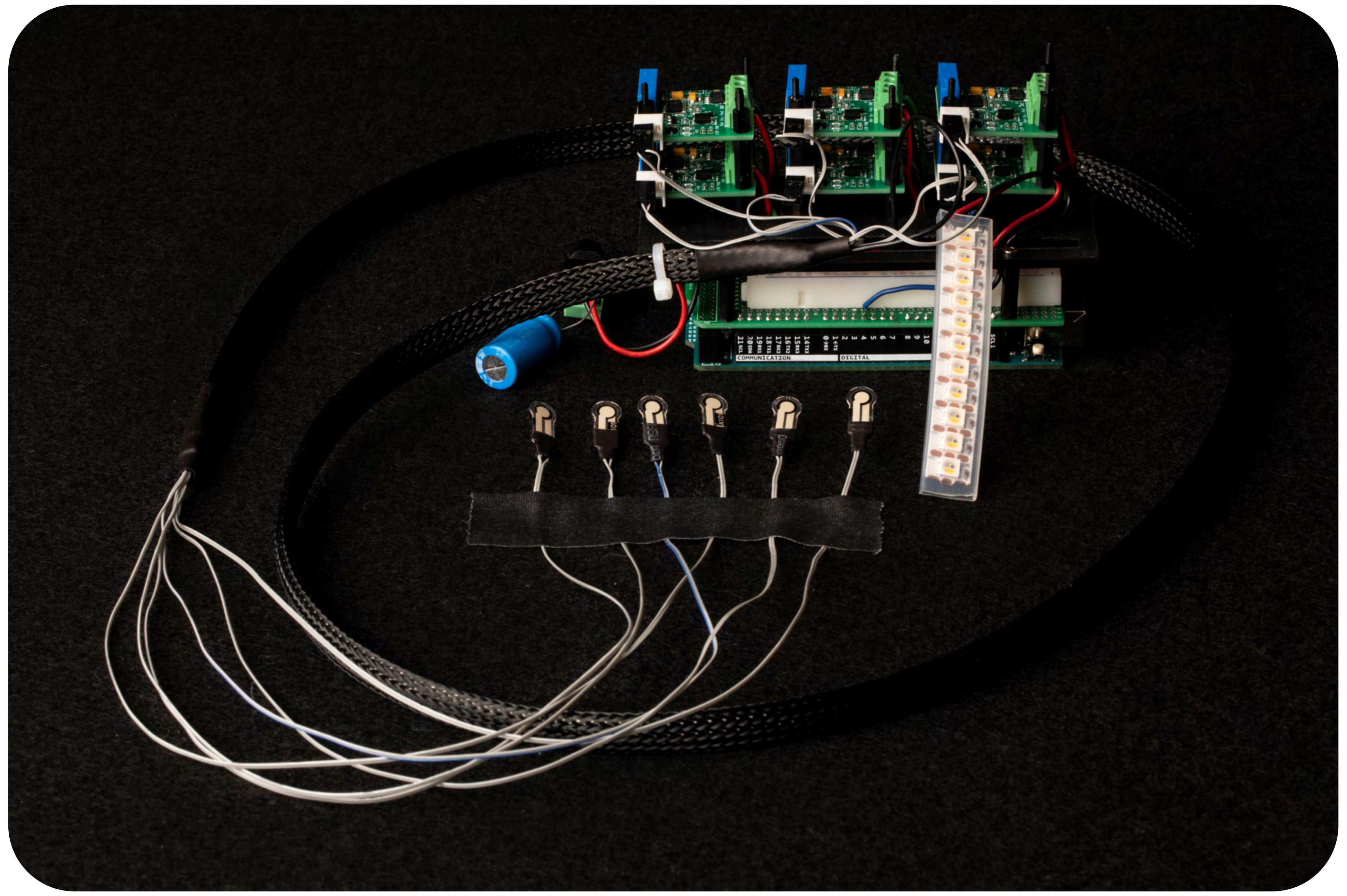
Developed user friendly pressure sensing tool which new new students used to complete NIH trial data collection.

Provided foundational research for incoming Master's student to work on simulated pressure validation.

