IS319: Avalanche Training in Virtual Environment

EG3301R Final Report
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MR Yip Seck Hong, Former President of Singapore Mountaineering Federation (SMF)

MS Joanne Soo, Founder of Ace Adventure Expeditions (AAE)

MR Khoo Swee Chiow, Founder of Dare to Dream

Executive Summary

Technological advancements in the area of Virtual Reality (VR) in the past decade have been growing exponentially and it is of no surprise that we may be closely approaching the advent of the Virtual Reality Age. VR is a technology which allows the user to be engaged in an immersive, simulated environment in which he is able to experience events that may not be possible in the physical world.

For this project, the team is focused particularly in potential areas of integrating the provision of haptic feedback and locomotion in VR. Through research as well as interviews with potential stakeholders, the team has identified a gap and a possible application area for incorporating VR with Avalanche Training.

Natural disasters such as avalanches are abrupt and hard to replicate safely in a controlled environment. Currently, there are no actual methods of simulating an avalanche and training mountaineers to react to it. Existing solutions for avalanche training are mostly theoretical in nature and there are no means for mountaineers to actually apply what they have learnt in theory to practical applications. The importance of such training is further exemplified by the fact that the current mortality rate for avalanche related accidents is 90%.

Given the difficulty and safety concerns to effectively prepare mountaineers for avalanches in the physical world, this is where the team feels the incorporation of avalanche training with VR technology can add the most value to such trainings. In a virtual environment, users will be able to safely train for avalanches in a controlled environment while also receiving the appropriate visual and haptics feedback, making them feel as though they are in a real avalanche.

Through thorough research, concept generation and selection, the team's final concept is an integrated system, with pulleys and bungee cords that will be used to elevate the user to a "swimming" position, akin to the position when he is caught in an avalanche. The system will also have several mechanisms such as resistance bands and motors so as to vary the amount of resistance felt by the user over the course of the simulation.

Ultimately, the aim of this project is to design a means to provide realistic avalanche preparedness training through simulation, so as to mentally and physically prepare mountaineers for an avalanche and equip them with skills necessary to save themselves during an avalanche.

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1. Project Clarification

1.1 Problem Description

There is an increasing number of mountaineers across the world, especially in Singapore, with more planning to scale Mt Everest out of interest (Chong, 2017). However, at the same time, avalanches are also gradually increasing in its prevalence due to rising temperatures as a result of climate change (Erickson, 2017). On average, avalanches claim the lives of at least 150 victims on average (National Geographic, 2014) with the main cause of death attributed to suffocation[1] (Ilgenfritz, 2011)

With the high risks involved in mountaineering, especially in cold climates, it is thus important for mountaineers to go through avalanche preparedness training. However, current solutions are expensive, where lessons are conducted overseas, (Kodas, 2010)and are limited to pre and post avalanche, where mountaineers can only read about what to do if they are trapped in an avalanche itself (Khoo S. C., personal communication, 2018). The reason for this is due to physical limitations, where actual avalanches cannot be simulated safely.

Fortunately, with technological advances in the realm of Virtual Reality (VR), avalanche simulation and training will soon become a reality. VR has the ability to bridge the gap between the unpredictable nature of our natural environment and the existing limitations in technology. As such, the team commits to integrate VR technology into avalanche training.

1.2 Value Proposition

There are 3 stakeholders in mountaineering- mountaineers, mountaineering trainers and adventure outfitters. Interviews with these 3 prominent stakeholders in Singapore's mountaineering scene were conducted and their needs were identified (Appendix 1).

Mountaineers need comprehensive and cost-effective training which prepares themselves for avalanches because it is important for them to be able to practice and understand steps to undertake in an avalanche.

Mountaineering trainers need a means of simulating an avalanche to better prepare their students in life-threatening situations because such realistic trainings can

[1] 75% of deaths caused by suffocation

prepare their students to react and respond in a timely fashion, thereby increasing their chances of survival.

Adventure outfitters need a way to lower the entry requirements, in terms of costs and availability, of mountaineering so that more people can pick up mountaineering and progress as avid mountaineers.

1.3 Design Statement

The project aims to design a means to provide realistic avalanche preparedness training through simulation, to mentally and physically prepare mountaineers, and equip them with skills necessary to save themselves during an avalanche.

2. Detail Design

2.1 Design Specification

With the limited time on the project, the team has scoped the project to focus on upper body simulation. Through this, the team came up with a comprehensive list of design specifications of which only selected ones will be addressed in this report, as prior work has already been done in making of the VR environment itself (by Clement and Yi Jiat during Special Term). Below is a table which summarises the specifications selected.

Cost		
Demand	Below $4000	Cost
Safety		
Demand	Reliable and sturdy set-up	Stability
Demand	Sufficient space between body and accessories	Minimise injuries
Head Mounted Display		
Demand	Natural human eye field of view • Field of view of at least 110 degrees	High field of view
Demand	Smooth and unhindered tracking and transition of images • Refresh rate of at least 90 Hz	Tracking and transition
Arm Tracking		
Demand	Seamless tracking *Hands-free tracking*	Tracking

	• High accuracy	
Haptics		
Demand	Force acting on arms and upper body • Simulate resistance from snow while swimming • Approximately 30 N on each arm (Appendix B)	Force feedback

Table 1: Selected Design Specifications

2.2 Design Considerations

To ensure that the user's experience is as realistic as possible, and that the team's designs meet the design specifications, the team came up with a list of considerations for each component.

2.2.1 Tracking

2.2.1.1 Head Mounted Display

Considerations:

- Reduce amount of clutter between user and HMD to prevent entanglement
- Able to be tracked at different angles seamlessly
- Allow the user to view the virtual environment smoothly

Proposed Solutions:

- Obtain a Head Mounted Display (HMD) that could allow for wireless tracking
- Choose a system that works together with the HMD seamlessly
- Will be using SteamVR lighthouse tracking system, with the HTC Vive Pro

2.2.1.2 Arm Tracking

Considerations:

- Provide a way for the user to attempt swimming strokes without feeling awkward
- Reduce the clutter (wire) and distance (size) between user and tracker to prevent collisions and damage
- Able to track at different angles and distances seamlessly (based on swimming motion)

Proposed Solutions:

- Minimise the number of trackers need for proper upper body tracking

- Choose wireless trackers that align with the system with good tracking
- Will be using/testing HTC Vive Controllers, HTC Vive Trackers and Custom Steam VR supported hardware tracking development kits (Steam VR HDK)

2.2.2 Mechanical Structure

2.2.2.1 Structure

Considerations:

- Dimensions of structure must fit the user's body size
- Must be sturdy to prevent injuries
- Able to be assembled and disassembled for storage and portability

Proposed Solutions:

- Look into the body dimensions of a Singaporean male
- Get aluminium profiles
- Use bolts and nuts instead of welding

2.2.2.2 Forces

Considerations:

- Amount of force must be close to amount of force experienced by user when he swims
- User's arm positions may affect the force exerted
- Applied force must be multi-directional

Proposed Solutions:

- Study forces and respective arm positions in swimming (breaststroke)
- Make use of resistance bands to gradually increase the force as the user's arm moves from one position to another
- Utilise multiple resistance bands in various directions

2.2.2.3 Position of User's Body

Considerations:

- User's body needs to be at an angle similar to swimming motion (breaststroke)
- User has to feel a normal reaction force on his torso, similar to the case when the avalanche comes, and the user's body is lying on ice

Proposed Solutions:

- Make use of a bench

- Change the angle of the bench to be at the corresponding angle

2.2.3 Haptics

2.2.3.1 Resistance in Swimming through Avalanche

Considerations:

- Provide users resistance in swimming motion (breaststroke) through avalanche
- Resistance produced in the motion needs to be able to target the arms muscles involved in the breast stroke motion without impeding normal movement
- Resistance experience by user needs to correspond accurately to the motion of the breast stroke and what is visualised in the software

Proposed Solutions:

- Usage of Electrical Muscle Stimulation (EMS)
- Study parameters within the EMS to produce a smooth resistance in the motion of breast stroke
- Implement the EMS to Unity via a printed circuit board that acts as a control centre for the EMS

3. Prototyping

3.1 Tracking

3.1.1 Making

Tracking is extremely important in VR. It allows the user to be simulated in the virtual environment, where the user is able to control the avatar accurately. With our choice of software (Appendix A), we need 3-point tracking to allow for smooth simulation. With the head mounted display tracking the head, we only need 2 trackers to track each arm. From initial tests (Appendix A) of the simulation using existing tracking devices, we found that it would not be ideal to settle with existing, on the market, tracking device for our simulation. Since even the most prominent and popular tracking devices faced complaints from users, we decided that it would be wise to consider making a custom tracker that will be more fitting for our simulations.

As such, Yong Song decided to procure a Steam VR supported hardware development kit to set out making a custom tracker. Based on the user feedback, he decided to design a tracker that is fitted at the wrist which should be more form fitting and have better weight distribution (Appendix A).

In the first iteration, he aimed to create a tracker that is as small as possible, similar to a watch design that can be attached to the wrist with a strap. The design was then 3D printed and incorporated with the hardware components and tested in simulations, which did not fare well in terms of tracking.

However, he learnt from this iteration and created a second prototype. Understanding that outright reduction of size could not solve the user's needs, he finally came up with a design that better utilises the space around the wrist. The second design was similar to a bracelet design, where the sensors are spread around the wrist, which could allow for better tracking while reducing the overall profile. However, this design was still not ideal. (Appendix A)

Thus, he created a third prototype that learned from the previous two failures. This prototype was similar to a bracer design that has a small profile and can be held firmly to the wrist. With initial testing and simulations being favourable, he then proceeded to integrate the tracker into the VR simulation by utilising the Steam VR software, along with configuration and render model creation. (Appendix A)

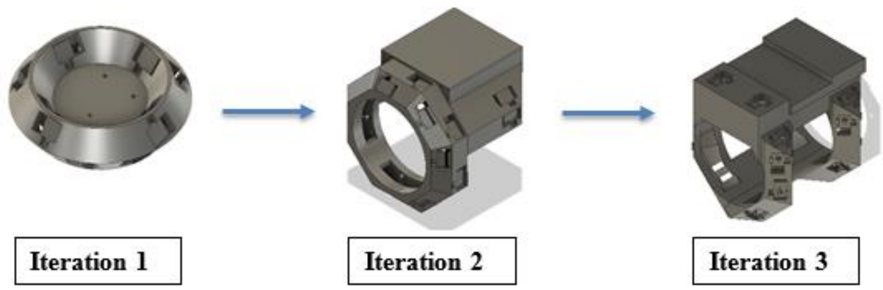

Figure 1: Progression of Iterations of Prototypes

Figure 2: Progression of VR Integration

3.1.2 Testing

On top of testing in between the prototypes for verifying the designs, where we were able to make iterative improvements (Appendix A), we also conducted with the initial users to verify that the final design worked better and more suited for our simulation compared to existing, on market, tracking devices.

Figure 3: User Testing

3.2 Mechanical Structure

3.2.1 Making

Haptics is one of the design considerations which the team has identified. It is an important component to improve realism (García-Valle, Ferre, Breñosa, & Vargas, 2017) for our users. As such, Jonita embarked on the design of a mechanical structure to generate haptic feedback for the user.

3.2.1.1 Structure

In the making of the structure, a study on the average body parts of a Singaporean male is done. The structure was then designed to a height of 1400 mm, width of 1000 mm and length of 2200 mm through a series of calculations based on the average Singaporean male as appended in Appendix B.

Aluminium parts and accessories were then purchased from Prestech as they have compatible accessories which the team requires in the prototype, and that they were able to deliver within 3 working days.

The parts were then subsequently assembled together using socket cap screws, rhombus nuts and angle brackets, as seem from the prototype to the right.

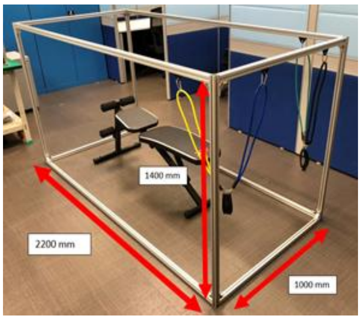

Figure 4: Dimensions of Mechanical Structure

3.2.1.2 Analysis of Forces

In order to provide haptic feedback for the user, Jonita first conducted an online research on the forces a swimmer experiences, and derived that the user experiences a force of 30 N on each arm as he swims (Appendix B).

Further on, resistance bands of varying resistances were then tested for the amount of force they can provide for the users in a single direction (Appendix B) in the first iteration. After getting these data, Jonita then went on to study the resultant forces of different resistance bands, and came to a conclusion that the green resistance bands are the most suitable for the users because they provided a resultant force of 30 N on each arm.

However, the first iteration came with limitations such as having huge amounts of slack in resistance bands as well as having a missing force in the direction when the user pushes his arms forward. Therefore, Jonita proceeded with the second iteration of making amendments to the resistance bands.

In the second iteration, the lengths of the resistance bands were altered by looping the resistance bands around the tool slider hook. As this resulted in increase in resistance, Jonita re-evaluated the resistances of the bands, and used the yellow bands instead of the green.

A third band was then added from the back, which provided the forward pushing force which was missing in iteration 1.

3.2.1.3 Position of User's Body

To make the experience for the user as realistic as possible, a gym bench with adjustable angles was purchased. The angle was then set to 30 degrees with respect to the ground, just as it is for a swimmer.

3.2.2 Testing

Having completed iteration 2 of the prototype, a test was then conducted among several users. Questions were then framed to relate the forces as felt by the users to a realistic swimming scenario. The results showed that when the user moves his arms in an out sweep motion, the experience was rather realistic. However, in other motions in swimming, the results were less than ideal because of the inaccurate muscle group being activated.

Nevertheless, this prototype allowed the team to learn about the forces as experienced in swimming.

3.3 Electrical Muscle Stimulation (EMS)

3.3.1 Making

Electrical muscle stimulation is often used in physiotherapy and rehabilitation in order to simulate usage of the muscle after prolonged inactivity due to injury or disability. It presented a useful mechanism in order to simulate the actuation of muscles involved in the breast stroke motion in swimming through an avalanche.

Figure 5: Digital EMS SEM43

The EMS works by sending a current through the electrode placed on the muscle, resulting in a contraction in the muscle when the parameters are above certain thresholds. These parameters include frequency, pulse width and current, which will be explained in detail in Appendix C.

Not only did the EMS address the challenges faced in the mechanical structure, it satisfied the design considerations of unrestricted range of motion in its portal form factor, targeted muscle group actuation in the 4-electrode pad placement and also calibration required in different users through the adjustable parameters.

3.3.2 Assembly

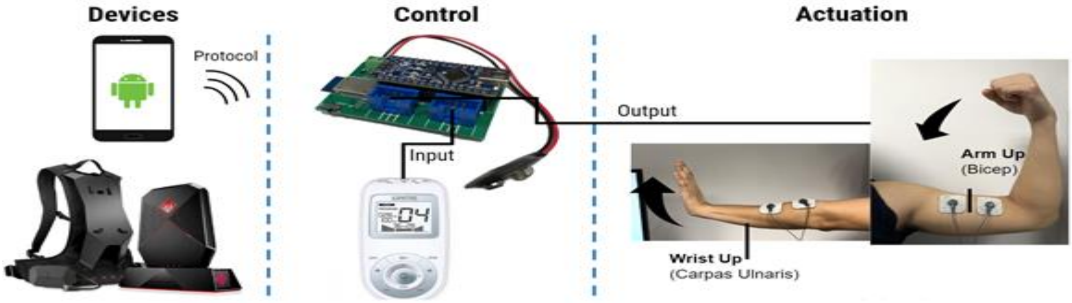

Figure 6: Force Feedback System with Open Sourced PCB

An open source PCB design called openEMSstim from HCI researcher Pedro Lopes was used to guide Jerome towards ordering the correct components to be fabricated and assembled. Additional modifications needed to be made to the existing EMS to connect with the PCB which allowed us to interact with the EMS via Bluetooth from an android phone or USB on a PC (Appendix C).

3.3.3 Testing

A user study was conducted with 5 users with different forearm and bicep measurements to determine the combination of parameters suitable for produce resistance in our simulation. As the focus of the project was on arm haptics, the electrodes were placed on the Carpas Ulnaris which actuates the muscles involved in causing the wrist to move up, and the Bicep which causes the arm to curl in.

Different combinations of the parameters were tested, and users would rate their experience based on the scale developed by Jerome. Most users commented on being initially “scared” of sensation of getting electrocuted. It was found that a larger current is required to actuate the arm compared to the wrist and a bicep/triceps with a larger measurement also required a larger current to actuate. A range of combinations of parameters were determined and calibrated based on the user (Appendix C).

Scale	
0	No Movement and No Sensation
1	No movement and Slight Sensation
2	Minor Movement and Sensation
3	Actuation of Fingers and Sensation
4	Gradual Actuation of Wrist and Sensation
5	Actuation of Wrist and Pain/Strain

Scale	
0	No Movement and No Sensation
1	No Movement and Slight Sensation
2	No Movement and Increased Sensation
3	Contraction of Bicep and Increased Sensation
4	Contraction of Bicep and Discomfort
5	Full Actuation of Arm and Pain/Discomfort

Figure 7: Scale of EMS experience for Wrist and Arm respectively.

