University of Toronto
Faculty of Applied Science and Engineering
APS112 & APS113
Conceptual Design Specifications (CDS)

Team #	0139	Date	Mar. 19, 2023

Tutorial Section	0126
Project Title	Simulation of Pressure Under the Foot
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Executive Summary

The client, Dr. Stephen Perry, a professor working with the Toronto Rehabilitation Institute, has requested a device that can accurately apply pressure to the foot sole. As suggested by the client, the design should be capable of working for a foot length of (9.5 ± 1.3) inches, taking customized pressure pattern inputs, then applying pressure in small areas precisely.

The design will operate primarily in a standard Ontario hospital room. The standard voltage in Ontario is 120 V with a standard frequency of 60 Hz, which limits the power supply of the design. Conditions such as temperature, humidity, and noise level define objectives (safety and usability) to maintain a comfortable hospital condition and not disturb the daily activities of stakeholders operating near the service environment. The presence of stakeholders such as physiology and kinesiology researchers and federal funding agencies define the broader considerations of the design. The design has to comply with Canada's Medical Devices Regulation stated by the Canadian Judiciary System.

The primary function of the design is to apply pressure to the foot. The objectives in the order of importance are identified as accuracy, safety, reliability, adaptability, and usability according to the client's wants. The constraints are listed as the size of the pressure exertion unit and the design, budget, temperature, and stimuli intensity.

The ideas were generated via free/structured brainstorming and were based on the functions of the device, which adhere to the objectives and constraints. A morphological chart was used to develop versatile design solutions by combining single ideas and multi-voting was used several times to determine the top sixteen solution ideas. Moreover, a graphical decision chart was used to determine the top three solutions, followed by pairwise comparison.

The top three designs were named based on their most notable characteristics (i.e. array of small sensors, adjustable barriers, boot to secure the foot), then elaborated on how each solution meets the functions, objectives, and constraints. The ideal design, ***NerveMapPro***, (array of small sensors) is chosen for its best accuracy due to the miniature size of the sensors and actuator, and the safety measure provided by the adjustable straps and railing, making this the recommended design for the client.

The measure of success details the upcoming stages in the design plan and the various test methods used including the sensitivity calculation for accuracy and temperature test for safety. The next step is to prototype the design by ordering the set of components that were listed in the section of alternative designs for the best solution.

1.0 Introduction

The client, Dr. Stephen Perry, researches environmental sensory information and physical reactions, focusing on footwear [1]. The client wants a device that can apply pressure to the foot during everyday activities to support his research on the intrinsic muscle. This report will define the problem by analyzing the service environment and stakeholders while establishing the scope, objectives, and constraints. This will be followed by the process of idea generation and selection of over 90 ideas, 3 alternative designs, details of one final proposed design, and measures of success to address the project's needs.

2.0 Problem Statement

The current apparatuses to simulate pressure use actuators with a diameter of 25mm which apply pressure in large areas [2]. The gap is the lack of precision from the existing apparatuses as seen in Figure 1. There is currently no device capable of applying and collecting pressure simultaneously in small areas precisely for healthy adults. There is also no way to easily create new simulated actions from inputting pressure pattern data.

The need for this project is a design to simulate pressure on the foot sole in small areas when the user sits, stands, or is prone. Additionally, the need is to customize pressure simulations with inputted data. The user of the design is an adult (ages 18-55) or an older adult (ages 55+). The operators include the person controlling the design and the person inputting pressure data.

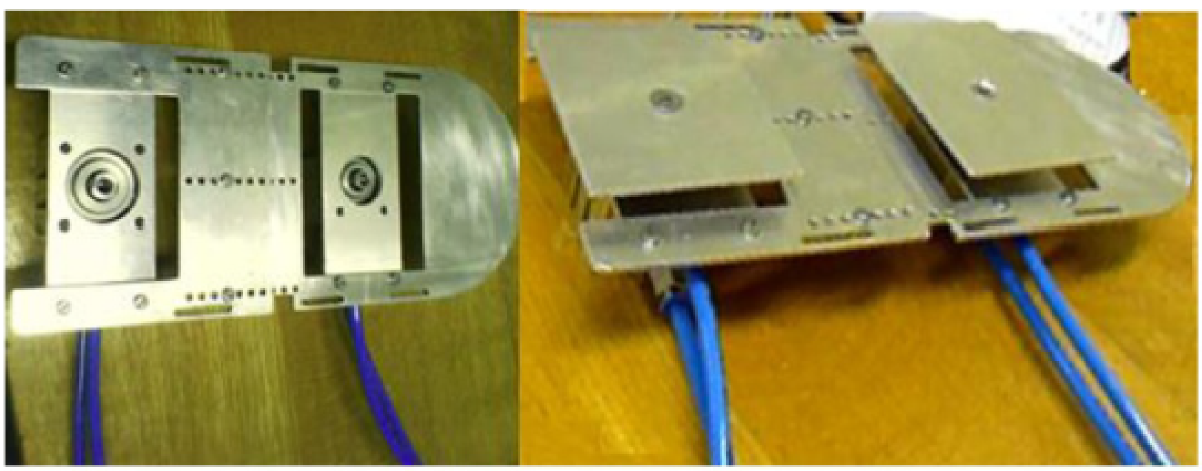

Figure 1: A current apparatus available for applying pressure on the sole [2].

The design's scope will be limited to applying pressure on a single, stationary foot sole in an indoor, controlled environment. Preset simulations include walking, standing, stepping up, stepping down, shifting weight, and turning as per the client's request. The design should not physically or psychologically alter the user or their foot.

3.0 Service Environment

The environment in which the design operates is described in Figure 2, with a focus on the physical, living, and virtual environments. The design will be in a controlled environment, like that of a hospital, as described by the project scope.

Figure 2: Toronto Rehabilitation Institute environment [3].

3.1.0 Physical Environment

The physical environment (Table 1) describes the statistical aspects of the hospital environment.

Table 1: Physical Environment and Details

Physical Environment (Hospital)	**Details (Guidelines)**
Temperature	Temperatures range from 21℃-24℃ [4].
Humidity	Comfortable humidex ranges from 20-29 [5].
Air Quality Health Index	Low health risk when AQHI is 1-3 [6].
Water Quality	Water has < 1 coliform bacterium/100 mL [7].
Sound Level	WHO recommends levels of 35 dB(A) during the day and 30 dB(A) during the night [8].
Light	Color temperature of about 4200 +/- 300 degrees K [9]. Illumination of at least 50 lx [9].

3.2.0 Living Things

Average level of bacteria in hospitals ranges from 75-1194 CFU/m [11].

Humans are present in the service environment (i.e., researchers, research participants and their families, nurses, and doctors).

3.3.0 Virtual Environment

Virtual Environment (Table 2) outlines the virtual systems available in hospitals.

Table 2: Virtual Environment and Details

Virtual Environment	Details
Internet	Internet connection is available. Recommended speed is 100mbps [12].
Power Supply	Canada has a supply voltage of 120V [13]. Power supply has an isolation of 4000 V (AC) [14].

4.0 Stakeholders

Table 3 considers the design's impacts on stakeholders and stakeholders' influences on the design, which generates constraints.

Table 3: Stakeholder Impacts and Influences

Stakeholder	Impacts/ Influences
Orthopedic companies (i.e. Podowell [15]) and their customers	**Positive impact**: The design can simulate plantar pressure distribution while walking, which helps design orthopedic devices to rehabilitate a patient to a normal gait [16].
People at risk of foot conditions I.e. Diabetes and arthritis patients	**Positive impact:** Simulations can generate data for research to improve the prevention of foot diseases like ulceration, which is common in diabetic patients [17]. A better understanding of pressure's effect on the foot can reduce pain and complications for arthritis patients [18].
Physical Therapists and their patients	**Positive influence:** The device can become an instrument-assisted soft tissue mobilization option for physical therapists to simulate motions for patients'

	rehabilitation [19].
Canadian Judiciary System	**Influence:** The Medical Devices Regulations ensure the safety and best interests of people using medical devices in experimentation. [20]
Physiology and Kinesiology Researchers	**Positive influence**: The design will allow for further studies of pressures on foot, whose data supports other researchers' development [21].
Federal Funding Agencies (i.e. CIHR)	**Influence:** Funding agencies provide grants for health research and directly affect the finances for a project [22].

5.0 Detailed Requirement

The solution should simulate the movement pressure on the entire foot sole to satisfy the client's needs (See Figure 3). It should also be more accurate and safer than the existing devices. The project will be considered successful based on the average objectives completion rate of 78% [23].

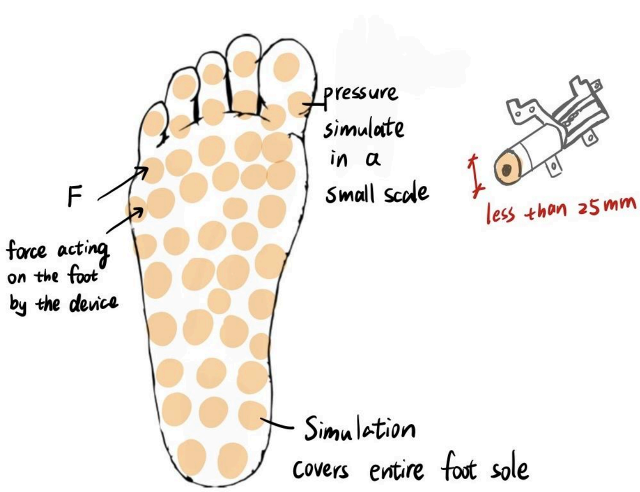

Figure 3: Detailed Requirements for the Project

5.1 Functions

One of the main functional bases is to "**apply mass**" and is used to determine the primary function. The black box method (Appendix A) and functional decomposition (Appendix B) were utilized to generate the secondary functions.

The primary function of the design is to **“apply pressure to the foot”.**
For secondary functions, the design will:

1. Secure the foot
2. Record the foot size and pressure of standing or record user-inputted pressure patterns
3. Record the user’s weight, and age
4. Calculate output pressure from inputted information
5. Precisely mimic pressure patterns on the foot for walking, standing, turning, upstairs, downstairs, and shifting weight (examples in Figure 4)
6. Unsecure the foot

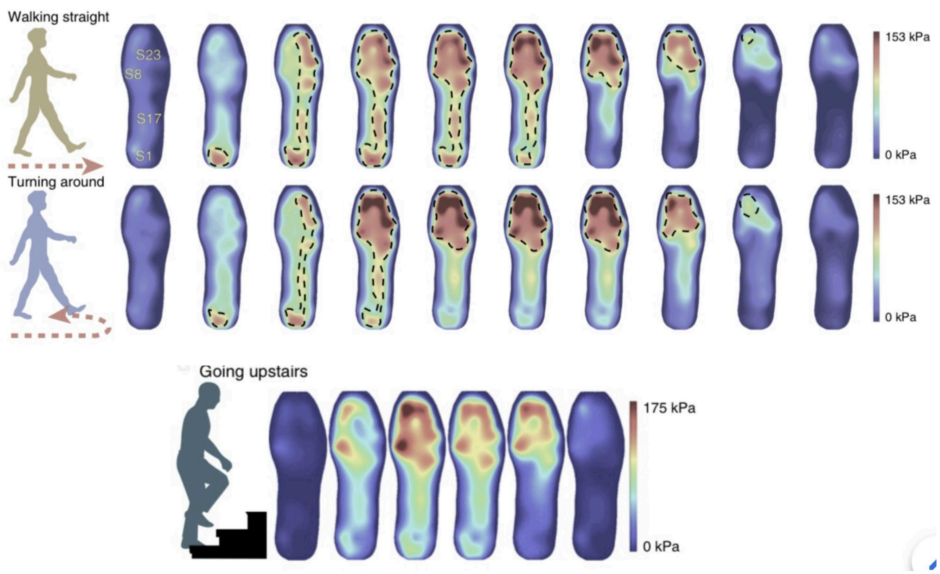

Figure 4: Pressure patterns to simulate various actions [24].

