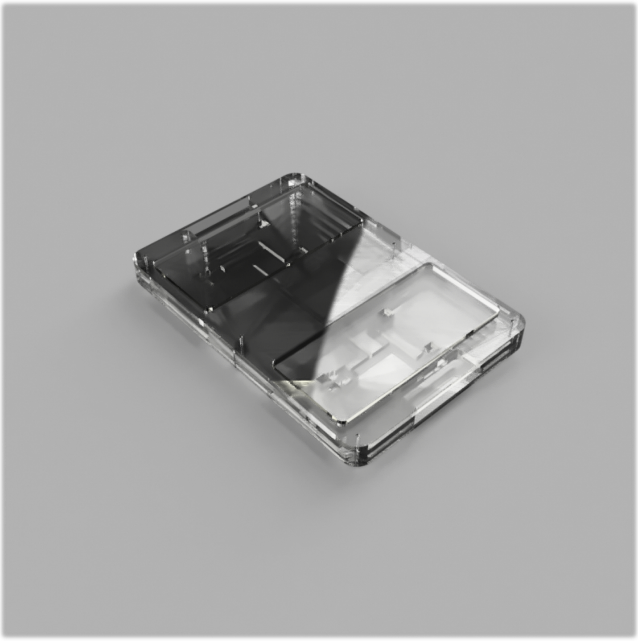

BALANCE BOARD

The Balance Board is a system aimed at solving a problem many face, balance impairment, through conditions like strokes and ABI (Acquired Brain Injury), balance impairment has meant that for some, quality of life has dramatically fallen. With the help of the Balance Board, medical professionals are able to tailor rehabilitation regimes to each individual patient for a faster recovery time.

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Year 12, 2016 Ballarat Grammar School

Systems Engineering Folio

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The Problem

Recovering stoke victims are faced with many challenges on their road to recovery. A possible effect of a stoke is the loss of their balance. This comes with it a whole new group of challenges for every day living.

Physiotherapy is the only effective methods to regain this skill, and be able to live an independent life again. The problem is, medical professionals are restricted by the tools they have access too. For situations like this, the only tools that are being used, apart from visual testing, are the Wii Fit and specialised equipment that “are expensive and require a dedicated area in the clinical facilities due to their size, weight and set-up.” *(Gil-Gómez, Lloréns, Alcañiz, & Colomer, Effectiveness of a Wii balance board-based system (eBaViR) for balance rehabilitation, 2011)*

As amazing as these technologies are, they are not built with this application in mind, and can be rather inaccurate and/or expensive. The problem here is that physiotherapists don’t have access to the right tools to be able to assess and monitor patients correctly.

A study also highlights the use for a need for a system such as this for ABI (Acquired Brain Injury) victims, being “the main cause of death and disability amount young adults.” *(Gil-Gómez, Lloréns, Alcañiz, & Colomer, Effectiveness of a Wii balance board-based system (eBaViR) for balance rehabilitation, 2011)* It states the “traditional balance training is based on the automatic repetition of specific movements… [which] provide a limited benefit to patients with balance disorders”. (Gil-Gómez, Lloréns, Alcañiz, & Colomer, Effectiveness of a Wii balance board-based system (eBaViR) for balance rehabilitation, *2011*) It also highlighted the usefulness of such a systems for “all levels of impairment” and allows “treatment to be carried out in a secure way”, having no bias of more successful treatment between “demographic (age and gender) or clinical (chronicity… and laterality).” *(Gil-Gómez, Lloréns, Alcañiz, & Colomer, Effectiveness of a Wii balance board-based system (eBaViR) for balance rehabilitation, 2011)*

The journal “highlights it’s potential to be used in clinical settings in order to improve balance”, showing “a significant improvement in static balance… compared to patients who underwent traditional therapy”. *(Gil-Gómez, Lloréns, Alcañiz, & Colomer, Effectiveness of a Wii balance board-based system (eBaViR) for balance rehabilitation, 2011)*

Design Brief

What is it?

The product is a Balance Rehabilitation system, designed for stoke victims and others who suffer from balance problems (such as ABI victims). The system will measure the different levels of pressure the user applies on each foot, giving medical professionals the ability to see how balanced patients are through visualisations of such data.

Why is it needed?

The Balance Rehabilitation system is designed for rehabilitation of those whom from balance impairment and have coordination problems, such as a stroke and Acquired Brain Injury. For victims, having these complications mean that it is unsafe to walk alone, as tripping or falling over could result in injury. Because of this, stroke victims usually require a caretaker, which takes away their sense of independence, and can also cost them, or their family, a lot of money with care taker fees, longer rehabilitation processes and more frequent medical fees.

Because the Balance Rehabilitation system is directly aimed and developed for stroke victims and their rehabilitation, medical professional will be able to gain accurate and relevant information that will allow for the better understand how clients are improving, enable the develop of more effective rehabilitation plans for clients, reducing the time of rehabilitation.

Function

The product will need to accurately visualise data such as “the user’s centre of balance and weight” *(Gil-Gómez, Lloréns, Alcañiz, & Colomer, Effectiveness of a Wii balance board-based system (eBaViR) for balance rehabilitation, 2011)*, relating to the patient’s balance. The information visualised will need to be relevant for medical professionals to be able to make more accurate medical judgements on how patients are progressing in their treatments, and what further course of actions are necessary to improve the patients balance and quality of life. I will need to research the best way to visualise, and what methods I can use to record such data. The product will also need to accurately measure the user’s centre of balance, and where they are positioning their weight while standing.

User Needs and Requirements

The product will need to be able to accommodate all different types of people, ranging from small to large, light to heavy. This factor will have quite a large impact on the choice of design for this reason. Also, being directed at people with a lack of balance, the product should be stable and able to grip to (to the user’s shoes). The product shouldn’t create unnecessary height, creating danger to the user in case of a fall.

Materials and Components

High quality components should be used because of the environment of use the product will be situated in – environments such as physiotherapist offices, hospitals and other medical places. Materials should also be durable because of the possibility for continuous use.

Employing high quality, durable materials will also decrease the possibility for the need of repair, essentially reducing costs of operating the product in the long run, and being able to rely on the products accurate data for longer without maintenance. The product should also be structurally sound, as users of all ranges of weight should be able to use this product. The use of strong materials will be crucial for this.

Environmental Use

The problem with current solutions and systems is that they "require a dedicated area in the clinical facilities due to their size, weight and set-up". *(Gil-Gómez, Lloréns, Alcañiz, & Colomer, Effectiveness of a Wii balance board-based system (eBaViR) for balance rehabilitation, 2011)* The product will be used in places such as physiotherapist offices and hospitals. Therefore, the product will need to be safe to transport and moved around – as environments such as these are always needing to be changed for effectiveness and efficiency reasons. The product should also be as light as possible, while maintaining structural integrity and 'ruggedness' for the purpose of safe movability and transport. In such dynamic workplaces, a product that is light and durable enough to be packed up and stored, but also easy to setup and use is incredibly useful and needed in such a context as this.

Safety

As the product will have a large electronic aspect to it, there should be checks and precautions to ensure no electrical hazards to users or to me while developing the board. This will include design criteria to check for electronic hazards such as exposed wires, dangerously high voltage, etc. Also, if need be, while producing the product, I will get a qualified electrician to help design and build any mains power transformers or other dangerous subsystems like such. The product should also not present as a tripping hazard – to minimise this, the transportability of the product will help to minimise this by allowing the storage of the unit while not in use.

Costs

In the context of what this product is being made for (medical professionals and their workplaces), there should be cost reductions where possible. While keeping this in mind, these places of work aren't known for using sub-par equipment, and do have access to reserves of revenue for equipment purchase (for products like this). The main focus, above reducing costs is to create a product that is accurate, durable and lightweight.

Waste

During the design stage, the use of computer aided design (CAD) software will help to accurately design the product and ensure that components will fit and functions where and how they are supposed to. During the production phase, the use of computer aided manufacturing (CAM) processes, such as 3D printing, CNC milling and laser cutting will ensure precise builds and cuts of material, minimising the amount of waste produced from human errors (like incorrect measurements, etc.) Because of the possibility of infrequent use, the product should have a sleep mode to preserve energy. Stopping power consumption from video output and reading values until required will help to reduce the carbon footprint of the product.

Quality Standards

Because of the environment of which this product will operate, safety and reliability is important. Safety is important because of the users (those whom are balance impaired) and the reputation to protect of the institutions (physiotherapists and hospitals). As this product has an electronic side to it, it will need to adhere to Australian laws regarding electronic products (which will need to be researched). Because of the nature of use of this product, having interactions with balance impaired people, the product should also be built to high standards of quality and durability to help ensure safety of users in regards to the use of the product.

Styling and Appearance

The product should be low profile and not try and stand out from every other product. This is because the product won't be designed to be visually attractive or especially appealing. While saying this, the product should be sleek, and have a 'medical' feel to it – as to blend in with it's surroundings. This will be done though the products shapes and materials. For example, the use of natural woods would not be suitable, as natural woods are not typically found in these environments. Materials such as plastics and metals would be a more suitable choice.

Performance and Durability

The product should be able to accurately read sensor data and convert that data into useful information through real time visualisation. The product should also be durable against weight applied to it and movement and transportation. Because strokes can occur in people of all sizes and ages, the product should be able to cater for this variable. Also, because of the dynamic nature of these workplaces, the product should be able to withstand being moved and stored, while maintaining accuracy.

Size

The product shouldn't take up unnecessary room, as physiotherapist offices can be small as they already are. Also, taking up unnecessary room may also create a hazard for others also working in the space – whether it be a tripping hazard, or not enough hazard to conduct their work in a safe manner. There is already a problem with existing products and systems, "[requiring] a dedicated area in clinical facilities". *(Gil-Gómez, Lloréns, Alcañiz, & Colomer, Effectiveness of a Wii balance board-based system (eBaViR) for balance rehabilitation, 2011)* Contrasting this though, this product may be used by people of all sizes and ages, the final product should be big enough to cater for people both big and small.

Maintenance

Because this is a specialised product, maintenance shouldn't be conducted by the user – both for safety reasons and for reasons of ensuring the quality of the repaired product. However, if the product does need to be repaired, all components within should be accessible to the repairer. This will mean that the product should be at very least semi modular.

Production Methods

Because I want to use a CAD - CAM approach to manufacturing the product, I will need to find processes that utilise this approach, that also product and can work with fabricated components and materials that are durable and are at a safe standard.

Research

Existing Products, Systems and Subsystems

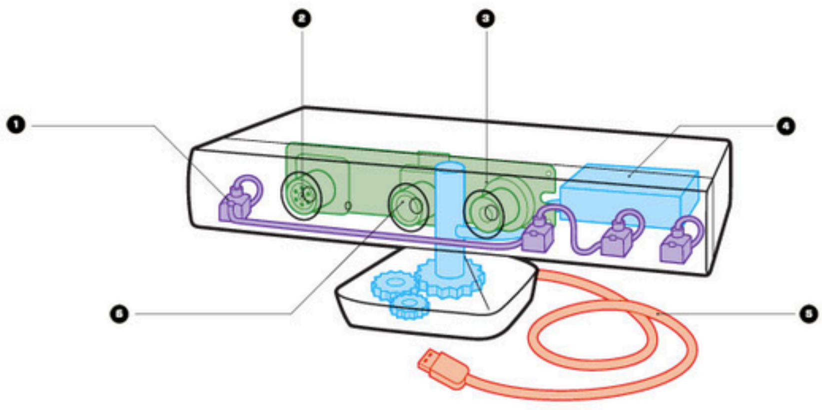
Xbox Kinect

How does it work?

The Kinect projects a pattern of infrared light into space. When the light hits a surface, a surface like our skin, the pattern becomes distorted. The cameras on the Kinect pick up this distortion and interpret this data into people using software in the Xbox add-on. The dual cameras also help to give the system a stereopsis ability, which allows it to read how close or far the surfaces are – just like how our depth perception works – with our two eyes (basically).

How is this product used for stroke victim rehabilitation?

The Kinect has played a large role in the advancement of personalised medical recovery. This platform is great for those who are suffering on a large scale, thought, for people whom are balance impaired, this system doesn't offer professionals the tools and information they need in order to facilitate the same personalised treatment that other victims get from this system. This comes from the lack of accuracy the Kinect offers, in terms of balance data. For someone who has a skewed walk or posture, being able to read data about the patient's overall posture and gate would help the professional greatly – but for balance impaired patents, professionals need to have access to more detailed information (for example, information on the weight distribution of each foot).



Pros and Cons

PROS	CONS
The unit is cheap.	Expensive when counting the cost of software.
It is accurate for overall diagnosis and monitoring.	Doesn't have the ability to measure the user's balance accurately, in detail
Low profile / low footprint.	
Readily available.	
Portable	

Wii Fit Balance Board

How does it work?

The Wii Fit Balance Board measures weight through 4 sensors in each of the corners. The Balance Board uses strain gauges (also referred to as Load Cells), which measure the strain that is applied to an object through the electrical resistance and that change that occurs as the material is stretched within it's limits of elasticity. The Board has a PCB inside of it that translates all of this data into information that it sends to the Wii Unit so that the user can see the changes in their balance on games that utilise this change.

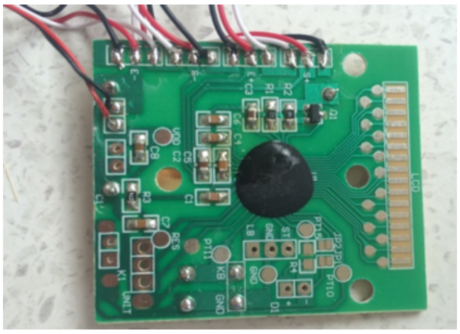
How is this product used for stroke victim rehabilitation?

This product is already used for stroke victims, and is "considered a valid portable low-cost tool for assessing standing balance". *(Gil-Gómez, Lloréns, Alcañiz, & Colomer, Effectiveness of a Wii balance board-based system (eBaViR) for balance rehabilitation, 2011)* In the Journal of Neuroengineering and Rehabilitation, research was conducted to find if products such as the Wii Fit Balance Board are effective at helping to rehabilitate patients and their sense of balance. It utilised games and other visualisations to encourage users to gain their balance back. It stated that "Patients using [the Balance Board] had a significant improvement in static balance (p = 0.011 in Berg Balance Scale and p = 0.011 in Anterior Reaches Test) compared to patients who underwent traditional therapy." *(Gil-Gómez, Lloréns, Alcañiz, & Colomer, Effectiveness of a Wii balance board-based system (eBaViR) for balance rehabilitation, 2011)*

Pros and Cons

PROS	CONS
Portable	Only works with Wii Unit
Durable	Cannot be customised to user
Measures user's balance	
Proven to be effective	

Bathroom Scales

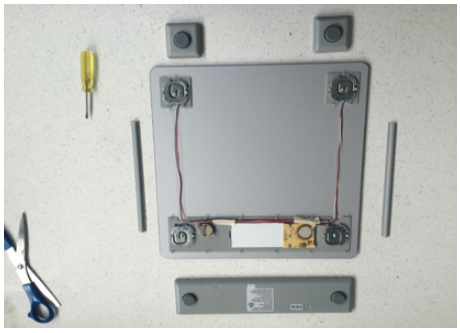


Being a system that needs to measure the weight / force applied, I thought that it would be appropriate to analyse how bathroom scales operate. Being a normal part of peoples every day lives, deconstructing a scale would help to give me an insight, and hopefully some more ideas on what the product may look like, and how components should be positioned to represent accurate data about balance and weight.

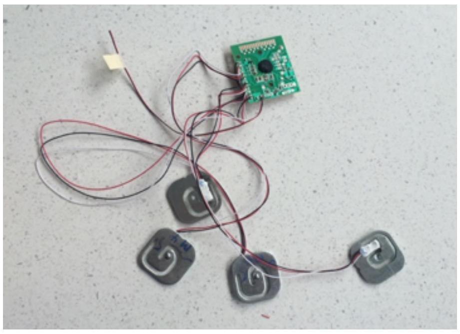
To achieve this, I decided to purchase a bathroom scale and disassemble it, with hopes that reverse engineering it would help to give me ideas about what components to use; specifically, sensors.

Disassembly

I first analysed how the system worked. Run off a series of 'Double A' batteries, the scales would be in a hibernation state until stepped on. When a user stepped on the device to wake it up, it would ask the user to step off again. I believe this is for calibration purposes, and even possibly setting a threshold. If I didn't step off during it's calibration phase, it would present an error message to me.



Next, using a common screwdriver, I levered the wire covers from the backside of the device to expose the wires leading to the two bottom sensors. I then levered off the caps of where the sensors were housed, which had rubber feet on the tops so that when the scales were on floor, of what usually would be tiles (a surface that doesn't naturally grip to surfaces), the device would be held in place. This exposed the main circuit boards and sensors of the scales.



I then took out the circuitry for what looked to be like the sensors. After some quick internet research, the sensors used in most bathroom scales, including this one, are called Strain Gauges. Strain Gauges use the electrical property of malleable, conductive material (like foil), that when its compressed or stretched its resistive properties change. Usually combines together to create what's called a "Wheatstone Bridge", used to measure the unknown electrical resistance.

The circuit board used for this device looked fairly complex at first, but after inspection, it uses SMD (surface mount devices) such as resistors and capacitors, which have copper tracks that lead to what I suspect to be an IC underneath the black dot. The black dot present on the board is what I assume to be some sort of heat dispersing material, used to preserve the chip underneath it. The pads on the right hand side of the board were to connect to the scales screen. This is achieved by a physical contact and alignment between pads the board and screen had.

The strain gauge looked fairly similar to other ones I found while browsing the internet. This particular one seems to rely on the middle point, signified by the bump in the middle, being manipulated by users standing on the device, and the caps that I pulled off at the beginning of the deconstruction pressuring them, creating the electrical resistance that strain gauges are used for.

Conclusion

Looking at these systems has given me an idea of the direction I want to head it, and hopefully, a direction on how the system should function in a manner that helps medical professionals attain the data they need to make informed decisions on a patient’s recovery and recovery strategy. I will continue to read, extract and use any relevant and useful information from the Journal of Neuroengineering and Rehabilitation that relates to what design factors that makes the Wii Fit Balance Board and their own ‘eBaViR’ so useful and successful for medical professionals, compared to alternative products.

Statement of Intent

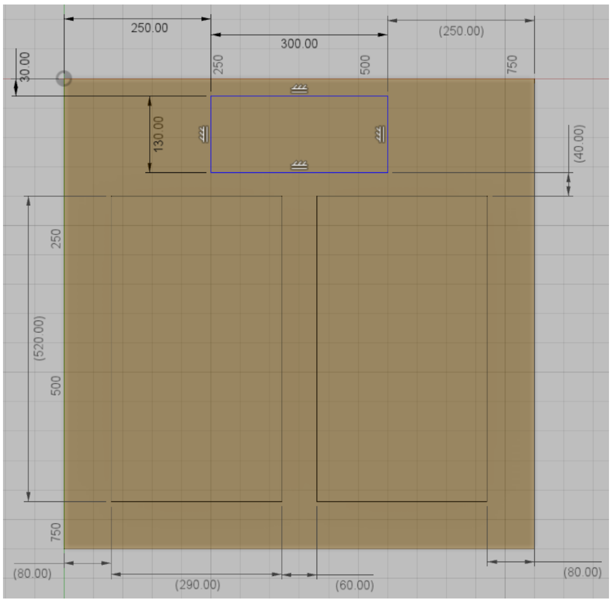
The product I intend to build should help physiotherapists, doctors and other medical professionals to better aid patients whom suffer from balance impairment, such as stroke and ABI victims. The product I plan to build will help medical professionals to diagnose and monitor patient recovery through a better method of measuring balance – being able to visualise, in real time, accurate data of the patient’s balance through sensors embedded within a device that patients can stand on.