3.3.4 Implementation

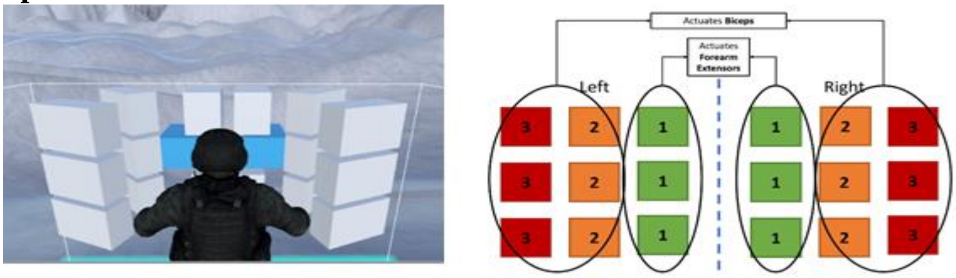

Figure 8: Mapping of EMS to Collision Boxes

In order to map the resistance to the motion of the breast stroke in our virtual simulation, the boxes in the collider system, which allowed the users to move forward when the correct sequence of boxes are touched, were mapped to the EMS.

Based on the feedback from the user study, the EMS is introduced progressively to the users by first actuating the forearm extensors when they encounter the first column of the collider system, then followed by the bicep in the 2nd and 3rd column. This allowed the experience to be more natural instead of a strong resistance at the beginning of the motion.

Figure 9: LED lighting up corresponding to Collision Boxes

4 Conclusion

In conclusion, this project allowed the team to utilise design thinking to frame the user's needs and pain points, come up with design considerations and then followed by the actual implementation of the team's design. Through this project, the team learned about the possibilities of integrating haptics into VR, which is a difficult task to do. Having studied about the forces involved in simulating resistance on arms, the team is now ready to explore the possibilities of creating a full-scale pulley system which will be a more complex system which involves a full haptics system.

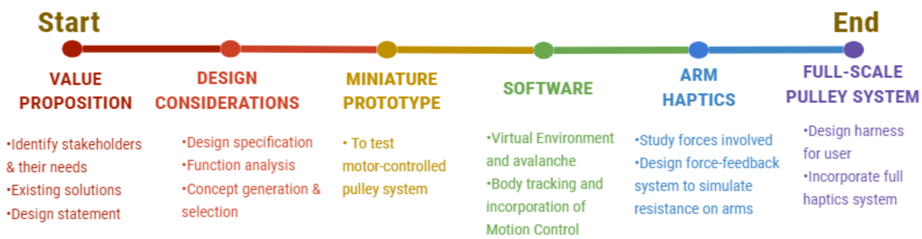

Figure 10: Project Timeline

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Appendix A – Tracking by Lim Yong Song

A.1 Tracking

The tracking design has 3 main considerations, where the user needs to be able to attempt swimming strokes without feeling awkward, the tracker needs to be able to translate the motions into the virtual environment smoothly and the tracker should be form fitting. With these considerations in mind, the team has chosen to use the Final IK plugin, in Unity, for our virtual avatar. The avatar also allows for minimal tracking points, by utilising inverse kinematics, to generate virtual body motion. As such, the choice of virtual avatar allowed us to minimise the amount of tracking points required, with only three-point tracking needed, where each point should be as far from each other as possible.

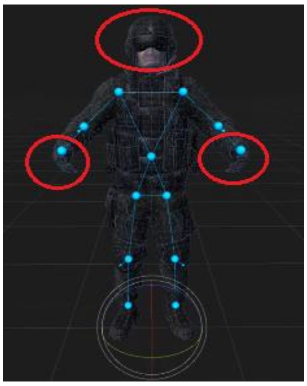


Figure 11: Virtual Avatar Used, where Head and Hands are tracked

With the head tracked by the head mounted display, HTC Vive Pro, which we have chosen based on specifications, the team now needs to focus on a tracking device for the hands that will be optimal for our simulations.

A.2 Initial experimentations

In the initial experimentations to get an optimal tracking device for the hands, the team tested out 2 of the most prominent trackers available, namely the HTC Vive controller and the HTC Vive Tracker.

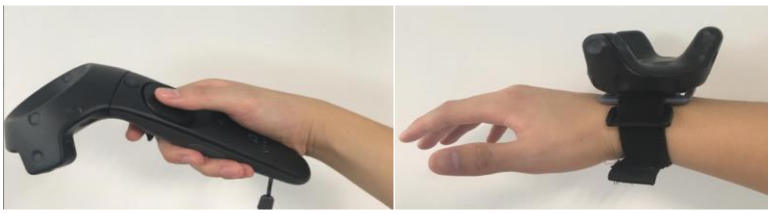


Figure 12: HTC Vive Controller & HTC Vive Tracker

In this experimentation, the team got 3 users to test out the tracking devices for our virtual simulation and we created a table to capture the key points and comments of the participants after several simulations, inclusive of low breaststrokes and high breaststrokes.

	Comments	
	HTC Vive Controller	**HTC Vive Tracker**
User 1	Tracks well but holding on to a device while swimming feels weird	Tracks well but the tracker seems to shake and flail a lot during rapid motion
User 2	Tracks well but it feels clunky to hold on to something when you are not pressing anything	Tracks well but the tracker hits the head mounted display at times, during high breaststroke, and feel it is unsafe
User 3	Tracks well but do not want to hold onto anything	Tracks well and it feels like a large watch

Table 2: Table of Comments from Initial Experimentation

From these data, the team noticed that it was paramount to keep the hands free for our simulation, especially as it does not require any input from a controller. On top of this, we need to address issues in the design of a Vive Tracker. Thus, we felt that would be best to create a custom tracker that would be customised for the project's needs. The reason why we felt that it was feasible was because Valve (the company that produced the VR system the team is using and HTC Vive controller/ trackers) also provides hardware and software support in the creation of custom controllers/ tracking devices that can be easily integrated into their system.

From the initial experiments, the team identified that the issues of the Vive Tracker were due to the size, where the device protrudes up to 5.5cm above the users' wrist, and distribution of weight, where most of the weight is focused above the wrist. These will be considerations that the team looks into during our design and prototyping phase.

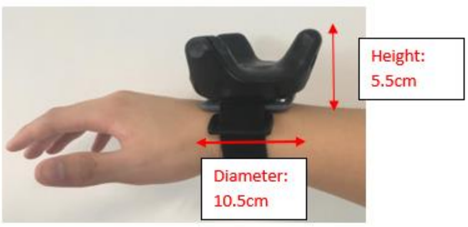


Figure 13: Dimensions of Vive Tracker

A.3 Hardware and software

In terms of hardware, as per recommendations, the team has decided on procuring the hardware necessary for a tracking device from a Valve supported company, called Virtual Builds. Providing one of the smallest hardware components required for SteamVR tracking, we purchased the pebble kit, which consists of the sensors, battery, and the VR core board, that houses the inertial management unit (imu) and processes the sensor positions. This will allow the design to be small and wireless, further improving on user experience during use.

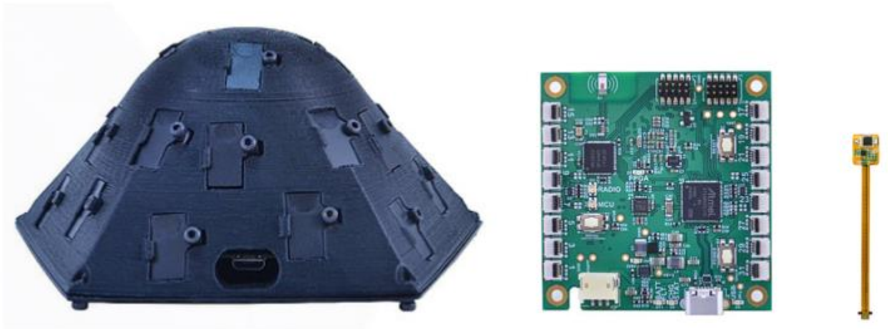


Figure 14: Pebble Kit comprising of 5x5cm Core Board and 1.3x1.2cm Sensors

In terms of software, the team decided on Autodesk Fusion 360, a computer aided design (CAD) software, to aid in designing a suitable case/housing for the tracker for 3D printing. The team also decided to use the tracking simulation and calibration software provided by Valve, called the SteamVR Tracking HDK. The SteamVR HDK includes programs that can simulate how well a design tracks at different orientations, rotations or translations, giving an overall score based on the performance, with 0 being the best score and 1000 being the worst. This program will be to help us determine the best sensor position placement and also improve on the overall design. On top of this, the SteamVR HDK also provides calibration tools that can be used in sync with the SteamVR setup that can help us integrate the tracker into the virtual environment. On top of this, the team also will be utilising the Blender software to create the render models, for the custom tracker, that will appear in the virtual environment.

Figure 65: Software used for Prototyping

A.4 Custom Tracker

Based on our initial experimentations and comments from the users, the custom tracker would set out to have be more form fitting and have better weight distribution.

A.4.1 Prototype 1

In the first design, the team set out to reduce the size of the tracker as much as possible. With a watch as inspiration, the team set out to calculate all dimensions required in order to house the hardware in as small a design as possible, while ensuring that enough sensors can fit on the design to ensure smooth tracking.

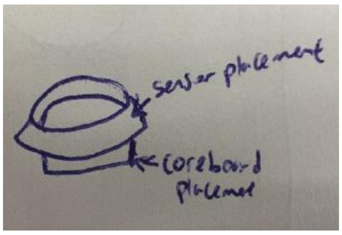


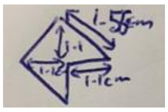
Figure 76: Rough Sketch of Prototype 1

With considerations that the 3D printer can print minimum 2mm cleanly, the core board is of 5x5cm size, and that sensors ports require at least 1.9x1.5cm to be housed safely, we made the following calculations:

Core board Placement:

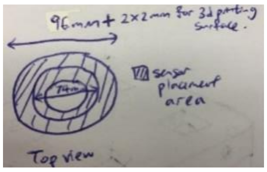
Minimum core board housing diameter = $\sqrt{(50^2+50^2)} + 4 \approx 74$ mm

Sensor Placement:



Minimum extension out of main body (for sensor placement at an angle of 45°) $= \sqrt{(15^2/2)} \times 2 \approx 22$ mm

Sensors will be placed along the 1.55cm face. This will allow for the most coverage of sensor while maintaining minimal usage of space, where the image to the right shows the region of placement.



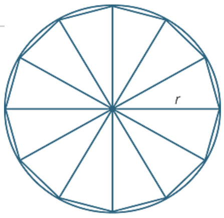
Calculations to confirm enough sensors can be placed:

Side length given the radius (circumradius):

If you know the radius (distance from the center to a vertex):

$$side = 2r \sin\left(\frac{180}{n}\right)$$

where:
r is the radius (circumradius)
n is the number of sides
sin is the sine function calculated in **degrees**



Following the above formula, the team then calculated the potential number of sensors that can fit into the design, where side will be 19mm (length of sensor slot), and n x 3 the potential number of sensors that can be placed (based on our sensor placement design), where we will need at least 24 sensors to be placed.

Max sensors that can be placed $= 3 \times (180/\sin^{-1}(19/(2*37))) \approx 36$ sensors

Figure 17: Calculations for Prototype

After confirmation that the design can work, the team then set out to create the 3D model using Autodesk Fusion 360:

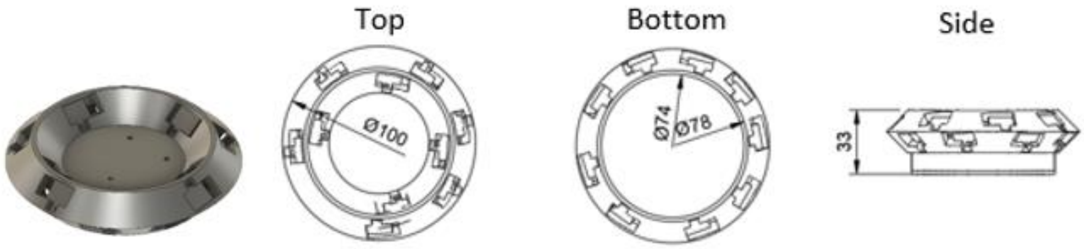


Figure 18: 3D and 2D Drawings of Prototype 1

After designing the 3D model, the team then placed the design in the SteamVR HDK simulation program to check the tracking performance:

Figure 89: Tracking Performance of Prototype 1

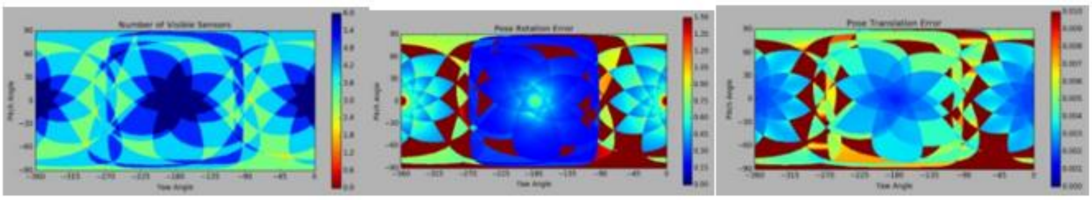


Figure 209: Data Generated by Simulation Software for Prototype 1

From the data generated by the simulation software, the team could see that this design was not ideal with an overall score of 228 (typical trackers hover around 100), and high amounts of rotation and translation error as seen from the dark red portions.

Despite this, the team still decided to 3D printed the design to test the physical design. The 3D printed design showed us that it was not good to aggressively cut the size of the tracker, as we found problems in trying to keep the wires in place. In doing so the condensed wires, near the core board, also resulted in interference of the antenna, and resulted in the tracker being unable to sync with SteamVR.

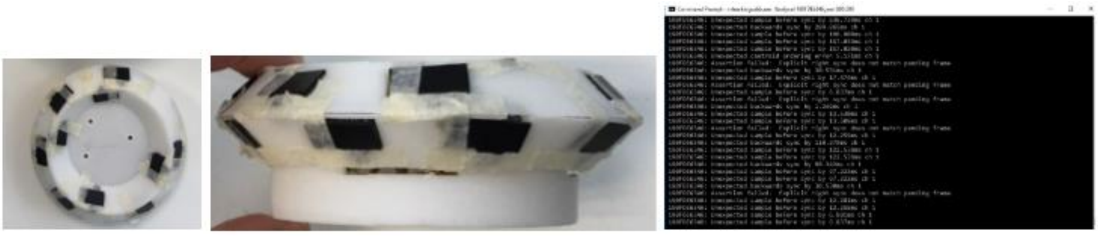


Figure 2110: Testing of Prototype 1

From this prototype, the team then understood that keeping the same design as a Vive tracker, but reducing the size, was not a viable solution as the sensors could not achieve good tracking when condensed in a small area.

A.4.2 Prototype 2

Learning from our prototype 1, the team understood that the size issue needs to be addressed in other ways, instead of the outright reduction of size. Through brainstorming and analysis of other tracker designs, the team found that it would be better to make use of the unutilised area around the wrist. By spreading the sensors around the wrist, considering a 7cm diameter, along with previously calculated data, the team was able to create a design with even smaller profile while improving the tracking performance.

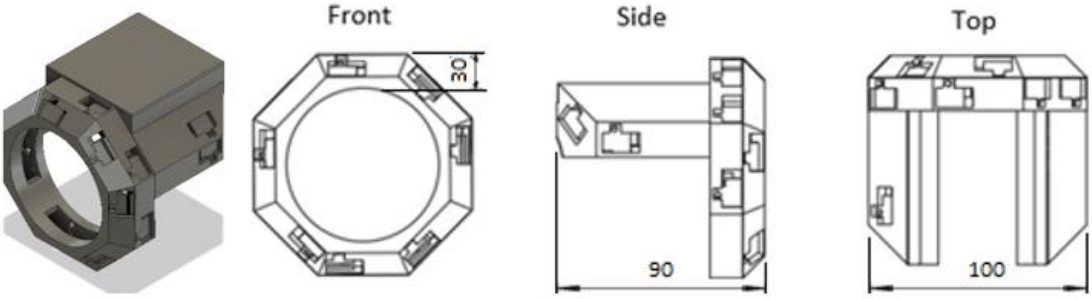


Figure 2211: 3D and 2D Drawings of Prototype 2

After designing the 3D model, the team then placed the design in the SteamVR HDK simulation program to check the tracking performance:

Figure 2312: Tracking Performance of Prototype 2

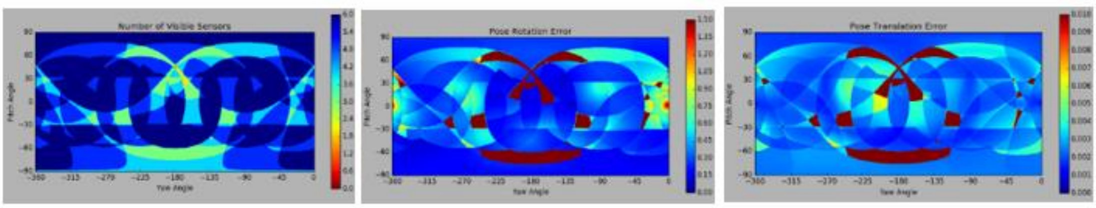


Figure 24: Data Generated by Simulation Software for Prototype 2

From the data generated by the simulation software, the team could see that this design was working well, and the rotation and translation error are vastly lower compared the prototype 1, as seen from the minimal dark red portions, and high amount of dark blue throughout.

