Orthopedic Solutions & Scientific Instrumentation Using the Deformation Displacement Array Sensor

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Abstract

The Deformation Displacement Array (DDA) Sensor is a design for a class of device meant to provide dynamic geometric data for deformable bodies with solid interiors – though hard bodies are also applicable. It is a matrix of pins fixed to linear displacement sensors, with required compression force increasing with distance. This allows for impression taking of a body pressed into the array with significant force, showing the geometric profile of an object's face under dynamic loading conditions. Additionally, a pressure map may be drawn from the same data set.

The sensor is being proposed as an element to upgrade the pipeline for pairing customers with orthopedic needs to rapidly manufactured, custom fitted, economical orthotics. We examined the technical processes, social impacts, and economic prospects of improving the existing supply chains. The DDA Sensor has broader, more versatile potential in other fields as well.

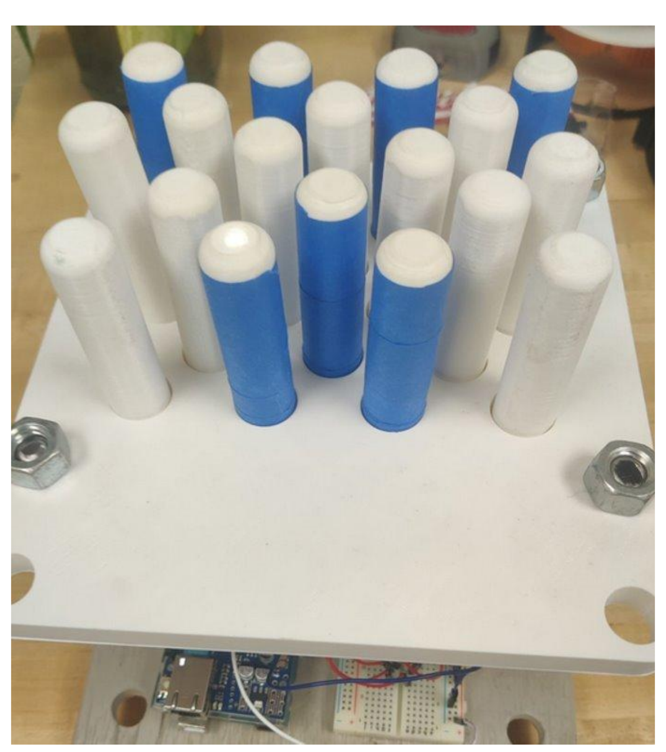
Background

The DDA Sensor concept originated from an idea to create custom mice and controllers by pressing a hand into putty, scanning the impression, and generating a 3D-printed plastic shell. However, gaps in scanning technology and a greater need for orthotic applications shifted the project's focus toward rapid orthotic manufacturing, aiming to assist disabled users.

Currently, obtaining orthotics in the U.S. involves expensive, time-consuming visits to specialists or using pharmacy kiosks that provide generic, one-size-fits-all options based on pressure readings. While some competitors offer at-home fitting kits, they use conventional technologies with similar limitations.

Professionally fitted orthotics work well but are costly, inconvenient, and inaccessible. Kiosk orthotics, on the other hand, fail to fit all shoes, accommodate unusual foot profiles, or precisely match individual arches. The DDA Sensor improves kiosk-based processes by capturing better-fitting, customized orthotic profiles in a timely and affordable manner.

Unlike traditional methods, which rely on static 3D scanning of undeformed feet, the DDA Sensor records the foot's geometry under load alongside pressure data. This dynamic approach captures the foot's splay and deformation, enabling the creation of 3D-printable orthotics tailored for superior comfort and fit.