Sensors Placed at Anatomically Relevant Points



Socket Pressure Validation Sensors



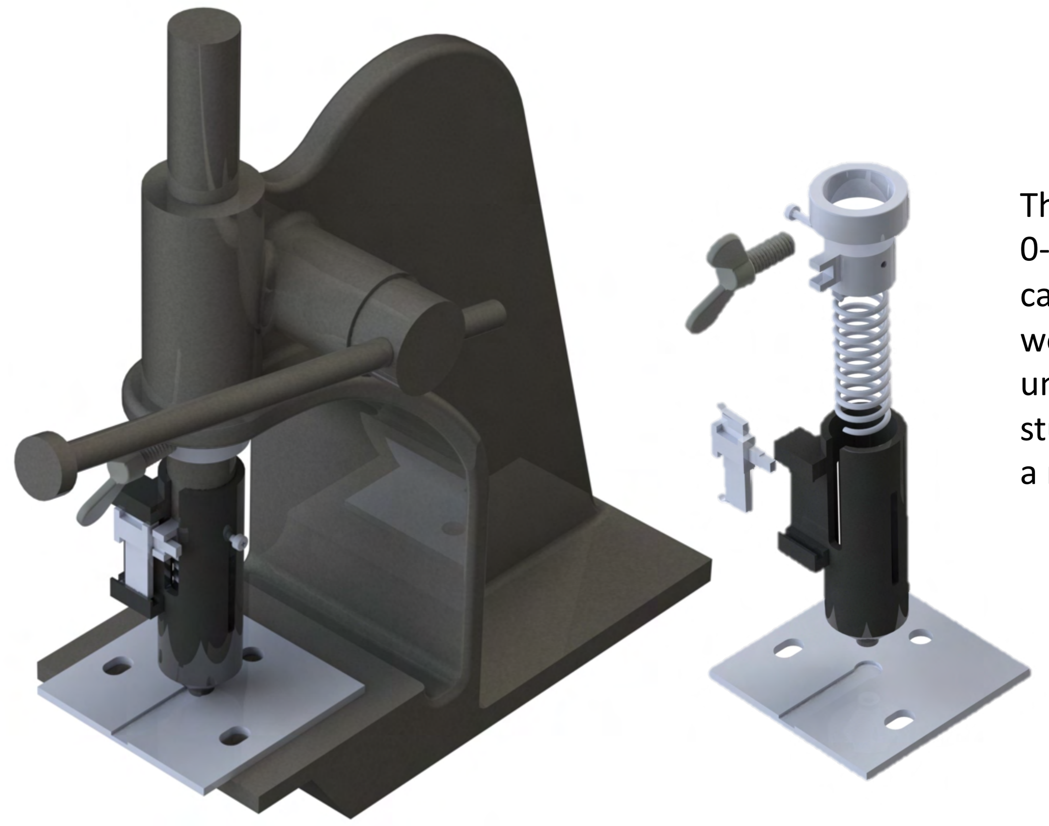
In-socket pressure sensing is unsolved problem. Force sensitive resistors (FSR) are commonly used, but researchers often present the data and ignore their flaws. The sensor behavior changes every time they are used, and gradually drifts while being used. Additionally, the behavior changes when the sensors are bent, as happens when inside of a socket.

After a few different attempts at a calibration method I determined it would be best to drop the ground-truth pressure measurements, and only do a relative and unitless pressure comparison between sockets.

Shortly after the development of this project researchers from University of Washington published their concerns over the use of FSRs for ground truth pressure sensing, an the impracticality of calibration.

Swanson, E. C., Weathersby, E. J., Cagle, J. C., and Sanders, J. E. (July 15, 2019). "Evaluation of Force Sensing Resistors for the Measurement of Interface Pressures in Lower Limb Prosthetics." ASME. *J Biomech Eng*. October 2019; 141(10): 101009. https://doi.org/10.1115/1.4043561