Understanding that the model is working well in the simulations, the team then 3D printed the design for physical testing. When tested with users, the 3D printed design showed us that there are still a lot of movements and shifts due to the lopped sided weight distribution and securing point being at the opposite side.

Figure 135: 3D Printed Model of Prototype 2

A.4.3 Prototype 3 (Final design)

Learning from the previous 2 prototypes, the team understood what was important in the design. In prototype 3, the design was more symmetric, similar to a bracer, where the secure point would be in the middle, along with a more even weight distribution.

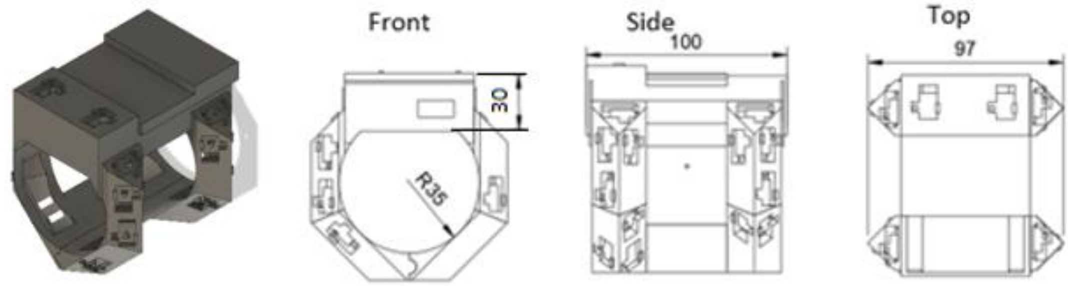


Figure 146: 3D and 2D Drawings of Prototype 3

After designing the 3D model, the team then placed the design in the SteamVR HDK simulation program to check the tracking performance:

Figure 157: Tracking Performance of Prototype 3

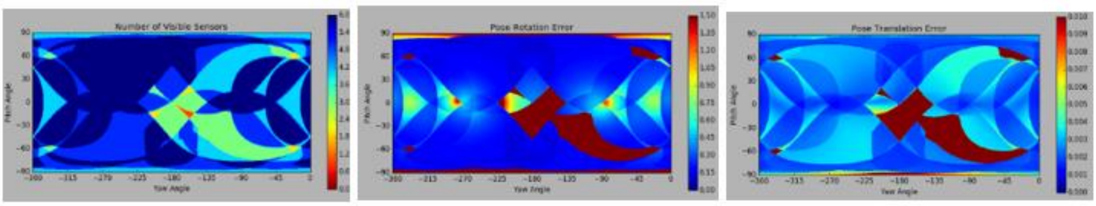


Figure 168: Data Generated by Simulation Software for Prototype 3

From the data generated by the simulation software, the team could see that this design was working well, and comparable to prototype 2.

Following this, the team 3D printed the design for physical testing. This design showed the most promising feedback and results thus far, so we proceeded with further development.

Figure 179: 3D Printed Model of Prototype 3

A.5 Virtual reality integration

A.5.1 Tracker configurations

After finalising the 3D model design for the tracker, the team would then need to create the json file that will govern the tracker behaviour. In this file, 2 major variables will be the "lighthouse_config" data, which governs the sensor position and overall positioning of the tracker and the “imu” data, which governs the orientation and movement of the tracker.

In order to get accurate position of the sensors for the “lighthouse_config” data, the team needed to label each sensor position and create the sensor position and normal table, where the normal are calculated following formulas provided:

The components for each unit normal vector can then be calculated with the following equations.

$$x_{normal} = \frac{x_{distal} - x_{surf}}{\sqrt{(x_{distal} - x_{surf})^2 + (y_{distal} - y_{surf})^2 + (z_{distal} - z_{surf})^2}} \quad (1)$$

$$y_{normal} = \frac{y_{distal} - y_{surf}}{\sqrt{(x_{distal} - x_{surf})^2 + (y_{distal} - y_{surf})^2 + (z_{distal} - z_{surf})^2}} \quad (2)$$

$$z_{normal} = \frac{z_{distal} - z_{surf}}{\sqrt{(x_{distal} - x_{surf})^2 + (y_{distal} - y_{surf})^2 + (z_{distal} - z_{surf})^2}} \quad (3)$$

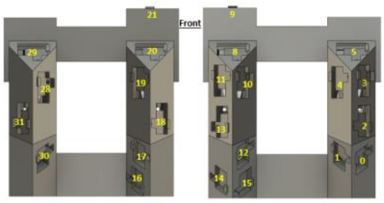


Figure 3018: Formulas for the Calculation of Position of Sensors & position of sensors

Sen no.	X_{surf} *(mm)*	X_{distal} *(mm)*	X_{normal} *(mm)*	Y_{surf} *(mm)*	Y_{distal} *(mm)*	Y_{normal} *(mm)*	Z_{surf} *(mm)*	Z_{distal} *(mm)*	Z_{normal} *(mm)*
0	31.915	32.915	0.500037	-38.272	-39.686	-0.707054	25.926	26.926	0.500037
1	32.969	33.969	0.500037	-28.565	-27.151	0.707054	24.642	25.642	0.500037
2	40.531	41.945	0.706857	-38.64	-40.055	-0.707357	7.519	7.519	0.000000
3	39.787	41.201	0.707107	-39.385	-40.799	-0.707107	-15.415	-15.415	0.000000
4	39.54	40.954	0.707106	-27.368	-25.954	0.707107	-14.616	-14.616	0.000000
5	35.678	37.092	0.706856	-34.194	-34.194	0.000000	-30.083	-31.498	-0.707357
8	35.789	37.203	0.707106	32.922	32.922	0.000000	-29.972	-31.386	-0.707107
9	19.052	19.052	0.000000	35.965	35.965	0.000000	-52.28	-54.28	-1.000000
10	40.703	42.117	0.706857	28.532	27.117	-0.707356	-14.506	-14.506	0.000000
11	40.476	41.89	0.707106	38.696	40.11	0.707108	-15.525	-15.525	0.000000
12	34.253	35.253	0.500038	28.497	27.083	-0.707053	23.261	24.261	0.500038
13	40.854	42.268	0.706858	38.317	39.732	0.707356	7.893	7.893	0.000000
14	18.961	19.961	0.500037	38.975	40.389	0.707054	37.885	38.885	0.500037
15	17.273	18.273	0.500038	28.092	26.678	-0.707053	39.668	40.668	0.500038
16	-16.538	-17.538	-0.500038	27.217	25.803	-0.707053	39.165	40.165	0.500038
17	-34.37	-35.37	-0.499861	29.128	27.713	-0.707304	24.036	25.036	0.499861
18	-40.867	-42.282	-0.707358	38.304	39.718	0.706856	6.542	6.542	0.000000
19	-40.927	-42.341	-0.707107	28.755	27.341	-0.707106	-14.215	-14.215	0.000000
20	-35.687	-37.101	-0.707107	34.279	34.279	0.000000	-30.074	-31.488	-0.707107
21	-19.065	-19.065	0.000000	35.77	35.77	0.000000	-52.28	-54.28	-1.000000
28	-40.363	-41.778	-0.707357	-28.192	-26.778	0.706856	-11.704	-11.704	0.000000
29	-35.767	-37.181	-0.707107	-32.85	-32.85	0.000000	-29.994	-31.408	-0.707107
30	-31.946	-32.946	-0.500038	-28.649	-27.235	0.707053	25.784	26.784	0.500038
31	-41.078	-42.492	-0.707108	-38.094	-39.508	-0.707106	6.397	6.397	0.000000

Table 3: Table for lighthouse_config Data

```
"lighthouse_config" : {
        "channelMap" : [ <sensor number>],
        "modelNormals" : [
              <each sensor's normal>
        ],
        "modelPoints" : [
              <each sensor's point>
        ]
},
```

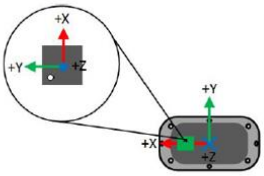
Figure 191: Json Portion to Populate with Table Data

To help with calculation and reduce human error, for the lighthouse_config data, the team created a simple C program script as shown below:

```c
#include <stdio.h>
#include <math.h>

int main()
{
        int num_sensor, i;
        float x_surf[32], y_surf[32], z_surf[32];
        float x_distal[32], y_distal[32], z_distal[32];
        double x_normal[32], y_normal[32], z_normal[32];
        double denominator[32];

        printf("Key in number of Arrays");
        scanf("%d", &num_sensor);
        printf("Key in Xsurfs: ");
        for (i=0; i<num_sensor; i++){
                scanf("%f", &x_surf[i]);
        }
        for (i=0; i<num_sensor; i++){
                scanf("%f", &y_surf[i]);
        }
        for (i=0; i<num_sensor; i++){
                scanf("%f", &z_surf[i]);
        }
        for (i=0; i<num_sensor; i++){
                scanf("%f", &x_distal[i]);
        }
        for (i=0; i<num_sensor; i++){
                scanf("%f", &y_distal[i]);
        }
        for (i=0; i<num_sensor; i++){
                scanf("%f", &z_distal[i]);
        }

        for (i=0; i<num_sensor; i++){
                denominator[i] = sqrt(pow((x_distal[i]-x_surf[i]),2)+pow((y_distal[i]-y_surf[i]), 2)+pow((z_distal[i]-z_surf[i]),2));

                x_normal[i] = (x_distal[i]-x_surf[i]) / denominator[i];
                y_normal[i] = (y_distal[i]-y_surf[i]) / denominator[i];
                z_normal[i] = (z_distal[i]-z_surf[i]) / denominator[i];
        }
        for (i=0; i<num_sensor; i++){
                printf("x_normal[%d] = %lf\n", i, x_normal[i]);
                printf("y_normal[%d] = %lf\n", i, y_normal[i]);
                printf("z_normal[%d] = %lf\n", i, z_normal[i]);
        }
        return 0;
}
```

Figure 202: C Programme Script

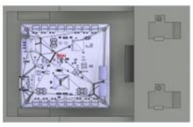
In order to get the accurate imu data, the team obtained the appropriate plus_x and plus_z value by comparing the 3D model orientation positions to the core board orientation position.




```
"imu" : {
   "acc_scale" : [ 0.998, 0.9982, 0.9912 ],
   "acc_bias" : [ 0.04646, -0.04264, -0.2414 ],
   "gyro_scale" : [ 1.0, 1.0, 1.0 ],
   "gyro_bias" : [ 0.06343, 0.01029, -0.02168 ],
   "plus_x" : [ 0, 1, 0 ],
   "plus_z" : [ 0, 0, -1 ],
   "position" : [ -0.040, 0.010, 0.0 ]
   }
```

Figure 213: Comparison of 3D Model Orientation to Core Board Orientation Position

Then the team determined the accurate position of the imu in the 3D model design.



IMU	X(mm)	Y(mm)	Z(mm)
imu	2.104	-19.656	-33.481

Figure 224: Position of imu in 3D Model Design

After which, the team proceeded with the imu calibration, with the SteamVR HDK, where the software will help to obtain an accurate value of the remaining parameters needed for the imu data, by calculating all 6 orientations of the physical imu.

```
Calibrating to gravity sphere, radius 9.8066
0.04417 accelerometer fit error (6 sample vectors x 8 subsamples per vector)

"acc_scale" : [ 0.998, 0.9983, 0.9915 ],
"acc_bias" : [ 0.05089, -0.03676, -0.2253 ],
"gyro_scale" : [ 1.0, 1.0, 1.0 ],
"gyro_bias" : [ 0.06253, 0.01054, -0.02128 ],
```

Figure 235: Calculation of 6 Orientations of Physical imu

The combination of the lighthouse_config and the imu data, then allows us to create an accurate json file to ensure proper tracking when we upload the json file into the tracker itself.

A.5.2 Render model

After tracker configurations has been completed, the team then needs to create the render model, with the corresponding .mtl, .obj, and .png file attached, in order for the tracker to show up in the virtual environment. The .mtl file describes the texture, colour and reflection map of the render model, based on the .png file, while the .obj file will determine how the object looks and is orientated in the virtual environment. To do this, blender, a 3D model creation software, would be utilised.

Firstly, the 3D model created in Autodesk fusion 360 would be imported into blender. Then incorporate the material and texture onto the model within blender itself. Following this, generate the UV map of the model that will texture the model correct. After which, the team just needs to export the files and place them according in the SteamVR folder and after adjusting the files so that they reference each other, the render model will appear in virtual reality.

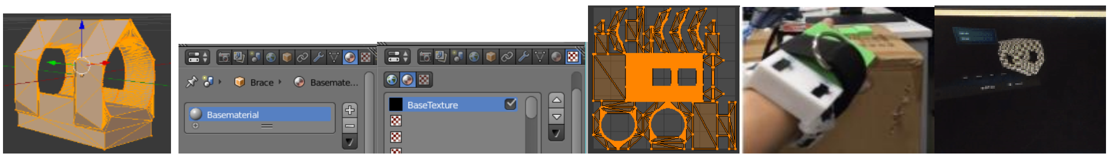


Figure 36: Progression of creation and integration of render model

A.6 Conclusion

Once the team has completed the design, the tracker can then be used in our simulation system with no additional configurations, since the virtual environment is based on SteamVR. Tests with users using the custom tracker also showed more favourable feedback compared to using a standard Vive Tracker, showing that we have met the requirements and considerations set up in the beginning.

Appendix B – Mechanical Structure by Jonita Chew

The design of the mechanical structure can be divided into 3 aspects –dimension of the mechanical structure, analysis of the forces involved, and the angle of the user's body. Each of these aspects will be mentioned in detail in the following segments.

B.1 Dimensions of Mechanical Structure

Most mountaineers in the world are males (The British Mountaineering Council, 2003). As such, the mechanical structure has been carefully designed to fit a Singaporean male. The body dimensions of a Singaporean male can be found in Figure 37 below.

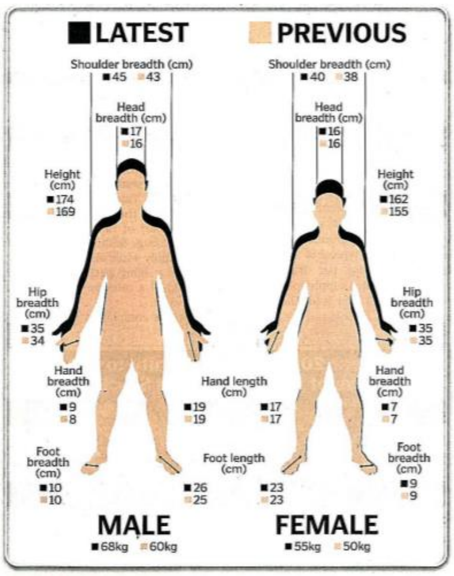


Figure 247: Body Dimensions of Singaporean Male

(Toh, 2010)

The overall dimensions of the mechanical structure are as follows:

Measurement	Dimensions (mm)
Height	1400
Width	1000
Length	2200

Table 4: Overall Dimensions of Mechanical Structure

Figure 38 below demonstrates the dimensions in the prototype.

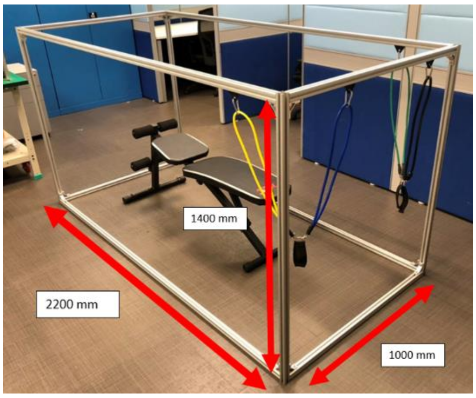


Figure 258: Dimensions of Prototype

B.1.1 Calculation of Height of Structure

The height of the structure is 1400 mm. This value is determined from the overall summation of the height of bench at an angled position, length of resistance bands, length of hook and tool slider, length of hook on Velcro strap, and clearance. The respective dimensions can be referred to in the Table 5 below.

Measurement	Dimensions (mm)
Height of bench at an angled position	440
Length of resistance bands	450
Length of hook and tool slider	225
Length of hook on Velcro strap	5
Clearance	270

Table 5: Variables Used in Calculation of Height of Structure

$$\begin{aligned}\textit{Height of Structure} \\ &= \textit{Height of bench at an angled position} \\ &+ \textit{Length of resistance bands} + \textit{Length of hook and tool slider} \\ &+ \textit{Length of hook on Velcro strap} + \textit{Clearance} \\ &= 440 + 450 + 225 + 10 + 5 + 270 = 1400\ mm\end{aligned}$$

It is worthy to note that a clearance of 270 mm has been added to provide for adequate leeway for the user when he moves his arms up and down. Figure 39 below demonstrates the variables in the prototype.