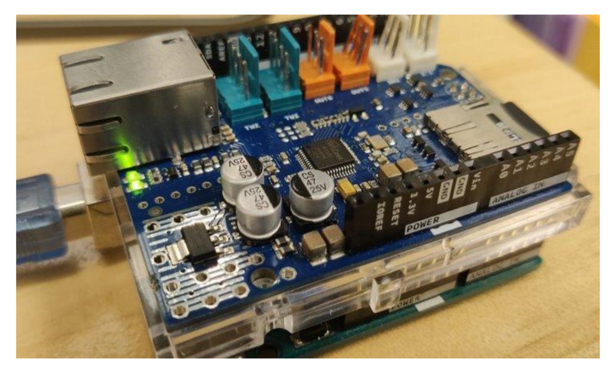
[Figure 1] The prototype DDA Sensor, with 18 visible pins, and 16 connected ones mounted to springs and linear potentiometers beneath its face plate.

Hardware Overview

The DDA Sensor concept is hardware-independent, meaning its core functionality—an array of spring-tensioned linear displacement sensors—can be implemented using various mechanisms. Our design uses off-the-shelf compression springs paired with linear potentiometers to measure displacement, housed within 3D-printed pistons mounted in a plastic frame.

Our prototype serves as a proof of concept, not a fully functional device. It employs just 16 pistons due to limitations of the microcontroller used for data collection. This low resolution isn't sufficient for generating usable 3D models, so we transitioned from physical testing to simulations involving thousands of DDA pins to refine the software pipeline.

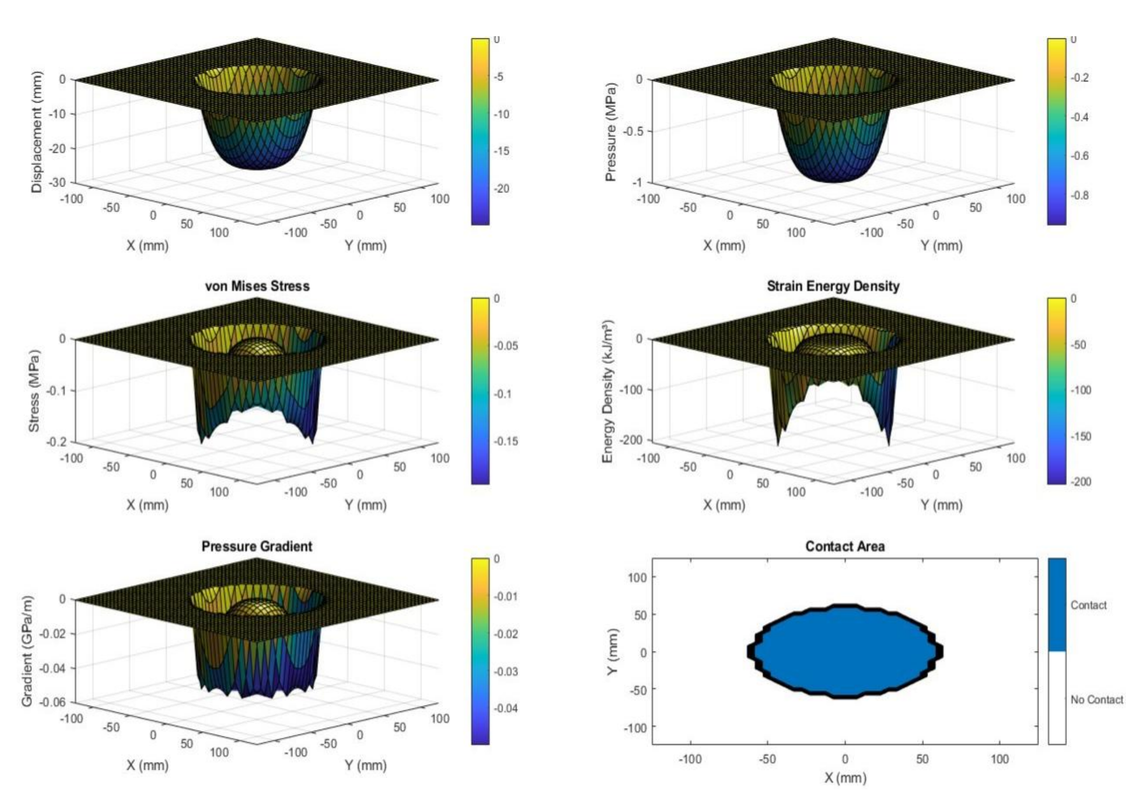
Achieving accurate geometry requires resolution on the order of hundreds of pins per axis. While the current prototype lacks the precision needed for practical applications, its overall size closely approximates that of a potential final product.