Mentee Project: Sensor Calibration Tool

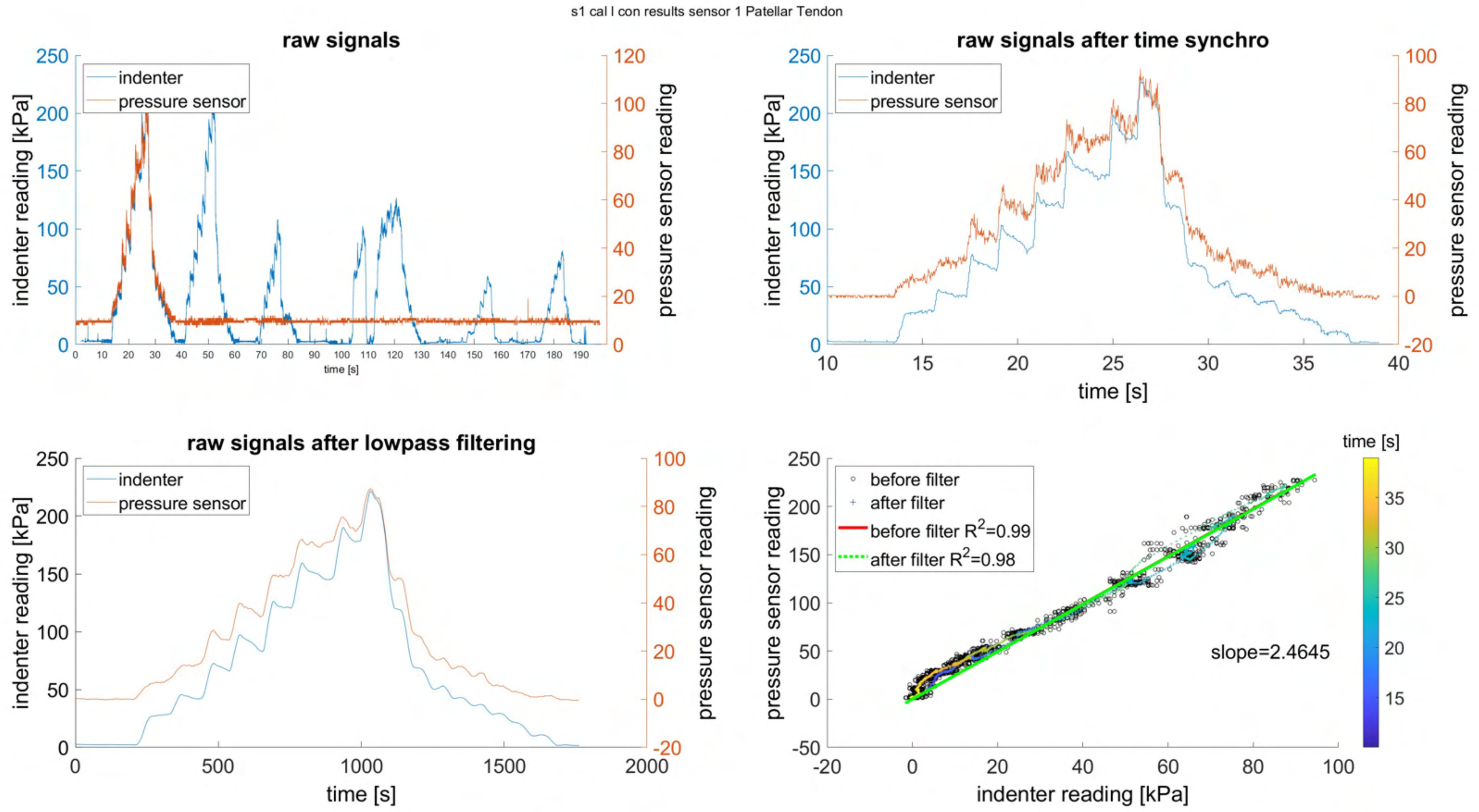


This is a custom force press that can apply and hold a desired load 0-50 N to an FSR. It was one of the tools I used in an attempt to calibrate the sensors. This was designed by an undergraduate working with me in the lab. I have worked project teams as an undergrad and mentored many elementary and high school students on their own projects, however, supervising a student was a new experience.