5.2 Objectives

The pairwise comparison method (Appendix C) was employed to rank the objectives. Table 4 showcases the objective goals and metrics from the how-why tree (Appendix D).

Table 4: Objectives and objective goals

Main Objectives (listed by priority)	**Reasoning** The design should:	**Metric**	**Goals** The design should:
Accuracy	Simulate pressure accurately and precisely for research use.	- Location of Pressure (mm) - Pressure (kPa)	- Create absolute tolerance for pressure position within **1.0 mm** based on the existing microdevice from a range of **±0.1 mm to ±1.0 mm** [25][26]. - Create absolute tolerance for pressure within **12.57 kPa** [27]. See Appendix M for calculations of tolerance.
	Have a large density to be stiff enough to accurately apply specified pressures.	- Density in g/cm^3	- Use high-density plastic (≥**0.97 g/cm^3**) for the top layer of the contacting surface [28].
Safety	Not make the user feel uncomfortable by preventing any section of the design from rising above 37°C.	- Temperature in °C	- Not exceeding **35°C** [29].
Reliability	Be just as durable in the given service environment and maintain its precision.	- Life span in years - Pressure in kPa	- Remain usable **within 25 years** from client recommendation. - Generate any specific pressure within **0-300 kPa when used repeatedly**. This pressure range is based on 0-278 kPa from source [24]
Adaptability	Accommodates different ages, foot sizes, and foot types	- Variability of pressure pattern provided	- Produce pressure data **for ages 18 and above**.

	for a range of users mentioned in the problem statement.	- Types of data - Size of foot - Types of foot	- Generate data in **sitting, standing, walking, turning, climbing stairs, and shifting weight.** - Generate pressure for foot length between **200mm-320mm** and foot width between **80mm-130mm** [30]. - Accommodate people with **different foot types.**
Usability	Function without redundant procedures.	- Number of procedures to function	- Provide **instructions and safety guidelines**. - Should function within **5 clicks** [31].
Other Objectives			
Noise Level	Produce comfortable noise levels.	- Noise level in dB(A)	- Make noise level less than **35 dB(A)** [8].

5.3 Constraints

Table 5 specifies the conditions from the client or regulatory bodies that the design must meet.

Table 5: Constraints and Metrics

	Constraint	Metric and Limits	Justification
Client	Size (the device that applies pressure)	At most **25mm** in diameter	Component's size must be smaller than the one in the existing design.
	Size of the design	Must accommodate for foot length between **210mm-300mm** and foot width between **84.1mm-127.2mm** [30]	The design must simulate the motion under the entire foot sole for all foot sizes
	Budget	Must **not exceed 30,000 CAD**	This limit is determined by the client.

User	Temperature perceived by the user	Must not exceed **44°C** [29]	The operating temperature must not cause the user any discomfort.
	Vibration frequency	Must not exceed **9Hz** [32]	The vibration produced must not cause a tight contraction of muscles.
	Pressure generated	Must not exceed **689 kPa** [33]	Pressure exceeding 689kPa will breach the human skin.
	Amount of current exposed to the user	Must not exceed **10mA** [34]	To protect experimenters, the design must not electrically shock the user.
Stakeholder	Noise level	Must not exceed **70dB** [35]	The noise produced must not harm the hearing of the people in the service environment.
Regulations/ Code	Power supply limit	Standard voltage: **120 V** (with a standard frequency of **60 Hz**) [13]	The design must comply with Canadian government power supply requirements.
	Electro-Magnetic Interference (EMI)	Must not exceed **868 MHz** and **1 W** of EMI over **1.00m** from the device. [36][37]	Not cause EMI with other hospital equipment/devices
	Safety	Must abide by legal regulation **SOR/98-282** sections 10 and 83. [20]	The design must comply with Canadian Medical Devices Regulation which ensures the safety of the test subject.

6.0 Alternative Design Generation, Selection, and Description

Figure 5 shows the process of how we generated and selected their ideas.

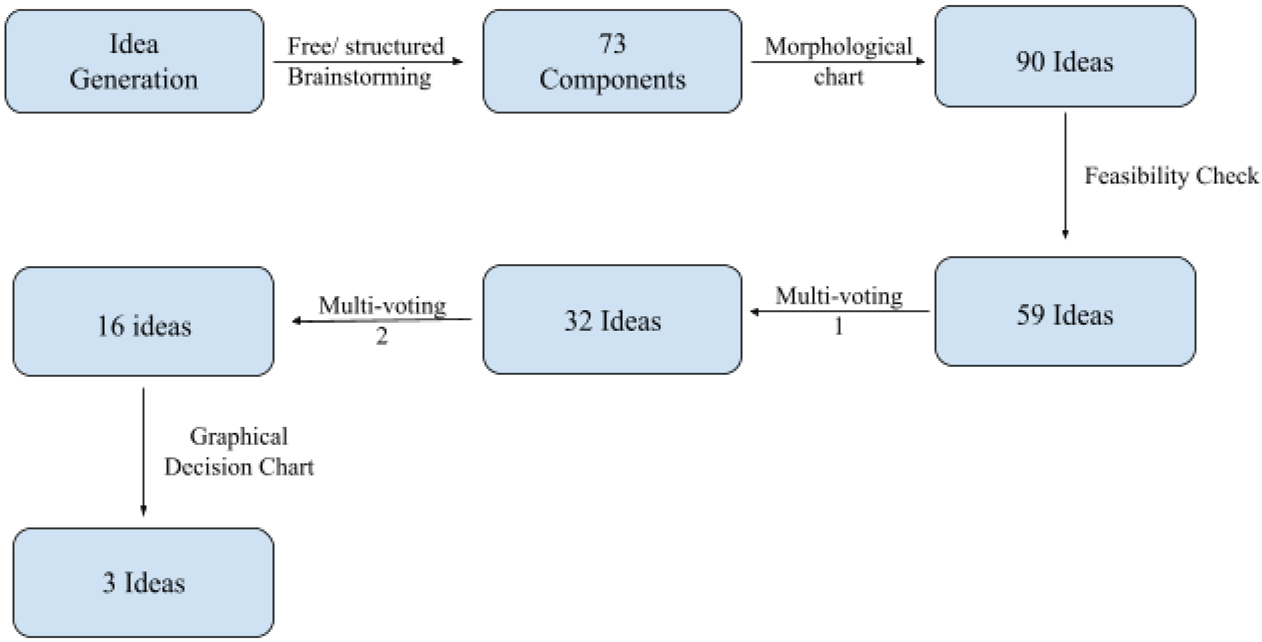

Figure 5: Idea Selection Process

6.1 Idea Generation

We used free/structural brainstorming and creativity methods like blue sky thinking, human nervous system analogy, and lateral thinking to generate 73 components (Appendix E). These categories were derived from the FOCs to ensure that all ideas target the objectives and needs of the client.

Morphological Chart

After the list of ideas was generated, our team utilized a morphological chart (Appendix F) categorized by functions from 5.1 to produce design solutions by combining ideas from each category. We also added another section for the components that did not fit into any functions.

6.2 Alternative Design Selection Process

After consolidating ideas from the morph chart, our team conducted a **feasibility check** and color-coded the ideas accordingly; red for violating constraints, green for feasible, and yellow for in-between (Appendix F). During consolidation, we had insufficient valid ideas so the morph chart was iterated until desired quantity was reached.

Multivoting

The team then implemented **multi-voting** twice to seek 15 ideas. Each team member received 10 votes for the first round and 6 votes for the second round(Appendix G).

Graphical Decision Chart

Afterwards, we implemented the ideas into a **graphical decision chart** with the axis of accuracy and reliability, which are ranked 1 and 3 objectives(Appendix H). We chose reliability over safety because the remaining ideas after multi-voting were equally safe.

After analysis and a group decision, we scored each idea out of ten for both objectives. Finally, we chose the top three ideas, numbered **3, 13, and 71**, that met both objectives the best as the three alternative designs for the project.

6.3 Alternative Designs

The following sections show 3 alternative designs for the proposed solution that all use a rack holding the actuators.

6.3.1 NerveMapPro

NerveMapPro's adjustable straps secure the user's foot. The force sensors located on the tip of each actuator measure standing pressure and computer software records user's information to calculate the desirable output. This information will be sent to the Actuonix linear actuators to apply pressure on the user's foot. Figure 6 shows how components are assembled to function, and table 6 includes more details about how NerveMapPro meets objectives.