[Figure 2] Our microcontroller, an Arduino board writing to an SD card for data transfer

Software Overview

For a visual proof of concept, it was essential to test a detailed sensor array with different deformable objects. The hardware real time data was simply not useful enough for a proof of concept and a larger data set was needed. Matlab was used to conduct detailed FEA analysis using a detailed sensor array map. Several different object faces were simulated, working towards a proof of concept. We began by testing basic geometric shapes like spheres and cylinders to establish baseline deformation patterns, then progressed to more complex objects like tires. Soft deformable objects, such as a simulated stuffed animal, presented particularly interesting challenges due to its non-linear material properties and complex surface interactions. When testing a standard foam eraser from the IS2 lab, we observed minute deformations that matched our simulation predictions, validating our model's accuracy at small scales.



[Figure 3] Simulated displacement response of a sample circular stuffed animal placed on the DDA sensor array

Hardware/Software Pipeline

CSV data is transferred from the Arduino and plotted using Python. The object used in scanned beforehand using an iPhone 3d scanner to generate a 3D mesh of the object in Python environment, allowing for easier viewing of the displacement. Although, the Python plots are not as detailed as the Matlab plots, they give a good indication of the displacement on the object in all planes instead of just one face. A foam eraser from the Inventor's Studio II classroom was used as test object.

The process to inscribe the eraser into a digital environment works very similar to how we want our final product to look like. Prior to inscribing the displacement of the object, the undeformed object is first converted into a 3d mesh using an iPhone 3d scanner. This process helps us map the object into a digital environment with higher accuracy. The object is then placed onto the sensor array and the displacement data from the potentiometers is measured and exported as a csv file onto the computer. From here, python is used to extract the data from the csv file and map the scanned mesh from before onto one image. This process simulates what you might see at your local orthotics with the Dr. Scholl's machine.