Potential Solutions

Design Options

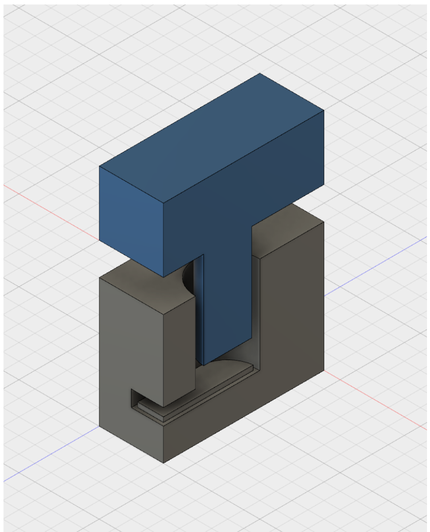
There are several aspects that variations can fall under.
1) How data is presented to medical professionals,
2) How the physical product will operate (e.g. the sensors and their placement) and look,
3) The nature of the products operation (self contained, with a screen or without, etc.)

The first option is the combination of the basic representation of data on an inbuilt screen and a simple square design for the body. The system would wake from sleep when a user steps on the footplates – operating similarly to how a bathroom scale would. An X Y graph block would allow medical professionals to see patients center or gravity, and how that changes while performing tasks such as standing on one leg. Also, present on the screen might



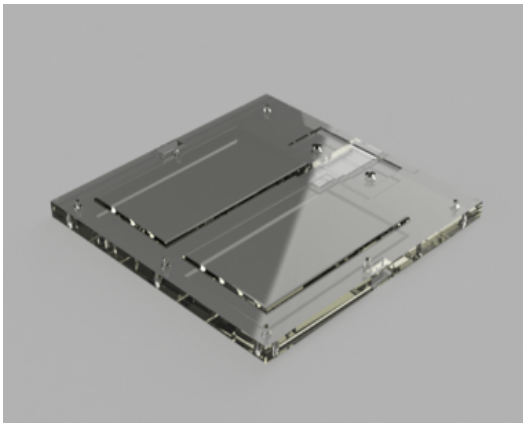
be the overall weight of the user, pending to finding if that is useful information to the medical professional.

Stepping on the footpads, the user's weight would be focused down to sensors located under four pucks on each of the footpads. A diagram of the concept is shown below. The blue T shape represents the footpad with a puck. When pressure is applied to the surface (top), it presses down onto the sensor, which would be connected to send signals to the microcontroller or Single Board Computer, which would then take that data and visualise said data as information on the inbuilt screen. This cuts down on the need for wires, as the product could be battery operated, and no external connections necessary external screens or power.

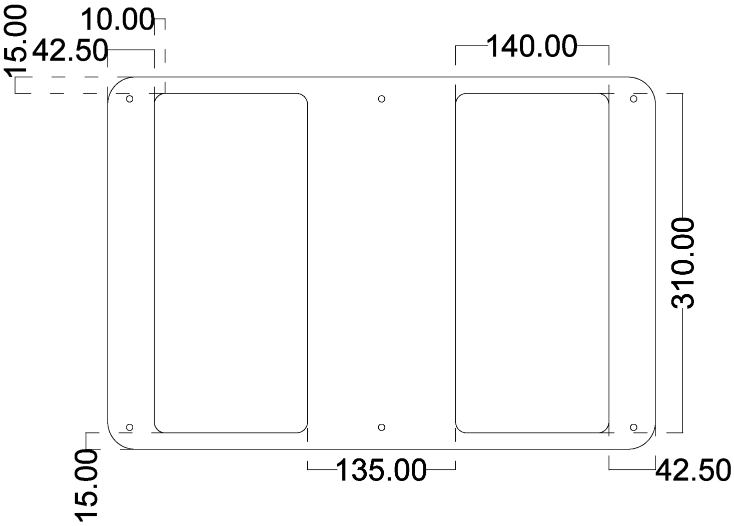


The design should also have features like handles on the side to help transportation. If it was too heavy because of the materials used to construct it, I could attach wheels to the bottom to stop the risk of back injury when lifting the device.

Advantages of this design is its simple to manufacture because of its basic design, being square with no tricky geometry to cut out with special tools or bits. It also can be self contained, meaning it takes up less room. The inbuilt screen also allows for data visualisation on the board itself, rather than needing to connect to an external screen. This is something highlighted in the Journal of Neuroengineering and Rehabilitation. One of the problems with current solutions is that they take up too much room in already cluttered environments. Having an inbuilt screen would help to reduce the required footprint for the system. Disadvantages of this design are that it is quite bulky. The screen means that the product becomes an extra 160mm long, which may become problematic, depending on what material I use to create it. If the material is heavy, like steel, then this will increase the overall weight of the product significantly. It also means that it will need a much larger space for storing the product – it may not fit under furniture or in other usual storage places.



Another solution would be to remove the inbuilt screen, eliminating lots of potentially unnecessary material and needed space that is needed to accommodate a screen in the device. This, in turn, would also help to cut costs. Without a custom sized screen would mean the products cost wouldn't have to factor in money needed for custom screens and extra material. The removal of space allows for the storage of the device in more confined spaces.

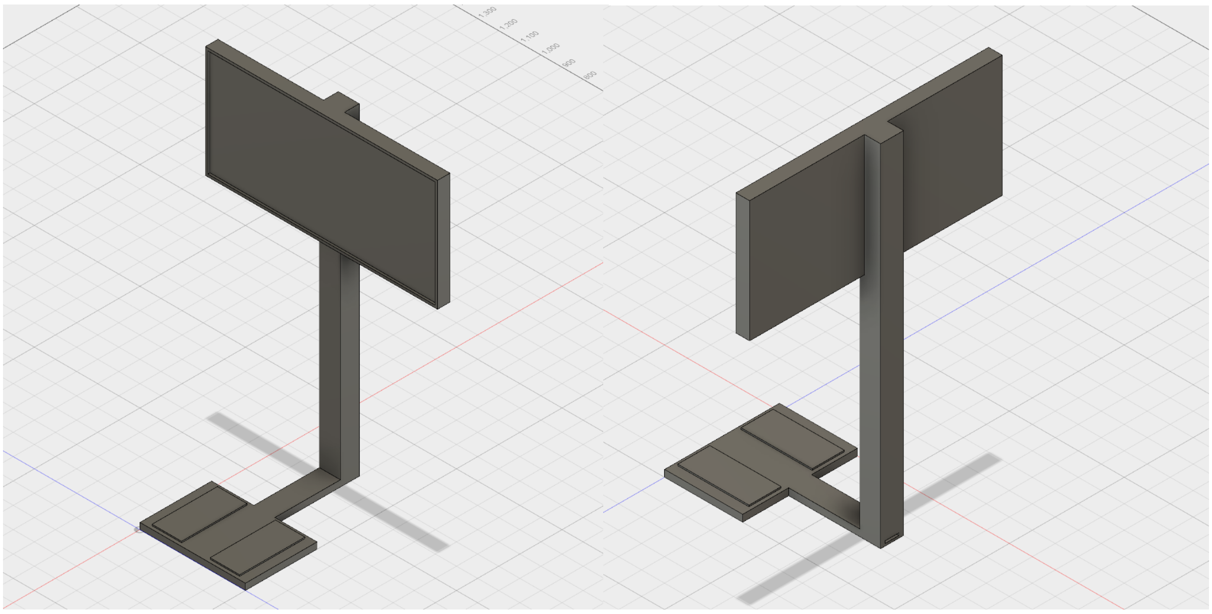


This would mean, that there would need to be an external screen available to see the visualised data. The result of this would mean the overall product would take up more room, but also would allow the choice of the size of screen required up to the medical professional. This freedom of choice would be very beneficial for older users with deteriorated eyesight who have problems with reading small screens. Medical professionals would also have the freedom to position the screen wherever they want to, which could lead to different ways of therapy (like moving the screen to one side of the user, and having them continue to try and balance themselves, seeing the difference that makes compared to having the screen front on, or on the other side of them).

The system would still work identical to the previous solution in terms of the sensors. The footpads would have pucks underneath them which would apply pressure to sensors underneath them.

This design could support battery operation, but it could also employ a wired approach. Even though wires introduce a potential tripping hazard, it would cut down on battery usage, and the possibility of loosing data mid-session. I see the data being more important than a tripping hazard, as on the whole, people can usually avoid this hazard with being aware. Having a warning with the product would help to combat this potential hazard.

Another option is to use the idea of integrating the output screen into the device. One of the problem before was that it was too small, which restricted the potential group of users to people who could see well. With a bigger screen, that would fix that problem.



In this design, the screen is integrated into the overall design. Because of the larger screen, the device would have to be operated from a wall power source as battery powered would not be a viable option. Being totally integrated (apart from the power source), medical professionals wouldn't have to have access to their own screens. Disadvantages of this design are that it would be very heavy and cost a lot – something that was considered a problem in the research done in the Journal of Neuroengineering and Rehabilitation. It would also be unstable because of the top heavy nature of having a large screen raised off the ground. This creates a hazard for both the user and the medical professionals – if the screen falls to the ground, the board will flip with it.

A final design may look like the design on the right.

Comparing these designs, and constructing a comparison table (below) that critiques the design options on points and features listed in both the Design Brief and the Journal of Neuroengineering and Rehabilitation, Design Option Two is the one I will be building. I predict it will be the most suited design in the context of the problem that I am building it for.

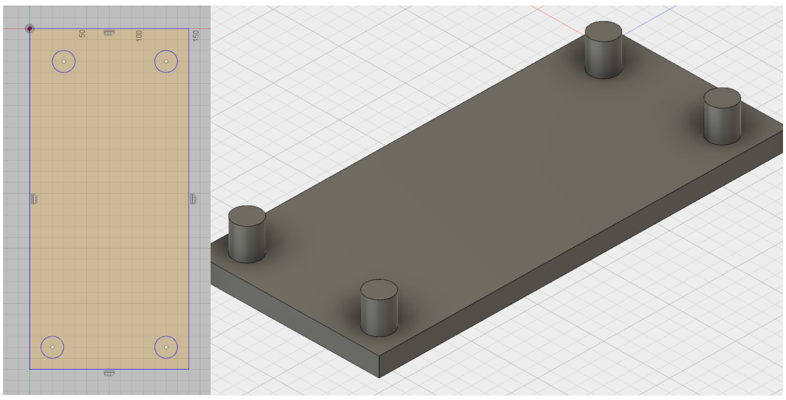
Transportation

A thought about the transportation of the device, the finalised option should have handles on each of the sides to assist with transportation. If the device became too heavy, because of heavy extremities like a screen, to safely move around by manually moving it, I would install wheels on the bottom that could withstand large amounts of weight applied to them (both from the user standing on it and the pure weight of the device itself), but also could lock in place (Like the ones shown to the right). If it was lightweight though, I would place rubber feet on the bottom. This would help give the device stability – stopping it from sliding around the floor. This could be a real problem that the device would face as hospitals generally have floors that don't allow objects to easily grip to it.

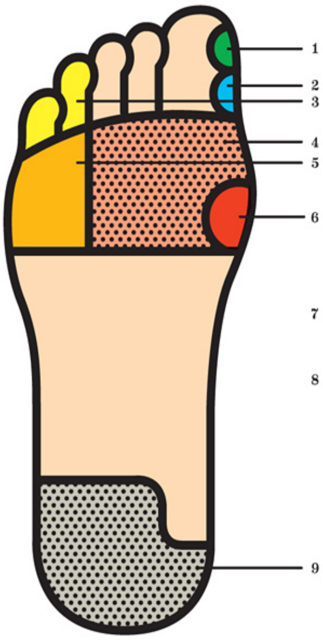
The Footpad

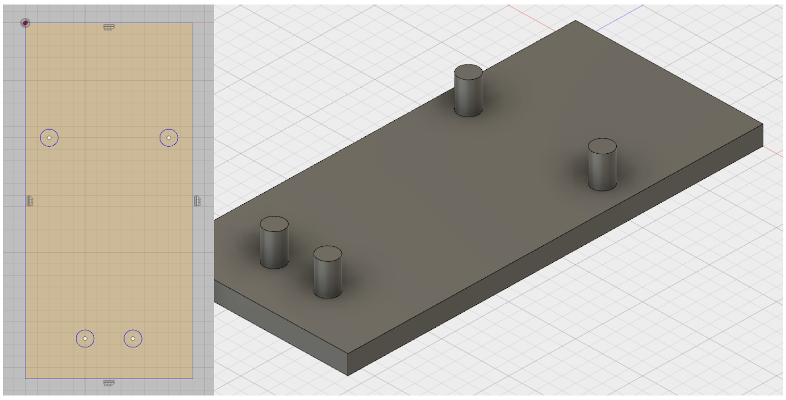
A feature present on all three of the design options are the footpads – the places designed for the user to stand on. The placement of the pucks, which help to focus the force which the user generates while standing on the device, will greatly impact the effectiveness of the device's sensors. If the pucks are placed incorrectly, then the weight applied wont be correctly measured if I use a material with any flexibility in it. This is because the material will absorb the force through bending or warping, creating false information that would eventually be displayed to the medical professional. If I end up using a strong material that doesn't give under the weight of a person (20kg – 160kg), I most likely won't have to worry incorrect data caused by warping or flexion.

The first option for the placements is the simplest design. Placing the pucks close to all four corners of the footpad, while leaving some room on each of the edges. This design would be suitable if I am using very strong, non malleable material – materials like steel, solid plastics like PLA or ABS. If I was to 3D print theses, I would need to have a 100% infill, or close to – to ensure there is no flex in the pads when pressure is applied.



This design, however doesn't sit the pucks under the four points of the foot where the most pressure is applied (Points 9 and 4, 5, 6 combined). Places that do press the most are the ankle and balls of the feet (while standing upright). A design that takes this into consideration could be made out of a more malleable material than those stated above, or be printed with a level of infill of around 60% - 90%. This would save a lot of money on printing, and would reduce the potential weight of the overall product.





This option would be the most suitable, and give a more accurate reading (because of the puck placement). Unless I choose to use a heavier material, and the first design deems to be suitable, I will most likely choose this design because of it's placement and accuracy.

Preferred Option Justification

When selecting which of the three designs I will carry onto the next phase of the project, I will be determining the most appropriate one for the context of the problem, and which will have the best possibility in resolving the problem.

Referencing relevant systems factors and their requirements outlined in the design brief will give me a guideline of which I can use to compare each design option, giving them a ranking between one and three – one being the design that correlates with the factor or requirement the least, and three being the option that demonstrates a solution to that requirement. Using this system, I will be able to rank the three design options, hopefully with an outcome that shows the preferred option, in relation to the requirements of the problem.

In relation to function, the design should have the ability to visualise data, whether that be from an external monitor or screen, or from a built-in screen. The design should also have the ability to measure a person's weight distribution and centre of balance. Given that all of the above design options achieve this, I have decided not to include this in the criteria as I believe it is redundant in the context of choosing the most appropriate design.

For the needs and requirements of users, the design option should "accommodate all different types of people, ranging from small to large, light to heavy".

The first design certainly has the capacity to achieve this point; likewise, with the second design. The third, however, may not. This would stem from the top-heavy nature of the design. Having a monitor raised above the ground by a single, thin post-like stand would create the real possibility for tipping over. This raises an issue over the safety of the user while they are standing on it, and already don't posses great balance skills to be able to safely move off the device without assistance. For heavier users, their weight would counter this effect, as their force would help to ground the device to the ground, if they were heavier than the raised screen.

The device "should also be stable and not create unnecessary height". I believe that each design achieves this as none are raised from the ground.

Systems Factor	**Design Option 1**	**Design Option 2**	**Design Option 3**
User Needs and Requirements	3	3	1

In relation to the environment of use, each design would need to be safe to transport and moved. Because of this, the design should use as little material as possible to help reduce weight. This is because excessive weight may cause muscular strains and ligament sprains if lifted incorrectly.

The first option attempts to assist with fixing the issue of transportation by having handles on either side of the case. Given its small size, I predict that it won't be excessively heavy, meaning that it would be safe to transport by carrying it.

The second option, like that of the first, has handles either side of its case. This design however would be lighter than the first because of the removal of the inbuilt screen. The screen would add weight to the device through the screen itself, but also through the extra material around the screen needed to protect and hold the screen to the device.

The third option would most likely be difficult to transport due to its size, but also its weight. Heavy on their own, large screens are known to be quite heavy. Adding this to the design, on top of the boards existing weight creates a possible hazard for transportation, if it required lifting.

Systems Factor	**Design Option 1**	**Design Option 2**	**Design Option 3**
Environment of Use	2	3	1

The preferred design should also take measures as to not create hazards, both in terms of the products electrical components and by the external body. If the product is too large, it has the potential to create workplace hazards in busy work areas. What may potentially be safe in quiet and open workspaces may not be safe in dynamic work environments such as hospital departments. To help minimise this, the device should also be able to be stored – which will be assessed later in the 'Size' component of the critique.

Both the first and second designs take design measures to not create hazards through their small form factor. The first design is self-contained, not relying on any external wires for things like power and video output. It achieves this through an on-board power source, batteries. Also, having an inbuilt screen removes the need for an external screen. The second design isn't self contained because of its need for an external screen and power source. If not treated with caution, these wires can become tripping hazards.

The third design, like the second, isn't self contained either. This design would however require less cables. Because its screen is in the design, it wouldn't need to expose cables between the on board computer and the video input of the screen. It would only need an external power cable from a wall port to power the unit. Though, this in itself creates an electrical hazard. To do this, I would need to create my own DC transformer so that I could power both units from a single power cable. Without a professional assisting me, there becomes a potential for damage of the unit, or serious hard to a person because of faulty wiring, insulation or other factors.

Systems Factor	**Design Option 1**	**Design Option 2**	**Design Option 3**
Safety	3	2	2

For this product to be successful in solving the issue on a large scale, it would need to be affordable for both large hospitals that have large funding for new equipment purchases, and also for smaller practises that may not have funding set aside specifically for equipment purchase. That being stated, the product also should not sacrifice on factors like accuracy and lifetime longevity to reduce costs. This would defeat the whole aim of the product, which is to provide medical professionals with the most accurate as possible information about patient's balance.

The first design option helps to reduce potential costs by incorporating a screen into its body. While a custom screen would be expensive to purchase as a one-off, if the device went into large scale production, this cost would become negligible because of the bulk order of screens. Also, its smaller footprint means that less materials are used, meaning that there are less costs associated with the materials required to build the device.

The second design option reduces the necessary footprint of the device even more because of its lack of inbuilt screen, which reduces its materials cost even further. Also, its ability to connect to existing screens would also give medical professionals the ability to choose a screen that would best suit their, or their patient's visual needs.

The third design option is predicted to be the most expensive out of the three due to its larger inbuilt screen. Also, it would need to be made from heavier materials or have weights in the bottom of it to counteract its top heavy nature. The addition of the screen also means that more material is used to support it, which adds additional costs to the materials side of the cost.

Systems Factor	**Design Option 1**	**Design Option 2**	**Design Option 3**
Costs	3	3	1

The size of the device is also critical in solving the issue. As stated in the Journal of Neuroengineering and Rehabilitation, current solutions aren't effective because of their need for dedicated environments. To help solve this issue, the designs should be small enough to be stored in places like cupboard, closets, behind and under furniture.