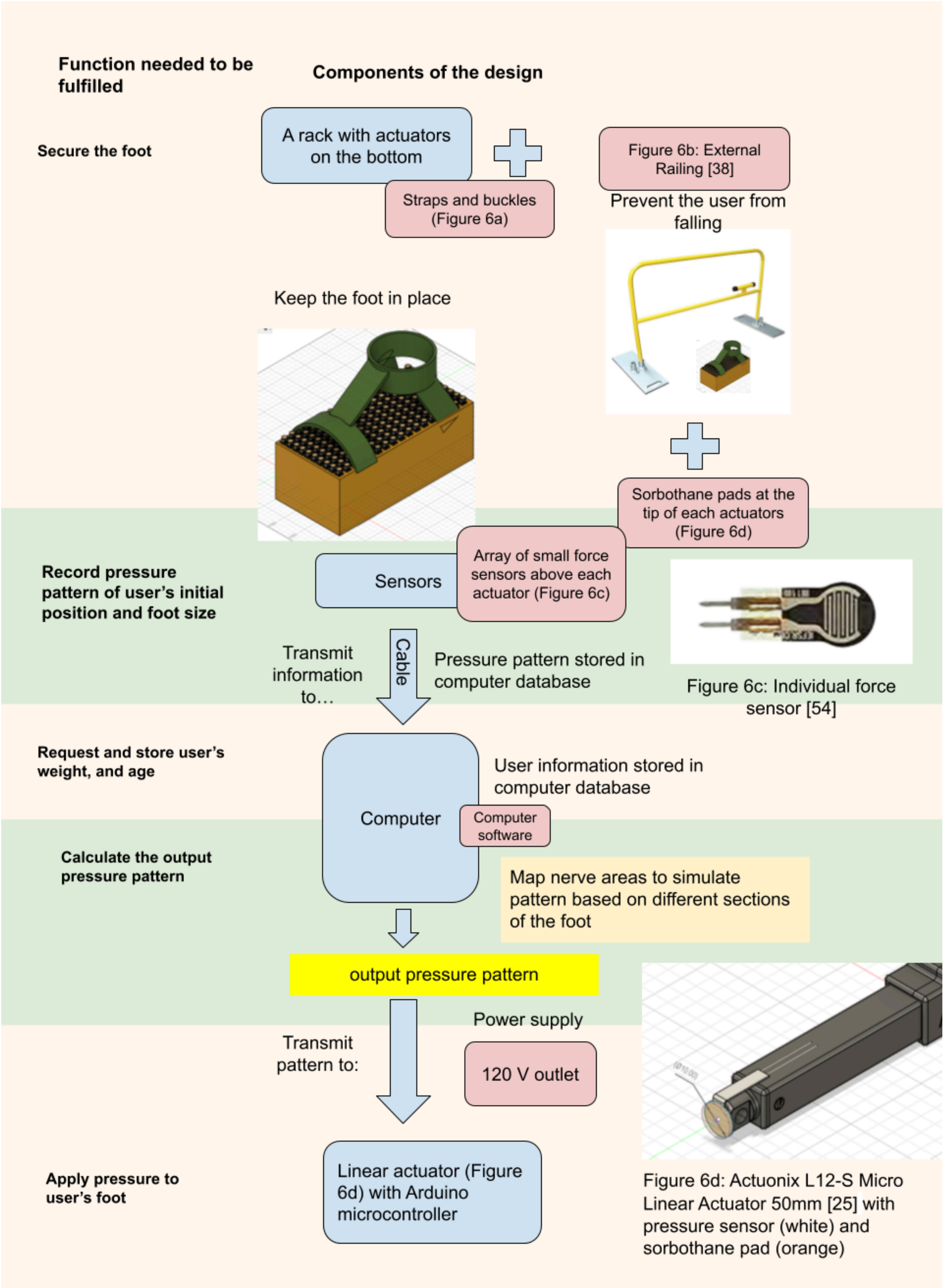

Figure 6: NerveMapPro components

Table 6: NerveMapPro meeting objectives

Objective	Objective Fulfillment	
Accuracy	Single Actuator	**±0.3 mm repeatability** **14x18 mm piston size** **1018 kPa** max pressure (Calculations: Appendix L)[25]
	Sensors	**±0.6% force repeatability** [54]
	10x17 actuator array Adjustable straps keep the foot stationary to increase position accuracy with little space for movement. The actuator's tip is made of a thin layer of sorbothane with a density of **1.330 g/cm^3** [39].	
Safety	Sorbothane and the plastic rack are thermal insulators, preventing the transfer of heat [40][41].	
Reliability	Actuators have a 180 day warranty [25].	
Adaptability	Actuator array's size (320x145mm) and adjustable straps accommodate most feet [30].	
Usability	User interface is computer software that will **function within 5 data inputs** [31].	
Others	Actuators make 55dB when 45 cm away [25].	

6.3.2 WebLinkedRigidBarriers

WebLinkedRigidBarriers's straps and rigid barriers secure the user's foot. A layer with 170 pieces of piezo ceramic plate pressure sensors [43] is inserted on top of the actuators to record the location of the foot and then the layer is removed. After a website records the user's information and output from the dielectric layer, it will calculate the desirable output. This information will be sent to the X-NA-E linear actuators to apply pressure on the user's foot. Figure 7 shows how components are combined to function. Table 7 evaluates WebLinkedRigidBarriers by objectives.

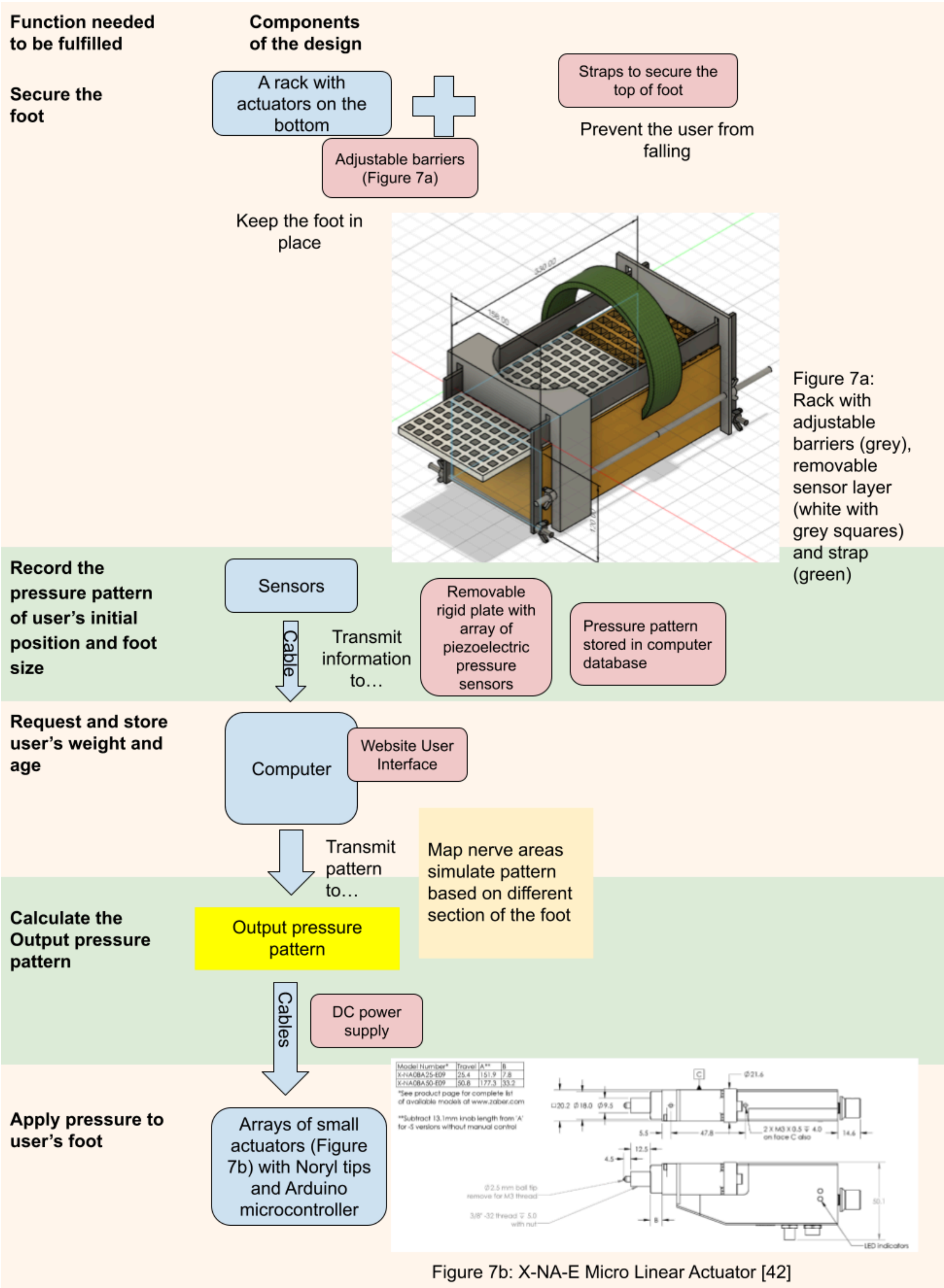

Figure 7: WebLinkedRigidBarriers components

Table 7: WebLinkedRigidBarriers meeting objectives

Objective	Objective Fulfillment	
Accuracy	Single actuator	**±1 µm repeatability** **40 µm** unidirectional accuracy **20x20 mm** piston size **70 kPa** maximum pressure (calculations: Appendix L) [42]
	Sensor	N/A
	7x16 actuator array Adjustable rigid barriers keep the foot absolutely stationary to increase position accuracy with no wiggle room. Tip is Noryl plastic with a density of **1.06 g/cm^3** [44].	
Safety	Noryl tips are thermal insulators that will prevent heat conduction from actuators [41].	
Reliability	Actuators have a 1-year warranty [42]. Websites rely on internet access which may not be consistent [45].	
Adaptability	Actuator array's size (320x140mm), adjustable barriers, and top strap accommodate most foot sizes [30].	
Usability	User interface is a **website** that will **function within 5 data inputs** [31].	
Others	Bluetooth is an EMI source [46].	

6.3.3 FootSensorSkiBoot

FootSensorSkiBoot's ski boot secures the user's foot. A dielectric layer with capacitive pressure sensors [24] (Figure 9) with a sorbothane insole to record standing pressure (Figure 8b) is fixed on the actuator array to increase user comfort and reduce usage procedures. A computer database stores information from the sensors and user input from a touchscreen to calculate the desirable output. This information will be sent to the SOViK linear actuators to apply pressure on the user's foot.

Figure 8 shows how combined components function. Table 8 showcases how FootSensorSkiBoot meets objectives.