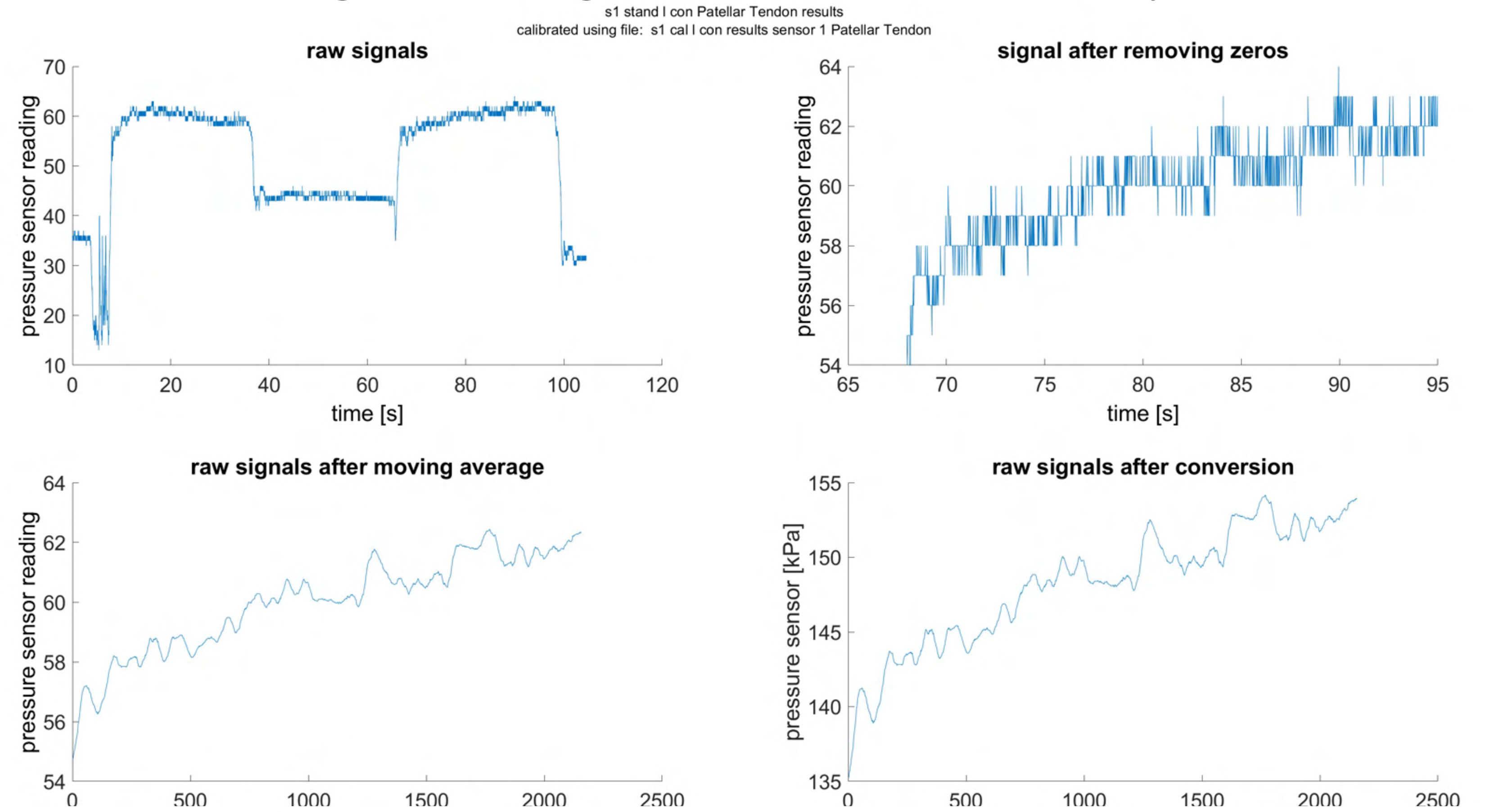
Calibrating FSR using the Indenter's load cell

The final attempted sensor calibration method involved squeezing the Indenter on the FSR sensors placed on the limb. This had the potential to calibrate the sensors in-situ and account for any bending. It proved to be unreliable, yet was still an interesting project. To bar graph below required managing 24 datasets for calibration, applying the calibration results in the correct order to 12 raw data sets. Followed correctly importing 12 calibrated datasets in order into the graph.

FSR-Indenter Calibration Best Fit



Converting raw analog sensor data to calibrated pressure



Pressure Comparison Between Novel and Conventional Sockets Under Load