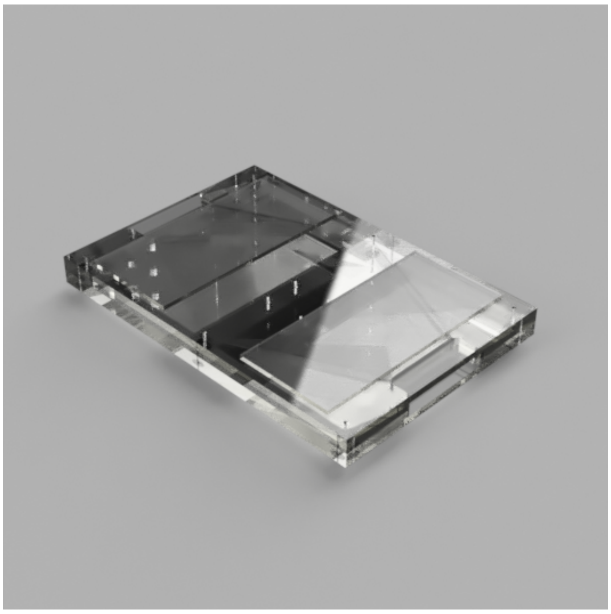
Both the first and second design options achieve this through their small size. This gives them the ability to be stored, out of the way of other daily activities. The same cannot be said about the third option. Because of its size, it would need a small room to be stored. This may create an issue for offices, wards and institutions that don't have the luxury of spare rooms – which is common in places of medical professions as space is generally well utilised.

Systems Factor	**Design Option 1**	**Design Option 2**	**Design Option 3**
Size	3	3	2

After comparing each design and ranking them according to which best fit the criteria set out in the design brief, I have been able to generate a table that shows the best design option that meets the requirements outlined above.

Systems Factor	**Design Option 1**	**Design Option 2**	**Design Option 3**
Function	-	-	-
User Needs and Requirements	3	3	1
Environment of Use	2	3	1
Safety	3	2	2
Costs	3	3	1
Size	2	3	2
Totals	**13**	**14**	**7**

Design Option Two will be the the design that I build, as I believe it carries with it the best possibility for meeting all of the needs outlined in the Journal of Neuroengineering and Rehabilitation, as well as the systems factors, found in the Design Brief.



Components, Electromechanical Concepts and Principles

Sensors

The sensors in this product will be key to giving accurate readings of the balance of patients. For this reason, much thought and research will need to go into choosing the right sensors for the device.

Strain Gauges / Load Cells

This type of weight sensor is commonly found in home appliances such as bathroom scales. Although they come in different package styles, this one being a compression disk package, the principle behind how they measure weight remain the same.

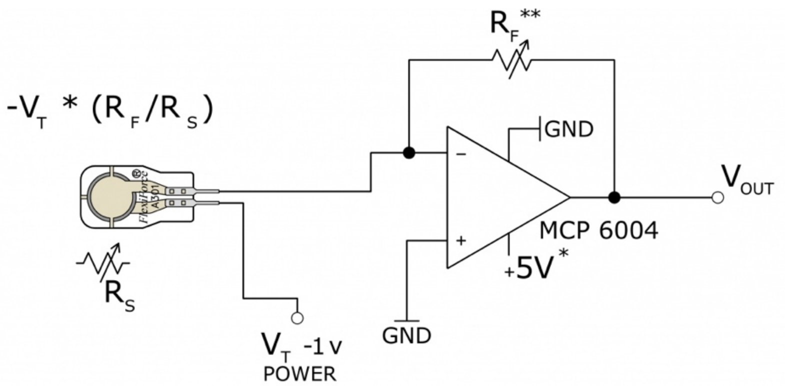
When force is applied to the top of the load (compression) cell, deformation (change) is converted into electrical resistance, which is a then digitally converted and compared to the original signal to give the difference. The electrical resistance is at its highest when there is no force applied to the sensor. When there is force applied, and the conductive material is compressed, electrons can more easily pass through – allowing more current. This difference of current is then applied to an algorithm or lookup table to give a more readable value, such as weight (or force) applied, or if there is weight present.

The signal that is outputted from the load cell is an analogue signal. Most Single Board Computers have on-board integrated circuits (ICs) that can convert this to a digital signal. If one doesn't though, I can use an Analogue to Digital Converter (ADC) IC to convert the signal into a digital one.

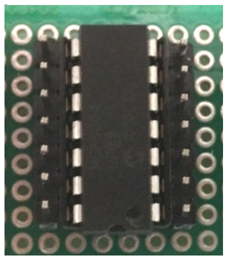
Piezoresistive Force Sensors (FSR)

Piezoresistive sensors work almost in the same way that load cells do. The more force applied to the pad on the sensor, the lower the sensor's resistance. This change in resistance can give a differential of voltage, which is typically applied to an algorithm or lookup table to give a more useful value, such as force (N) or weight (Kg) applied.

Usually, these sensors don't have the same weight range as strain gauges do. Tekscan, one of the main manufacturers of these sensors supply a guide to adjusting the force range of the sensors using an Operation Amplifier (OpAmp) IC. According to their website, these sensors can sense up to 1000lbs, which is 453.59 kilograms – much higher than I need to sense, which will give a good buffer room.

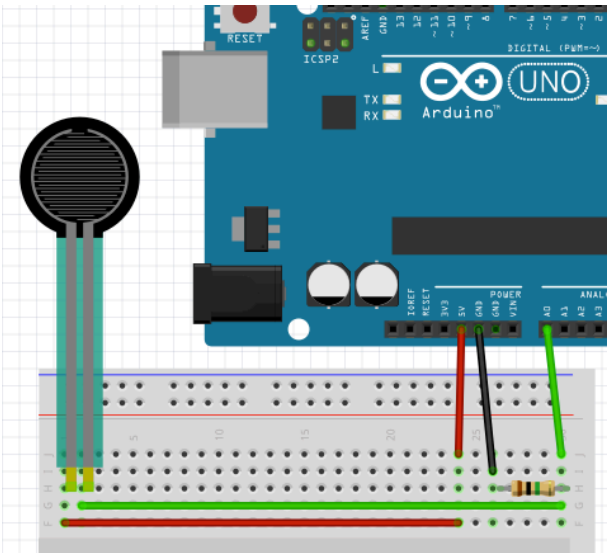


By applying a feedback resister to the MCP6004, a lower driving voltage (-0.5 V, -0.10) and a resistor of around 1KΩ will allow for a reading of higher force.



I decided to conduct an experiment to see the readable output of both the amplified and non amplified signals from the piezoresistive sensors. Because I only wanted to see the serial output of the sensors, I decided to use an Arduino Uno as my microcontroller.

In the first experiment, I didn't amplify the signal, and used a 1MΩ resistor, as per recommended on the Tekscan website. For the second experiment, I used an Operational Amplifier, the MCP6004. This IC has four operational amplifiers in it, which is why I chose to use this particular one. If it worked well, I would only have to use two in the final product, instead of needing eight or four dual amps. Using a 10KΩ resistor in place of the 1MΩ (as stated to do, lower the resistance of the resistor, on the Tekscan Website), I wrote some code and ran it off an Arduino Uno – reading the serial input from the analogue pin A0. I tested the piezoresistive sensors with a range of weights over a number of times, each time recording the average to an excel spreadsheet.



The code was very basic for this experiment:

```
void setup() {
  Serial.begin(9600);
}

void loop() {
  int sensorValue = analogRead(A0);
  Serial.println(sensorValue);
  delay(1);
}
```

The results for the first experiment, without amplification, show that this method isn't a viable option for measuring the weight of different people, as the sensors don't posses the level of accuracy (the results have too much variation between readings) that is required for the products context. The standard deviation for Weights 20kg and below is seen to be within an acceptable range (0.03 – 0.04), whereas for weights about 20kg the standard deviation is much larger (0.27, 0.25). 120kg also presents a barrier for the unamplified circuit, as it tops out around its 5V input (represented by 1023, which is the digital limit of the 10-bit ADC IC).

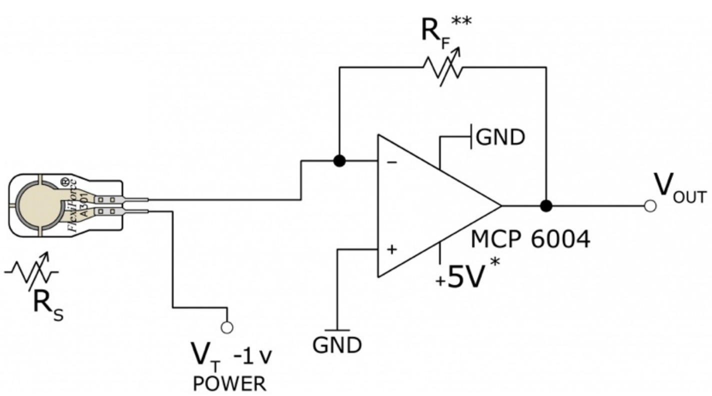
Weight (Kg)	**Trial 1**	**Trial 2**	**Trial 3**	**Trail 4**	**Trial 5**	**Averages**	**Std. Deviation**
10	81	78	79	87	86	4.1	82.2
20	204	200	214	198	207	6.3	204.6
50	397	452	430	443	427	20.9	429.8
75	696	707	662	722	668	25.6	691
120	1021	1001	1023	998	1023	12.6	1013.2

In the second experiment, with an operational amplifier, results were a lot more promising towards a viable option for the sensor selection.

Weight (Kg)	**Trial 1**	**Trial 2**	**Trial 3**	**Trail 4**	**Trial 5**	**Averages**	**Std. Deviation**
10	20	23	23	25	24	1.87	23
20	45	45	42	44	43	1.39	44
50	114	113	113	113	114	0.55	113
75	170	272	272	269	270	1.52	171
120	270	272	272	269	270	1.34	271

With the operational amplifiers in the circuit to help adjust the sensors weight range, as it more weight is applied, the average deviates less that what was seen from the previous configuration.

The calculation to find the voltage output is: $V_{out} = -V_T \times (\frac{R_f}{R_s})$



An example of an expected result would be:

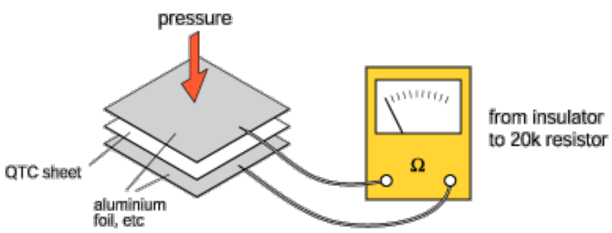
$$Vout = -5V \times 10K\Omega/800N$$, which should equal 62.5.

From these experiments, I am determining that the piezoresistive sensors are not a viable option without the operational amplifiers. This is because the bare sensors cannot take the amount of force this is required for this project while accurately recording data.

Quantum Tunnelling Composite

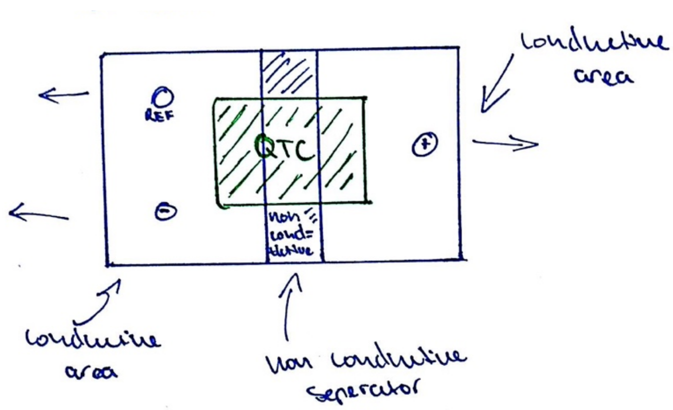
Quantum Tunnelling Composite (QTC) has some amazing properties to it. It's made up of metals and non-conducting elastomeric binder. The pills (the type of package of which they come in) utilise quantum tunnelling. Without any pressure applied, the conductive elements inside the QTC (the metals) are to far apart to conduct electricity. When force is applied, the particles move closer and electrons can tunnel through the pill.

These pills are used for touch switches, motor speed controllers (using force), sports performance analysis (an example is fencing where the fencer's suit is covered in pills that give feedback of where and how hard they are hit). It's important to note that QTC behaves much differently than the alternative sensors. QTC's resistance goes down exponentially, compared to strain gauge and piezoresistive sensors dropping resistance linearly. This allows the resistance to change by a factor of up to 10^{12} between pressured and unpressured states. This might present further challenges if I need to use operational amplifiers, which produce a linear output. This will be something to research further if QTC is the most suitable option.



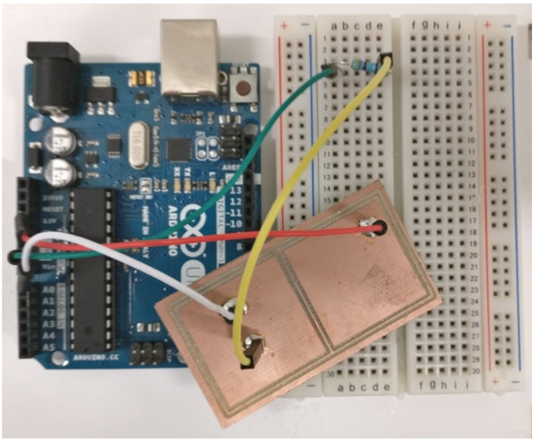
Another problem with using QTC is that they are only commercially available in their 'Pill' packages, which are 4mm x 4mm x 1mm in size. This may product another issue of how to house the QTC, and whether or not such a small sized piece of QTC could remain resistive under 1400N of pressure, or whether, like unamplified piezoresistive, it wont posses any resistance after a certain amount of weight.

I decided to conduct a test to determine whether or not this type of sensor would work with the amount of force that I am applying to it, which is anywhere between 200N (20kg) and 1400N (140kg). Please note here that I am rounding these calculations up. This gives a more readable set of numbers, while also providing a good buffer zone.



Firstly, I created a prototype PCB that allowed me to test what may be in the final product if I do choose to use QTC.

A basic diagram is show on the left, where there are two side of conductive material (copper in this case), with three leads. On the right hand side, there is the Positive terminal which will use 5V.
On the other side, there is a reference pin, which will lead to the analogue input of the Arduino Uno. Also on the left side is the ground pin. Between the ground pin on the PCB and the Arduino, I placed a 1MΩ resistor. This works as a pull-down resistor. If I connected the ground pins together without bridging them with the resistor, I wouldn't be able to read any current as all of the electricity would bypass the Reference terminal and go straight to the Ground terminal.



Connecting up all the pins, I conducted the experiment with the same weights as I did in the previous experiment. The code was the same as the previous experiment.

Results from the experiment show that QTC isn't a viable option for the system. Also, after some deep research on the internet, QTC has a maximum force rate of 100N, which is much lower than the boards requirements. Unfortunately, I was unable to find this information prior to experimenting with QTC. Peratech, the company that holds the IP license to QTC technologies, doesn't give any useful specifications to the use of QTC.

Conclusion of Sensors

SENSOR	WEIGHT RANGE	FOOTPRINT	ACCURACY	AVALIABILITY	COST	TOTAL
STRAIN	2	1	1	3	2	9
FSR	2	2	2	2	1	9
QTC	2	3	3	1	3	12

* The highest total is deemed the best sensor for this product. Each design is ranked 1-3, 3 being the best design in the category and 1 being the worst.
** Weight Range is the range of weight the sensor is able to sense.
** Footprint is the physical size of the sensor. This part of the criteria is crucial to maintain a small footprint in the overall product – a key point specified in the Journal of

Neuroengineering and Rehabilitation being one that needs addressing in new systems, and a problem in existing ones.
** Accuracy is the sensors ability to give the same reading over and over for the same weight or force applied. This could also be named 'Repeatability'. The importance of this point is that the system needs to give accurate data to medical professionals so that they can tailor more personalised recovery programs to individual patients. Having accurate data will allow them to make said plans more effective in both short term and long term recovery phases.
** Availability is the commercial availability of the product. It is important to have access to the sensors fast, in case of need for repair. If the system needs repairing, many victims may go without proper analysis and treatment because of such.
** Cost is a major part of the product. While main goals are accuracy and portability, another key point highlighted in the Journal of Neuroengineering and Rehabilitation was the expensive nature of existing equipment. Reducing the cost of equipment will make these products available to more institutions, giving people who may not be well off the same opportunities for a faster rehabilitation experience.

From this comparison table, I have chosen to use the QTC. From this comparison chart, I have concluded that they are the more appropriate choice when compared to the FSRs and Strain Gauges in relation to weight range, footprint, accuracy, availability and cost. What should be noted here is that when I was comparing the sensors, I used the weight range possible from the amplified circuit of the piezoresistive sensors, instead of their natural range.

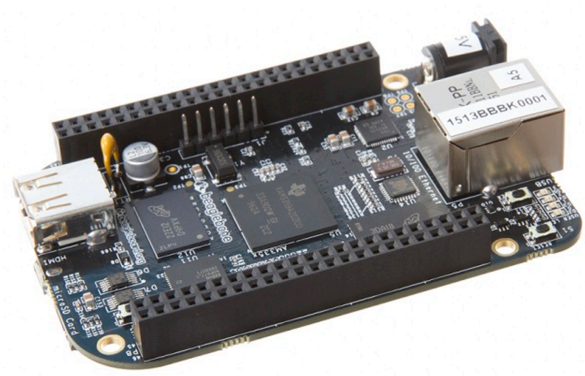
Single Board Computers (SBC) / Microcontroller Unit (MCU)

The SBC or MCU will be the brains of the device. It will handle all of the data coming from the sensors, and then be responsible for projecting that data into information onto a screen. I need to research the different options that are readily available, as this will help determine how I set up the final system – whether I will need multiple, different or similar, development boards to perform their own tasks, or if I can simplify it down to one or two boards, each responsible for their own roles (video output, running the game, recording data for Physiotherapists, reading sensor data, etc.)

Beaglebone Black Rev C

Features of the Board

AM335x 1GHz ARM Cortex-A8 Processor
512MB DDR3 RAM
4GB 8-Bit eMMC Flash Storage
3D Graphics Accelerator
NEON Floating-Point Accelerator
USB Client for Power & Communications
USB Host
Ethernet
Micro HDMI Video Output
2x 46 Pin Headers
MicroSD Storage Expandability



Analysis of the Board

What could it do for the project? What are its limits?

The BeagleBone Black would be an excellent board for this project in many ways. Theoretically, this board should be able to run the .exe game for the user's feedback on how well they are balancing. It should also be able to handle all of the sensor inputs, and be able to interpret the data itself. Another process it could perform is handling all of the user inputs, such as choosing a high difficulty, making the board move with the linear actuators – though, this should probably be handled by a separate MCU, dedicated to this role. In theory, this board should be able to do all of the above. I will run some tests and see how likely it would be able to handle all of the above jobs.

Is it readily available, and is it cost-effective?

This board is readily available online, and in stores close to me. Pricing at $89.95, this is a very cost effective board, considering its possibilities in the system.

Raspberry Pi 3

Features of the Board

Cortex-A53 1.2GHz Quad Core Processor
Broadcom VideoCore IV GPU
1GB LPDDR2 RAM (900 MHz)
10/100 Ethernet
2.4 GHz 802.11 Wi-Fi
4x USB Hosts
Bluetooth 4.1 Classic, BLE
3.5mm Audio Out
Full HDMI Video Out
40 Pin Headers
MicroSD Storage Expandability
Camera Serial Interface (CSI)
Display Serial Interface (DSI)

Analysis of the Board

What could it do for the project? What are its limits?