Using displacement data and the variables we already know about the mass of the object and the spring constant of each spring, we can easily map the displacement, force, pressure, stress, and strain of the object inscribed onto the sensor array. Although these results are not as accurate as the results found in the simulation, they help give a good idea of how our process looks like to map the di
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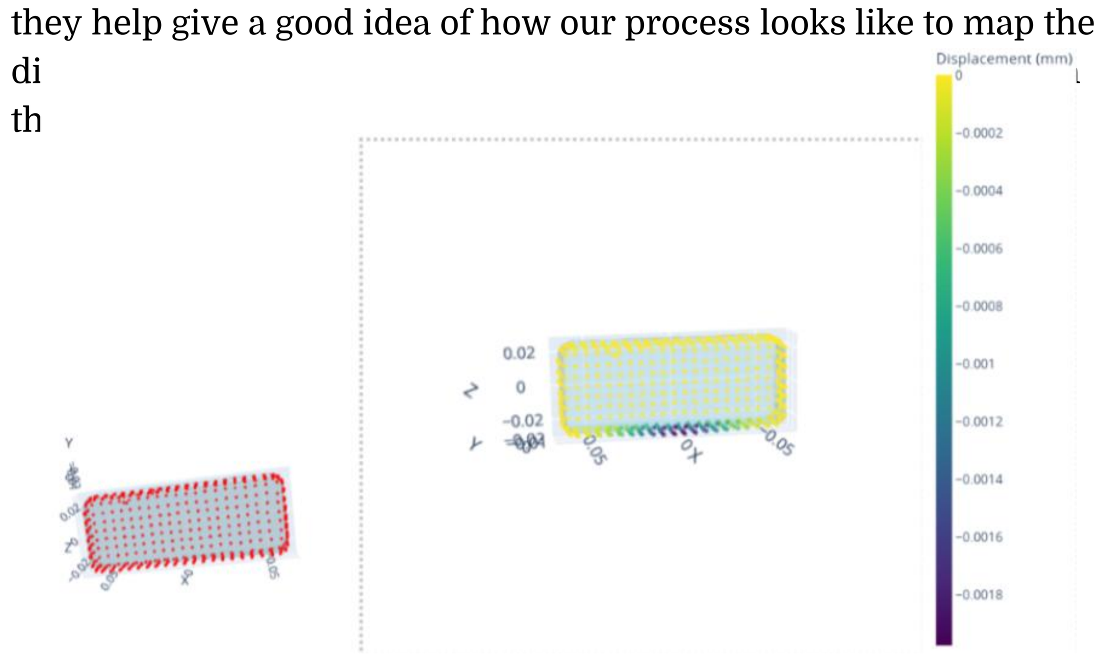
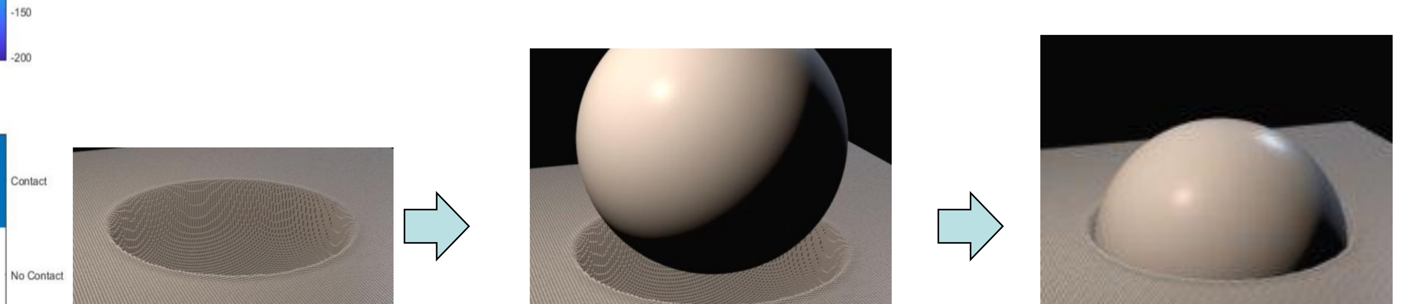


[Figure 4] Simulated displacement response of a foam eraser from IS2 classroom

Houdini's physics engine helped us to create detailed visualizations that clearly demonstrated this process to stakeholders as shown in the figure below



[Figure 5] Simulated displacement response of a sphere on a sample DDA array

Device Potential & Human Impact

HARDWARE PROSPECTS

Future hardware will require pin diameters of 5mm or smaller, with minimized spacing and compact actuation mechanisms. Two main design paths are likely:

- Increasing the vertical footprint by relocating mechanisms beneath the pins to reduce spacing.
- Designing custom hardware that integrates pins and displacement sensors into unified units, possibly using conductive coatings for contact-based sensing.

The second option, though requiring more upfront investment, is more efficient long-term and will be the focus for Prototype 2.

SOFTWARE PROSPECTS

Improved point-to-polygon interpolation and a streamlined software suite for data collection, model generation, and printing are key goals. Leveraging and potentially customizing open-source tools will help accelerate development.

HUMAN IMPACT

Hannah consulted Dr. Grace Ferguson from the University of Pittsburgh Medical Center to explore patient-oriented and socioeconomic considerations, including FDA approval and design recommendations for Version 2. The discussion highlighted the non-technical challenges in addressing broader market needs.

The sensor, as part of a larger pipeline, enhances orthotic manufacturing with faster, cost-effective processes. Key consumer markets include recovering athletes, maternity patients requiring adjustable orthotics, and individuals with asymmetrical or evolving foot profiles. Some cases may require a doctor's prescription, but the custom-fit and rapid production benefits address critical gaps in current orthotic solutions.

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- Dr. Grace Ferguson, MD (UPMC) – Public Health and Human Impact Consultation

Software and Tools used:

- Python(SciPy), MATLAB, Arduino IDE, Open-Source Phone Scanner, PrusaSlicer, OnShape, Houdini

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