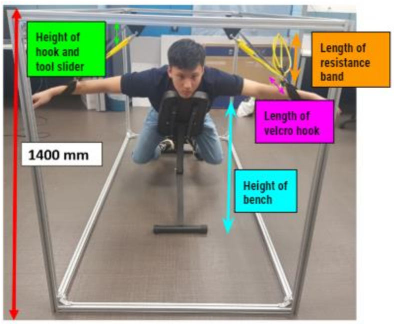


Figure 269: Visual Representation of Variables in Prototype

B.1.2 Calculation of Width of Structure

The width of the structure is 1000 mm. This value is determined from the overall summation of the shoulder breadth and twice the upper arm length of the user.

The upper arm length of the user is calculated as follows.

$$\boldsymbol{Arm\ span\ of\ male = \frac{Height - 377.3}{0.770} = \frac{1740 - 377.3}{0.770} = 1769\ mm}$$

$$\boldsymbol{Upper\ arm\ length = \frac{Arm\ span - Shoulder\ breadth - 2 \times Hand\ length}{4}}$$

$$\boldsymbol{= \frac{1769 - 450 - 2 \times 190}{4} = 235\ mm}$$

Measurement	Dimensions (mm)
Shoulder breadth	450
Upper arm length	235

Table 6: Variables Used in Calculation of Width of Structure

$\boldsymbol{Height\ of\ Structure = Shoulder\ breadth + 2 \times Upper\ arm\ length = 450 + 2 \times 235 = 910\ mm \approx 1000\ mm\ (Nearest\ hundredths)}$

Considering that the supplier does not supply aluminium profiles of accuracy up to the tenths, an upper rounding estimate to the nearest hundredths is made. Figure 40 below demonstrates the variables in this prototype.

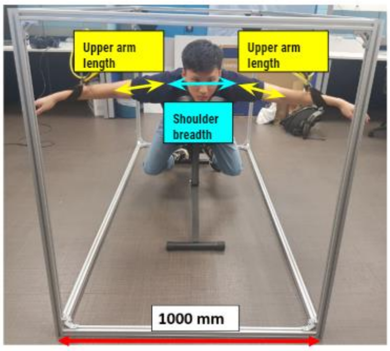


Figure 40: Visual Representation of Variables in Prototype

B.1.3 Calculation of Length of Structure

The length of the structure is 2200 mm. This value is determined from the overall summation of the height of male, lower arm length and length of hand.

The lower arm length of the user is calculated as follows.

$$\boldsymbol{Arm\ span\ of\ male} = \frac{\boldsymbol{Height - 377.3}}{\boldsymbol{0.770}} = \frac{\boldsymbol{1740 - 377.3}}{\boldsymbol{0.770}} = \boldsymbol{1769\ mm}$$

$$\boldsymbol{Lower\ arm\ length} = \frac{\boldsymbol{Arm\ span - Shoulder\ breadth - 2 \times Hand\ length}}{\boldsymbol{4}}$$

$$= \frac{\boldsymbol{1769 - 450 - 2 \times 190}}{\boldsymbol{4}} = \boldsymbol{235\ mm}$$

Measurement	Dimensions (mm)
Height	1740
Upper arm length	235
Hand length	190

Table 7: Variables Used in Calculation of Length of Structure

$$\textbf{Height of Structure} = \textbf{Height} + \textbf{Upper arm length} + \textbf{Hand length} = \textbf{1740} + \textbf{235} + \textbf{190}$$
$$= \textbf{2165 mm} \approx \textbf{2200 mm}\ (\textbf{Nearest hundredths})$$

Considering that the supplier does not supply aluminium profiles of accuracy up to the tenths, an upper rounding estimate to the nearest hundredths is made. Figure 41 below demonstrates the variables in this prototype.

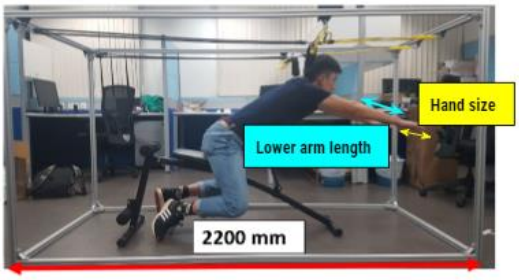


Figure 41: Visual Representation of Variables in Prototype

B.2 Analysis of Forces

In an avalanche, the most important action to take is one which helps you to increase your chances of survival, and it is to swim breaststroke rigorously (Puskaric, 2018). In 2009, a skiier reportedly survived an avalanche by swimming breaststroke (Brettman, 2009). This finding led the team to study the forces experienced by a user when he is swimming.

B.2.1 Forces Experienced by Swimmer

The average sprinting speed among swimmers is 1.64 m/s (Lee, 2017). This corresponds to an average drag force of 59.3 N based on the Table 8 below.

	Fd (N) 1.0 m·s^{-1}	Fd (N) 1.3 m·s^{-1}	Fd (N) 1.6 m·s^{-1}	Fd (N) 1.9 m·s^{-1}	Fd (N) 2.2 m·s^{-1}	k_P 2.2 m·s^{-1}	k_A 2.2 m·s^{-1}	Pd_P (W)	Pd_A (W)
1	31.5	40.2	56.0	77.7	115.6	23.9	35.9	231	346
2	37.2	46.3	66.0	88.0	130.0	26.9	40.4	327	491
3	30.8	44.4	58.8	75.8	116.5	24.1	36.2	260	390
4	34.2	47.0	64.0	82.0	128.1	26.5	39.8	270	406
5	32.3	42.3	58.2	92.2	126.0	26.0	39.0	297	444
6	29.6	44.0	49.8	71.8	100.3	20.7	31.1	200	300
7	29.0	45.4	62.1	86.0	121.7	25.1	37.7	271	406
8	32.7	48.3	58.8	87.8	120.3	24.9	37.4	302	454
9	30.0	43.0	57.4	76.0	115.4	23.8	35.7	230	345
10	34.1	46.1	61.8	86.9	125.1	25.8	38.7	279	418
mean	32.1	44.7	59.3	82.4	119.9	24.8	37.2	267	400
SD	2.5	2.4	4.6	6.7	8.6	1.8	2.7	38	57

Fd: average force during passive drag measurements; k_P: speed specific drag in passive conditions (at a speed of 2.2 m·s^{-1}); k_A: speed specific drag in active conditions (at a speed of 2.2 m·s^{-1}: $k_A = 1.5 \cdot k_P$); $Pd_P = k_P \cdot V_{30}^3$; $Pd_A = k_A \cdot V_{30}^3$.

doi:10.1371/journal.pone.0162387.t002

Table 8: Drag Forces Experienced by Swimmers at Various Swimming Speeds

(Gatta, Cortesi, & Zamparo, 2016)

For swimming at constant speed, the drag and thrust force are equal (Figure 49). Hence, the team took the thrust force to be 59.3 N, or 60 N for simplification. This also mean each arm needs to generate a thrust force of approximately 30 N.

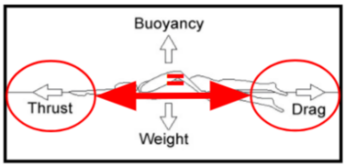


Figure 272: Physical Demonstration of Thrust and Drag Forces

B.2.2 Iteration 1

In the first iteration, the team focused on generating forces in 3 directions using 4 resistance bands, as shown in Figure 43 below.

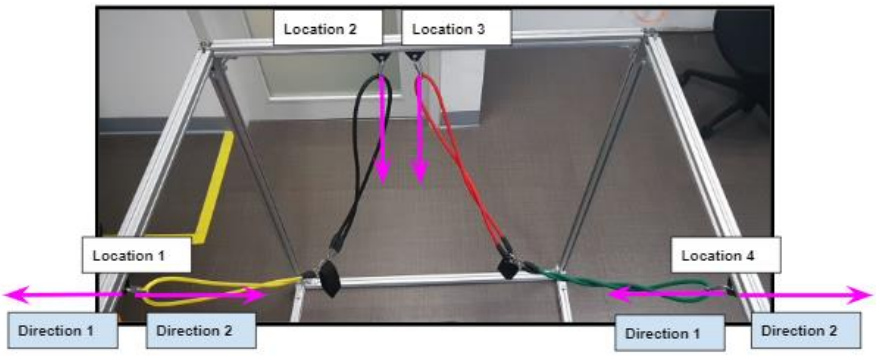


Figure 283: Representation of Direction of Forces in Prototype

The resistance bands will be mounted on 4 local points on the aluminium profiles, and the forces exerted by the user will be tracked at these 4 locations with a hook scale. A series of tests by 3 users with different coloured resistance bands showed differing forces in the various locations and directions, as shown in Table 9 below.

Tester 1 Height: 164cm Gender: F	Location 1 (N)		Location 2 (N)	Location 3 (N)	Location 4 (N)	
	Direction 1	Direction 2			Direction 1	Direction 2
Yellow	5	5	15	25	5	5
Green	5	10	25	30	5	10
Red	10	10	30	30	10	10
Blue	20	20	50	55	20	20
Black	20	20	65	65	20	20

Tester 2 Height: 178cm Gender: M	Location 1 (N)		Location 2 (N)	Location 3 (N)	Location 4 (N)	
	Direction 1	Direction 2			Direction 1	Direction 2
Yellow	5	15	25	30	10	20
Green	5	15	20	25	5	15
Red	10	10	40	40	10	10
Blue	15	15	50	50	15	15
Black	20	20	60	65	20	20

Tester 3 Height: 169cm Gender: M	Location 1 (N)		Location 2 (N)	Location 3 (N)	Location 4 (N)	
	Direction 1	Direction 2			Direction 1	Direction 2
Yellow	0	0	30	30	0	0
Green	20	20	30	30	20	20
Red	15	20	40	45	15	20
Blue	25	25	50	55	25	25
Black	30	30	60	65	30	30

Table 9: Amount of Force Experienced by 3 Users

Table summarising the average forces exerted by the 3 users is as follows.

Average Height: 170cm Gender:	Location 1 (N)		Location 2 (N)	Location 3 (N)	Location 4 (N)	
	Direction 1	Direction 2			Direction 1	Direction 2
Yellow	6.67	6.67	23.33	28.33	5	8.33
Green	10	15	25	28.33	10	15
Red	11.67	13.33	36.67	38.33	11.67	13.33
Blue	20	20	50	53.33	20	20
Black	23.33	23.33	61.67	65	23.33	23.33

Table 10: Average Force Experienced by 3 Users

Upon having these data, the team proceeded with the calculations of the resultant forces when two bands of the same colour are used on each side.

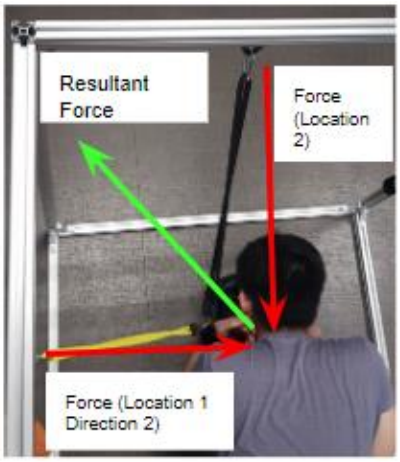


Figure 294: Direction of Forces and Resultant Force

$$\text{Resultance Force} = \sqrt{(\text{Force}^2_{\text{Location 1 Direction 2}} + \text{Force}^2_{\text{Location 2}})}$$

Based on the calculations, the team derived at the following results as shown in Table below.

Colour of Resistance Band	Resultant Force (N)
Yellow	24.3
Green	29.2
Red	39.0
Blue	53.9
Black	65.9

Table 11: Resultant Force Experienced by User for Different Resistance Band Colour

As such, the team decided to use the green resistance bands, which provide a 29.2 N force on each arm. This number is relatively close to the 30 N as experienced by a swimmer. However, the team noted that this set up resulted in huge amounts of slack in the resistance bands, and that a force the user supposedly feels when the he pushes his arms forward is missing. Therefore, the team proceeded with Iteration 2 by changing the locations of the resistance bands.

B.2.3 Iteration 2

Learning from iteration 1 that the resistance bands are too long, and caused too much slack, the team shortened the resistance bands by looping the bands around the tool slider hook. However, while the resistance bands are shortened, and with less slack than before, the overall resistances increased, just as in springs in parallel. Hence, a re-evaluation of the resistance bands to use is required.

Yellow bands are of the least resistance, followed by green bands. Therefore, the team decided to start off with the yellow bands, as shown in Figure 45. In direction

1, the resistance band provides a force of 30 N. In direction 2, the resistance band provides a force of 20 N. This provides an overall resultant force of 36 N on each arm, which is very close to the 30 N as experienced by the swimmer. Since the amount of resultant force is the lowest in this configuration of yellow bands, the team did not experiment with bands of other colours.

$$\text{Resultance Force} = \sqrt{(\text{Force}^2_{\text{Direction 1}} + \text{Force}^2_{\text{Direction 2}})}$$

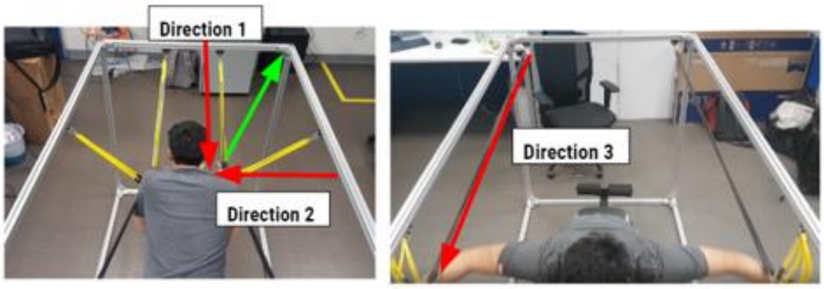


Figure 305: 3 Directions for Forces Experienced by User

In order to provide a force (drag force) which is missing in iteration 1 when the user pushes his arms forward, a third band is added on each arm. This third band can be found in Figure 45 above.

Each individual band has been tried for the amount of force it provides for the user. We note the amount of force in Table 12 below.

Colour of Band	Force (N)
Yellow	10
Green	15
Red	20
Blue	25
Black	30

Table 12: Amount of Force Experienced by User

Considering that the drag force as experienced by the user is 30 N on each arm, the black band has been chosen for the prototype.

B.3 Angle of Bench

In order to simulate an environment as realistic as possible, the user needs to be in the right swimming position. The angle of the swimmer's body with respect to horizontal can range from 10 to 30 degrees (Štumbauer, Maleček, & Šimberová, 2013).

The team took the upper limit of 30 degrees, which the user requires as it provides for a training of greater rigour. This can be seen in Figure 46 below.

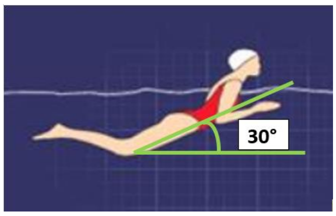


Figure 316: Visual Representation of Swimmer's Body at an Angle of 30 Degrees

Upon finding out the best angle for the user, the prototype bench has also been set to the angle of 30 degrees as shown in Figure 47 below.

Figure 327: Visual Representation of Bench at an Angle of 30 Degrees

In order to do further verification that the angle of 30 degrees is indeed the most compatible with the users, a further test has been conducted, in which the number of strokes used to "win" the game condition is recorded. The results as shown in Table 13 below reflect that the angles of 0, 10 and 50 degrees are not ideal for the user, considering that at least one of the three users is unable to "win" the game condition, even after 3 tries. For the angles of 20, 30 and 40 degrees, users are able to "win" the game condition, which indicates that these angles may be suitable for the users.

Position	Angle (Deg)	Tester 1	Tester 2	Tester 3
1	0	-	20	-
2	10	-	25	-
3	20	54	23	43
4	30	48	24	39
5	40	41	24	38
6	50	40	-	40

Table 13: Results from Test Conducted to Determine Suitability of 30 Degrees Bench Angle

B.4 Testing

In order to verify the effectiveness of the prototype, a test was designed to compare the user's experience with and without the resistance bands. Overall, the results showed that for the out sweep and re-entry motions, the experience for the testers was the most realistic. However, some of the feedback the testers provided were that the resistance bands hindered their movements and were not very realistic due to the fact that only one muscle group is activated instead of multiple muscle groups. The test questionnaire and results can be found in Appendix 2.

B.5 Limitations

In all, even though this prototype is good for providing a force in a single direction, and that the forces can easily be altered by using different resistance bands and changing the lengths of the resistance bands, the team acknowledges that for a multi-directional haptic feedback in which the user requires, this method may not be the most ideal.

In addition to this, considering that the resistance bands are only attached to one portion of each of the user's arm, the forces will only be concentrated around these regions, instead of being spread across the user's entire arm, as it will be in an avalanche.