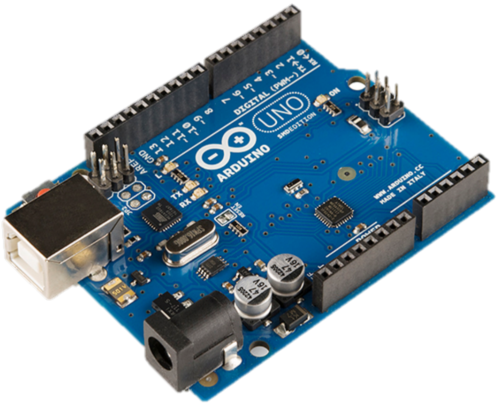
This development board, fresh out of production, tops the list for performance. This board would suit this project well, as a quad core, 1.2GHz CPU – paired with a Broadcom GPU – would make for a theoretically lag minimised experience, running the .exe gamification for the patient's balance feedback. Being able to handle the video output is one thing, but this board should also be able to handle all of the other necessary processes to make the system operate, taking in user inputs to actuate the platform, doing calculations from sensor inputs, etc., with ease – thanks to its Quad Core CPU.

I would like to run some SysBench benchmarking tests on the board to see if it could handle all of the processes required for the project – but even if it cannot, it should be able to take the grunt of the work, possibly allowing for a smaller, cheaper board to pick up what the Raspberry Pi 3 Model B cannot.

Is it readily available, and is it cost-effective?

As the board has just come out of production, preorders are insane and the board is incredibly difficult to source for larger numbers than two at a time. Costing $99.95, this board is incredibly cost-effective, considering for the power of the board.

Arduino Uno



Features of the Board

7 - 12V Input
ATmega328P 16MHz Clock, 8-Bit
AVR Architecture
32KB Flash Memory (0.5KB used for the Bootloader)
2KB of SRAM
1KB of EEPROM

Analysis of the Board

What could it do for the project? What are its limits?

This is a pretty underpowered board, considering the scope of this project. I picked this board first, as I was the most experienced with this board. If I were to use it, it may be able to drive a transistor based circuit for the actuators – using data fed from another board to trigger different movement sequences. It may also be able to do the calculation processes for the sensor inputs, then feed that information to another board for it to react to the patient's changes in balance. This wouldn't be my first choice though, as it may create unnecessary lag in the game's controls – frustrating the user and making the data less reliable as the patient may try to correct for this lag, therefore giving incorrect results.

Is it readily available, and is it cost-effective?

Absolutely is it readily available. If need be, I would have no trouble getting as many of these development boards. For what it is, this board is incredibly cost effective, as it is produced by many manufactures – and can even be fabricated 'in-house' if absolute need be, as the ATMEL chips are also readily available. It's hard to judge how much these boards are, as the cost fluctuates, but they can be bought from around $10-20 usually.

Intel Edison

Features of the Board

Dual Core 500MHz Intel Atom CPU
Single Intel Quark MCU 100MHz
1GB LPDDR3 RAM
4GB eMMC Flash Storage
Broadcom 802.11 a/b/g/n Wi-Fi (2.4GHz & 5GHz)
microSD Expandability

Analysis of the Board

What could it do for the project? What are its limits?

This board is perfect for doing anything communications and calculations wise. It perfect for data interpretations, controlling motors, etc., but it lacks far behind in the operating system side of things (mainly because it wasn't made to be a small computer, rather like a small CPU).

A major issue of this board is that it isn't a computer made for anything graphical. This board is more suited in more data-pure focused project – like that of something in the IoT, sensor / monitor spectrum. For that reason, I am excluding it from the project, because if I need a board to specifically crunch numbers from data to information that I can more easily work with, I would rather use a platform like the Arduino Mini or Arduino Uno R3.

Is it readily available, and is it cost-effective?

If I were to use this, I may need to order them from overseas. This would add to the cost, because of shipping. It would also take time. There is a possibility of there being delays because of border control. For just over $50, this board is very cost-effective, though, possibility not as cost effective as some of the other boards. Also, it might not be viable option, since I would need another board to do all of the visual output of the product.

Development Board Comparison Chart

	BeagleBone Black	**Raspberry Pi 3**	**Arduino Uno**	**Intel Edison**
Display Output?	Micro HDMI	Full HDMI	Not Suitable	N/A
Clock Speed	1GHz	1.2 GHz, Quad	16MHz	500MHz
RAM	512Mb DDR3	1Gb	2Kb	1Gb
On-board eMMC	4Gb		32Kb	4Gb
Expandable Memory	MicroSD	MicroSD		MicroSD
GPIO	2 x 46 (92)	40	20	26
Analog	7	OS Assigned	6	6
Digital	65	OS Assigned	14 (6 PWM)	20 (4 PWM)
Other Inputs	USB Host USB Client Ethernet	4 x USB Host Ethernet DSI Wi-Fi Bluetooth	N/A	Wi-Fi Bluetooth
OS Compatibility	Debian Android Ubuntu	Raspbian Ubuntu MATE Noobs	N/A	Yocto Linux (CLI only)

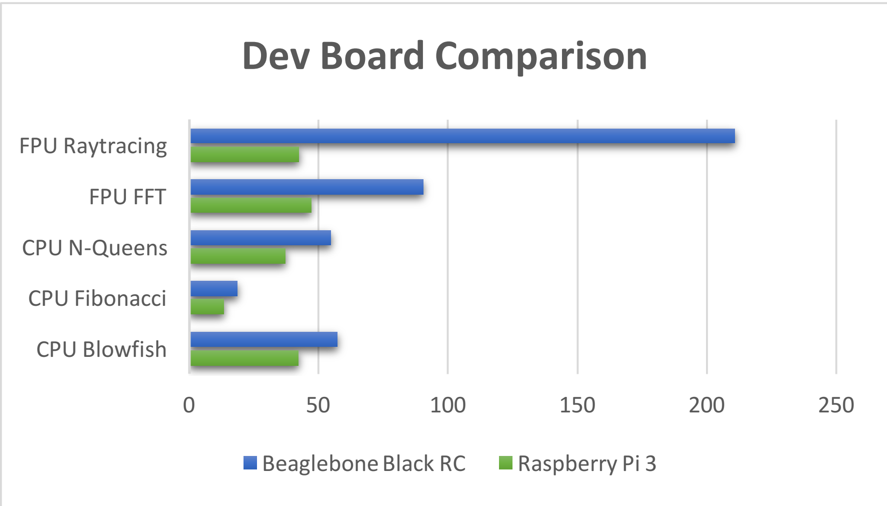
Evaluation

From this information, the boards that I can see being possible solutions are the Beaglebone Black Rev C and the Raspberry Pi 3. The others I wont consider because they can't do all of the functions required all in one package, unlike the board that can (Raspberry Pi and Beaglebone Black). For example, even though the Intel Edison is a powerful board, and would be able to handle most processes of the board, it cannot display a desktop natively. I would need to use a VNC Viewer to display a graphic user interface (GUI), which would slow the chip down exponentially. The Arduino isn't a viable option for this project because of its slow speed (in this context), and its inability to process and output video.

The Raspberry Pi and Beaglebone Black can both take SPI bus inputs from a chip like the MCP3008. This helps to increase the reliability of data going from sensors to the board. They also have incredibly fast CPUs (and GPUs), which will help both with processing and displaying the information on screens. I would like to do further speed tests to determine which one I will use in the product, as simultaneously interpreting SPI Bus data, graphing the data and displaying said data to a screen can be an intensive set of processes.

HardInfo Results

The lower, the better.



	Raspberry Pi 3	Beaglebone Black	Intel Celeron M	PowerPC 740/750
CPU Blowfish	42.11	57.27	26.19	172.82
CPU Fibonacci	13.54	18.65	8.14	58.08
CPU N-Queens	37.21	54.83	--	--
FPU FFT	47.14	90.50	--	--
FPU Raytracing	42.31	210.83	40.88	161.31

From these tests, I can see that the Raspberry Pi beats the Beaglebone is all areas of both algorithmic based tests and graphics tests. This can probably be attributed to the Raspberry Pi's on-board graphics processing unit (GPU) – giving it a major jump of efficiency when it comes to graphics performance (as seen in the FPU Raytracing test). Comparing the CPU based tests, the Pi also wins over the Beaglebone. This may be attributed to the Pi's slightly faster CPU, and its quad core structure – allowing multiple calculations to be performed at one time.

Analogue to Digital Converter (ADC) IC

A lot of popular development boards have in-built Analogue to Digital Converters on their boards, but unfortunately the Raspberry Pi does not. This, however, doesn't mean I have to choose a different board though. With the use of an ADC chip, I can use the Raspberry Pi's SPI Bus pins to communicate all data over 3 pins. This also gives me the benefit of choosing which ADC will both perform to the level we require, while not having to spend more on an ADC chip that has features that this board doesn't need.

Analog to Digital converters convert 'real-world' signals, signals such as light level, sound level, etc., into digital signals so they can be manipulated by digital equipment, such as computers. In this context, I will be taking the 'real-world' signal of current flow, and converting it to a range (between 0 and 1024) so that I can graph the data into useful information for medical professionals.

SPI lines usually consist of four channels (or more, depending on whether or not you're using more than one 'Slave'). The first is SCK, which is Clock from Master. This is the oscillating signal that keeps all the devices in time with each other. The two are often described together. The first is the MOSI channel, which stands for Master-Out, Slave-In. The other is MISO, Master-In, Slave-Out. These channels are used for the communication between two nodes. MOSI is used for communication from the Master to the Slave. The MISO is used to transmit data from the Slave to the Master. The final channel is SS, Slave Select. This channel is used to wake up and send/receive data when multiple slaves are present. Unlike the other three channels which can connect to any and all SPI nodes on the network, each Slave has a dedicated line. There are integrated circuits that can be connected to the same SS channel together, but they are addressable (such as addressable LED drivers).

Understanding the different features

SPI Interface

The SPI interface, usually found of development boards and integrated circuits that can transmit large quantities of data in real-time. The system was developed my Motorola and has become an industry standard in most, if not all high end embedded systems. SPI works with having one node (point of communication) being designated as the 'Master', while all others connected via SPI are called 'Slaves'.

The benefit of SPI over other methods like Serial Ports (RX & TX) is that communication methods such as Serial is that there is no control over when data is sent from one device to another, and there is no guarantee that both devices are running at precisely the same rate. To fix this problem, SPI (and all other asynchronous serial connections) uses separate lines for data and a clock that keeps all devices in perfect sync. The clock is a simple oscillating signal that tells the receiver exactly when to send bits of data.

RoHS Compliance

RoHS is the acronym for Restriction of Hazardous Substances. Banned substances under RoHS are lead, mercury, cadmium, polybrominated biphenyls, polybrominated diphenyl ethers, hexavalent chromium, and four different phthalates (DEHP, BBP, BBP, DIBP). This can give users assurance that components in the board are free of restricted substances, which is important in the context of health services, where this board will be operating.

Bit Rate (Resolution)

Most of the cheaper ADC chips are branded as being 8-bit, 10-bit, 12-bit or 14-bit. This means that the value of each sampled point is stored in a fixed-length variable (variable are digital methods of storing, referencing and using data – data like integers, strings, floating point numbers, Boolean values, etc.).

If this variable uses eight bits, this means the variable can hold values between 0 and 225. This can be found by using the calculations $variable\ length = 2^n$, where 'n' is equal to the number of bits. For example, 8-bit, 10-bit, 12-bit and 14-bit chips have the following variable lengths:

8-bit:	2^8	=	256 value range (0 – 255)
10-bit:	2^10	=	1,024 value range (0 – 1023)
12-bit:	2^12	=	4,096 value range (0 – 4095)
14-bit:	2^14	=	16,384 value range (0 – 16383)

What the ADC IC does is divide the signal by 'n' possible parts between the maximum (225 for 8-bit ADC chips) and minimum (always 0). If the signal is between two of these parts, it will either round up or down to the closest part. This results in a loss of quality, because the 'true' data isn't being represented.

One way to determine the number of bits necessary for an ADC is by calculating the tolerable noise level. Because the values from the sampled signal will be "rounded" several times to the nearest digital equivalent, this provides what is called "quantisation noise". The Signal-to-Noise ratio (SNR), which measures the noise level, can be easily calculated through this algorithm: $SNR = 6.02 \times n + 1.76\ dB$

The higher the SNR, the better. From this equation, we can see that an 8-bit ADC has an SNR level of 49.9dB ($6.02 \times 8 + 1.76\ dB$), and a 14-bit ADC provides an SNR level of 86.04dB.

Sampling Rate

An ADC circuit takes samples from time to time, and converts that sample into a number, based on its voltage level. The frequency on which this sampling occurs is called the sampling rate. If a sampling rate of 44,100 Hz is used, this means that per one second, 44,100 points will be sampled. The distance of each point can be calculated by $distance = \frac{1}{sample\ rate}$.
From this, we can find that the distance of each point using a 44,100 Hz ADC, each point will be 22.675 µs (microseconds).

This means that when sampling occurs, any point or change in between these samples will be suppressed. The higher the sampling rate, the more perfect the analogue signal will be represented in the digital format. The problem with that though is the higher the sampling rate, the more perfect the output quality will be, but the more storage space you will need. There is a balance between storage space constraints and quality that needs to be achieved.

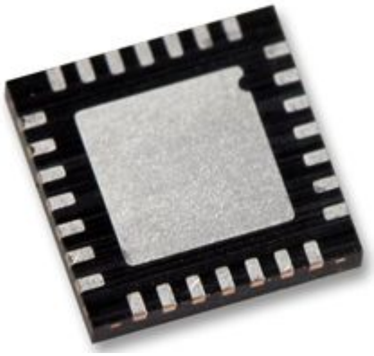
ADC Comparisons

MCP3008

Features

10-bit Resolution
200k Sampling Rate (SPS)
Supply Voltage Min, 2.7V
Supply Voltage Max, 5.5V
No. of Pins, 16
RoHS Compliant: Yes
$5.20 each, widely available

ADS1118



24-bit Resolution
1.9k Sampling Rate (SPS)
Supply Voltage Min, 2.7V
Supply Voltage Max, 3.6V
No. of Pins, 28
RoHS Compliant: Yes
$10.44 each, not widely available

MAX11410

16-bit Resolution
860 Sampling Rate (SPS)
Supply Voltage Min, 2V
Supply Voltage Max, 5V
No. of Pins, 10
RoHS Compliant: Yes
$12.28 each, widely available

Conclusion

ADC	Bit Res.	SPS	V. Min	V. Max	RoHS	Cost
MCP3008	10-Bit	200K	2.7V	5.5V	Yes	$5.20
ADS1118	24-Bit	1.9K	2.7V	3.6V	Yes	$10.44
MAX11410	16-Bit	860	2.0V	5.0V	Yes	$12.28

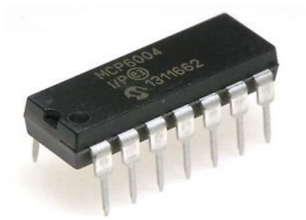
To give a fair competition between these chips, I found a range of commonly used ADC integrated circuits that all use the SPI interface that I require in the project (to minimise wires and traces). Looking at the specifications of each of these integrated circuits, I am determining that the MCP3008 is the most appropriate choice for my solution. This is because of its high sample rate and its low cost. While either of the other integrated circuits could have done the jobs required in this project, the MCP3008 gives the best value for its cost – while being the one with the widest availability. Is it also RoHS compliant, which important for this product, because of its place of operations (hospitals, medical environments, etc.)

Operational Amplifiers

Operation amplifiers are linear devices that are used for direct current (DC) amplification, and are therefore used heavily in signal conditioning and filtering. They can also be used for mathematical operations like adding, subtracting, integration and differentiation.

Basically, operational amplifiers (op amps) are voltage amplifying devices designed to be used with external feedback components (like resistors and capacitors) between their input and output terminals. These feedback components determine the resulting function of the amplifier.

Being a three terminal device, consisting of two inputs, one called the inverting input (-), and the other called the non-inverting input (+). The third terminal is the operation amplifiers output which can both sink and source either a voltage or current.



For this project, I will be using the operational amplifier MCP6004 because of my prior experience with it. I have used it to do similar circuits to this, having a weak 'real-world' signal, and amplifying said signal for a microcontroller or SBC (single board computer), like the Raspberry Pi.

This specific operation amplifier IC has four amplifiers built in the chip, meaning there isn't a need to have 8 single operational amplifiers, or 4 dual operation amplifiers. It is also RoHS compliant, which is very important considering the context of this product's workspace (medical environments).

Materials

The material that is chosen for the product will play a major role in the successfulness of the end product. Because the product may be used by people of varying weights, I am defining my weight range as 20kg (a typical weight of a small child), to 140kg (weight of a heavy adult). This gives me a quantifiable range that I can work with when I am selecting which material I will use for the final product.

The main criteria for when selecting material will be the cost of the material, the strength of the material, the availability of the material and the the durability of the material. This set of criteria will help guide me to find the most suitable material for this project. The three materials that I have chosen to investigate are acrylic sheets, steel and PLA/ABS plastics.

Acrylic

Acrylic is a transparent thermoplastic material that is described as having “outstanding strength, stiffness and optical clarity” – Curbellplastics.com. The plastic is widely used for applications like transportation applications, retail fixtures, architectural purposes and more. Being extruded, the sheets of Acrylic can be ordered is most thicknesses, ranging form 2mm all the way up to 20mm at my local plastics warehouse. Because they can be manufactured to all lengths, this helps cut costs of excess material and wastage. Acrylic is also great for bonding together, using solvent cements and also it very light, compared to most materials its size and strength.

From face value, this option seems to be a very viable option, and should definitely be considered. A typical sheet of acrylic that my school buys though its 740mm x 320mm and a 5mm thick sheet costs $33 and a 10mm thick sheet costs $66.

Steel

Steel is known for its strength and its use in industry contexts. While it may be an option to construct the whole assembly out of steel, this will most likely make the device too heavy because of steels weight. A better solution involving steel is the possibility for using it as a frame, combining it with another material that is lighter. In this way, the device would benefit from having the strength of having a steel frame while it would maintain a certain amount of lightness to it because of the combination with another, lighter material. This method would also help keep costs to a minimum, as steel can be very expensive for both the raw material and also to process. An added benefit of using steel is that it can be manufactured and cleaned to a high cleanliness level – one of the reasons why it is used so widely in the medical industry.

ABS Plastics

ABS stands for Acrylonitrile Butadiene Styrene and like Acrylic, it too is a thermoplastic. Thermoplastic describes the way that the material responds to heat (the opposite characteristic is called thermoset). Thermoplastics become a liquid at certain temperatures, which makes them perfect for extrusion – like that in a 3D printer. They can be injection moulded, cooled and re-heated again without significant degradation (loss of quality of structural integrity). ABS is used widely used because it has a strong resistance to corrosive chemicals and/or physical impacts. Also, the plastic is also relatively inexpensive, durable and strong. It it often used widely used in objects and appliances like power-tool housings, plastic face-guards on walls, computer peripherals like computer mice and keys on keyboards. While it is a strong plastic, it may not be a good option to use on its own. Coupled with another material like steel would help give the product strength and structural integrity while maintaining lightness of the overall device; and keeping costs to a minimum.

Conclusion

While the combination of steel and either ABS plastics or Acrylic plastics would give the product the most structural integrity, it would also take a long time to manufacture as I couldn’t manufacture the frame myself and would have to outsource the job. I have chosen to use Acrylic plastics because I can but the sheets in the exact dimensions of a laser cutting machine I have access too. This will allow me to make multiple prototypes, both rough and working prototypes with the acrylic material, while being able to make modifications and changes where necessary and not have to wait for days, even weeks for a new frame or part.

Processes

I will be investigating the different processes relating to the components and materials that I have chosen. This research will give me a better understanding on what I can design and how I can build the final product. Also, it will allow me to find ways to minimise wastage of materials though precise designing (like CAD/CAM methods).