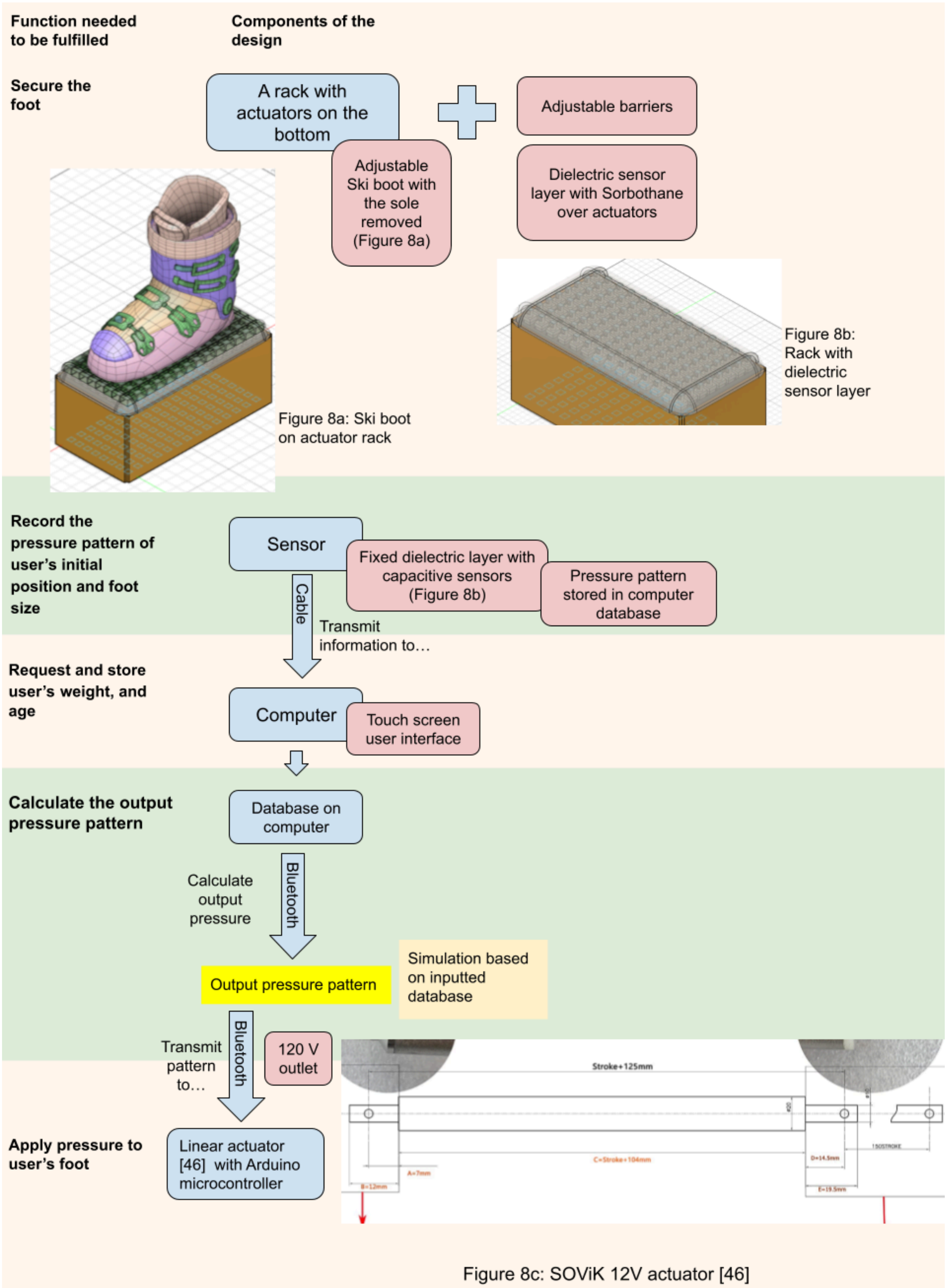

Figure 8: FootSensorSkiBoot components

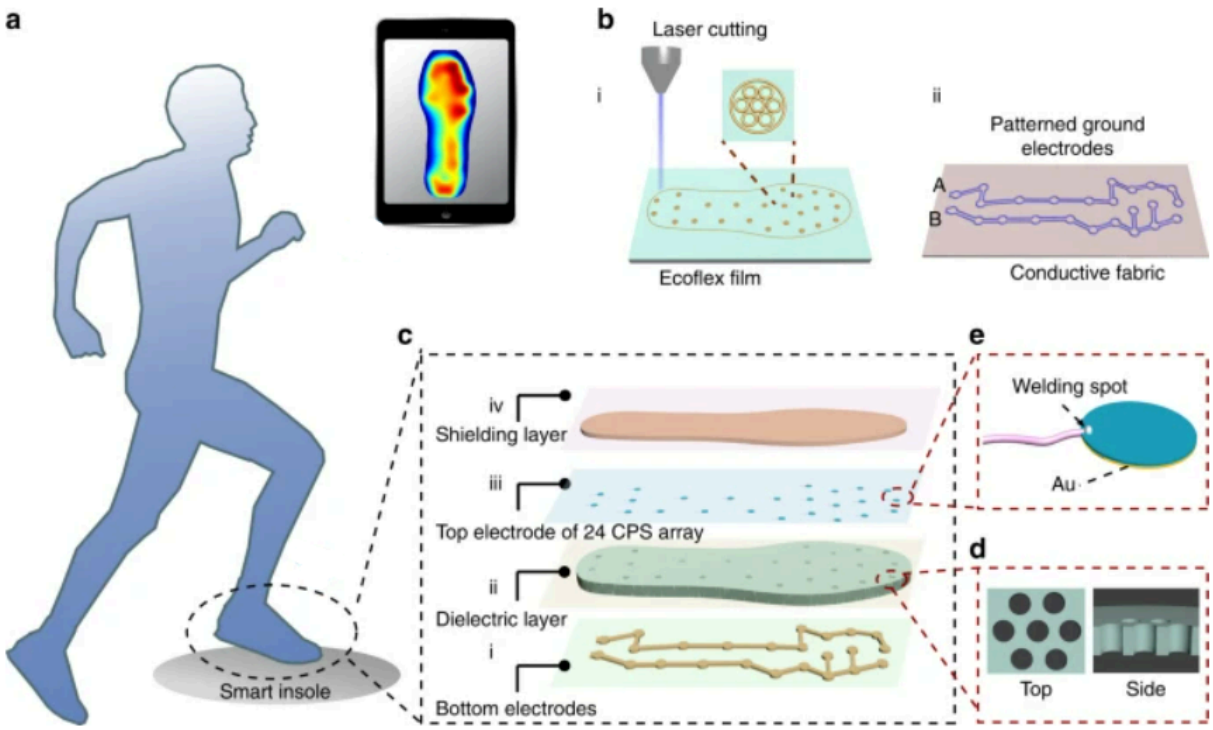

Figure 9: Dielectric sensor layer with capacitive sensors to be adapted to a sheet instead of an insole. [24]

Table 8: FootSensorSkiBoot meeting objectives

Objective	Objective Fulfillment	
Accuracy	Single Actuator	**±1 mm repeatability** **20x20 mm piston size** **1248kPa** maximum pressure [26]
	Sensors	**±5% capacitance repeatability** [24]
	7x16 actuator array Adjustable ski boots keep foot and ankle stationary to increase position accuracy with no wiggle room. Sorbothane layer density: **1.330 g/cm³** [39].	
Safety	Sorbothane is a thermal insulator: will not conduct heat from actuators [41].	

Reliability	No warranty [26]. Sensors are linear and stable over 15000 uses [24]
Adaptability	Skiboot has limited size adjustability [47].
Usability	User interface is an intuitively usable **touchscreen**. Will **function within 5 data inputs** (5 clicks) [31].
Others	Actuators make 60 dB [26].

7.0 Proposed Conceptual Design

By utilizing the Pugh method and the weighted decision matrix (Appendix J), "***NerveMapPro***" is considered the optimal design that maximizes objective achievement to satisfy the client's needs (See Figure 10).

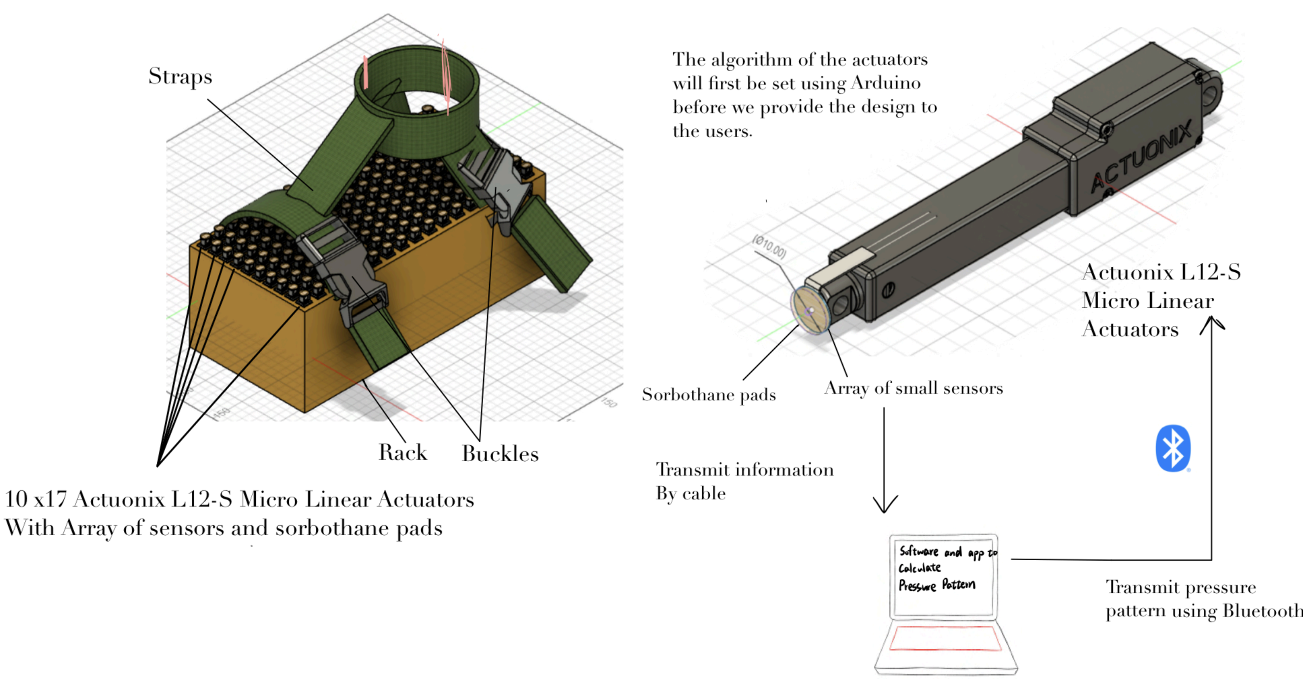

Figure 10: Implementation for NerveMapPro

The existing designs on the market cannot **accurately** record and simulate foot pressure simultaneously. Through the sensor array [47], ***NerveMapPro*** can meticulously read the user's foot pressure, store it in a computer database, and use computer algorithms [48] and nervous system data to calculate the pressure output of each actuator to mimic pressure patterns on the foot [25].

The selected design strongly meets the crucial objectives of accuracy [25], power supply, data connection method, and degree of adaptation. Using rails (Figure 11b) and a rack for actuators and straps with sorbothane pads ensures comfort, guarantees the lifespan of the equipment [49], and effectively fixes the position of the user's foot. The power supply of 120V, the simultaneous usage of the app and bluetooth to receive user data, and the connection of the equipment with cables, ensure the adaptability and usability of the device in a hospital environment.

While using Bluetooth will result in EMI, the range [50] satisfies constraints, promoting adaptability and usability with the wireless transfer method [51]. The characteristics of ***NerveMapPro*** effectively address FOCS so the team thinks it meets the client's needs best.