Lastly, the extensive use of resistance bands in this case resulted in the bands rubbing against the back of the user, which induced a lot of discomfort in the user. The inevitable slack in resistance bands also caused the user's palms to hit the resistance bands, which hampers his swimming movements.

Nevertheless, this prototype served as a good starting tool for the team to learn about the forces and angles involved in swimming.

Appendix C – Electrical Muscle Stimulation by Jerome Wong

C.1 Electrical Muscle Stimulation Parameters and their Effects

The SEM 43 Digital EMS/TENS dispenses biphasic square waves with 3 parameters that can be calibrated depending on the user: frequency, pulse width and current.

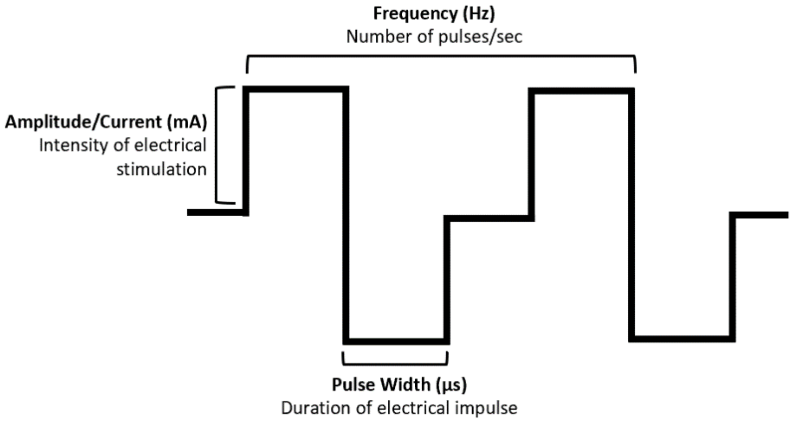


Figure 338: Waveform of electrical impulse

C.1.1 Frequency

Frequency describes the number of pulses of current that is sent to the electrode per second. At low frequencies (eg. Below 40hz), the arm actuation is jerky and the pulses of current felt by the user is perceptible. This does not fit into the design consideration of a smooth resistance that users need to experience through the breast stroke motion. At higher frequencies, pulses of the current became less perceptible and arm actuation is smoother.

Type I fibres tend to be activated at around 20-35hz, type IIa fibres between 30-50hz and type IIb fibres between 45-70hz.

C.1.2 Pulse Width

Pulse Width describes the duration of each pulse of current. The larger the pulse width, the deeper and wider the current is felt.

Pulse Width	Indications
50µs	Large myelinated fibres (sensory touch)
100-200 µs	Normal neuromuscular system
>200 µs	Small myelinated fibres

Table 14: Pulse width to muscle activation table

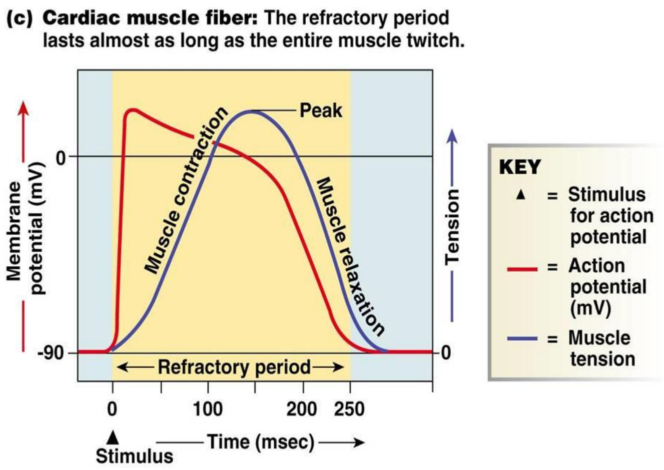


Figure 349: Refractory Period of Muscle Fibre

A high pulse width does not necessarily lead to a stronger actuation as after depolarisation of a nerve's member potential, there must be a period of repolarisation (refractory period) where no stimulus will cause another impulse.

C.1.3 Current

The current refers to the amplitude of the width. This is translated to the intensity of the electrical stimulation or the amount of energy flowing/unit time.

It is found in general that a larger current is required to actuate a larger muscle group.

C.2 EMS Testing

A user study involving 5 members of differing bicep and triceps sizes were conducted to investigate the combinations of parameters that would be suitable for our simulation. Users are instructed to straight then arm out with their wrist in a neutral flat position parallel to the arm. The current is slowly increased, and the user is asked to rate the experience base on the scale developed for the bicep/wrist. This is repeated methodically with the different combinations of the parameters with the results tabulated below.

As the current is increased progressively, users go through the phases until the noxious phase is reached. For the virtual simulation, the motor phase is the point at which resistance is felt and applicable to our system.

Phases	
Sub-Sensory Phase	When the current is very low. No feeling is felt
Sensory Phase	When there is current is higher. There is a tingling sensation
Motor Phase	Motor Neurons are actuated
Noxious Phase	Pain is induced with motor neuron actuation

Table 15: Different phases of electrical stimulation

C.2.1 Wrist Extensors Data Collection and Analysis

Scale	
0	No Movement and No Sensation
1	No movement and Slight Sensation
2	Minor Movement and Sensation
3	Actuation of Fingers and Sensation
4	Gradual Actuation of Wrist and Sensation
5	Actuation of Wrist and Pain/Strain

Figure 50: Electrode Placement for Wrist Actuation and Wrist Actuation Experience Scale

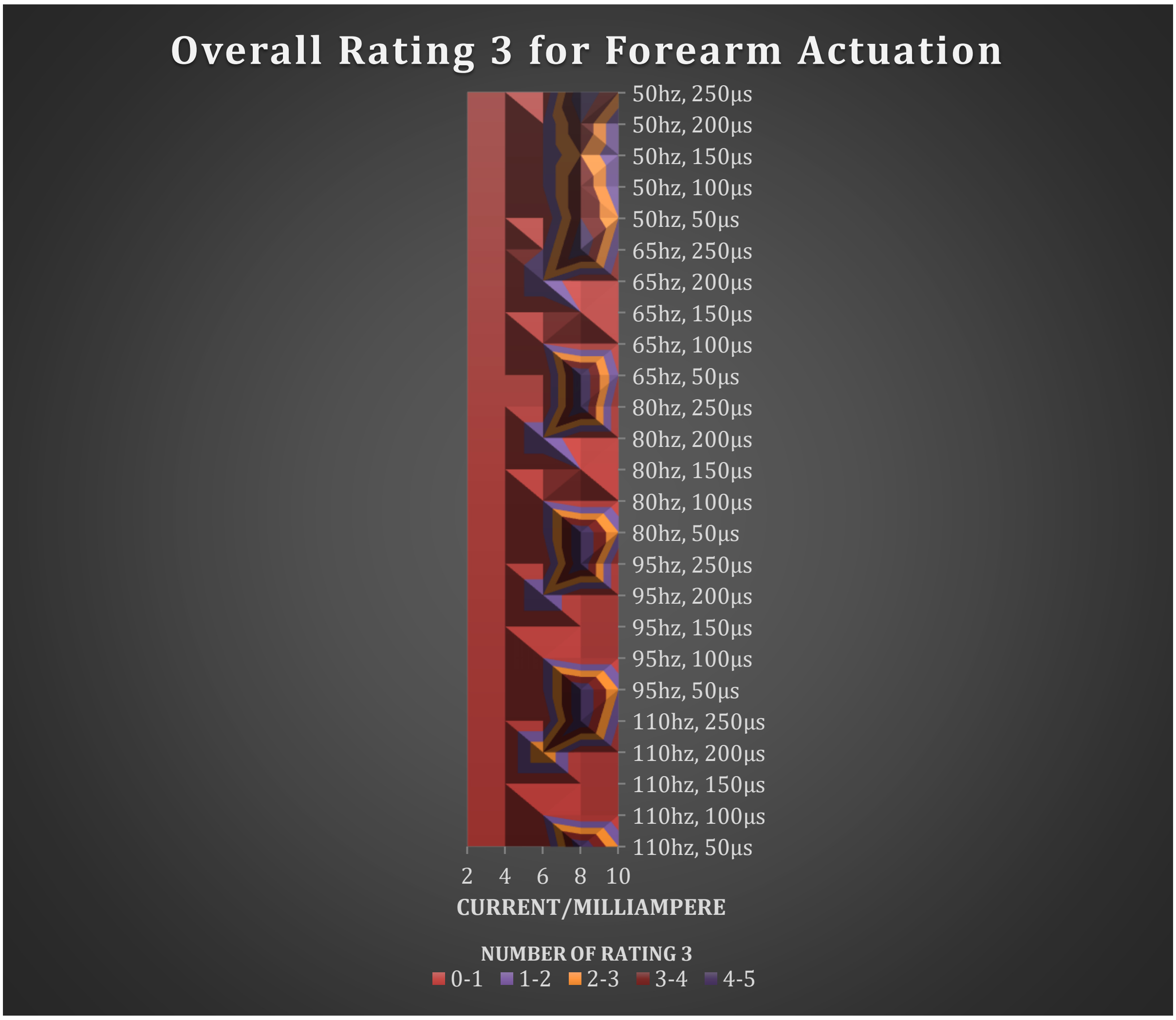


Figure 51: Surface Map of Overall Rating 3 for Wrist Actuation

Rating 3 provided resistance without causing discomfort to the user. The surface map above shows the overall trend of the Experience Rating 3 experienced by all 5 users. A large portion of rating 3 congregated at the extreme ends of the pulse width (50µs, 200µs, 250µs) and at a higher current (≥8mA). Individual profiles of the users are plotted using Matlab and can be found in Appendix 3.

Frequency: 50hz	Pulse Width: 50µs					Pulse Width: 100µs				
Forearm Circumference/cm	24.5	27.3	29.4	30.1	31.2	24.5	27.3	29.4	30.1	31.2
Current/mA	Scale					Scale				
2	0	0	0	0	0	0	0	0	0	0
4	1	1	1	1	1	1	1	1	1	1
6	2	2	2	2	2	3	2	2	2	2
8	3	3	3	3	3	4	3	3	3	3
10	-	3	-	4	3	-	3	-	4	4

Frequency: 65hz	Pulse Width: 50µs					Pulse Width: 100µs				
Forearm Circumference/cm	24.5	27.3	29.4	30.1	31.2	24.5	27.3	29.4	30.1	31.2
Current/mA	Scale					Scale				
2	0	0	0	0	0	0	0	0	0	0
4	1	1	1	1	1	1	1	1	1	1
6	2	2	2	2	2	4	2	2	2	2
8	3	3	3	3	3	5	4	4	4	4
10	-	3	-	4	3	-	5	-	5	5

Frequency: 80hz	Pulse Width: 50µs					Pulse Width: 100µs				
Forearm Circumference/cm	24.5	27.3	29.4	30.1	31.2	24.5	27.3	29.4	30.1	31.2
Current/mA	Scale					Scale				
2	0	0	0	0	0	0	0	0	0	0
4	1	1	1	1	1	1	1	1	1	1
6	2	2	2	2	2	4	2	2	2	3
8	3	3	3	3	3	5	4	4	4	4
10	-	3	-	4	4	-	5	-	5	5

Frequency: 95hz	Pulse Width: 50µs					Pulse Width: 100µs				
Forearm Circumference/cm	24.5	27.3	29.4	30.1	31.2	24.5	27.3	29.4	30.1	31.2
Current/mA	Scale					Scale				
2	0	0	0	0	0	0	0	0	0	0
4	1	1	1	1	1	1	1	1	1	1
6	2	2	2	3	2	3	2	2	2	2
8	3	3	3	3	3	4	4	4	4	4
10	-	3	-	4	3	-	5	-	5	4

Frequency: 110hz	Pulse Width: 50µs					Pulse Width: 100µs				
Forearm Circumference/cm	24.5	27.3	29.4	30.1	31.2	24.5	27.3	29.4	30.1	31.2
Current/mA	Scale					Scale				
2	0	0	0	0	0	0	0	0	0	0
4	1	1	1	1	1	1	1	1	1	1
6	2	2	2	2	2	3	2	2	2	2
8	3	3	3	3	3	4	4	4	4	4
10	-	3	-	3	4	-	5	-	4	5

Frequency: 50hz	Pulse Width: 150µs					Pulse Width: 200µs					Pulse Width: 250µs				
Forearm Circumference/cm	24.5	27.3	29.4	30.1	31.2	24.5	27.3	29.4	30.1	31.2	24.5	27.3	29.4	30.1	31.2
Current/mA	Scale					Scale					Scale				
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	3	2	2	2	2	3	2	2	2	2	2	2	2	2	2
8	4	3	4	3	3	4	3	3	3	3	3	3	3	3	3
10	-	3	-	4	4	-	3	-	4	4	-	3	-	3	3

Frequency: 65hz	Pulse Width: 150µs					Pulse Width: 200µs					Pulse Width: 250µs				
Forearm Circumference/cm	24.5	27.3	29.4	30.1	31.2	24.5	27.3	29.4	30.1	31.2	24.5	27.3	29.4	30.1	31.2
Current/mA	Scale					Scale					Scale				
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	4	2	2	2	2	4	3	2	3	3	2	2	2	2	2
8	5	4	4	4	4	5	4	5	4	4	3	3	3	3	3
10	-	5	-	5	5	-	5	-	5	5	-	3	-	4	4

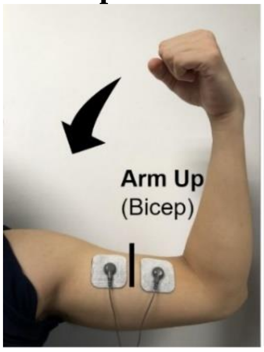
Frequency: 80hz	Pulse Width: 150µs					Pulse Width: 200µs					Pulse Width: 250µs				
Forearm Circumference/cm	24.5	27.3	29.4	30.1	31.2	24.5	27.3	29.4	30.1	31.2	24.5	27.3	29.4	30.1	31.2
Current/mA	Scale					Scale					Scale				
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	4	2	2	2	2	4	3	2	2	3	2	2	2	2	2
8	5	4	4	4	3	5	4	5	4	4	3	3	3	3	3
10	-	5	-	5	5	-	5	-	5	5	-	3	-	4	4

Frequency: 95hz	Pulse Width: 150µs					Pulse Width: 200µs					Pulse Width: 250µs				
Forearm Circumference/cm	24.5	27.3	29.4	30.1	31.2	24.5	27.3	29.4	30.1	31.2	24.5	27.3	29.4	30.1	31.2
Current/mA	Scale					Scale					Scale				
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	2	2	2	2	2	2	3	3	2	3	2	2	2	2	2
8	4	4	4	4	4	4	4	5	4	4	3	3	3	3	3
10	-	5	-	5	5	-	5	-	5	4	-	3	-	4	3

Frequency: 110hz	Pulse Width: 150µs					Pulse Width: 200µs					Pulse Width: 250µs				
Forearm Circumference/cm	24.5	27.3	29.4	30.1	31.2	24.5	27.3	29.4	30.1	31.2	24.5	27.3	29.4	30.1	31.2
Current/mA	Scale					Scale					Scale				
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	2	2	2	2	2	2	3	2	3	3	2	2	2	2	2
8	5	4	4	4	4	4	4	5	4	4	3	3	3	3	3
10	-	5	-	5	5	-	5	-	5	5	-	3	-	4	4

Figure 53: Data Collected for Wrist Actuation at Forearm (Carpas Ulanaris)

C.2.2 Bicep Data Collection and Analysis



Scale	
0	No Movement and No Sensation
1	No Movement and Slight Sensation
2	No Movement and Increased Sensation
3	Contraction of Bicep and Increased Sensation
4	Contraction of Bicep and Discomfort
5	Full Actuation of Arm and Pain/Discomfort

Figure 54: Electrode Placement for Arm Actuation and Arm Actuation Experience Scale