Designing

When designing components and products, the industry standard says to use Computer Aided Design (CAD) methods. This can be achieved through applications and programs like Autodesk AutoCAD, Adobe Illustrator and EagleCAD. Each of these programs have their own unique functions that the others don't do as well, or at all (naturally), however, choosing the correct program will have a great impact on the quality of the final product through the ability to tweak parameters such as dimensions, angles and even going back and retracing steps to find where potential errors may arise when manufacturing the product. It is most likely that no one program will fulfil all of my needs – therefore I can see myself using a range of programs to design and built various components and parts of the Balance Board.

Autodesk Fusion 360

Autodesk Fusion 306 is a CAD/CAM program with a plethora of functionality. Fusion 360 allows users to design, engineer in 3D space, simulate, make high-quality renders and animations and create tool pathways for 3D printing or CNC milling. A very versatile and intuitive program, to me, it offers the ability to create tool paths for CNC milling and 3D printing, which will be beneficial if I choose to use on of those manufacturing methods over laser cutting. It also allows me to create realising representations of the product, as so if I decide to create the device in lays as a workaround for laser cutting or CNC milling thinner layers.

Autodesk AutoCAD 2016

Another Autodesk program, AutoCAD is typically used to create simplified, yet detailed and accurate documentation of drawings. Mainly for working in the 2D space, AutoCAD is one of the industry standard tools for creating technical drawings digitally and is known for its plethora of features. With a ever-growing community of users – there isn't a feature on the program that doesn't have a tutorial from the people at Autodesk, or someone from their large professional community.

Adobe Illustrator CC

Illustrator is Adobe's answer to the scalable vector-based demand in the artistic industry. While not often used for any technical drawings or others of the like, Illustrator is a great, simple program for getting 2D ideas down. Because you can export 'Art boards' to SVG, designed made in Illustrator can then be imported into more professional, 'solid' programs such as the Autodesk Suite.

Cadsoft EagleCAD

EagleCAD is slightly different than any of the other programs on this list. Eagle is designed for electronic designers, featuring an extensive schematic based editor, allowing designers to create "easy-to-read" representations of a product's electronic design. Like AutoCAD, there is a booming community for Eagle., with a large collection of professional users creating easy to follow tutorials for how to use Eagle. The program is also able to create PCB layouts and has a built-in auto-router, allowing for a faster development process.

Materials and Components Fabrication

When evaluating which process type to use for fabrication of the final product, the criteria that should be applied to every option should be the cost of each process (ranging from ‘Low’ to ‘High’), availability (whether I can do it, or I have to outsource the job to another company), quality of final product and speed (having to wait for a component or piece of the device to be completed would hold back development).

Programming

Because I will be running the device with a Raspberry Pi, this gives me a lot of freedom as to which language to use for the project. I am going to choose Python though, as I have used Python frequently in the past. Another benefit with using Python is its wide community. This will mean that solutions to nearly any problems I might have will most likely already have been solved, and solutions documented on websites like Stack Overflow and the Python forums.

I will be dividing the code into three sections, based on their function. The first will be the input section of code, which will be responsible for taking in all of SPI data from the MCP3008. The next second of code will be that interpretation and transformation of the data into information. The final section of code will be responsible for outputting the information onto the screen via graphs.

Input

The great thing about Python is its range of modules that can be imported to give the language a lot more flexibility. In other languages, modules are often called libraries or blocks. I plan on using a module called SPIDev which lets Linux to interact with the Raspberry Pi’s SPI Bus directly though code. It also allows me to set parameters like clock speed and which pins are responsible for what signals (MISO, MOSI, etc.). I will monitor and store the data from each of the sensors into variables that I can use to perform algorithmic actions to create useful data.

Interpretation and Transformation

During this stage, I wont be interacting any external modules. I will be assigning data previously stored into variables so that they are ready to be used in the output section of the programming.

Output

For the output section of the programming, I will be using a suite of modules called SciPy and NumPy. These modules are known for their usefulness when handling mathematical data because of the built in algorithms. Matplotlib, a module that comes with the suite will be responsible for graphing the data into an X Y graph. This will show the centre of balance of the user standing on the platform.

Evaluation Criteria

Subsystem	**Evaluations**	**Points Allocated**	**Points Awarded**
Sensors	How accurately can the sensors weight various amounts of weights?	7	
	How accurate are the sensors over multiple uses?	5	
Electronics	Are the components inside the system safe for a medical context?	5	
Size and Safety	Does the product introduce any electrical hazards to its environment of use?	7	
	How well does the system accommodate for both with those of small stature to those with large stature?	7	
	Can the physical product be used by people of a range of weights? (20kg - 140kg)	7	
	Is the product safe to stand on? (Is it slippery? Is it unnecessarily high?)	7	
Construction Qual.	Is the product made of high quality, high durability materials?	5	
	Is the product predicted to need regular maintenance?	3	
Information	Does the information displayed help to make smarter medical decisions for balance rehabilitation?	7	
Aesthetics	Does the product fit in with its surroundings?	3	
Transportability	Can the product be safely transported by person?	5	
Physical Size	Is the product small enough to store?	5	
Availability	Is the product cost efficient?	5	
	Does this product have a price that makes it widely accessible?	3	
Totals		**86**	

Design

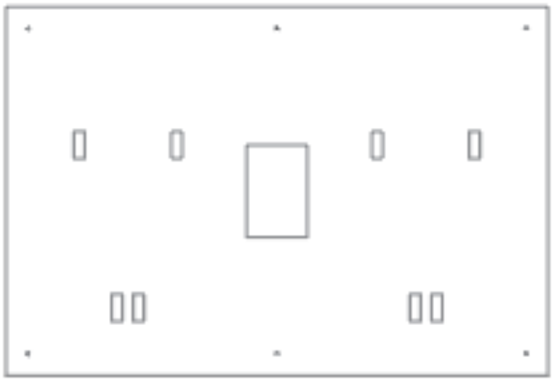
Sketches & Prototypes

Version 1, Sketches

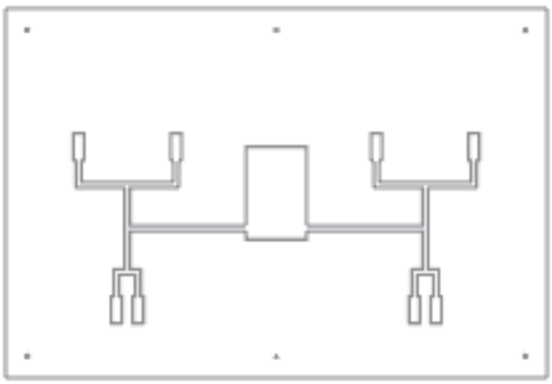
In the first version of the product, I worked to the goal of fitting all of the components and connections into the design chosen previously. My goal was to minimise the size of the device where I could while still adhering to the design factors.

The first layer will house the two footpads on which the user will stand. Under these footpads will be the pucks which have direct contact with the weight sensors. Previously I thought about gluing the layers together, but I soon realised that doing so wouldn't allow repairs or modifications to be conducted easily or without damaging the unit. As so, I opted for a nut and bolt technique which I will hide by using small form bolts (M3) and rubber feet to hide the bottoms of the bolts.

The second layers hold the responsibility for giving clearance to the Raspberry Pi unit from the first layer – hence, the cut out in the middle. The rectangle holes are guide holes that will stop the pucks from moving off the top of the sensors. It will also help keep the footpads from moving any way bar vertically, helping to ensure the users safety by stopping the potential horizontal movement caused by gaps.



Both the third and fourth layers are the same. Their purpose is to give plenty of clearance to the wires, and give them channels to the Raspberry Pi unit. Layers three and four also sport the same rectangles which allow the sensors to sit in. The exact cut of the sensors for the rectangles restricts these sensors from moving, ensuring that the pucks stay aligned with the part of the sensor where the force needs to be applied.



The final layer is quite basic compared to the others. Its role is to give the sensors and Raspberry Pi unit a surface to sit on, so they don't fall out from the bottom of the device. It also closes off the bottom of the wire channels.

Version 1, Prototype

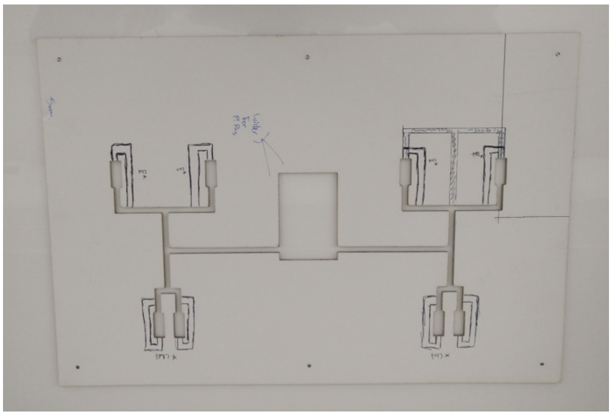
When choosing which material to cut this version out of, I opted for some foam board. This is because it's relatively cheap, and I know I will need to make several adjustments before I feel comfortable with cutting actual Acrylic, which is much more expensive. It also takes less time to cut on the laser cutter, meaning I can continue to develop the design faster.

To be able to cut the foam board, which originally came in large rectangular sheets of around 3m x 1m, I had to measure out smaller rectangles that would fit onto the laser cutters cutting bed of 720mm x 340mm. To do this, used a metre ruler and a right angle ruler.

The material cut very well on the laser. Modifications that I wanted to make to the first layer were the rounding of the footpads. In having rounded edges, rather than square ones, I hope to give the board a more professional finish while replacing the footpads if necessary would be easier as they wouldn't have to be perfectly 90 degree angles in the corners. Also, in all of the layers I decided to round the corners. This decision was based off a safety concern. Acrylic can be very sharp, so by rounding off the corners, I hope to reduce the rick to operators and users cutting themselves of the corners of any of the layers.

For the second layer, I didn't feel that anything needed tweaking, apart from the global rounding of edges of the boards.

The third and fourth layers found the most change. Because of the design of the sensors, with wires protruding out either end, I deemed it better to create channels for wires around the rear of the sensor slots. The alternative option was the bend the wires around the pucks of the footpads, but I had fears that if wires became lodged between the sensor and puck, it would give inaccurate readings – severely altering the effectiveness of the device.

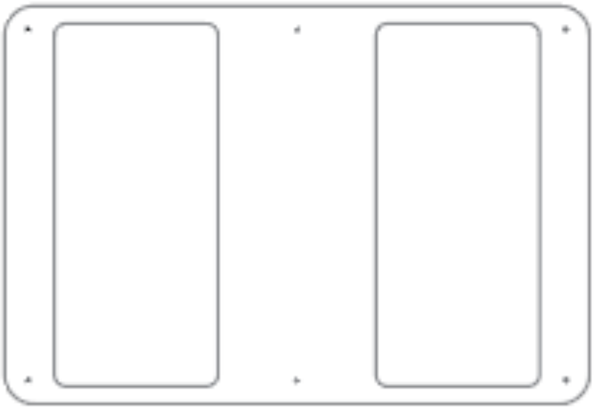


The final layer also didn't have much change done to it. I did however mark places where I thought adhesive rubber feet could go to help with the stability of the device on hospital floors, which don't usually naturally grip to surfaces like Acrylic.

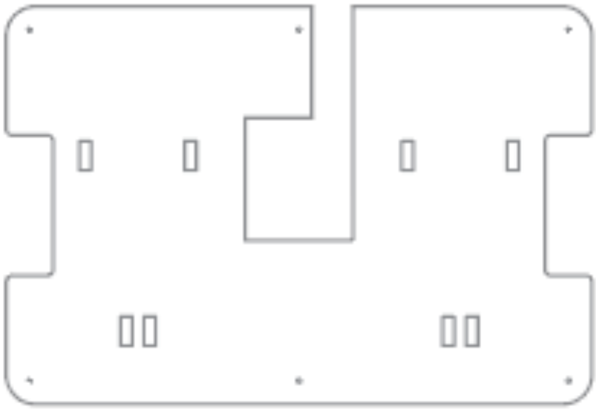
Version 2, Sketches

Taking these modifications into consideration, I went back to the drawing boards to implement them into version two of the design. As well as all of the features outlined above, I reflected on the design options and the requirements the design had too meet. In that, I added the handles to the device by making rounded edged rectangle cut outs on all the layers bar the top and bottom ones. I also realised that the Raspberry Pi was completely closed off from the outside world, which presents the problem of how I was going to get video cables out from, and power connectors into the device. To rectify this, I changed the Pi's orientation so that the power port and HDMI port face the front of the board, and made a cut out for wires to come in and out of the board.

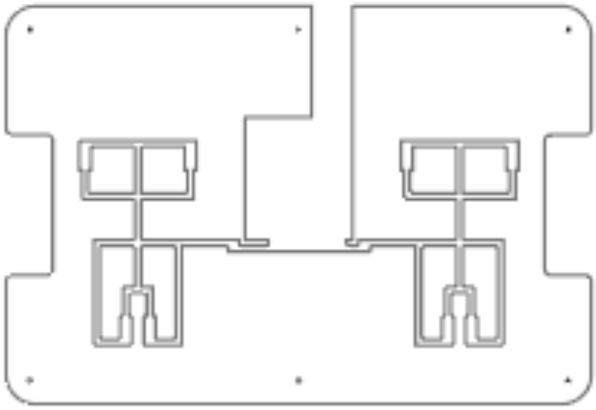
The first layer's modifications include the global change from square edges to rounded ones. This can be seen from the board itself and also on the footpads.



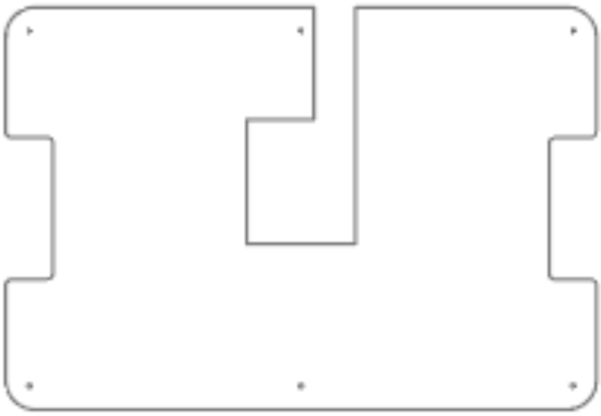
Layer two's modifications include the rounded edges, handles on either side of the board and the new orientation and cable cut out for the Raspberry Pi unit.



Layer three saw the introduction of the wire channels for the wires protruding around the back of the sensors. Also, with the change in the Pi unit's orientation, I had to make a new cut out so that the wires enter the Pi units' space where the pins are. This was to save the amount of wire required to connect the sensors to the Pi.



A big change was the removal of the wire channels and sensor slots on layer four. After evaluating the previous version of the design, I concluded that the wires didn't need two layers, and would also meant that the sensors sit higher, closer to the footpads. This means that the pucks don't have to be as tall. I kept the Raspberry Pi unit's cut out though, to drop it down – giving the pins the most clearance possible between the top of the pins and the top layer.



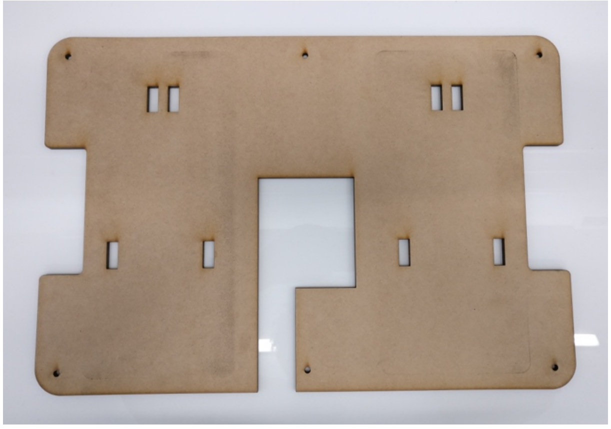
The final layer remained mostly the same too, although I added 2.7mm holes so that the Pi could me mounted directly onto the device. I thought this would help preserve the unit when being transported and stored, because before when it wasn't secured down, the Pi would rattle around its enclosure. I had fears this could damage the connections between the Pi's pins and the sensor's connectors.

Version 2, Prototype

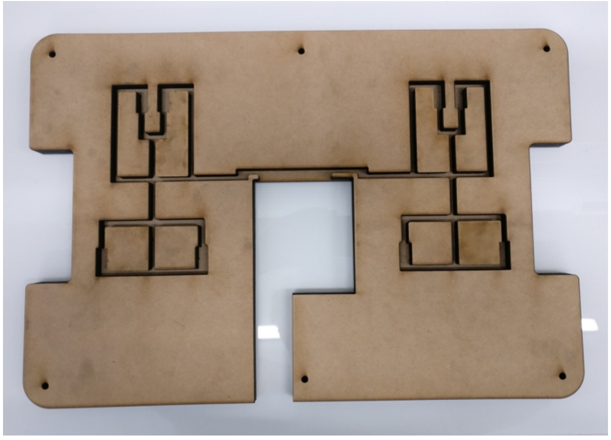
For this version, not only did I want to examine the board's features, I also wanted to see how high the final design would be. Because of this, I chose to use medium density fibreboard (MDF), as it was a cheap option and came in sheets of the same thickness as the final boards Acrylic would be (5mm and 10mm thick). Cutting this prototype to its actual height would give me a better understanding of whether or not the device needed to be shorter.

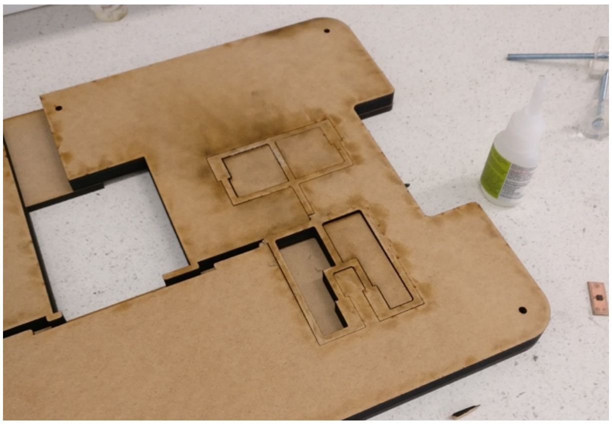
The first layer turned out really well. I used 10mm thick MDF to give the device some overall density, but I knew that if I needed to cut off some height, I could use 5mm thick material instead. Unfortunately, during the cutting phase of the top and bottom layers, I set the screw holes to 5mm instead of 3mm. To hold all the layers together while evaluating it, I cut out some wide (7mm) Acrylic washers to clamp the layers together.

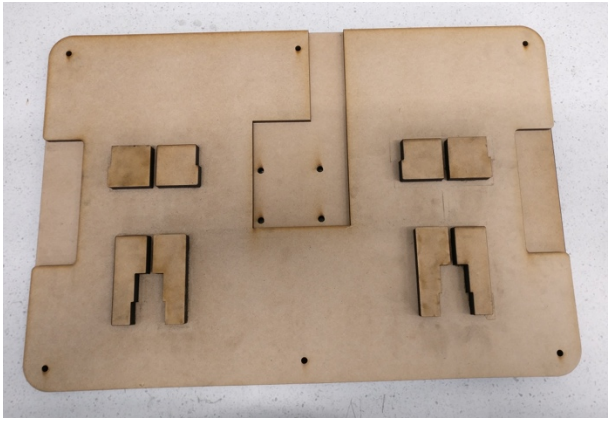
Layer two I cut out of 5mm thick MDF. Because its purpose is only to give clearance to the Pi unit, I chose to trial the thinner material – fully aware that if the Pi needed more clearance later, I could use the 10mm instead.