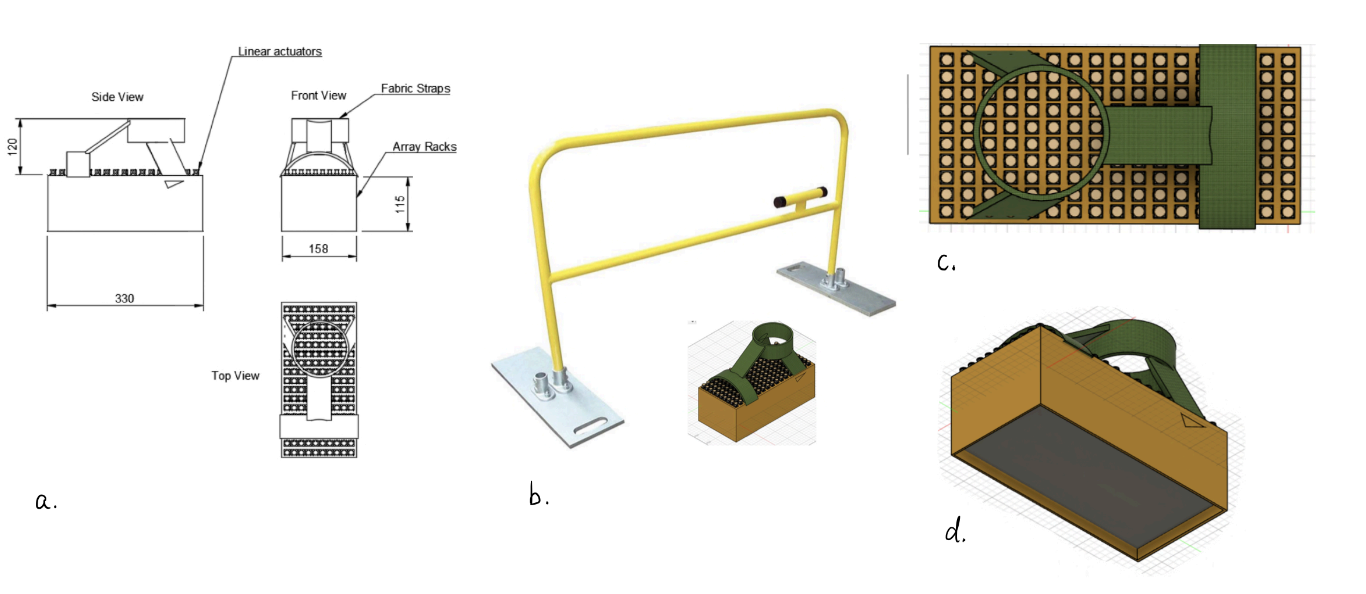

Figure 11: a) *NerveMapPro's* length dimension in mm. b) The external rail prevents falls c), d) Design from different perspectives

8.0 Measures of Success

The success of the design will be initially estimated to ensure it meets the safety and accuracy, the top two objectives. Then, our team will prototype part of the design (detailed plans in Appendix K).

8.1 Accuracy for sensors

The design needs to create absolute tolerance for pressure within **12.57 kPa**, which is calculated from its inverse proportionality to sensitivity (See Figure 12). Our team will use one sensor with an ohmmeter to prototype by using Arduino Uno from March 26th to April 1st to measure the pressure and the resistance across the sensor to calculate the sensitivity and the accuracy of the design.
The sensitivity of the array of pressure sensors will decrease with increasing pressure [52]. Sensor sensitivity is calculated from resistance with no load (R_0), change of resistance (ΔR), and applied

pressure (P) (equation 1).

$$S_p = |\Delta R / R_0| \times 1/P \qquad (1)$$

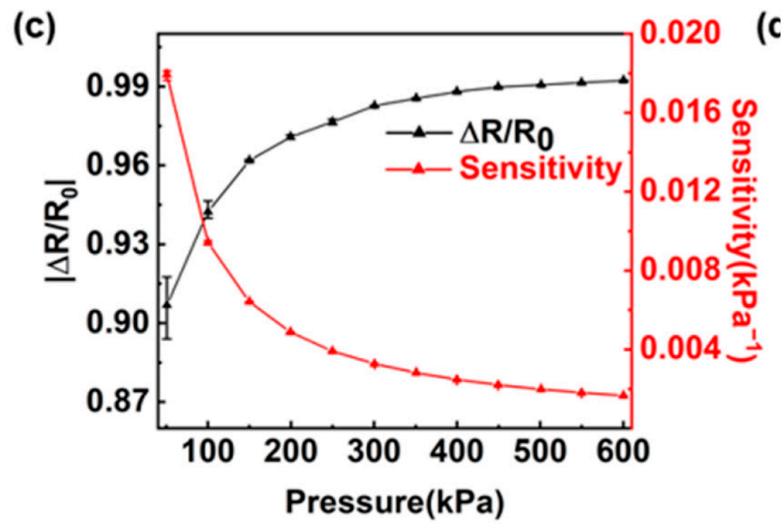

Figure 12: Sensitivity of array of sensors[52]

8.2 Accuracy for Actuators

The location of pressure stimulation of an Actuonix micro linear actuator has ±0.3mm repeatability which meets the accuracy objective of ±1.0 mm for displacement [25].

Since ***NerveMapPro*** combines actuators with sensors and sorbothane pads, we will use a dial indicator (Figure 13) to measure the linear displacement of an actuator and sensor from April 2nd to April 9th. We will calculate the accuracy by using absolute error measurement(equation 2)[53].

Absolute Error = | Measured Displacement - Specified Displacement | (2)

The process will be repeated to get a comprehensive average of its position's accuracy.

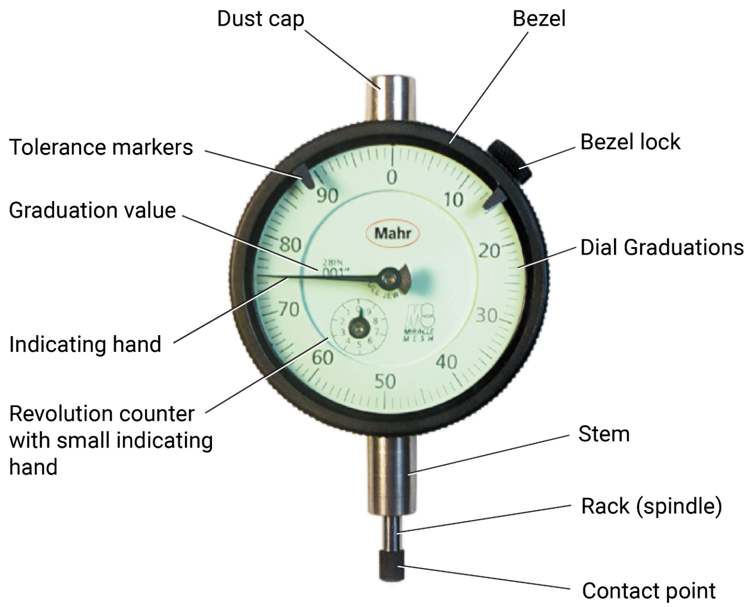

Figure 13: Dial Indicator

8.3 Safety of the design

The success of safety will be measured in both stages, from March 26th to April 8th, to examine that every section of our design meets the objective of not exceeding **35°C**. Our team will use an infrared thermometer to monitor the temperature generated by one actuator. We will estimate the array temperature (T_{array}) with the room temperature (T_{room}) and the temperature difference between one actuator and room temperature (ΔT) (equation 3). After finding the heat generated by one actuator we will use superposition to find the approximate heat that will be applied by the design [55].

$$T_{array} = T_{room} + 170\Delta T \qquad (3)$$

9.0 Conclusion

This report delineates the detailed requirements of the project and the proposed conceptual design selection process. ***NerveMapPro*** was chosen in ideal selection for best meeting the client's need for accuracy and reliability while passing the feasibility and safety checks. ***NerveMapPro*** proved to be more accurate than ***FootSensorSkiBoot*** due to the lack of dielectric layer and smaller repeatability error of the chosen actuator. Additionally, ***NerveMapPro*** proved to be more reliable than both ***WebLinkedRigidBarriers*** and ***FootSensorSkiBoot*** due to its array of actuators and lack of dielectric layer. Afterwards, we created measures of success to ensure the designs satisfy the needs of the client. Next step for this project is doing a prototype to analyze the accuracy and safety of the design to be prepared for the detailed design specification stage.

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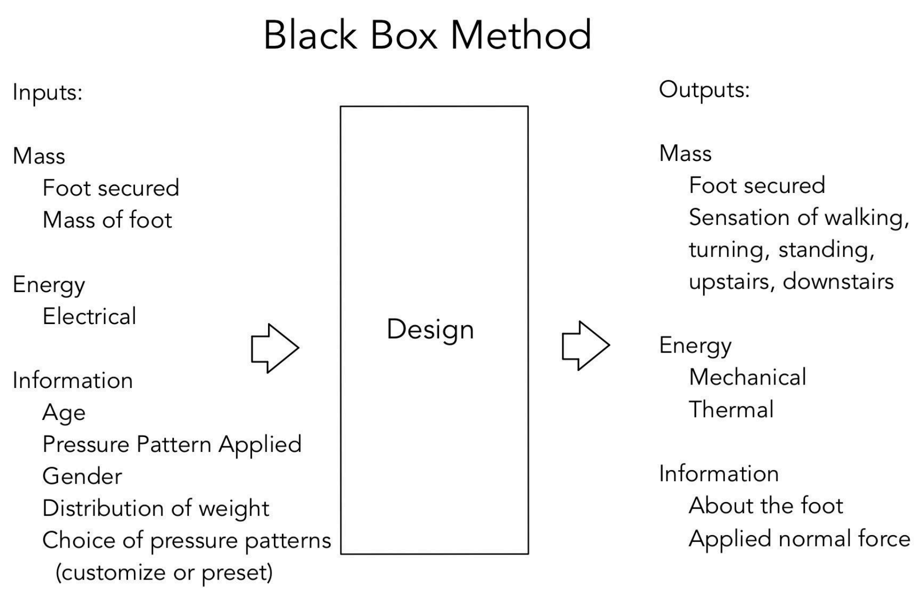
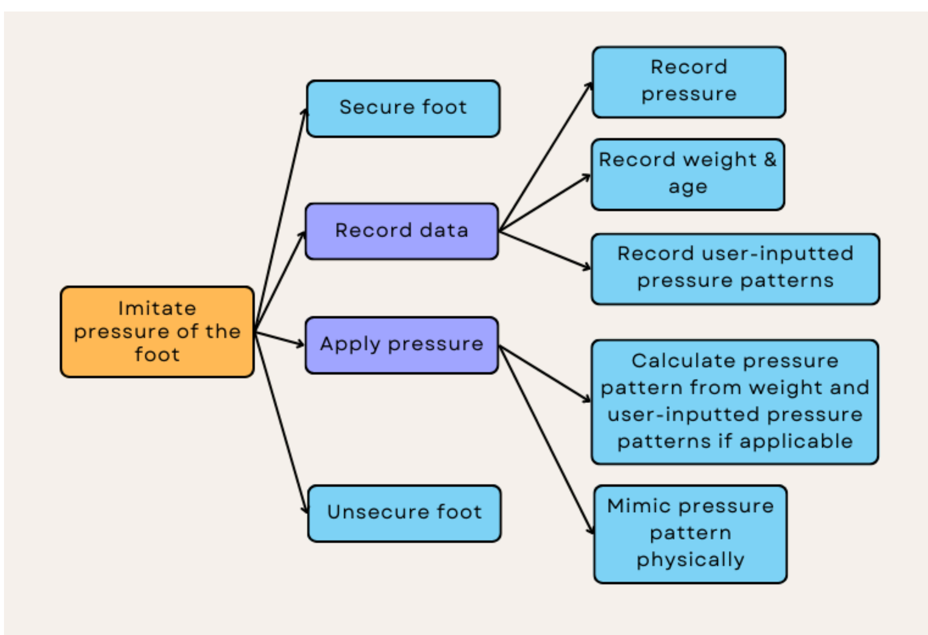
Appendices