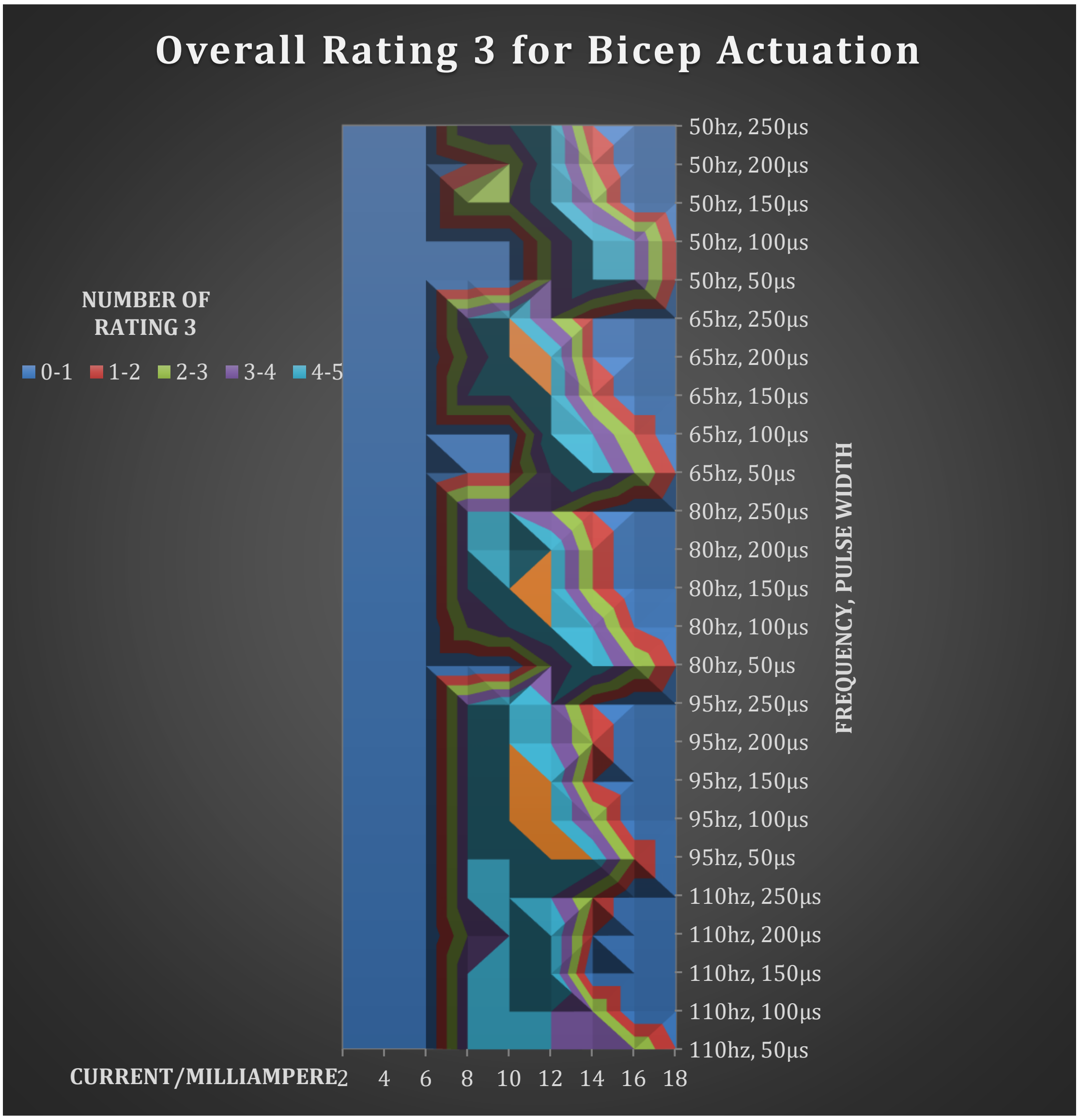


Figure 55: Surface Map of Overall Rating 3 for Arm Actuation (Bicep)

Bicep actuation required a larger current compared to wrist actuation. Similarly, at the Bicep, Rating 3 provided resistance without causing discomfort to the user. The overall rating 3 for all 5 users congregated towards a mid to high range current (8mA-16mA) across all pulse widths. The individual profile of the users are once again plotted using Matlab and can be found in Appendix 4.

	Frequency: 50hz									
	Pulse Width: 50µs					Pulse Width: 100µs				
Bicep Circumference/cm	28.3	29.4	31.2	33.2	35.4	28.3	29.4	31.2	33.2	35.4
Current/mA	Scale					Scale				
2	0	0	0	0	0	0	0	0	0	0
4	1	1	1	1	1	1	1	1	1	1
6	2	2	2	2	2	2	2	2	2	2
8	2	2	2	2	2	2	2	2	2	2
10	2	2	2	2	2	2	2	2	2	2
12	3	2	2	3	3	3	3	2	3	3
14	3	3	3	3	3	3	3	3	3	3
16	3	3	3	4	3	4	3	3	3	4
18	-	4	-	4	3	-	4	-	4	4
	Frequency: 65hz									
	Pulse Width: 50µs					Pulse Width: 100µs				
Bicep Circumference/cm	28.3	29.4	31.2	33.2	35.4	28.3	29.4	31.2	33.2	35.4
Current/mA	Scale					Scale				
2	0	0	0	0	0	0	0	0	0	0
4	1	1	1	1	1	1	1	1	1	1
6	2	2	2	2	2	2	2	2	2	2
8	2	3	2	2	2	2	2	3	3	3
10	2	3	2	2	2	2	2	3	3	3
12	3	3	3	2	3	3	3	3	3	3
14	3	3	3	3	3	4	3	3	3	3
16	4	3	4	3	3	5	4	4	3	3
18	-	4	-	4	3		5	-	4	4
	Frequency: 80hz									
	Pulse Width: 50µs					Pulse Width: 100µs				
Bicep Circumference/cm	28.3	29.4	31.2	33.2	35.4	28.3	29.4	31.2	33.2	35.4
Current/mA	Scale					Scale				
2	0	0	0	0	0	0	0	0	0	0
4	1	1	1	1	1	1	1	1	1	1
6	2	2	2	2	2	2	2	2	2	2
8	2	2	2	2	2	3	2	3	3	2
10	2	2	2	2	2	3	2	3	3	3
12	3	3	2	2	3	3	3	3	3	3
14	3	3	3	3	3	4	3	3	3	3
16	4	3	4	3	3	5	4	4	4	3
18	-	4	-	4	3	-	5	-	5	4
	Frequency: 95hz									
	Pulse Width: 50µs					Pulse Width: 100µs				
Bicep Circumference/cm	28.3	29.4	31.2	33.2	35.4	28.3	29.4	31.2	33.2	35.4
Current/mA	Scale					Scale				
2	0	0	0	0	0	0	0	0	0	0
4	1	1	1	1	1	1	1	1	1	1
6	2	2	2	2	2	2	2	2	2	2
8	2	3	3	3	3	2	3	3	3	3
10	2	3	3	3	3	3	3	3	3	3
12	3	3	3	3	3	3	3	3	3	3
14	3	3	3	3	3	4	3	4	3	3
16	3	3	4	4	4	5	4	5	4	4
18	-	4	-	5	5	-	5	-	5	5
	Frequency: 110hz									
	Pulse Width: 50µs					Pulse Width: 100µs				
Bicep Circumference/cm	28.3	29.4	31.2	33.2	35.4	28.3	29.4	31.2	33.2	35.4
Current/mA	Scale					Scale				
2	0	0	0	0	0	0	0	0	0	0
4	1	1	1	1	1	1	1	1	1	1
6	2	2	2	2	2	2	2	2	2	2
8	2	3	3	3	3	2	3	3	3	3
10	2	3	3	3	3	2	3	3	3	3
12	2	3	3	3	3	3	3	3	3	3
14	3	4	4	3	3	4	3	4	4	4
16	4	4	5	4	4	5	4	5	4	4
18	-	5	-	5	5	-	5	-	5	5

Figure 56: Data Collected (50 µs - 100 µs) for Arm Actuation at Bicep

	Frequency: 50hz														
	Pulse Width: 150µs					Pulse Width: 200µs					Pulse Width: 250µs				
Bicep Circumference/cm	**28.3**	**29.4**	**31.2**	**33.2**	**35.4**	**28.3**	**29.4**	**31.2**	**33.2**	**35.4**	**28.3**	**29.4**	**31.2**	**33.2**	**35.4**
Current/mA	**Scale**					**Scale**					**Scale**				
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
8	2	3	3	3	2	2	2	2	2	3	2	3	3	3	3
10	2	3	3	3	2	2	2	2	3	3	2	3	3	3	3
12	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
14	3	3	4	4	3	4	3	4	3	4	4	4	4	4	3
16	4	4	5	4	4	5	4	5	4	4	5	4	5	4	4
18	-	5	-	5	5	-	5	-	5	5	-	5	-	5	5

	Frequency: 65hz														
	Pulse Width: 150µs					Pulse Width: 200µs					Pulse Width: 250µs				
Bicep Circumference/cm	**28.3**	**29.4**	**31.2**	**33.2**	**35.4**	**28.3**	**29.4**	**31.2**	**33.2**	**35.4**	**28.3**	**29.4**	**31.2**	**33.2**	**35.4**
Current/mA	**Scale**					**Scale**					**Scale**				
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
8	2	3	3	3	3	2	3	3	3	2	2	3	3	3	3
10	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3
12	3	3	3	3	3	3	3	3	3	3	4	4	3	3	3
14	4	3	4	3	4	4	3	4	4	4	4	4	4	4	3
16	5	4	5	4	4	5	4	5	4	4	5	4	5	4	4
18	-	5	-	5	5	-	5	-	5	5	-	5	-	5	5

	Frequency: 80hz														
	Pulse Width: 150µs					Pulse Width: 200µs					Pulse Width: 250µs				
Bicep Circumference/cm	**28.3**	**29.4**	**31.2**	**33.2**	**35.4**	**28.3**	**29.4**	**31.2**	**33.2**	**35.4**	**28.3**	**29.4**	**31.2**	**33.2**	**35.4**
Current/mA	**Scale**					**Scale**					**Scale**				
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
8	2	3	3	3	3	2	3	3	3	3	2	3	3	3	3
10	3	3	3	3	3	2	3	3	3	3	2	3	3	3	3
12	3	3	3	3	3	3	3	3	3	3	3	4	3	4	3
14	4	3	4	3	4	4	3	4	4	3	4	4	4	4	3
16	5	4	5	4	4	5	4	5	4	4	5	4	5	4	4
18	-	5	-	5	5	-	5	-	5	5	-	5	-	5	5

	Frequency: 95hz														
	Pulse Width: 150µs					Pulse Width: 200µs					Pulse Width: 250µs				
Bicep Circumference/cm	**28.3**	**29.4**	**31.2**	**33.2**	**35.4**	**28.3**	**29.4**	**31.2**	**33.2**	**35.4**	**28.3**	**29.4**	**31.2**	**33.2**	**35.4**
Current/mA	**Scale**					**Scale**					**Scale**				
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
8	2	3	3	3	3	2	3	3	3	3	2	3	3	3	3
10	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
12	3	3	3	3	3	4	3	3	3	3	3	3	3	4	3
14	4	4	4	4	3	4	4	4	3	3	4	3	4	4	4
16	5	4	5	4	4	5	4	5	4	4	5	4	5	4	4
18	-	5	-	5	5	-	5	-	5	5	-	5	-	5	5

	Frequency: 110hz														
	Pulse Width: 150µs					Pulse Width: 200µs					Pulse Width: 250µs				
Bicep Circumference/cm	**28.3**	**29.4**	**31.2**	**33.2**	**35.4**	**28.3**	**29.4**	**31.2**	**33.2**	**35.4**	**28.3**	**29.4**	**31.2**	**33.2**	**35.4**
Current/mA	**Scale**					**Scale**					**Scale**				
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
8	2	3	3	3	3	2	3	2	3	3	2	3	3	3	3
10	2	3	3	3	3	2	3	3	3	3	2	3	3	3	3
12	3	3	3	3	3	3	3	3	3	3	2	3	3	3	3
14	4	4	4	4	4	4	4	4	4	3	3	4	4	4	3
16	5	4	5	4	4	5	4	5	4	4	4	4	5	4	4
18	-	5	-	5	5	-	5		5	5	-	5	-	5	5

Figure 57: Data Collected (150 µs - 250 µs) for Arm Actuation at Bicep

C.3 Force Feedback System

C.3.1 Prototype Assembly

The parts used in the fabrication of the open source PCB involved in our project can be found via the link: https://github.com/PedroLopes/openEMSstim. This provided the basis of which a separate device can interact with the EMS indirectly.

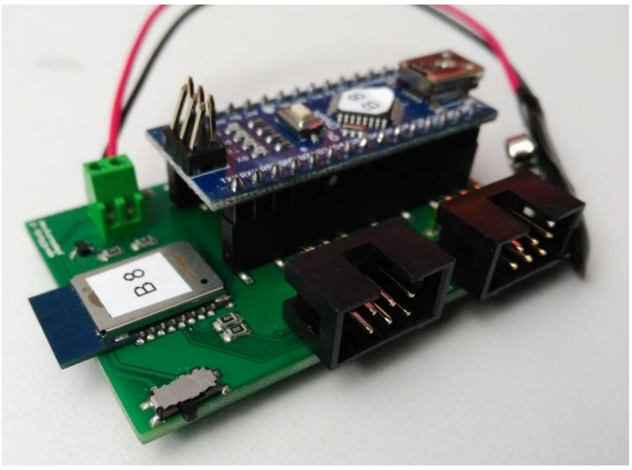


Figure 58: Open Source openEMSstim PCB by HCI Researcher Pedro Lopes

C.3.2 Communication Protocol

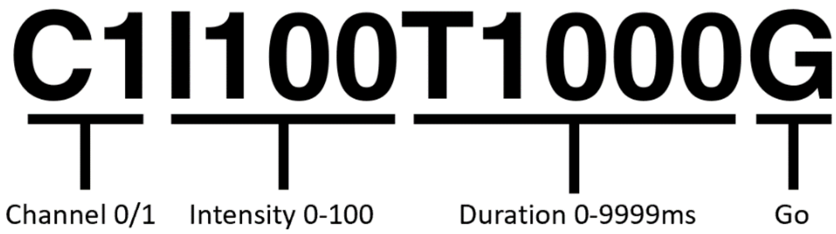


Figure 59: Communication Protocol used to Communicate with the PCB via the Devices

A communication protocol is used to interface with the PCB via the devices. “C” refers to the channel (0/1) which opens the respective channel for the current to be output to. “I” refers to the intensity which can range from 0-100% based on the parameters and current that is set. “T” refers to the time which can range from 0-9999ms, indicating the duration of the pulses of current that will be output to the electrodes. “G” refers to started or stopping of the EMS. The communication protocol can be sent via Bluetooth or USB.

C.3.3 Integration into Unity3d (Virtual environment)

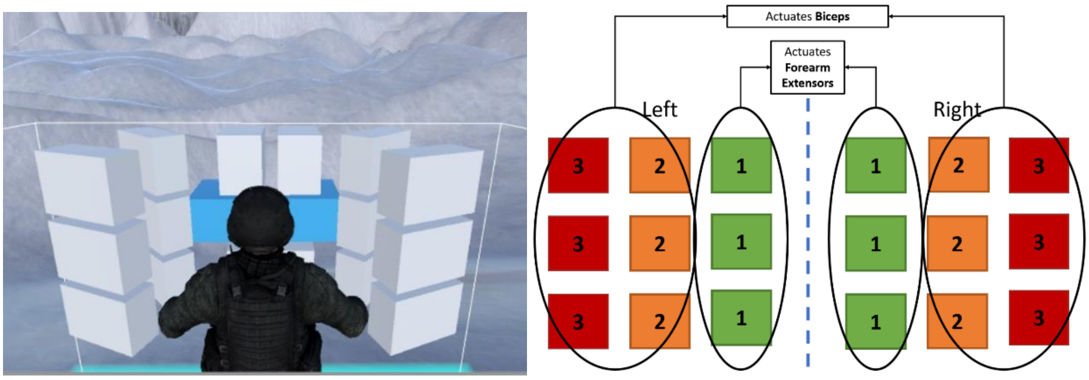


Figure 60: Collider System and Mapping of EMS to Collider Boxes

```
if (CubeIsHit[0] || CubeIsHit[6] || CubeIsHit[12])
{
    openEMSstim_1.sendMessage(message_to_stimulate_left_1);
}
if (CubeIsHit[1] || CubeIsHit[2] || CubeIsHit[7] ||
        CubeIsHit[8] || CubeIsHit[13] || CubeIsHit[14])
{
    openEMSstim_1.sendMessage(message_to_stimulate_right_1);
}

if (CubeIsHit[3] || CubeIsHit[9]  || CubeIsHit[17])
{
    openEMSstim_2.sendMessage(message_to_stimulate_left_2);
}
if (CubeIsHit[4] || CubeIsHit[5] || CubeIsHit[10] ||
        CubeIsHit[11] || CubeIsHit[16] || CubeIsHit[17])
{
    openEMSstim_2.sendMessage(message_to_stimulate_right_2);
}
```

Figure 61: C# Script to Integrate PCB to Unity3d Plugin provided by Pedro Lopes

Making use of the Unity3d example for the openEMSstim PCB, a script was written to automate the output of EMS to the electrodes based on the Collider Boxes.

When the user of touches the 1st column, the communication protocol "C0I100T0300G" is sent to the Arduino. This causes the channel 1 of the EMS to output the calibrated current at 100% intensity for 300ms. When the user touches the 2nd or 3rd boxes, the communication protocol "C1I100T0100G" is sent to the Arduino which causes channel 2 of the EMS to output the calibrated current at 100% intensity for 100ms. This corresponds to the Forearm and Bicep Actuation Respectively.

C.4 Limitations

The study conducted provided a range of values for use in our simulation. However, the experience rating defers from user to user based on their individual tolerance for pain as well as composition at the forearm and bicep. A much larger sample size and parameters of the user need to be considered for the results to be extrapolated to other users. Careful calibration for each user still needs to be done to use EMS as a viable haptics system for our simulation.

Additionally, the current iteration of the prototype only allows Unity3d to communicate with the Arduino on the PCB via USB which may sometime leads to an overflow of byte size due to restriction of hardware. This causes the communication to jam and the EMS to not be felt by the user. Subsequent iterations should move towards implementation of a Bluetooth module within Unity3d for the communication protocol to be transmitted.