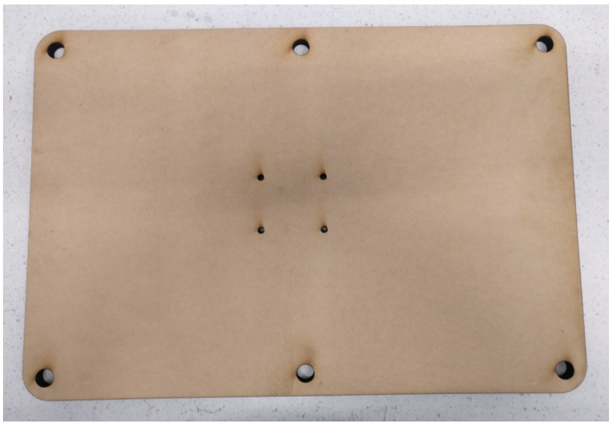
Layer three and four layer over each other to create the wire channels and sensor slots that I designed on their plans. To keep the square and rectangle cut outs from moving, I scratched the surface of layer four and the bottom faces of the cut outs, then used super glue to keep them in place. The layers will stay aligned when I screw them together. For the gluing process, I used the interior pieces from when layer 3 was cut. A picture of the process is shown below.



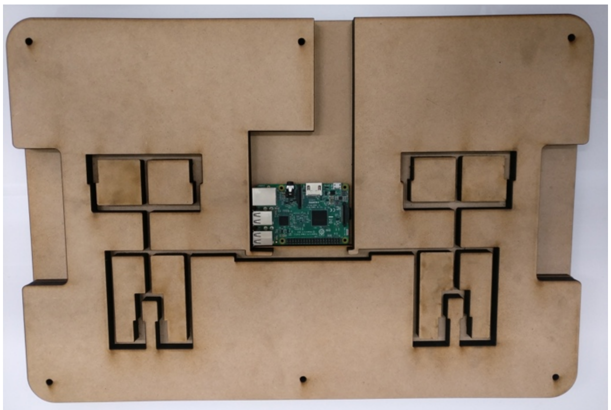




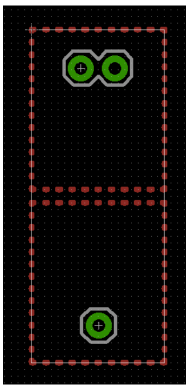
The final layer didn't see much change from last time, apart from the Raspberry Pi's mounting holes. I referenced documentation that I found on Element14's website, under the Raspberry Pi 3 webpage. It gave me the diameters (2.7mm) and spaces between each of the holes. I cut this layer out of 10mm. I will also do this in the final product because even though it can be cut from 5mm, 10mm thick Acrylic will give a strong base to stand on.

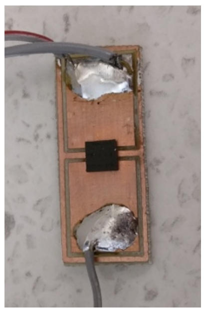


Tests, and Findings



I wanted to conduct a test with the sensors and Raspberry Pi with the prototype. The purpose of this test was to make sure the pucks were long enough to reach the sensors and the wire cut outs could house all the wires necessary for the project. I designed and milled four QTC Pill sensors that could be used in the final design, which had a divider in the middle with no copper, so that when the QTC was pressed, it would act as a bridge and allow current to flow from one side to the other. I used a breadboard to connect all of the wires to power, ground and pins to the MCP3008. The results of the test were interesting, and not what I had predicted. The QTC sensors weren't sensing the weight that I was applying past a certain point.



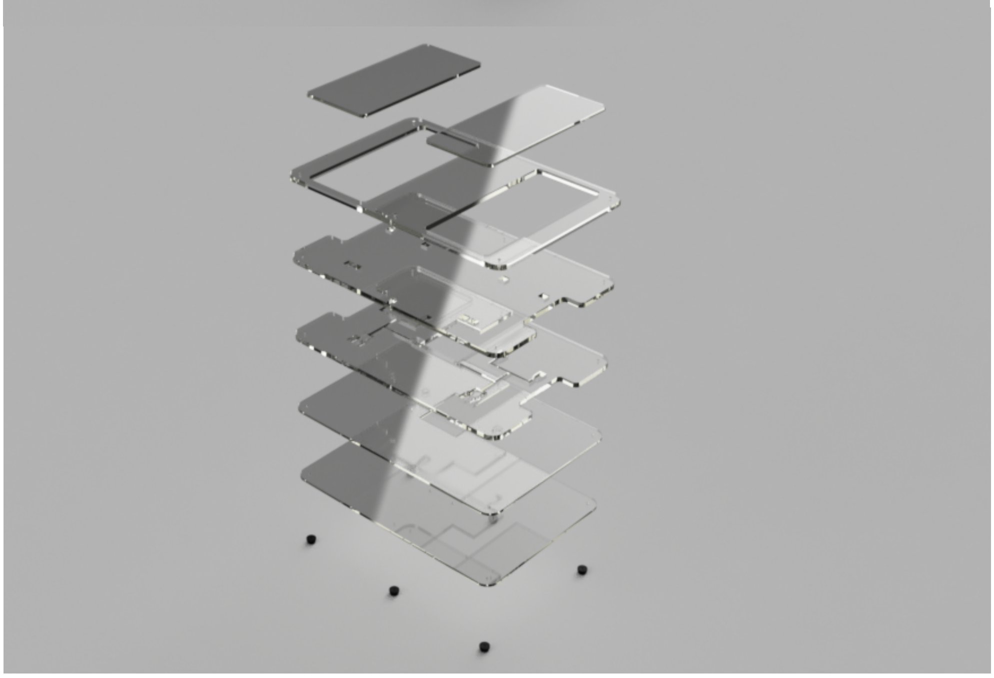


After much internet research, I found that QTC Pills have a maximum force capacity of around 100N, which is roughly 10kg – much less that the minimum I require for this project. Because of this, I will be switching back to Force Sensitive Resistors in the final design, as they can sense up to 4000N of force applied to them, using an operational amplifier and feedback loop. What this will mean for my design is that the sensor slots will change slightly to accommodate for the new sensors, and the channels for the wires protruding out the back of the QTC sensors will be removed. This is actually beneficial, as it allows layer three and layer four to be completely separated again, meaning less chances of things going wrong in the final design. These changes will be reflected and shown in the working drawings in the Final Design section.

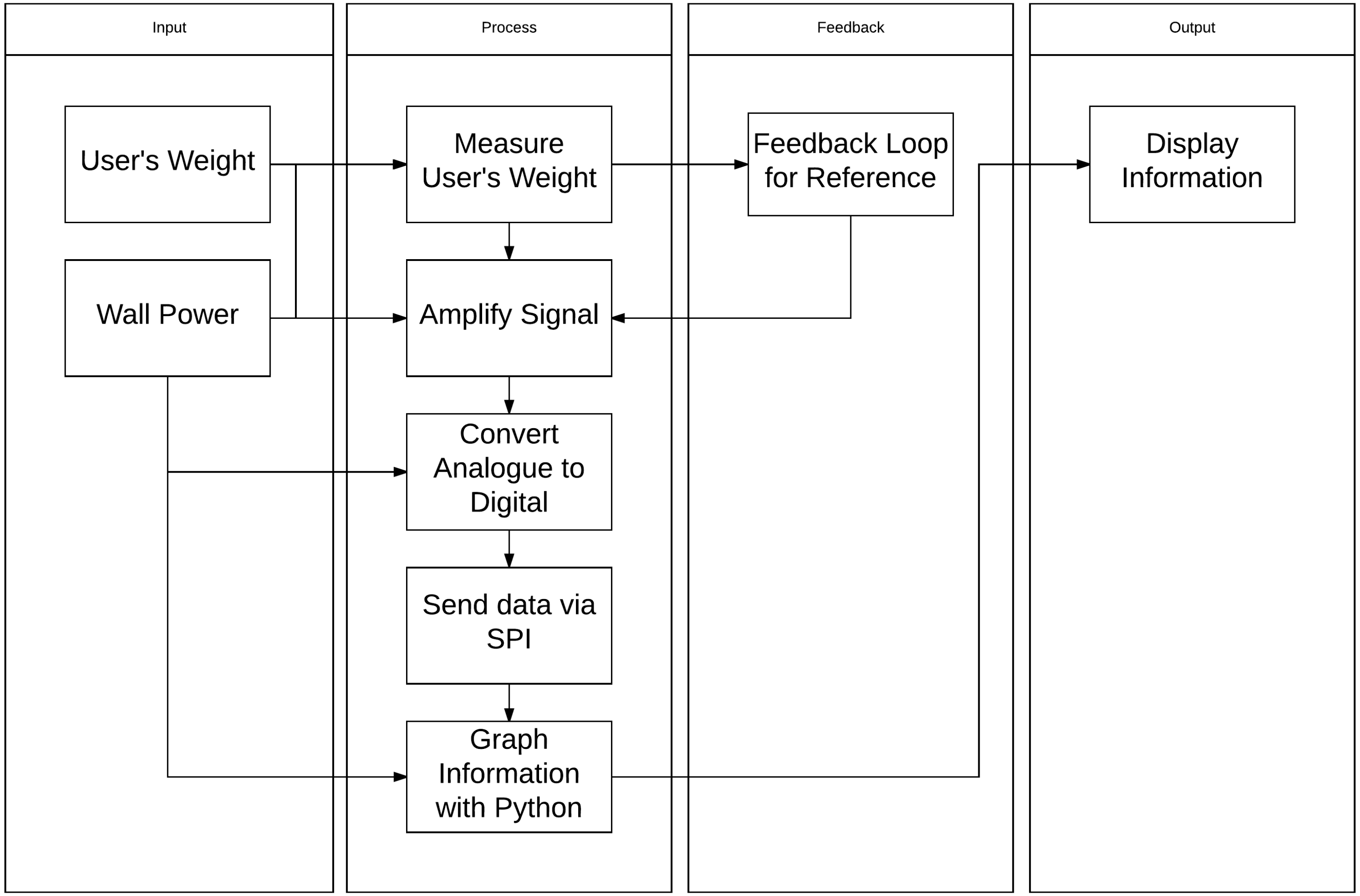
Final Design

After rigorous testing of each of the prototypes and making corrective changes to the design and a switch of components, I feel confident that the design won't need further modifications. I have finished renders in Autodesk Fusion 360 of what the final design will look like.

Fusion360 Renders



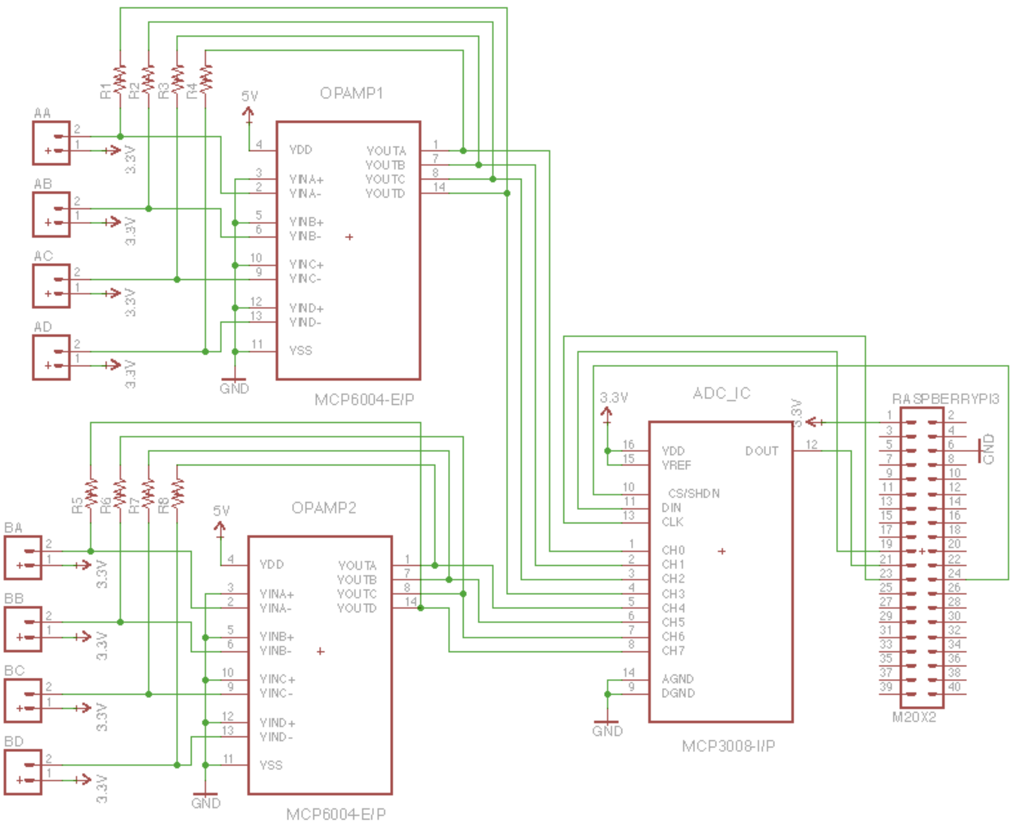
Block Diagram



When the user steps onto the board, the sensors embedded will measure the resistance from the force sensitive resistors. After such, the signal will then need to be amplified, and then converted into a digital signal so that it can be sent and used by the Raspberry Pi Board. Once received by the board via SPI communication, the data will be graphed into more usable and relevant information. The graphs will then be displayed on the connected screen or preferred output.

For a feedback loop, to amplify the signal, a feedback loop between the sensors and the amplifiers will give a reference voltage.

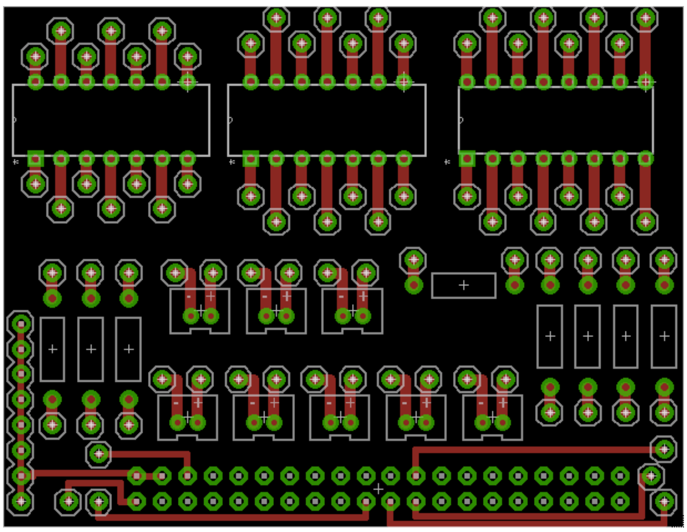
Schematic



Turning the block diagram into a schematic of the whole design, bar the sensors (which are represented by the block terminals on the left hand side), I was able to visualise where connections would need to be made to complete each step, outlined in the block diagram, of the system.

PCB Sketches

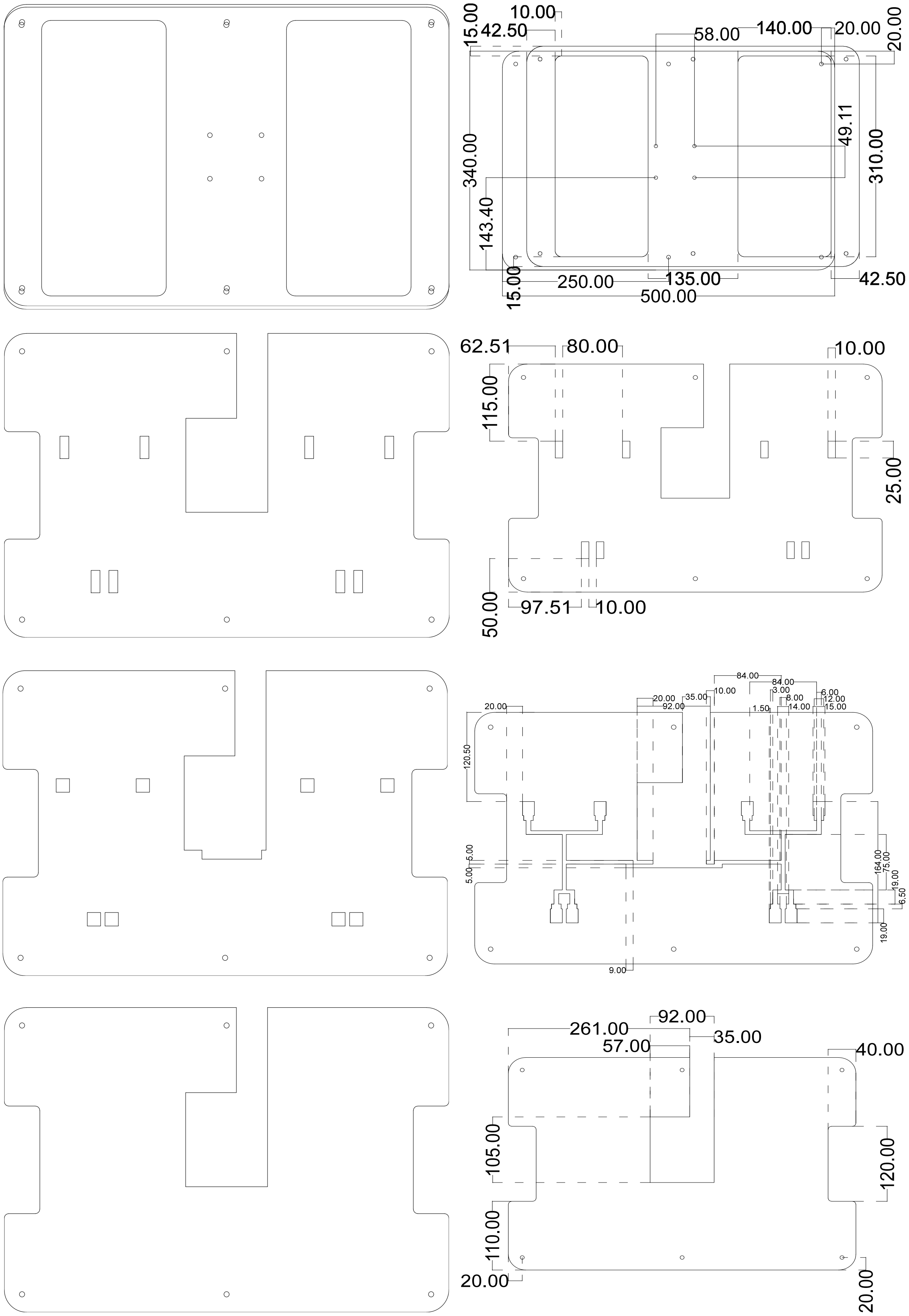
In EagleCAD, the PCB software that I used to create the schematic, I was able to create a PCB diagram easily with its inbuilt CAM Processing feature. Because I wouldn't have the ability to mill more than a one-layer PCB, I would need to connect each component myself, most likely using single core wire.



To accomplish this, I connected each of the necessary pins of components to a single copper trace and hole terminal. This would allow me to solder wires to tracks, allowing me to create clean connections. In jumper like style, I would connect each hole to its designated position.

Instead of soldering the ICs directly to the board, I will place them in IC saddles, so they can be replaced if need be.