Appendix A: Black Box Method used to generate secondary functions



Appendix B: Functional Decomposition of Design's Primary Function

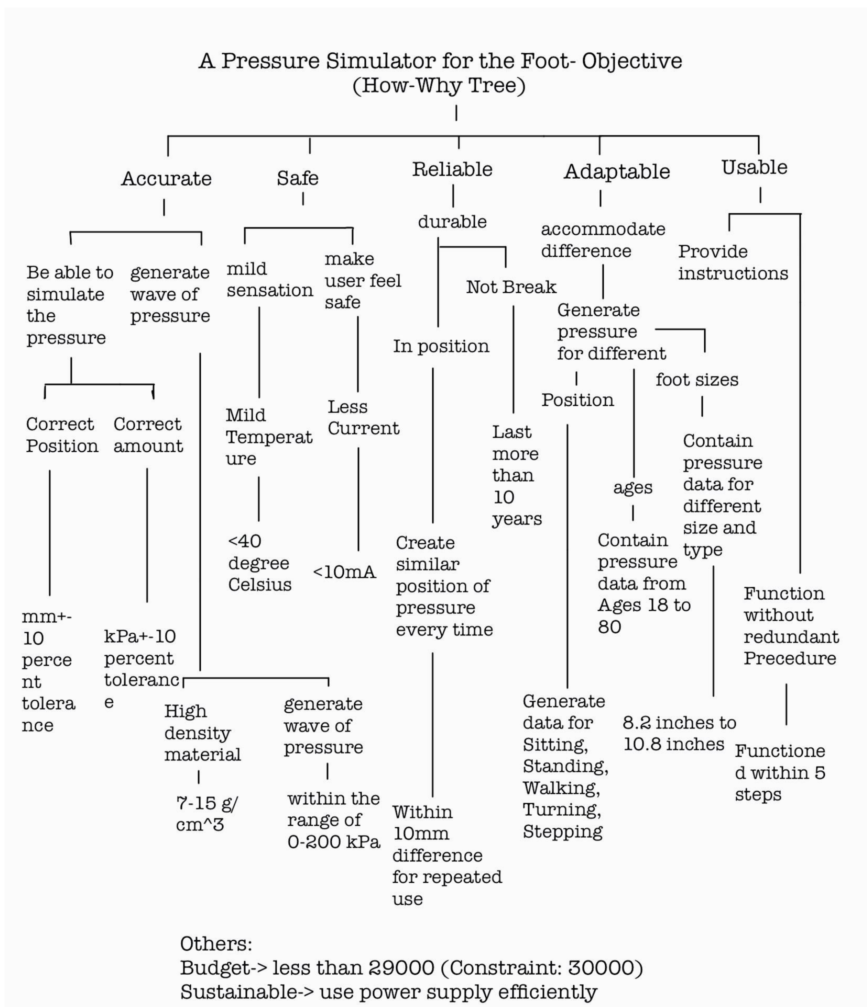


Appendix C: Pairwise-Comparison Method for Main Objectives

Table 9: Pairwise-Comparison Method for Objectives

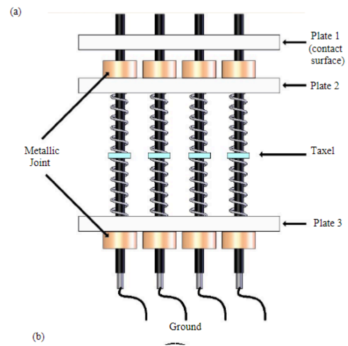
Objective	Accuracy	Safety	Adaptability	Reliability	Useability	Total	Rank
Accuracy	-	1	1	1	1	4	1
Safety	0	-	1	1	1	3	2
Adaptability	0	0	-	0	1	1	4
Reliability	0	0	1	-	1	2	3
Useability	0	0	0	0	-	0	5

Appendix D: How Why Tree for Objective Goals



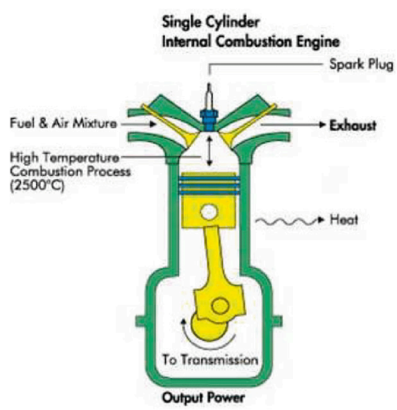
Appendix E: Free Brainstorming/ Structure brainstorming(blue sky riding)
Table 7: Free Brainstorming/ Structure brainstorming(blue sky riding):

- Actuators
    1. Electrical:
        - AC motors,
        - DC servomotors,
        - stepper motor,
        - solenoids



- https://www.researchgate.net/publication/224635450_A_compact_tactile_display_for_the_blind_with_shape_memory_alloys
-

    2. Pneumatic: compressed air as driving force
    3. Hydraulic: hydraulic fluid to amplify the control/command signal
    4. Motor (pushing up and down?)
    - Benchmarking:

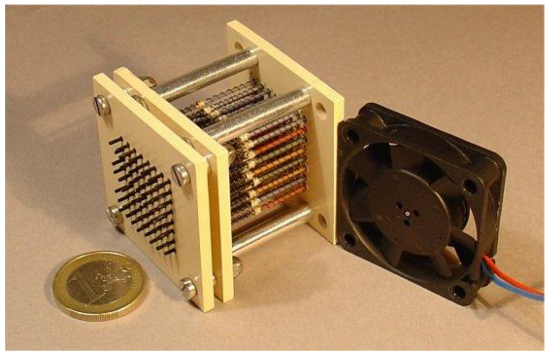


    - Soft actuators for mimicking different terrains
- Advantages for different types of actuators or motors: https://jhfoster.com/automation-blogs/motors-vs-actuators-for-industrial-systems/
- Monkeys pressing foot (and control their nervous system)
- 2 Humans applying pressure with fingers
- Springs - use spring force to apply force on foot

- Control:
    - Arduino (like c)
    - Rpi (python?)
    - Bluetooth
    - Laptop or desktop(like 100 cables coming out of it)
    - Jetson (mini computer)
    - Lego robotics controller “free technically”
    - Phone
    - Remote control
    - Teensy microcontroller
    - Soundwaves
    - Electromagnetic waves
    - ESP32 microcontroller (wifi and bluetooth compatible)
    - ESP8266 - very cheap 3USD

- Pressure mapping system (sensing the pressure)
    - Dielectric layer
    - Biological analogy: human skin/ animal skin
    - Array of small sensors
    - High density metals: iron with plated surface
    - Use array of springs

- Transmitting signals (from user interface to pressure appliers)
    - Radio
    - Bluetooth
    - Wifi
    - Cable (i.e. USB)
    - Electromagnetic waves
    - Microwave
    - Soundwave
- Prototyping
    - 3D printing the chassis
    - Online structured creation
    - Make modular actuators (so only prototype a small portion)
- Power supply
    - Use 120 V outlet to supply power
        - AC (outlet, diesel generator?)
    - DC (batteries,
    - DC voltage generator)
    - Solar energy
    - Wind energy
- Material contacting the foot
    -

- Assembly
    - A foot cast with open bottom
    - A rack for actuators and straps to secure foot
    - A rack for actuators and adjustable barriers that keep foot in place
    - A shoe with actuators on bottom
    - Smooth contact surface:
    - Get like 10 of these(benchmarking)
        - 
        - https://www.researchgate.net/publication/224635450_A_compact_tactile_display_for_the_blind_with_shape_memory_alloys

- Input
    - website
    - sound
    - face recognition
    - fingerprint recognition

    - application
    - terminal
    - voice control
    - A touch screen connecting to the pressure simulator

Calculating the pressure patterns:

- Use an application
- Make a simulation of pressure and then output the pressures on the device
- Use programs
- Research patterns for 2 or more age groups, then inter and extrapolate to get patterns.
- Measure foot dimensions of inputted pattern data, then scale it to user foot size
- Map muscles on the foot, then apply pressure based on each muscle
- Map nerve areas (areas with same sensory nerve) on the foot, then apply pressure based on each area

Appendix F: Morph Chart for Idea Generation and Selection

Morph chart and Feasibility check

Feasible In-Between Not Feasible

1. Secure & Unsecure Foot	2. Record the pressure of standing or record user-inputted pressure patterns	3. Record the user's weight, age, and foot size	4. Calculate output pressure from inputted information	5. Precisely mimic pressure patterns on the foot for walking, standing, turning, upstairs, downstairs, and shifting weight	6. Others
1.1 A foot cast with open bottom 1.2 A rack for actuators and straps to secure foot 1.3 A rack for actuators and adjustable barriers that keep foot in place	**Pressure mapping system (sensing the pressure):** 2.1 Dielectric layer 2.2 Biological analogy: human skin/ animal skin 2.3 Array of small sensors	3.1 Website 3.2 Sound control based on different language 3.3 Face recognition fingerprint recognition 3.4 Application 3.5 Terminal	4.1 Use an application 4.2 Make a simulation of pressure and then output the pressures on device 4.3 Use programs 4.4 Research patterns for 2 or more age	5.1 Linear Actuator 5.1.1 AC motors, 5.1.2 DC servomotors, 5.1.3 stepper motor, 5.1.4 solenoids 5.2 Pneumatic:compressed air as driving force 5.3 Hydraulic: hydraulic fluid to amplify the	**Smooth contact surface:** 6.1 Sorbothane (A polymeric material used for shoe insole) 6.2 Leather 6.3 Cork covered with cotton 6.4 No insole 6.5 Metal

1.4 A shoe (boot) with actuators on bottom 1.5 A sandal-style shoe with actuator on bottom 1.6 Use a splint or brace to immobilize the foot 1.7 A new cast could be used every time when people try to use the design	2.4 Use array of springs 2.5 a small, thin, and flexible mat or insole to record pressure	3.6 Voice control 3.7 A touch screen connecting to the pressure simulator **Transmitting signals (from user interface to pressure appliers):** 3.8 Radio 3.9 Bluetooth 3.10 Wifi 3.11 Cable (i.e. USB) 3.12 Electromagnetic waves	groups, then inter and extrapolate to get patterns. 4.5 Measure foot dimensions of inputted pattern data, then scale it to user foot size 4.6 Map muscles on the foot, then apply pressure based on each muscle 4.7 Map nerve areas (areas with same sensory nerve) on foot, then apply pressure based on each area 4.8 Input a database	control/command signal 5.4 Motor (pushing up and down?) 5.5 Soft actuators for mimicking different terrains 5.6 Monkeys pressing foot (and control their nervous system) 5.7 2 Humans applying pressure with fingers 5.8 Springs - use spring force to apply force on foot 5.9 use actuator arrays **Control of pressure appliers:** 5.10 Arduino (like c)	6.6 Foam and rubber with air filled in (the ones like touch screen pen) 6.7 High density metals: iron with plated surface **Power supply:** 6.8 Use 120 V outlet to supply power 6.9 AC diesel generator 6.10 DC batteries 6.11 DC voltage generator 6.12 Solar energy 6.13 Wind energy