Appendix 1 - Interview Transcripts

Table of interviewees:

Interviewee	**Title**	**Stakeholder Group**	**Related Experience**
Joel Lim	NUS Mountaineering President	● Mountaineer ● Mountaineering Trainer	● Been climbing for 3 years
Yip Seck Hong	Former President of SMF	● Mountaineer ● Mountaineering Trainer	● Been climbing for > 40 years ● President of SMF for 25 years
Joanne Soo	Founder of AAE	● Adventure Outfitter	● Event organiser fo ● r mountaineering clubs for 8 years ● Adventure solutions business owner for 18 years
Khoo Swee Chiow	Founder of Dare to Dream	● Mountaineer	● Part of first Singaporean team to reach the summit of Mount Everest ● 38 years of climbing experience

"Generally, all the new members think we train too hard, until they go there and realise it is still challenging." – MR Lim

"There is no real way to train for an avalanche, and as of current, it is still very much theory based." –MR Yip

"We want to introduce new courses for aspiring mountaineers to follow in order to help them progress as a mountaineer more easily." –MS Soo

"Experience plays a huge part in safety, and people who are insufficiently prepared pose safety risks to themselves and also to people around them" –MR Khoo

Interviewee	Transcript
MR Joel Lim	• Singapore terrain has a lot of physical constraints and VR can be used to simulate such environments and applied in training • There are NUS Mountaineering Club members who have a fear of heights, which are commonly exhibited with climbing steep mountains or abseiling and VR can be a useful medium to help in this area. • Although training can be comprehensive and targeted, members still frequently face challenges when climbing the mountain itself • Specialised equipment for climbing are fairly expensive and not readily available for people outside of NUS Mountaineering Club, which may deter people from starting mountaineering as a sport • Testing or simulation of equipment before purchase or rental would be optimal due to their expensiveness • VR can be applied in training situations especially when it comes to simulation of environment or of places which are physically constrained
MR Yip Seck Hong	• Singapore Mountaineering Federation lacks specialised courses for mountaineering • Singapore Mountaineering Federation emphasizes more on sports climbing instead of mountaineering due to issues of terrain • Existing courses in Singapore are held by experienced climbers but do not follow strict guidelines and, instead, are based on experience and textbooks • Trainings done in Singapore include, rope work, tenting or cardio, which are trainings that can be done in any terrain, so that we can shorten the training required overseas as overseas training is expensive • Overseas trainings can be from India, Indonesia, China to Netherlands or USA, with trainings costing approximately $200/day in European countries • There are many type of ice training, like self-arrest, weather training, avalanche training, rock fall spotting, crevice training, snow cave

	digging, but certain parts of training can only be done in theory, for example, self-rescue when caught in an avalanche • Avalanches are quite common throughout Nepal, but the most common accident that people experience are rock falls • Although the probability of getting caught in avalanche is small, it has a high mortality rate (90%). So self-rescue techniques are important to increase survival rates • In high risk climbs, guides are very important in helping ensure the safety of the climb by identifying accident hazards and understanding rescue procedures. However, certification for guides can take at least 10 years to achieve resulting in local guides being very expensive. • On top of this, there are increasing numbers of people interested in solo-climbing, which can be dangerous with lack of training since there is no prerequisites or certification required for climbers to start a climb • It should also be noted that some guides do not speak English and communication with the guides are difficult at times. • Mountaineers also need to be proficient in ice tools and certain mountaineering equipment, even though such equipment and their training can be expensive • Singapore mountaineering groups are also very isolated due to lack of outreach, and when combined with the average expense of expeditions being from $3000-$5000 (3 weeks expeditions, inclusive of guides, porters and accommodation), less experienced climbing groups might not be sufficiently prepared when they skim. • Sports climbing is on the rise in Singapore, and can lead to higher interests in mountaineering, so proper mountaineering training should be available to ensure safety of the mountaineers
MS Joanne Soo	• Ace Adventures was founded to help Singaporeans try out adventure travel and started out focusing on overseas trekking

	• However, interests for mountaineering, especially climbing Mount Everest, has increased over the years and the business has pivoted towards mountaineering • Since mountaineering involve more preparation and training, due to the intensity and risks compared to trekking, Ace Adventures has also been providing information on such matters through calls, emails and their website • With more information due to the internet, there are also misinformation, which can be hard to spot for inexperienced climbers, so Ace Adventures helps to correct such problems while also promoting their adventure travel • To help support new climbers, Ace Adventures has recently rolled out a new business model that follows a roadmap which supports new climbers by providing trainings and climbs of increasing difficulty to help them progress in mountaineering • However, there are limitations in their roadmap, which is that certain intermediate climbs and trainings are time restricted. For example, ice-climbing training in China only has a 2-3 month window around February and alpine-climbing training is only open during the May to June period, which is hard to get enough people. Thus, climbers still need to be mostly self-prepared • To cater for the lack of training and the safety concerns, Ace Adventures always tries to avoid avalanche-prone areas for climbs, although they acknowledge that avalanches can still happen anytime • Mountaineers also adapt differently on the mountains, but it is commonly mental barriers that stop deter climbers from moving forward or going for climbs in the first place, because they are scared that they might not make it back alive • It would be good if trekkers or mountaineers can have the opportunity to experience the mountains beforehand as it can help them gauge the situation in the mountains and how to respond to certain events

	• VR can be used to market the mountains as it can give them a sense of adventurism when experiencing it instead of just watching a video • VR can also be used to teach fundamentals and safety aspects of climbing but actual skills and experience should still be done in real life if possible • With the increase in popularity of sports climbing in Singapore, more people are interested in the actual climb as they want to climb the real stuff and feel the real experience of being in the mountains
MR Khoo Swee Chiow	• Although he has been climbing for over 30 years, he has never been caught in an avalanche, and attributes this to experience and knowing when and where to climb. • However, he agrees that accidents still happen frequently and mountaineering carries extreme risk, and safety is paramount. • It is good that mountaineering does not have much regulations, so anyone can start their journey. However, there are times when people are underprepared and cause safety risks to themselves and people around them. • Training before scaling mountains is important and there are many aspects to it. For example, how to use crampons, ice axe, abseiling, altitude training or climbing. • Although expensive, everyone should go through mountaineering training, for example, he went for a 10 days mountaineering course in New Zealand that taught them how to climb rock, ice, snow, how to access route safety, by looking at the slope, risks and weather conditions and develop their mountain sense • The specifics of the course included flying into a mountain hut which is surrounded by mountains, before they are directed to certain areas based on experience levels. After which they start with learning some theory and rope training before setting out on the routes to train in the mountains, with one aspect being put in a crevice and learning how to get out (which is the most commonly trained skill set)

	• However, such trainings are still limited, for example there is no way to safely stimulate self-rescue when trapped in an Avalanche, so they can only learn about it in theory through books • From what he read from books, during an avalanche, it is advisable not to struggle too much, and try to swim to stay at the top right before the avalanche stops and snow settles. If not possible, an air gap should be created just before the snow stops to ensure that you get enough oxygen when trapped below the surface. If done properly, it can improve survival rates and if not, most people will die from the lack of oxygen within minutes. • Feels that an avalanche simulator has a lot of potential and applications if it can be realistic and encompass a lot of the different scenarios and perspectives • On top of avalanche training, there are also a lot of mountain safety aspects to prepare for (like how to apply first aid, how to get a person off the mountain safely/quickly, how to get off the rock wall when you get injured, or how to address AMS(acute mountaineering syndrome), with equipment checks (to prevent frostbite) and fitness/technical training also being important • Experience is very important in accident prevention and we still need to climb the mountain itself to gain the experience

Appendix 2 – Questionnaire and Results

	Questions	Tester 1	Tester 2	Tester 3	Tester 4	Tester 5
Profile	What is your height? (cm)	173	155	163	169	160
	What is your `swimming proficiency?	Basic	Advanced	Intermediate	Basic	Basic
	How often do you swim?	Once a year	Once every 2 weeks	Once a month	Less than 5 times a year	Once a month
	Have you gone to mountainous regions with snow?	Never	Yes, Seoraksan	Never	Never	Never
Without Resistance Bands	On a scale of 1-10, how comfortable is this position?	1	6	5	6	4
	Someone Counts	42	49	42	30	36
	On a scale of 1-10, how realistic is the simulation?	3	5	4	6	5

	What is your overall experience of the simulation?	Gamey, watching 3D movie, breathing need to take note	There's no force, the view realistic	No proper indication of whether I am doing the right stroke or not	Very tiring on the arms	Feels strange due to lack of force
With Resistance Bands	On a scale of 1-10, how comfortable is this position?	2	6, feels like flying	5	4	5
	On a scale from 1-10, how close is this force you feel to actual swimming? (Out sweep)	4	7	8	6	5
	On a scale from 1-10, how close is this force you feel to actual swimming? (In sweep)	2 (force on palm)	6	4	3	4
	On a scale from 1-10, how close is this force you feel to actual swimming? (Recovery)	3	4	4	2	3
	On a scale from 1-10, how close is	4	6	6	4	5

	this force you feel to actual swimming? (Re-entry)					
	Someone Counts	41	38	39	32	40
	On a scale of 1-10, how realistic is the simulation?	5	6	6	7	6
	What is your overall experience of the simulation?	Jerky, unnatural movement	Resistance encounter is wrong, the points are wrong	Better than without the resistance bands, it feels more realistic	Feels like I had a good workout	Feels restrictive and my hands keep hitting the bands