Working Drawings

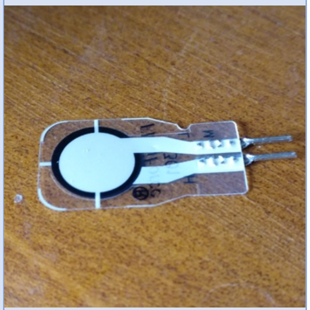
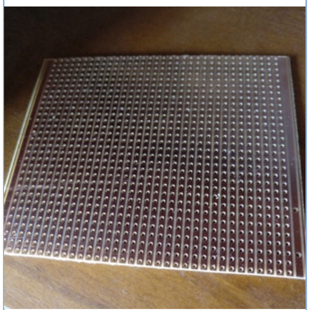
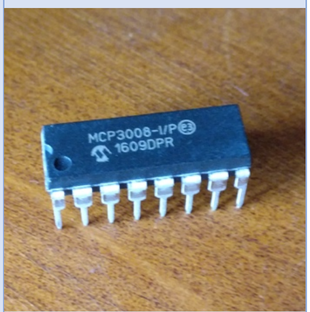


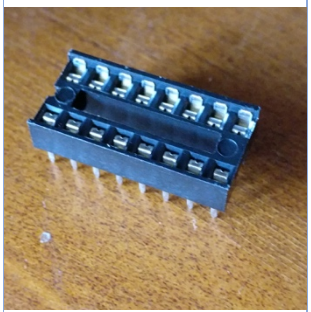
Code

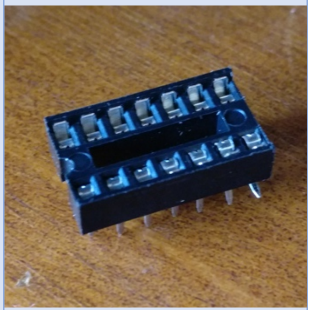
```
import time
import Adafruit_GPIO.SPI as SPI
import Adafruit_MCP3008

# SPI configuration
CLK  = 18
MISO = 23
MOSI = 24
CS   = 25
mcp = Adafruit_MCP3008.MCP3008(clk=CLK, cs=CS, miso=MISO, mosi=MOSI)

# Print nice channel column headers.
print('| {0:>4} | {1:>4} | {2:>4} | {3:>4} | {4:>4} | {5:>4} | {6:>4} | {7:>4}
|'.format(*range(8)))
print('-' * 57)

# Main program loop.
while True:
  sensorValues = [0]*8

  for i in range(8):
    sensorValues[i] = mcp.read_adc(i)

  # Print the information in readable columns
  print('| {0:>4} | {1:>4} | {2:>4} | {3:>4} | {4:>4} | {5:>4} | {6:>4} | {7:>4}
|'.format(*sensorValues))

  # Sleep for 0.5 seconds
  time.sleep(0.5)

except KeyboardInterrupt:
  break
```

Costs

Item	Quantity	Cost (Total)	Comments	Images
10mm Acrylic	3x	$168.00	740mm x 440mm	
5mm Acrylic	2x	$69.00	740mm x 440mm	
Nuts	10x	$3.10	M3	
Bolts	10x	$7.60	M3 x 70mm	
Wire	2x	$6.00	Various Colours	
Raspberry Pi	1x	$55.50		

A301 Sensor	1x (Pack of 8)	$118.65	445N Style	
Strip Board	1x	$3.15		
MCP3008 IC	1x	$5.10		
MCP6004 IC	2x	$1.16		

Rubber Feet	6x	\$6.65		
PCB Headers	3x (Rows of 8)	\$6.20	Breakaway Style	
Resistors	8x	\$2.80	1K	
IC Saddle	1x	\$0.24	16 Pin Saddle	

IC Saddle	2x	$0.16	14 Pin Saddle	
Total		**$453.31**		

Proposed Diagnostic Tests

I have decided that I want to separate the diagnostic testing of the board into three areas. This decision was based on my hope that the tests will reveal any inaccuracies and modifications and tweaks required to optimise the board. The separation of tests will also help to diagnose problems and the sources of such problems.

The first area is the general board itself. Dubbed 'Board Diagnostics', this test will help troubleshoot any major issues with the Raspberry Pi, connections between power and video out and any of the peripherals like mouse and keyboard. Problems like these need to be addressed before the other tests, as they will greatly effect the outcome of other diagnostic tests, or even prevent the possibility for other tests to occur.

The second area I will test is being dubbed the 'Sensory Diagnostics' stage. This stage will focus entirely on the values from the sensors, amplifies and ADC integrated circuit. Included with the Board's operating system will by a Python script that will read and print all eight of the SPI channels in raw data columns. By doing so, I will be able to test the variation between each of the sensors, and have a better idea, if there are issues later on in the diagnostic tests, where the problem is stemming from (mainly, which of the sensors is causing the issue, if it is sensor related).

The final area will be testing the Python program, written to graph and display the information. These tests will range from opening the program to evaluating how well it reacts to changes in weight / force distribution. Examining this will help me to ensure that the software will have the best chance at being effective when being used in real-world situations with patients and medical professional.

I have written a number of steps, and subsequently a number of criteria and questions to go with each step below. These tests will be carried out later in the project, and the final results, which should be accurate, relevant and qualified should be presented in a convenient manner, such as a table – which will help to evaluate the overall device.

Board Diagnostics

1. Plug in Balance Board to HDMI compatible screen and wall power.
    a. Is the Balance Board booting into the desktop?
    b. Are the peripherals working?
2. Turn the board off via the wall.
    a. Will the board reboot?
    b. Are there any errors that occur when the board is rebooted?

Sensory Diagnostics

1. Open the Sensor Diagnostic program on the Desktop.
2. Step onto the board with both feet positioned evenly.
    a. Are the channels displaying the same number, with a margin of 100?
    b. Are there any channels not displaying data (either constant 0 or 1023)?
3. Step onto the left side of the board, then the right.
    a. Is the program displaying data for each individual foot?
    b. Is the data roughly the same for each side?
4. Step off the board.
    a. Is every channel displaying 0 for their inputs?

Program Diagnostics

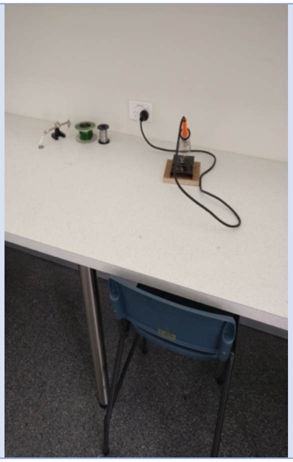
1. Open the Balance Board program on the desktop.
    a. Are the graphs for each foot and the board as a whole loading?
2. Step onto the Board.
    a. Is the program displaying an error?
    b. Is the program displaying data for the board?
3. Step onto each side of the Board.
    a. Is the program displaying data for each individual foot?
4. Step off the Board
    a. Does the Balance Board program show any activity?

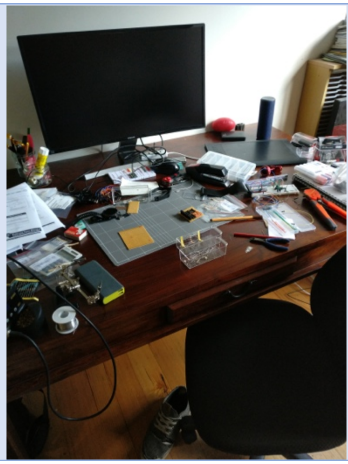
Tool Risk Assessments

Tool	Use	Risk	Risk Control	Protective Equipment
Soldering Iron	Soldering electronic components, wires and ICs to PCBs.	Burns. Electric Shocks. Flying solder. Inhalation of fumes.	Ensuring tested and tagged Solder in eye. Soldering in an open environment.	Glasses Gloves
CNC	Cutting circuit boards from CAD files onto copper boards.	Inhalations of dust. Cutting one's self from sharp edges of material. Electricity. Crowded room.	Testing and tagged. Using the extractor while in use. Wearing gloves when handling sharp material. Closing the lid while in use. One person near the machine at a time. Securing materials down.	Glasses Gloves Footwear
Laser Cutter	Cutting materials, such as acrylic, with the use of a high powered laser.	Inhalation of toxic fumes. Blinding from laser. Burning one's self. Electricity.	Using the extractor when cutting materials. Lid must be closed while in use. Wearing gloves when handling sharp material. Never using carcinogenic materials. Never have water or fluid near by. Testing and tagged.	Goggles Ear Muffs Footwear Gloves
Desk Drill	Drilling the pilot holes of the PCBs the CNC made as to solder the connections to them.	Cutting one's self. Hair getting caught by drill. Tie getting caught by drill. Electricity.	Should be used safely and appropriately. Using a hairnet if you have long hair. Not wearing a tie while drilling. Observe at all times to prevent accidents. Ensured tested and tagged.	Hair Net Goggles
Band Saw	Cutting the QTC Sensors from their PCB array	Cutting extremities.	One at a time around the machine. Wearing ear muffs.	Goggles Ear Muffs

		Stray pieces of copper in one's eye. Noise. Busy environment.	Wearing gloves while cutting. Wearing glasses to protect eyes.	Footwear Gloves
Wire Cutters	Cutting and stripping wires.	Pinching one's self	Using the tool appropriately and safely.	
Pliers	Bending and correcting wire placements with more accuracy than hand correction.	Pinching one's self	Using the tool appropriately and safely. Keeping extremities away from pinching points.	
Third Hand Holders	Holding wires or PCBs while soldering.	Pinching one's self	Using the tool appropriately and safely.	

Work Environment Risk Assessments

Tool	**Image**	**Risk**	**Risk Control**
Systems Room		Because of the collaborative nature of the space, the biggest risk will be other people operating in close proximity. Another risk may be a cluttered or messy working environment. This may mean that objects or tools get knocked around while working, potentially hurting someone or damaging the tools.	To minimise this risk, I will operate in an area of the room that isn't being used by many people. I will also maintain a clean working environment around the room, and encourage others to do the same when working. Also, if there is a mess around my working area, I will take care of it before I being working, as to avoid any damage to others, myself or the tools.

Laser Cutting Room		- The main risk while operating in the laser cutting room is the cluttered nature of it. This presents major tripping hazards. - Another hazard is the fumes that come from the laser cutter while in use. This can be amplified if the machine's extractor isn't on, or working fully. - Another risk is exposure to the laser in the laser cutter.	- This is a hard risk to control, as it is a very small room. A potential solution is to clear the walkway of any materials or tripping hazards before I start working, and maintain the clear space while working. - To minimise this risk, I will always ensure that the extractor is on and working before I start cutting any material. Also, the use of non-carcinogenic materials will minimise the harmful fumes I breathe in while working. - To prevent any harmful exposure, I will ensure the lid is closed while the laser is in use.
Home Study		- Because of the cluttered nature of the desk and room, as it is too a shared space of work, the major hazard of this environment will be other people and a messy working station.	- I will minimise risk through organising my equipment and materials before I start work, and cleaning up after myself prior to leaving the work station so that it's clean for the next time I use it.

GANTT Chart

	Weeks											
Step	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Cut Layers												
Import Drawings into AutoCAD												
Place Materials onto Laser bed												
Plot and Cut layers												
Assemble Footpads												
Use template to mark puck places												
Score and glue pucks to footpads												
Construct Raspberry Pi Shield												
Cut board to size												
Solder components to board												
Create connections between components												
Cut unwanted connections												
Assemble Board and Sensors												
Embed Sensors												
Mount Raspberry Pi												
Connect Shield to Sensors												
Connect rubber feet to bolts												
Bolt Layers together												

I have planned to finish the project quite early because I want to leave enough time at the end of the project for testing and folio writing. I am also aware that this time may be used for further testing and development if need be.

Production Sequence

Cutting Layers

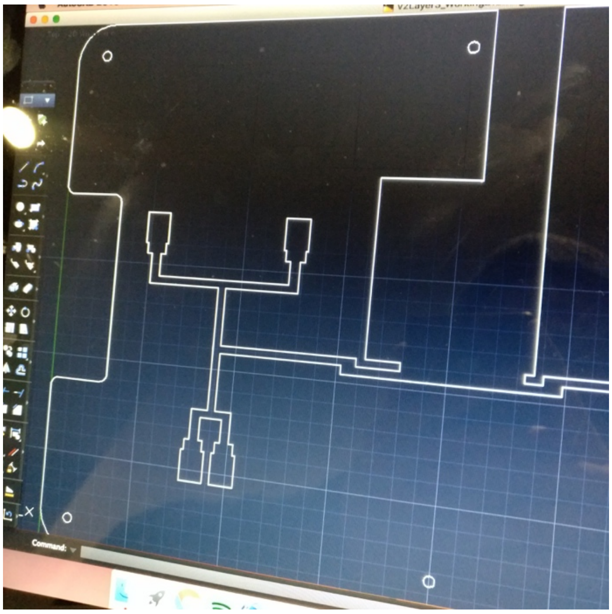
Importing Drawings into AutoCAD

Steps

- Import Drawing files onto Laser Cutting Desktop.

Discussion

Because I had completed the designs on AutoCAD, all that was required for me to do was move the design slightly away from the sides. This will help to ensure that cuts don't have crooked edges or scored sides.



During this step, I measured a number of sides on each of the drawings and compared the measurements to the annotated working drawings from the original files. This was the ensure the accuracy of each cut and minimise wastage because of the need to cut another piece of material, due to errors in importing.

Before I moved on to the next step, I turned on the laser engraver and the extractor. This was to make sure that both were working properly, and that the laser engraver had time to level its bed.

Safety Measures

- Ensuring the lid of the laser cutter is closed while cutting in later steps.
- Turning on the extractor.
- Confirming that the laser engravers bed was fully lowered before moving on.

Materials

- 10mm Acrylic
- 5mm Acrylic

Equipment

- Laser Cutter & Engraver
- Extractor
- Laser Cutter Desktop with AutoCAD software
- USB for file transferring

Steps

- Remove paper protectors from Acrylic sheets.
- Attach height guidance tool, then adjust laser engraver height.
- Place one sheet per cut onto the laser engravers bed.

Discussion

The sheets of Acrylic come with a layer of adhesive paper to prevent scratches on the sides of each sheet while shipping or being transported. If I were to cut the sheets with this protective layer on, I would risk the laser because of a potential flare up from burning the paper, possibly damaging the laser. To minimise this risk, I peeled off these layers before I placed each sheet in.

To ensure that the laser was in focus, to ensure the most precise cut, I attached the height guidance tool that came with the laser engraving machine to the laser head and adjusted the height of the laser head until the guidance tool barely touched the Acrylic.

After this, I replaced the tool back into its case and stored it with the other shipped tools and checked that the lid was fully closed, ready for the next step.

Safety Measures

- Slowly lower the head down onto the material, as to not damage the head or the tool.
- Check to see that there aren't any leftover pieces of material protruding over the honeycomb layer, so that the Acrylic sheets lay flat across the whole bed.

Materials

- 10mm Acrylic
- 5mm Acrylic

Equipment

- Laser Engraver
- Height Guidance Tool

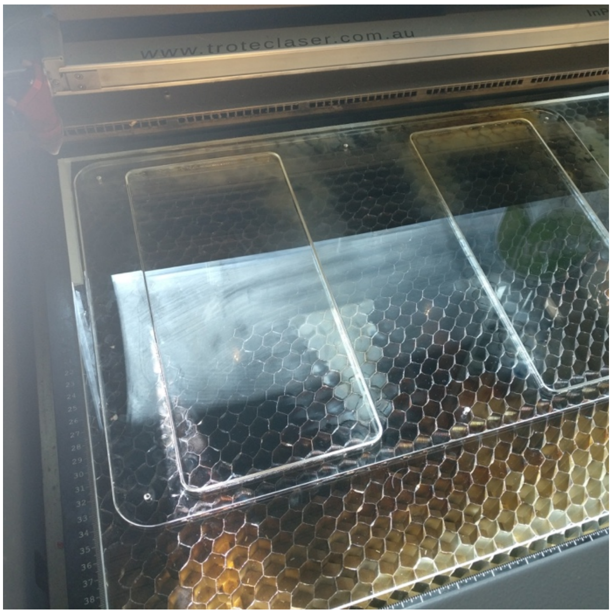
Steps

- Configure settings for each of the heights of the Acrylic (5mm & 10mm).
- Plot drawings from AutoCAD for printing.
- Cut Acrylic sheets with appropriate settings

Discussion

After placing an Acrylic sheet on the laser engraver's bed, removing the protection paper and adjusting the height of the laser, I used AutoCAD's plotting function to send the laser engraver cutting instructions.

I specified the width and length of the bed and correcting for AutoCAD's auto-scaling to 1mm = 1mm (instead of 'Fit to Page'). I configured the 10mm Acrylic cut setting to Power = 92%, Speed = 0.2%. For the 5mm Acrylic I used the setting Power = 85% and Speed = 0.6%. Setting those, I then went back to the drawing and set the width of the lines to 0.05mm and the colour to complete red, signalling a cut to the engraver.



I then sent the plotted instructions to the printer and repeated this until all of the separate layers were finished, being 3 in total. Because I wasn't able to finish cutting all of the layers due to others needing the laser cutter, I stored the finished layers and uncut sheets of Acrylic together in my Systems room. This was to ensure others wouldn't use my material and to protect the already cut sheets from being knocked over and trampled on.

Safety Measures

- Ensuring the top of the laser cutter is closed while cutting.
- Turning on and making sure the extractor is working while cutting the Acrylic.
- While moving the Acrylic to and from the laser cutting, being careful of the sharp sides and corners of the sheets.

Materials

- 10mm Acrylic
- 5mm Acrylic

Equipment

- Laser Engraver
- Extractor
- Laser Cutter Desktop with AutoCAD software

Assemble Footpads

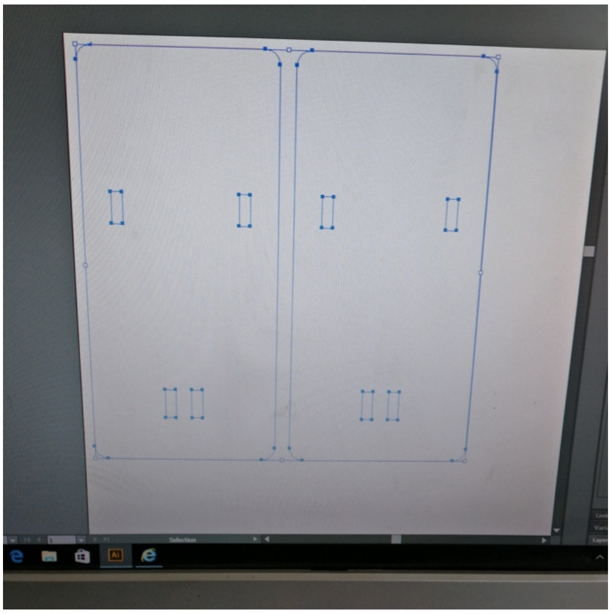
Mark puck places, score and glue pucks to footpads

Steps

- Align template to footpad.
- Using a file, score the footpad through the holes on the template where the pucks will be glued.
- Score each side of the halves and glue two together to create one puck.
- Using the template and marks made previously, glue the pucks to the footpads.

Discussion

Because of the height requirements for the pucks to reach the sensors, I would need to cut 20mm layers of Acrylic to have a single layer puck. The laser engraver that I have access too has a maximum cutting height of 10mm, and because of this, I will need to cut two 10mm halves and glue them together.



On the Acrylic footpads, I will use a template cut out made from 3mm MDF to give me a precise location of where to glue the pucks to the footpads.

Acrylic doesn't bond well without a rough surface, so I will scratch the top and bottom of each half with a sharp object, like a file, to assist the glue in gripping to the two surfaces. Using the template that I previously used to mark and score the footpads, I will glue the pucks to the bottom of the footpads.