		3.13 Microwave 3.14 Soundwave 3.15 Internet (upload to website) - cable		5.11 Rpi (python?) 5.12 Bluetooth 5.13 Laptop or desktop(like 100 cables coming out of it) 5.14 Jetson (mini computer) 5.15 Lego robotics controller 5.16 Phone 5.17 Remote control 5.18 Teensy microcontroller 5.19 Soundwaves 5.20 Electromagnetic waves	

				5.21 ESP32 microcontroller (wifi and bluetooth compatible) 5.22 ESP8266 - very cheap 3USD	

Morph chart for Idea Generation

Morphs Feasible In-Between Not Feasible						
Idea Number	Function 1	Function 2	Function 3	Function 4	Function 5	Others (5.10-5.15 is moved to this column)
1	1.1	2.2	3.3, 3.8	4.1, 4.2	5.2, 5.12	6.4, 6.8
2	1.4	2.4	3.1, 3.4, 3.10	4.1, 4.6	5.8, 5.10	6.1, 6.8
3	1.2	2.1	3.4 3.9, 3.11	4.2, 4.8	5.1, 5.9, 5.13	6.1, 6.8
4	1.3	2.3	3.7, 3.11	4.5, 4.7	5.1.1, 5.13	6.2, 6.11

5	1.3	2.4	3.5, 3.11	4.5, 4.6	5.2, 5.16	6.1, 6.10
6	1.6	2.4	3.1, 3.15	4.3, 4.8	5.2, 5.11	6.6, 6.9
7	1.2	2.3	3.1, 3.12	4.3, 4.8	5.5	6.5, 6.10
8	1.2	2.5	3.1, 3.10, 3.11	4.5, 4.1	5.1, 5.13	6.5, 6.8
9	1.7	2.3	3.6, 3.9	4.4, 4.3	5.6, 5.16	6.12
10	1.5	2.2	3.4, 3.12	4.1, 4.8	5.4, 5.9	6.1, 6.8
11	1.5	2.3	3.4, 3.14	4.3, 4.6	5.3, 5.12	6.4, 6.10
12	1.3	2.5	3.5, 3.13	4.4, 4.6	5.7	6.3, 6.11
13	1.3	2.1	3.1, 3.4, 3.11	4.1, 4.7	5.4, 5.9, 5.13	6.1, 6.11
14	1.4	2.5	3.1, 3.10	4.2, 4.3, 4.5	5.1, 5.14	6.1, 6.8
15	1.2	2.3	3.5, 3.14	4.3, 4.4	5.1, 5.13	6.4, 6.8
16	1.5	2.3, 2.1	3.4, 3.11	4.3	5.1.1, 5.21	6.6, 6.9
17	1.3	2.3	3.7 ->3.5	4.4	5.5	6.1, 6.8
18	1.1	2.3	3.1, 3.8	4.5	5.7	6.2, 6.13
19	1.3	2.5	3.6, 3.9	4.8	5.6	6.3
20	1.1	2.3	3.1, 3.8	4.5	5.8	6.2
21	1.3	2.4	3.7 ->3.5	4.4	5.3	6.6, 6.8
22	1.7	2.4	3.5, 3.8	4.8	5.1.4	6.5, 6.13
23	1.4	2.1	3.6, 3.9	4.7	5.7. 5.13	6.4

24	1.7	2.2	3.3, 3.11	4.8	5.1.1	6.6, 6.12
25	1.5	2.5	3.4, 3.11	4.7	5.1.4	6.1, 6.13
26	1.1	2.1	3.7, 3.11	4.5	5.1.3	6.2, 6.10
27	1.3	2.5	3.5, 3.9	4.7	5.3	6.1, 6.12
28	1.7	2.1	3.4, 3.11	4.5	5.1.3	6.6, 6.11
29	1.6	2.3	3.4, 3.11	4.8	5.5	6.1, 6.10
30	1.1	2.5	3.4, 3.11	4.2	5.5	6.2, 6.8
31	1.6	2.2	3.4, 3.9	4.7	5.5	6.6, 6.12
32	1.2	2.1	3.7, 3.11	4.1	5.1.4, 5.10	6.2, 6.8
33	1.2	2.1	3.5, 3.9	4.1	5.3, 5.17, 5.21	
34	1.2	2.1	3.7, 3.11	4.6, 4.7	5.1.4, 5.11	6.10
35	1.2	2.4	3.5, 3.14	4.2	5.5, 5.13	6.11
36	1.4	2.3	3.7, 3.11	4.1	5.1.4, 5.10,	6.10
37	1.4	2.3	3.6, 3.9	4.3	5.3, 5.10	6.11
38	1.4	2.1	3.6, 3.9	4.4, 4.5	5.3, 5.10	6.11
39	1.4	2.1	3.6, 3.8	4.6, 4.7	5.3, 5.10	6.11
40	1.4	2.3	3.5, 3.11	4.3	5.1.3, 5.21,	6.8
41	1.3	2.1	3.7, 3.11	4.1	5.1.3, 5.10,	2.13
42	1.3	2.3	3.5, 3.14	4.2	5.5, 5.13	6.11

43	1.3	2.1	3.7, 3.10	4.2	5.4, 5.15	6.10
44	1.3	2.1	3.4, 3.11	4.3	5.2 5.21,	6.8
45	1.3	2.3	3.5, 3.11	4.3	5.1.3, 5.21,	6.8
46	1.3	2.3	3.5, 3.15	4.8	5.1.2, 5.12, 5.18	6.12
47	1.3	2.3	3.6, 3.7, 3.15	4.8	5.1.2, 5.13, 5.18	6.11
48	1.2	2.2	3.3, 3.6, 3.14	4.3, 4.4	5.6, 5.15	6.3, 6.12
49	1.1	2.3	3.1 3.10	4.8 4.3 4.2	5.1.1 5.11	6.2 6.8
50	1.4	2.1	3.4 3.9	4.3 4.5 4.8	5.9	6.3 6.9
51	1.7	2.5	3.5 3.11	4.4	5.2 5.13	6.1 6.10
52	1.2	2.3	3.1 3.15	4.5 4.8	5.1.1 5.10	6.1 6.8
53	1.5	2.5	3.5 3.9	4.7 4.3	5.3	6.3 6.11
54	1.1	2.3	3.3 3.7 3.9	4.2 4.3	5.9 5.21	6.1 6.11
55	1.6	2.5	3.1 3.10	4.5	5.1.4 5.22	6.3 6.10
56	1.7	2.3	3.4 3.9	4.1 4.4	5.4 5.14	6.6 6.8
57	1.2	2.1	3.4 3.15	4.2 4.8	5.2 5.13	6.1 6.12
58	1.6	2.2	3.2 3.4	4.4	5.8	6.3 6.13
59	1.4	2.3	3.7 3.8	4.2 4.5	5.2 5.18	6.4 6.8
60	1.2	2.1	3.1 3.15	4.3	5.6 5.12	6.3 6.9

61	1.1	2.2, 2.4	3.2, 3.14	4.4, 4.8	5.3, 5.5, 5.12	6.2, 6.8
62	1.2	2.1	3.2, 3.10	4.3, 4.4	5.1, 5.21	6.3, 6.8
63	1.1	2.4	3.7, 3.14	4.6,4.7	5.3, 5.10	6.2, 6.11
64	1.3	2.4	3.3, 3.11	4.1, 4.4	5.2, 5.13	6.2, 6.9
65	1.2	2.5	3.7, 3.10	4.4, 4.5	5.3, 5.12	6.3, 6.10
66	1.3	2.2	3.4, 3.11	4.1, 4.6	5.2, 5.16	6.1, 6.9
67	1.1	2.1	3.3, 3.15	4.1, 4.7	5.1, 5.12	6.1, 6.10
68	1.2	2.4	3.3, 3.10	4.1, 4.5	5.3, 5.16	6.2, 6.11
69	1.4	2.3	3.4, 3.9	4.2	5.1.2, 5.10	6.1, 6.12
70	1.2	2.2	3.3, 3.15	4.1, 4.6	5.3, 5.16	6.1, 6.9
71	1.4	2.3	3.7, 3.9	4.1,4.7	5.1, 5.13	6.1, 6.8
72	1.2	2.3	3.7, 3.11	4.3	5.4	6.5, 6.9
73	1.6	2.1	3.4 3.13	4.1 4.5	5.1.2 5.11	6.3 6.8
74	1.3	2.4	3.4 3.15	4.2 4.8	5.3 5.16	6.4 6.9
75	1.4	2.1	3.1, 3.9	4.6, 4.7	5.1, 5.4, 5.10	6.1, 6.8
76	1.2	2.1	3.4, 3.9	4.8	5.1, 5.5, 5.13	6.1, 5.10
77	1.5	2.1	3.1, 3.9	4.2	5.9, 5.13	6.6, 6.8
78	1.7	2.2	3.7, 3.9	4.1	5.1.2, 5.10	6.1, 6.12
79	1.1	2.1	3.3, 3.9	4.5	5.1.2, 5.11	6.1, 6.10

80	1.3	2.3	3.6, 3.9	4.8	5.2, 5.11	6.1, 6.13
81	1.6	2.2	3.1, 3.9	4.2	5.3, 5.11	6.6, 6.10
82	1.7	2.5	3.4, 3.11	4.3	5.4, 5.13	6.1, 6.12
83	1.3	2.1	3.3, 3.9	4.4	5.5, 5.10	6.1, 6.12
84	1.2	2.4	3.5, 3.11	4.5	5.3, 5.10	6.6, 6.13
85	1.7	2.3	3.7, 3.10	4.1	5.1.3, 5.11	6.1, 6.11
86	1.6	2.5	3.1, 3.10	4.3	5.3, 5.17	6.1, 6.10
87	1.5	2.1	3.7, 3.10	4.4	5.1.4, 5.12	6.1, 6.13
88	1.3	2.3	3.5, 3.11	4.1	5.5, 5.10	6.1, 6.12
89	1.5	2.3	3.5, 3.9	4.1	5.5, 5.10	6.1, 6.12
90	1.5	2.3	3.5, 3.9	4.1	5.5, 5.11	6.1, 6.12

Appendix G: Multi-voting

Multi-voting 1.0- 59 feasible ideas

#	Coco	Winnie	Rachel	Akshaj	Nenad	Emre		Total
1								
2								
3		I	I	I	I	I		5
4		I						1
5								
6								
7								
8								
9								
10								
11								
12								
13				I	I	I		3
14					I			1
15					I			1
16			I					1

17		I	I			I		3
18								
19								
20								
21			I	I		I		3
22								
23								
24								
25					I			1
26								
27								
28								
29			I					1
30					I			1
31								
32	I							1
33								
34								
35								

36								
37								
38								
39								
40	I	I	I	I		I		5
41								
42								
43								
44		I						1
45	I							1
46								
47								
48								
49			I					1
50								
51								
52		I		I	I			3
53								
54								

55		I			I			2
56								
57						I		1
58								
59								
60								
61								
62			I	I				2
63	I							1
64								
65	I							1
66								
67								
68	I							1
69	I							1
70								
71	I	I		I		I		4
72								
73								