Appendix 3 – EMS Profile of Users for Wrist Actuation

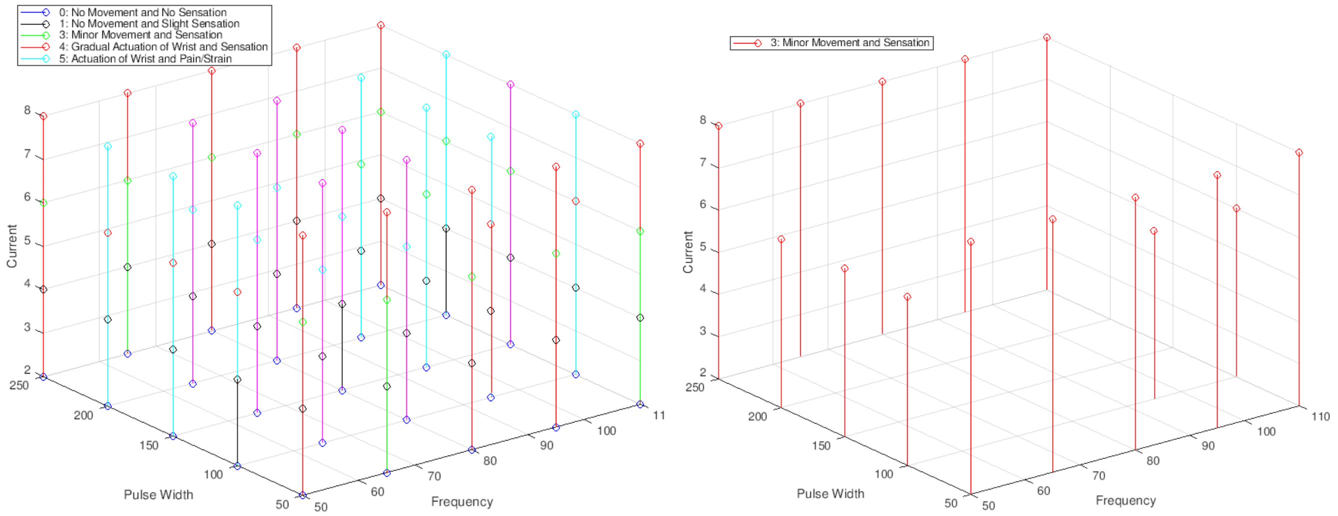


Figure 62: EMS Profile (Raw/Filtered) of User with 24.5cm Tricep Size

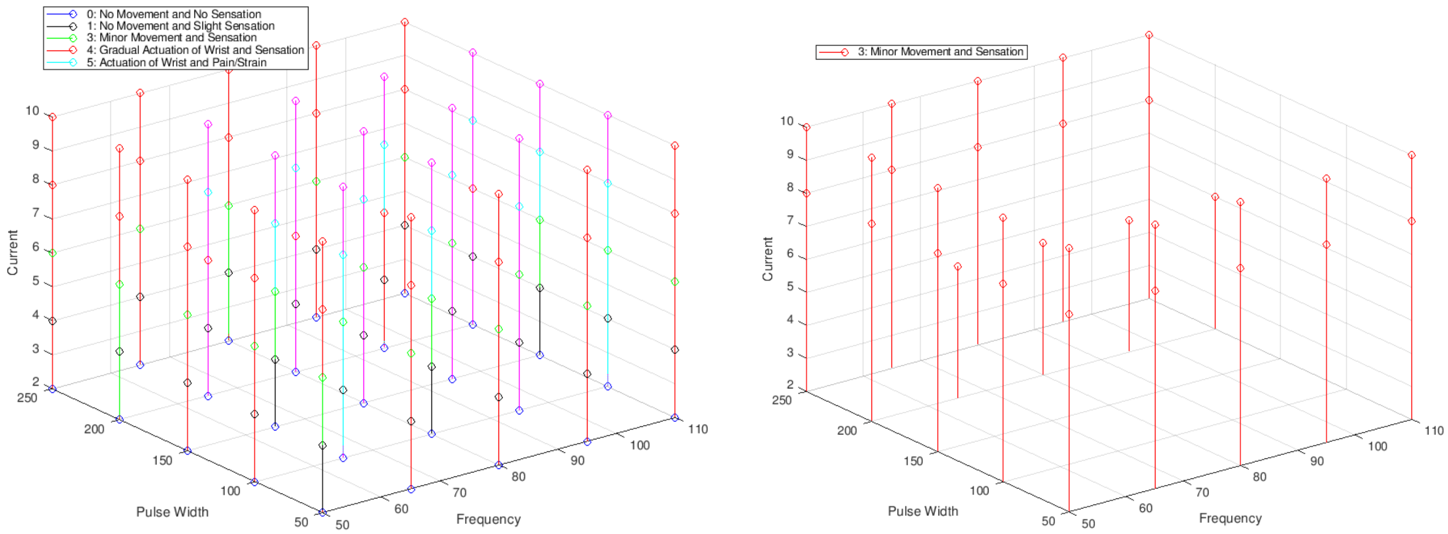


Figure 63: EMS Profile (Raw/Filtered) of User with 27.3cm Tricep Size

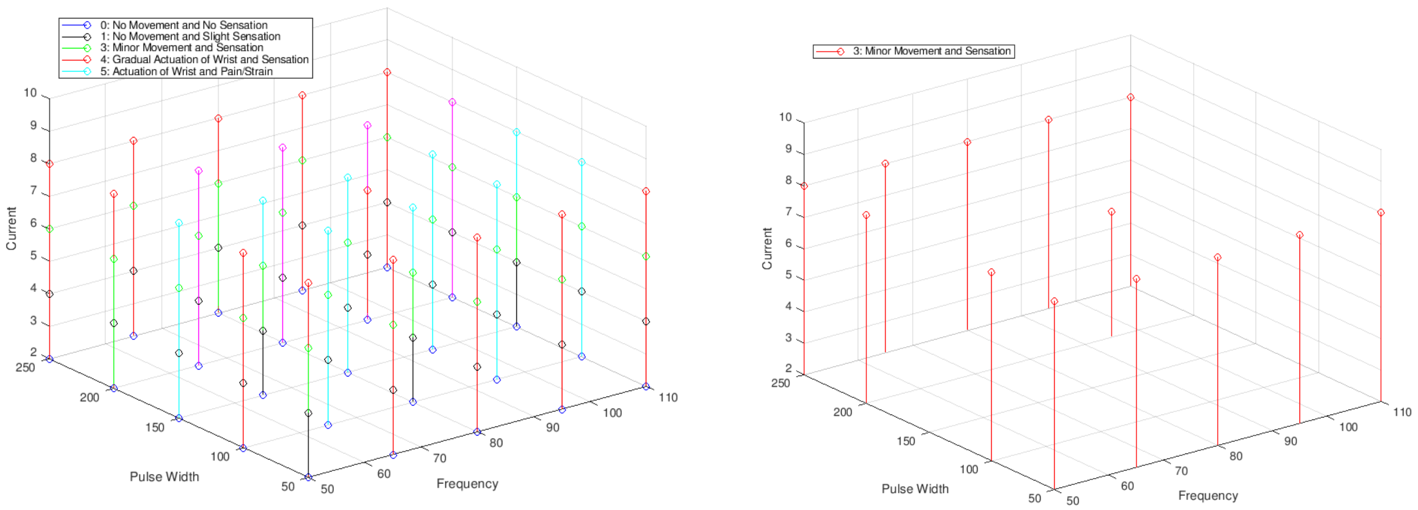


Figure 64: EMS Profile (Raw/Filtered) of User with 29.4cm Tricep Size

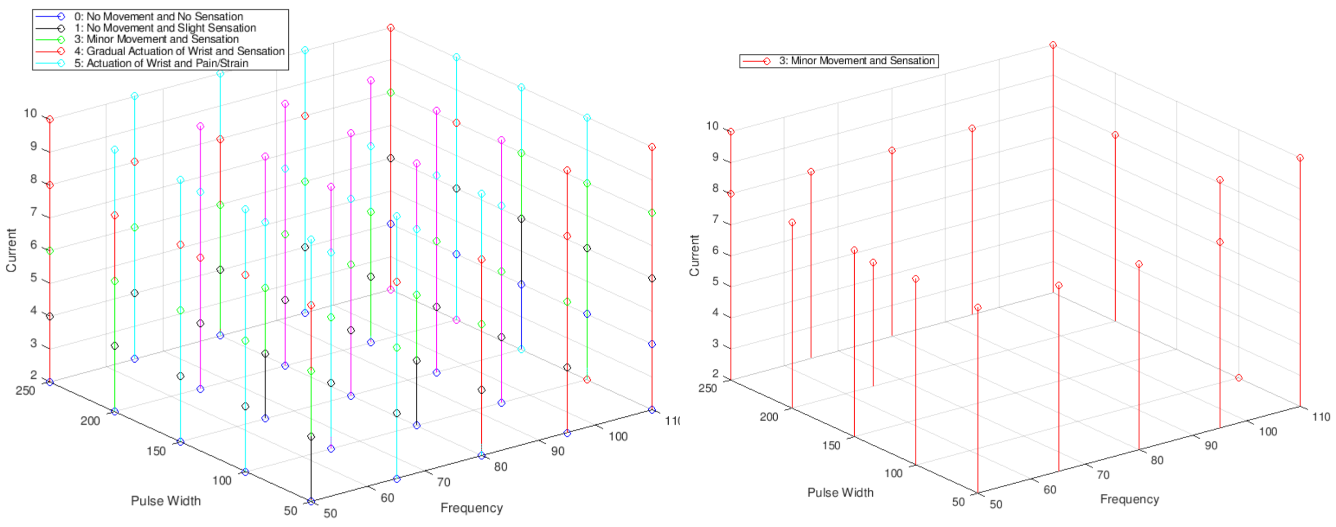


Figure 65: EMS Profile (Raw/Filtered) of User with 30.1cm Tricep Size

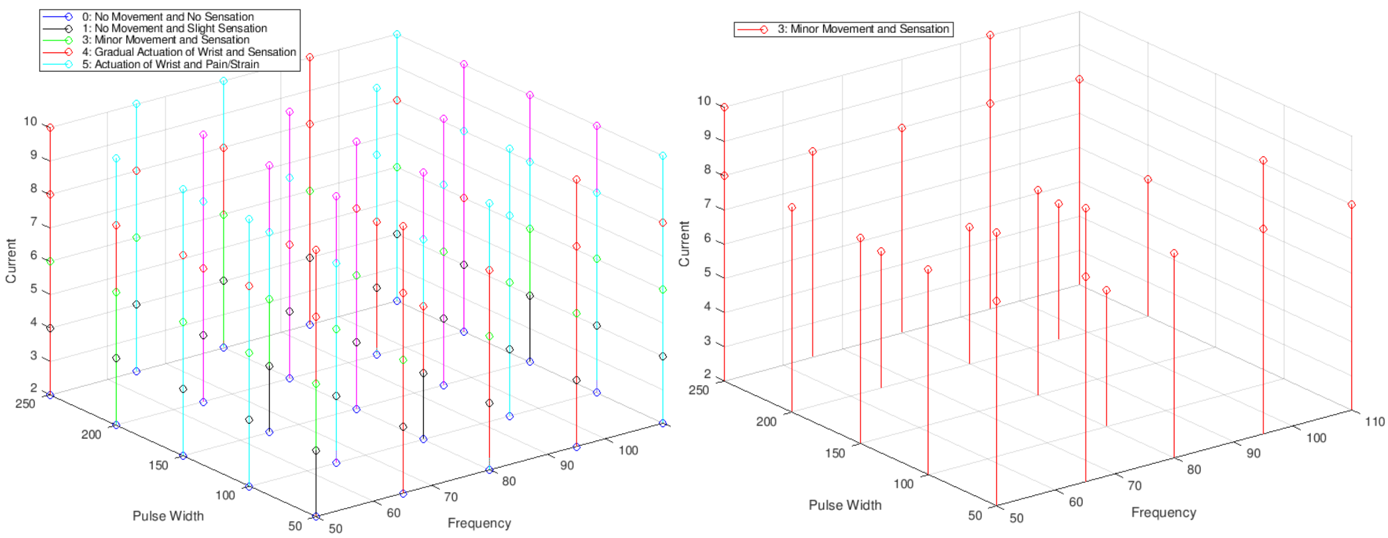


Figure 66: EMS Profile (Raw/Filtered) of User with 31.2cm Tricep Size

Appendix 4 – EMS Profile of Users for Arm Actuation

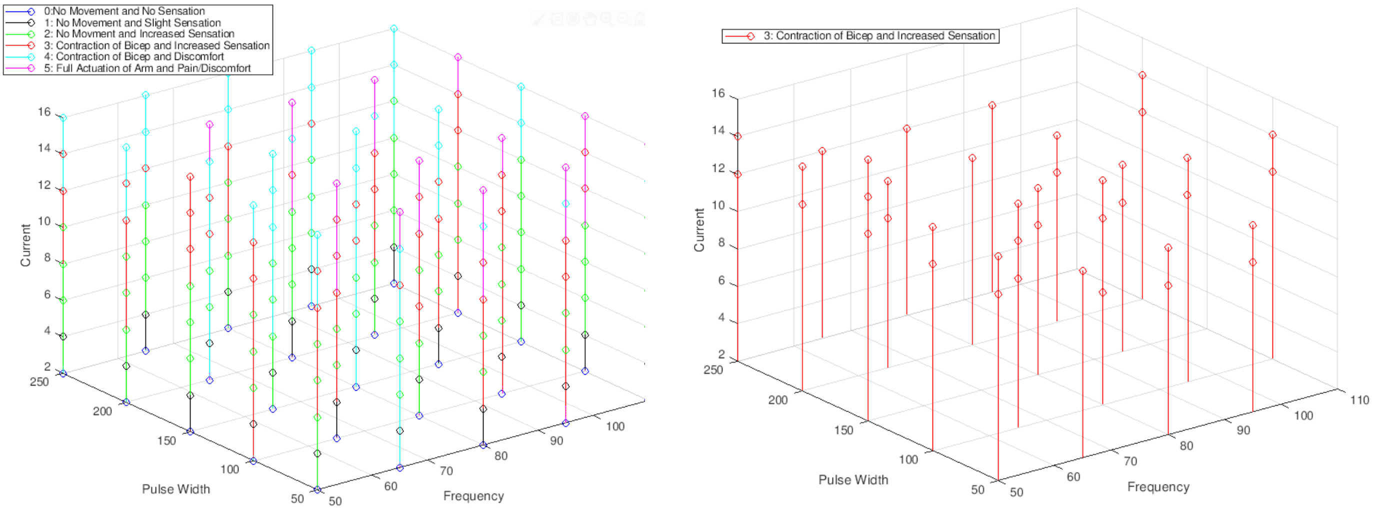


Figure 67: EMS Profile (Raw/Filtered) of User with 28.3cm Bicep Size

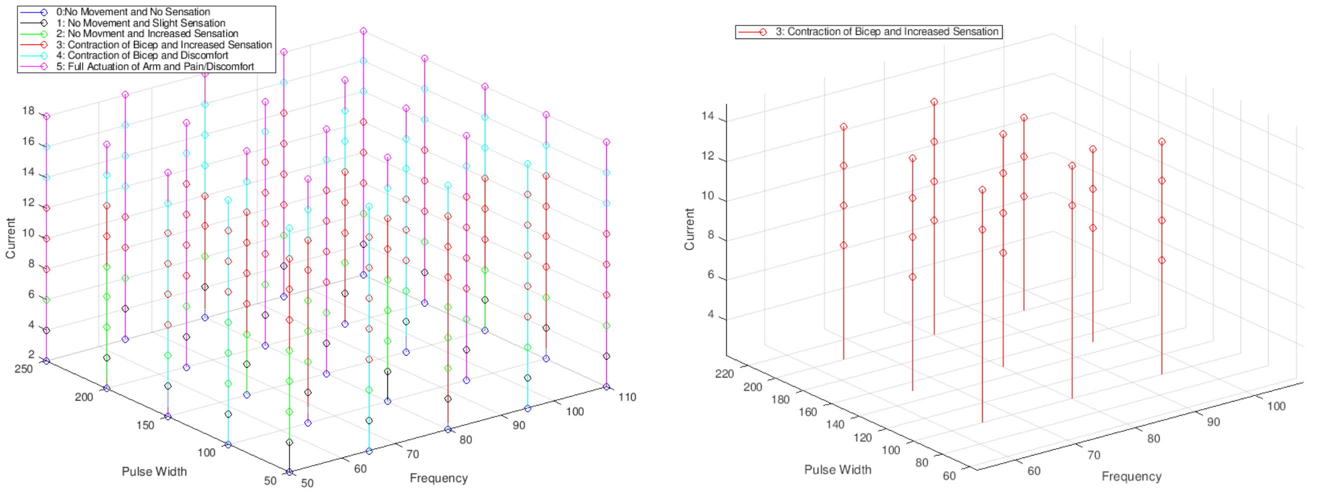


Figure 68: EMS Profile (Raw/Filtered) of User with 29.4cm Bicep Size

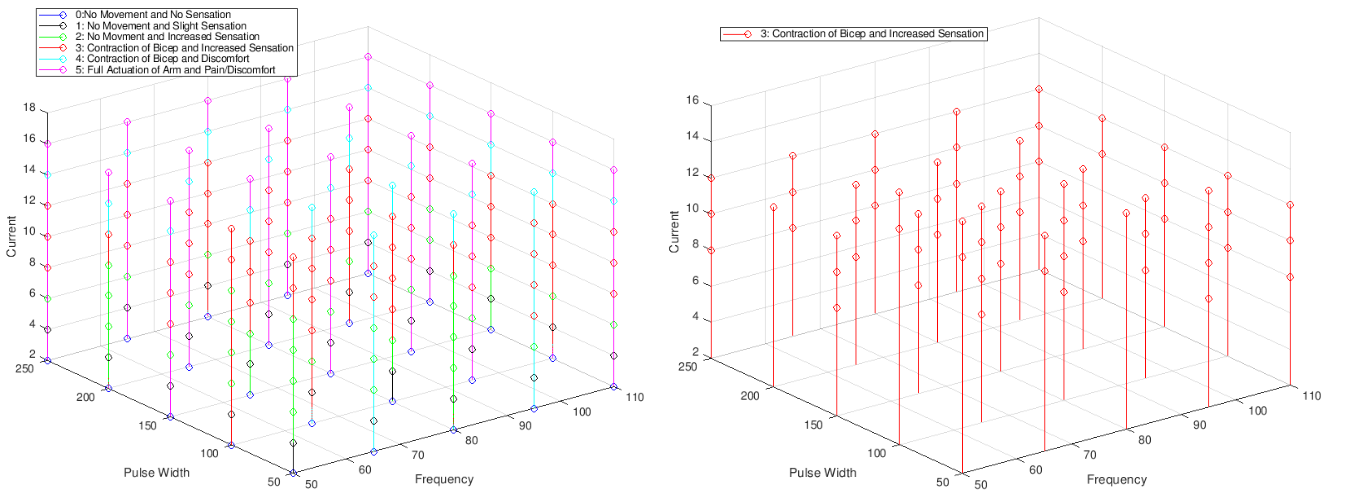


Figure 69: EMS Profile (Raw/Filtered) of User with 31.2cm Bicep Size

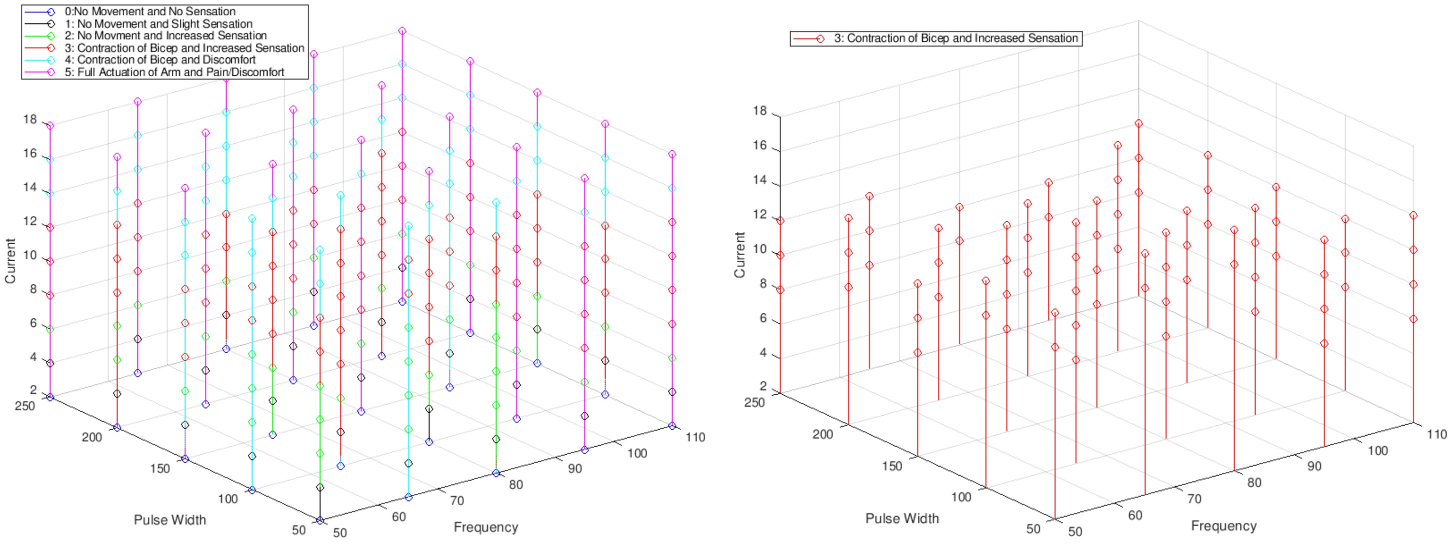


Figure 70: EMS Profile (Raw/Filtered) of User with 33.2cm Bicep Size

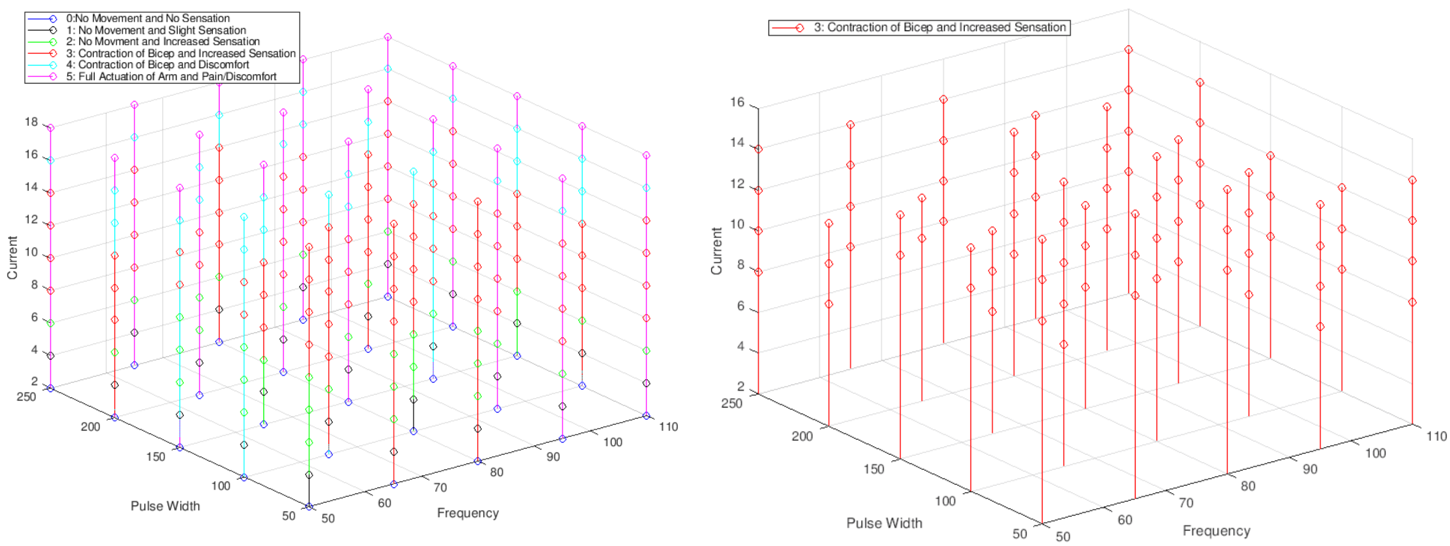


Figure 71: EMS Profile (Raw/Filtered) of User with 35.4cm Bicep Size