74								
75								
76								
77		I		I	I	I		4
78								
79	I							1
80								
81								
82								
83								
84			I	I	I	I		4
85								
86	I			I				2
87			I					1
88		I						1
89								
90						I		1

Multi-voting 2.0

6 votes per person

Idea Number	Coco	Winnie	Rachel	Akshaj	Nenad	Emre		Total
3	I	I	I	I	I	I		6
4	I							1
13	I			I		I		3
14				I				1
15								
16								
17		I	I			I		3
21			I			I		2
25								
29			I					1
30	I							1
32								
40	I	I	I		I	I		5
44								
45								
49								
52		I		I	I			3
55								
57								
62			I					1
63								
65								
68								

69								
71	I	I				I		3
77		I		I	I			3
79								
84								
86				I				1
87					I			1
88								
90					I			1

Appendix H: Graphical Decision Chart

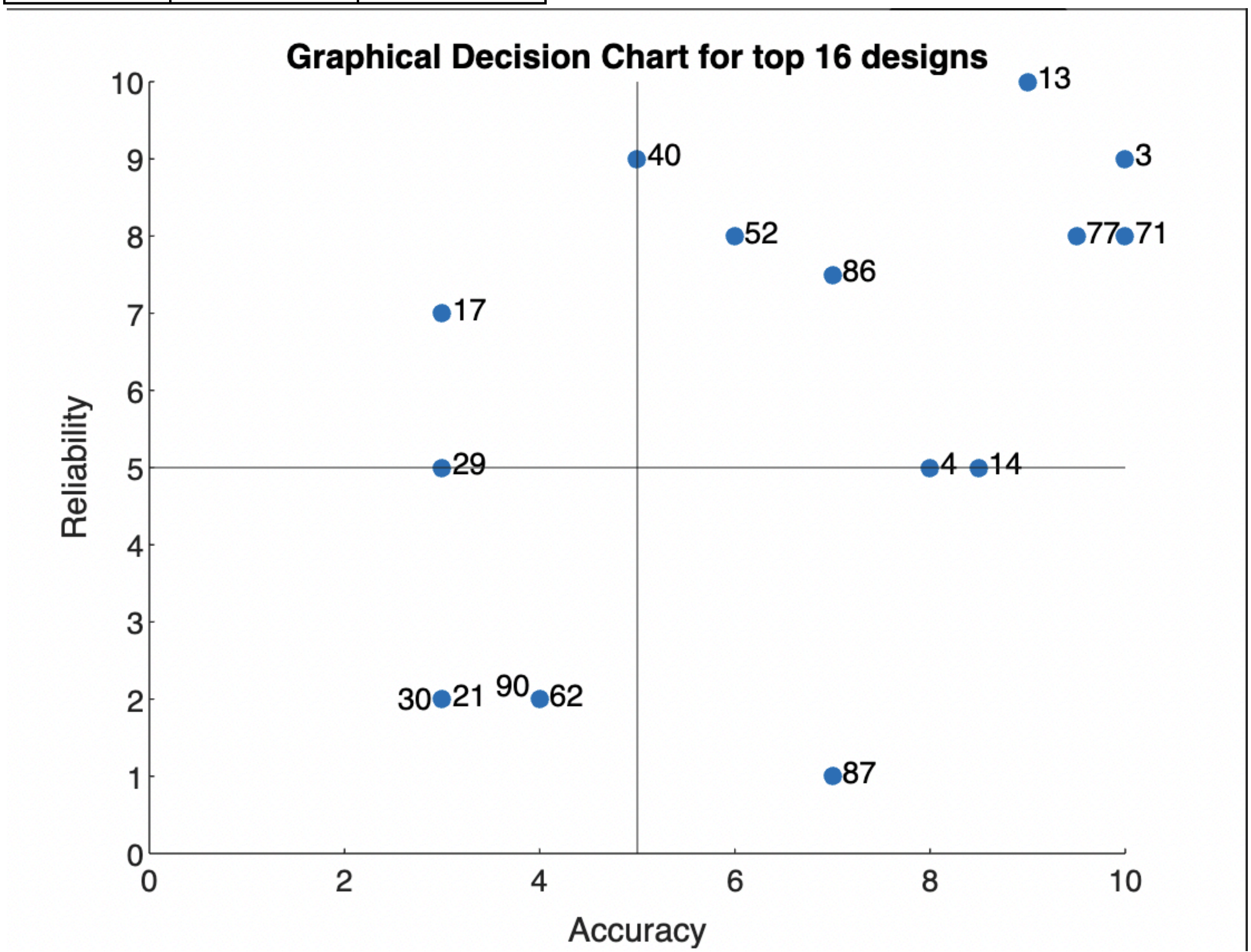
Graphical decision: Accuracy and reliability

We skip safety because that is hard to rank: it is a yes or no situation.

Scale: 10 - good
1 - bad

Idea #	Accuracy	Reliability
3	10	9
4	8	5
13	9	10
14	8.5	5
17	3	7
21	3	2
29	3	5
30	3	2
40	5	9
52	6	8

62	4	2
71	10	8
77	9.5	8
86	7	7.5
87	7	1
90	4	2



Appendix I: Solution Summary

Solution summary

Solutions 3, 13, 71

	1. Secure & Unsecure Foot	2. Record the pressure of standing or record user-inputted pressure patterns	3. Record the user's weight, age, and foot size	4. Calculate output pressure from inputted information	5. Precisely mimic pressure patterns on the foot for walking, standing, turning, upstairs, downstairs, and shifting weight	6. Others
3	1.2 A rack for actuators and straps with Buckles to secure foot +rail	2.3 Array of small sensors (a sensor on each actuator)	3.4, app 3.9, Bluetooth 3.11 Cable	4.1, 4.7- App, Map nerve areas, then apply pressure based on area	5.1, 5.9, 5.13, 5.10, Arduino - Linear actuator, arrays of small actuators, laptop, Actuonix actuator [38]	6.1, 6.8 Sorbothane pads (for comfort?), outlet 0.5 mm thick (for no reason
13	1.3 A rack for actuators and adjustable barriers that keep the foot in place (note to Coco: make these racks different)	2.1 - Dielectric (can be removed)	3.1, 3.4, 3.11 - Website, App, Cable	4.1, 4.7 - App, Map nerve areas, then apply pressure based on area	5.9, 5.13 5.10 array of actuators, laptop,, arduino X-NA-E actuator [42]	6.11 voltage source (DC power supply)
71	1.4 Ski boot	2.1- Dielectric (fixed with sorbothane	3.7, 3.9 - touchscreen, bluetooth	4.2, 4.8 Simulation, database	5.1, 5.10, 5.21 or 5.22 Linear actuator, laptop arduino	6.1, 6.8 Sorbothane sheet, outlet

		sheet)			microcontroller SOViK actuator [46]	

Appendix J: Weighted Decision Matrix and Pugh Method

Value of 0% Does not meet objectives
Value of 20% Meet objective weakly
Value of 40% Meet objective somewhat
Value of 60% Meet objective mostly
Value of 80% Meet objective strongly
Value of 100% Prominently meet objective

Objectives	Rank (From Pairwise Comparison)	Weighted (Determined Through Discussion)
Accuracy	1	35%
Safety	2	25%
Reliability	3	20%
Adaptability	4	10%
Usability	5	5%
Others	6	5%
Total		100%

Idea #	13	3	71
Accuracy	.35 x .85 = 29.75%	.35 x .85 = 29.75% Same as idea 13: Actuators are smaller, but straps allow movement	.35 x .65 = 22.75% Less than idea 13: Actuator repeatability error is slightly higher and dielectric layer

			may affect pressure application
Safety	.25 x 1.00 = 25%	.25 x 1.00 = 25% Same as idea 13: Using a similar device, so heat production is similar	.25 x .100 = 25% Same as idea 13: Using a similar device, so heat production is similar
Reliability	.20 x .70 = 14%	.20 x .80 = 16% More than idea 13: An array of sensors is more reliable (and replaceable) than a dielectric layer	.20 x .70 = 14% Same as idea 13: Uses a fragile touchscreen
Adaptability	.10 x 1.00 = 10%	.10 x 1.00 = 10% Same as idea 13: Straps can adjust to any size	.10 x .90 = 9% Less than idea 13, ski boots have limited adjustability
Usability	.05 x .75 = 3.25%	.05 x 1.00 = 5% More than idea 13: Does not need to remove a layer before operation	.05 x 1.00 = 5% More than idea 13: Has a touch screen for easy user interface
Others (EMI)	.05 x 1.00 = 5%	.05 x .70 = 3.5% Less than idea 13: Bluetooth emits EMI	.05 x 1.00 = 5% Same as idea 13: No EMI
Totals	**88%**	**89.25%**	**80.75%**

Pugh:

Idea #	Datum: 13	3	71
Accuracy	0	0	-1
Safety	0	0	0
Reliability	0	1	0
Adaptability	0	0	-1

Usability	0	1	1
Others (EMI)	0	-1	0
Sum	**0**	**1**	**-1**

Appendix K: Online Simulated Motion Platform and Prototype

Besides prototyping the design in the real world, our team will utilize Tinkercad 3D and circuit design platforms to ensure the functionality of the ***NerveMapPro***.

Objectives	Simulated Platform	Prototype for the future In Engineering and Computer Science Library
Accuracy on Location and Force	• The time delay is within the desired range • All actuators can function simultaneously • Pressure is simulated in the area	Pressure Mapping: • Pressure sensing machine • Compare the actual data and the input data Pressure Simulation: • Use Arduino Uno to connect design with actuators to check the imitation of the pressure
Safety	• The voltage applied to branches are less than 120V	• Use a thermometer to measure instrument temperature
Reliability	Not Applicable Components' lifespan provided by companies	• Need long-term use to confirm
Adaptability	Not Applicable	• Input data on the code and check the successfulness
Others	Not Applicable	• Use mobile decibel meter to measure noise level • Borrow EMI calculator to calculate EMI from the prototype

Appendix L: Calculations for maximum pressure in Tables 6, 7 and 8

Table 6: (idea 3)	Maximum force: 80N [38] Contact surface: 10mm diameter circle Maximum pressure = $F/A = 80N / 0.005^2 m / \pi$ = 1018 kPa
Table 7: (idea 13)	Maximum force: 25N [42] Contact surface: 20x20 mm square add-on to tip Maximum pressure = $F/A = 25N / 0.02m/0.02m$ = 62.5 kPa
Table 8: (idea 71)	Maximum force: 98N [46] Contact surface: 10 mm diameter circle Maximum pressure = $F/A = 98N / 0.005^2 m / \pi$ = 1248 kPa

Appendix M: Calculations for accuracy

The cross-sectional area of the device is 63.6mm^2 and the maximum force applied by it is 80N [38].

$$Pressure = Force/Area = 80\ N/6.36x10^{-5}\ m^2 \simeq 1257\ kPa$$

Thus, the maximum pressure is 1257 kPa.

Using the Tolerance Calculator [25]:

Maximum Pressure: $1257\ kPa \times Percentage\ Error:\ 1\% = 12.57\ kPa$