Materials

- Footpad Halves
- Pucks
- Footpads
- Super glue

Equipment

- Footpad template
- File

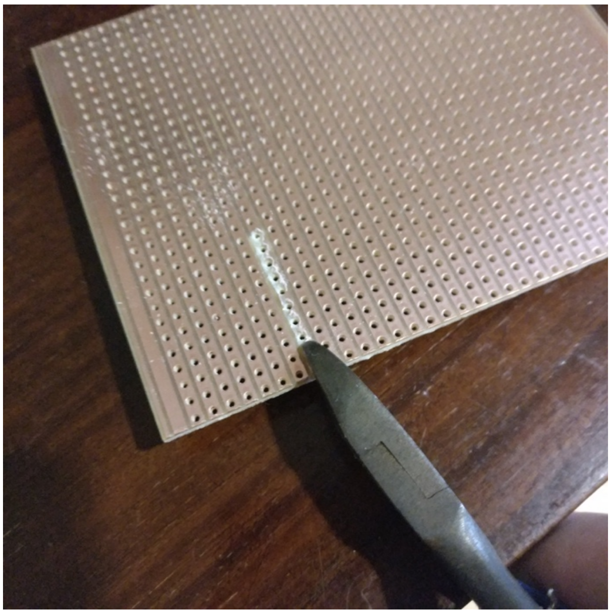
Construct Raspberry Pi Shield

Steps

- Measure and the strip board to a size of 60mm by 65mm.
- Cut the board to size using wire cutters and a Dremel.

Discussion

The strip boards that I purchased came in 300mm x 300mm squares, which is much more than I need for this project. Also, the slot for the Raspberry Pi wouldn't be large enough to fit it, so I will need to cut it to a size of 60mm by 65mm. This is the size of the Raspberry Pi board, excluding length of the Ethernet and USB ports on the left hand size. This small size will also allow the shield to fit directly over the Raspberry Pi with no overhang on any of the sides.



Because I will be using a Dremel to score the tracks that I will cut, and then cut the board with some wire cutters, I should use eye protection in case stray pieces of strip board become projectiles that could potentially cause harm to my eyes.

After measuring and making the board with a ruler and pencil, I scored the lines which I wanted to break. Next, I used the wire cutters to break the board down the dremelled lines.

Because some of the edges were very sharp, I changed the engraving bit in the Dremel to a sanding one with an abrasive edge and took away the edges that may cause harm to myself or anyone else modifying or repairing the board.

Safety Measures

- Gloves
- Eye Protection

Materials

- Strip Board

Equipment

- Digital Calliper
- Dremmel
- Diamond tip engraving piece
- Pencil
- Ruler

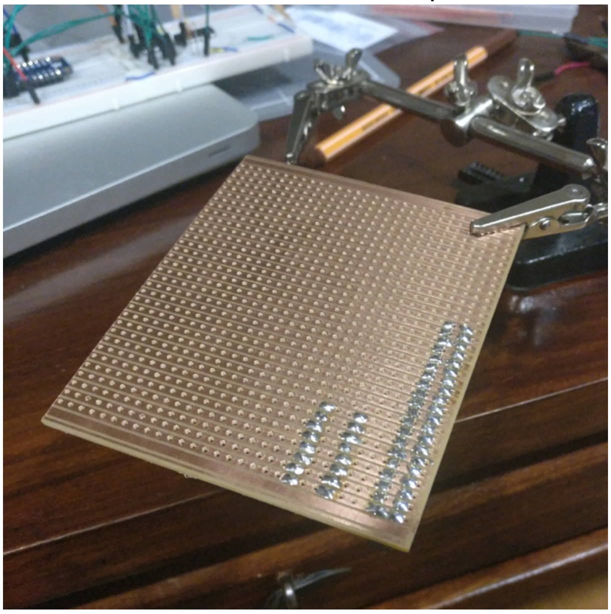
Steps

- Solder Components to Strip Board.
- Checking for unwanted connections between tracks.

Discussion

After the board is cut, I then placed all of the components in the board before I soldered them in. This is because I wanted to see if any of the components needed to be rearranged as to fit everything onto the board.

After all components were arranged in the most optimal positions, I then marked where I would cut the copper trail in a later step with a Dremmel. I would do this so pins that were on the same track, but weren't necessarily meant to connect wouldn't join. This also allowed for the board to be much smaller as I didn't require a separate track for every component.



After marking and double checking that everything was in their correct positions, I then began to solder the components to the strip board. I used the least amount of solder possible; for two reasons. One, was to conserve solder used and two, because if I needed to unsolder a component from the board, solder wick would work a lot more effectively on smaller amounts of solder.

Safety Measures

- Wearing heat resistant gloves to prevent burns from direct contact with the soldering iron.
- Soldering in an open environment or having ventilation or fan to extract any harmful fumes away from my face where I could potentially breathe the fumes in.

Materials

- Sized Strip Board
- 10x 1K resistor
- 2x 14 Pin IC Saddles
- 1x 16 Pin IC Saddles
- Raspberry Pi Connector

Equipment

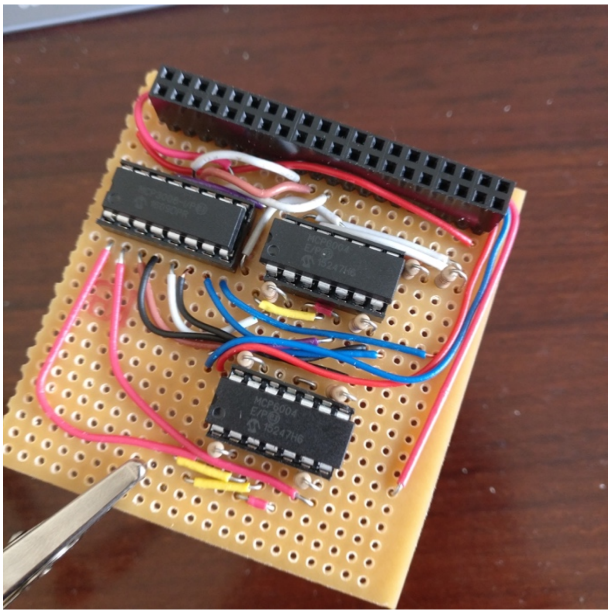
- Soldering Iron
- Solder
- Solder wick
- Steel wool, to clean soldering iron tip

Steps

- Measure and cut wires to appropriate lengths to create connections between components.
- Strip ends of wires and tin them for easier joining.
- Solder wires from one position to another to create necessary connections between components.

Discussion

Because I was using strip board and not a routed PCB, I needed to create connections from one component to another by using wires. While this was possibly a less tidy method of making a Raspberry Pi Shield (also known as a HAT), though it did work for this project. The problem that I was facing with designing a PCB style HAT for the amplification and SPI communication between the sensors and PI was that I would require either a double sided PCB or multiple layers, which in the time and budget that I had for this project, wouldn't be a feasible option.



Once I measured the length of wires I needed to create the connections, I cut single core wire and stripped the ends. When I ran out of solid fore, I used multicore wire and tinned the ends so that it was easier to solder them into place. I continued to do this, following the schematic I developed, which can be found under the Final Design section of the folio.

Safety Measures

- Wearing heat resistant gloves to prevent burns from direct contact with the soldering iron.

Materials

- Wire
- Strip board with components

Equipment

- Soldering Iron
- Solder
- Solder wick (if necessary for mistakes)
- Steel wool, to clean soldering iron tip
- Wire stripping tool

Steps

- Using a Dremel, hand route all of the unwanted connections between tracks.
- Check to make sure connections that were originally wanted have not been severed in the process of dremelling.

Discussion

As strip board makes a copper connection to every component that's soldered to each track, which would prevent the integrated circuits from working (because some pins on the same track need 5V and the others need GND), I needed to cut this connection.

Using a diamond engraving tip on a hand Dremel, I marked which tracks needed cutting and where, then carefully and slowly dremelling the tracks. While doing so, I was cautious not to cut any deeper than necessary. If I cut too deep, I risked damaging components on the other side or making the strip easy to snap.

After cutting each line, I would stop, brush off the excess dust from the board and copper, then inspecting each track to see if there were any remaining connections that I missed. This happened a couple of times, so to fix it, I would carefully Dremel these places lightly until the copper tracks were broken.

Safety Measures

- Being cautious of the Dremel while in use, as to not score or injure myself.
- Using a third hand to hold the strip board in place while dremelling the tracks.
- Wearing eye protection, like sunglasses or goggles to protect my eyes from any stray pieces of copper.

Materials

- Completed strip board

Equipment

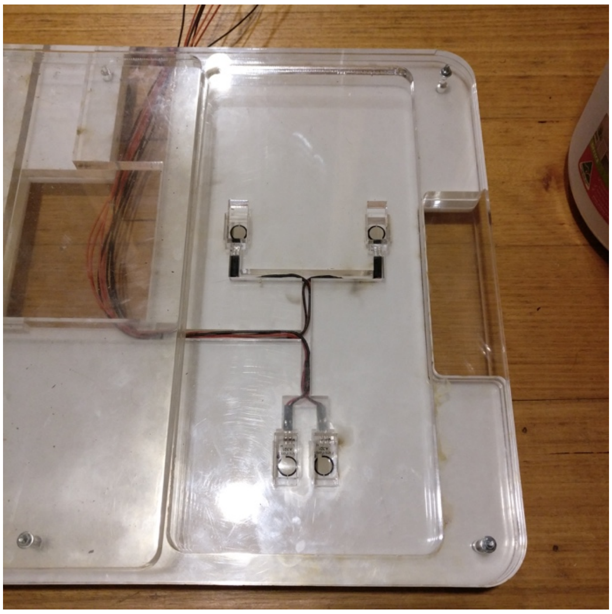
- Dremel
- Diamond tip engraving piece
- Third hand holder
- Eye protection (sunglasses or goggles)
- Brush

Assemble Board and Sensors

Steps

- Bolt layers 5, 4 and 3 together, making sure to run the bolt through a washer and the rubber foot before inserting them through the pre-cut bolt holes in each layer.
- Create wires to connect the sensors to the Raspberry Pi Shield.
- Heat shrink any exposed parts of the wires.
- Insert the sensors into the board and connect them to the wire connections.
- Neatly running the wires through the wire tracks into the Raspberry Pi's cut out.
- Insert footpads.

Discussion



First, I will join a female connector to the end of a piece of wire and heat shrink the connection to create a barrier between the exposed wire and other wires.

Before assembling the rest of the board, because doing so would block my ability to bolt the Raspberry Pi to the bottom layer and run the sensor cables through the wire channels. I will assemble the rest of layers later and only join the bottom three. First, I will connect the wires to the sensors with a female pin connector on the end of a wire, which will plug into the terminals of the sensors. Then I will run the wires through the channels, lead them to the Raspberry Pi slot and sit each sensor into a cut out.

Safety Measures

- Awareness of any dangers, such as burning fingers, when shrinking the heat shrink tubing.
- When cutting the heat shrink to size, being careful not to cut myself.

Materials

- Wire
- Heat shrink
- Bolts
- Nuts
- Rubber bolt-on feet
- Sensors

Equipment

- Matches, lighter or other source of heat

Steps

- Mount the Raspberry Pi to Layer 5
- Attach the Raspberry Pi Shield (HAT)
- Solder the wires to the Shield.
- Bolt the rest of the layers together (layers 2 and 1).

Discussion

Once the wires are in place, I then mounted the Raspberry Pi to the last layer, Layer 5. Making sure that the Raspberry Pi's power and video out ports were directed at the cut out towards the front of the board, I used the mounting screws that came with the Pi and secured in into place.

After the Raspberry Pi was secured, I connected the Pi to the Shield via the 40 pin header. Then I connected the sensors to the board by soldering the wires to the correct places on the copper tracks.

Safety Measures

- Wearing heat resistant gloves to prevent burns from direct contact with the soldering iron.

Materials

- Raspberry Pi
- Bolts
- Nuts
- Washers
- Raspberry Pi Shield / Completed strip board

Equipment

- Soldering Iron
- Solder
- Steel wool (for cleaning the soldering iron's tip)

Steps

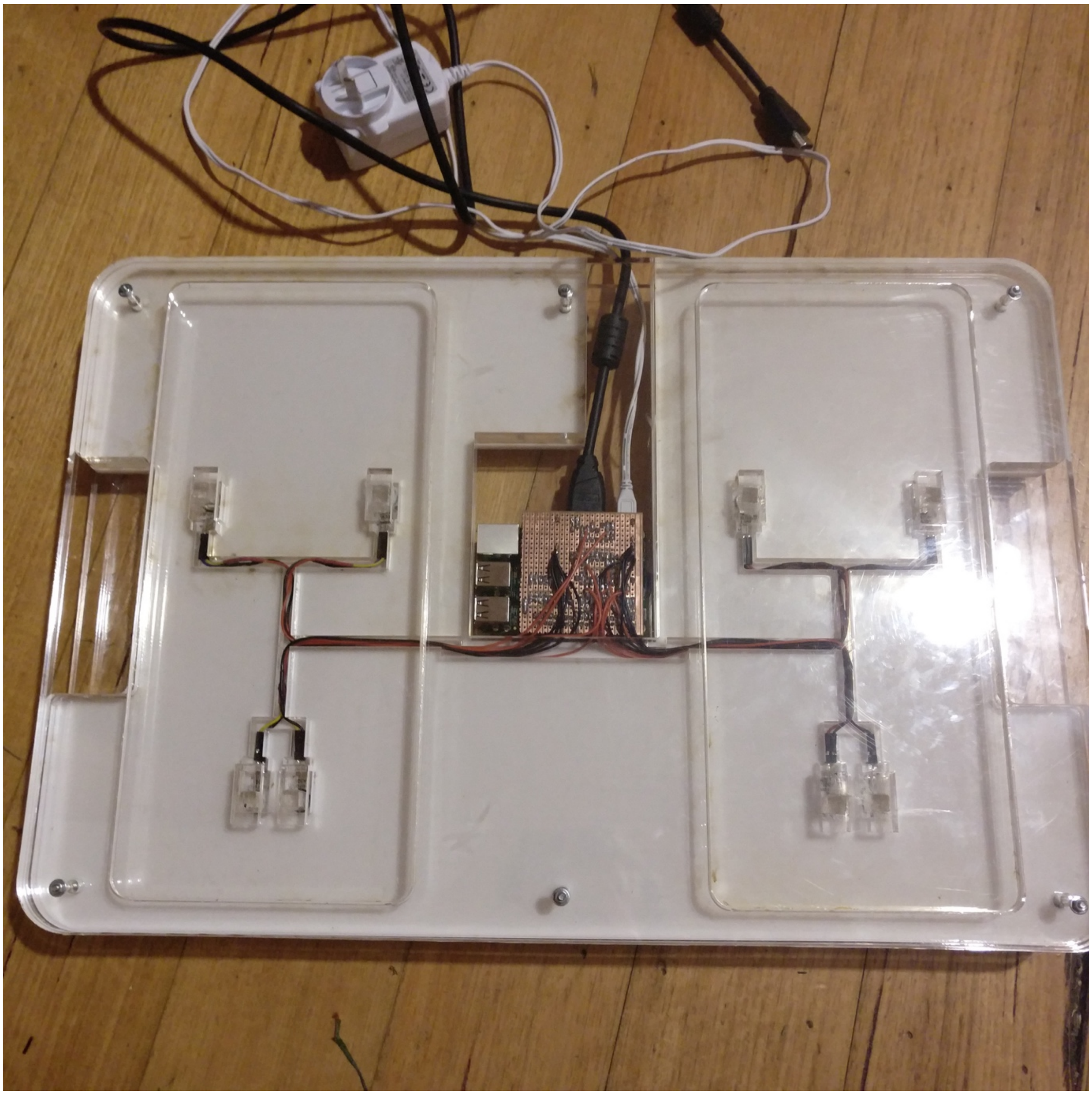
- Connect remaining layers on top of previously assembled layers.
- Secure all layers together using nuts and washers.

Discussion

After everything was soldered and connected, I connected the power and HDMI cables to the Raspberry Pi and assembled the rest of the board, bolting the remaining layers of Acrylic to the already partially assembled board.

Materials & Equipment

- Remaining layers of Acrylic (Layers 1 & 2)
- Screwdrivers to tighten bolts



Diagnostic Testing

Outline

Board Diagnostics

1. Plug in Balance Board to HDMI compatible screen and wall power.
    a. Is the Balance Board booting into the desktop?
    b. Are the peripherals working?
2. Turn the board off via the wall.
    a. Will the board reboot?
    b. Are there any errors that occur when the board is rebooted?

Sensory Diagnostics

1. Open the Sensor Diagnostic program on the Desktop.
2. Step onto the board with both feet positioned evenly.
    a. Are the channels displaying the same number, with a margin of 100?
    b. Are there any channels not displaying data (either constant 0 or 1023)?
3. Step onto the left side of the board, then the right.
    a. Is the program displaying data for each individual foot?
    b. Is the data roughly the same for each side?
4. Step off the board.
    a. Is every channel displaying 0 for their inputs?

Program Diagnostics

1. Open the Balance Board program on the desktop.
    b. Are the graphs for each foot and the board as a whole loading?
2. Step onto the Board.
    a. Is the program displaying an error?
    b. Is the program displaying data for the board?
3. Step onto each side of the Board.
    a. Is the program displaying data for each individual foot?
4. Step off the Board
    a. Does the Balance Board program show any activity?

Results

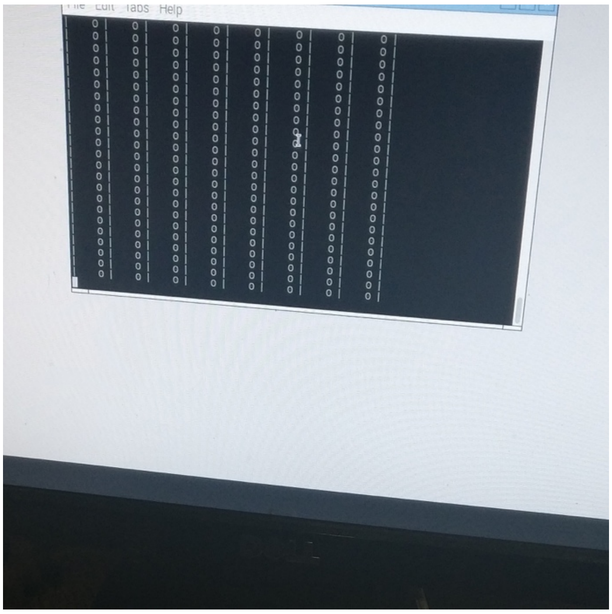
Board Diagnostics

When I plugged in the video output (HDMI cable) to a screen and the power port into a wall socket, the system booted into the Raspbian Desktop as it would like normal. This shows to me that they aren't any crossed power pins or tracks on the Shield, which I found to make the board restart as I assume it has a safety feature that when the power is tripped, such an event will occur. Likewise, to the success of the boot, the wireless keyboard and wireless mouse also worked without an issue, allowing me to control the system directly. I also had the ability to use SSH to terminal into the Raspberry Pi, and subsequently start a VNC server, which allowed me to remotely connect to it via VNC Viewer on an external computer on the same Wi-Fi network.

I then turned the board off from the wall, waited 30 seconds for a power cycle to occur, then switched it back on. There were no errors that occurred, and everything worked just as it did beforehand.

Sensory Diagnostics

Once the device was booted and onto the Desktop, I opened the Sensor Diagnostic program, which presented me with a terminal window and eight columns of numbers, representing each of the SPI channel inputs coming from the ADC.



The program presented me with all columns I would predict. Firstly, they presented as all being zero, which told me that they were all connected, as if they were generating random numbers between 0 and 1023, then the lines wouldn't be connected.

I then stepped onto the board and tried to manoeuvre my weight as close to the centre of the board as possible to create an even distribution and equal number across all columns.

The numbers across the columns, while standing very still and straight, read "90, 91, 92, 92, 90, 91, 93, 90", which is the predicted output for my weight. Not only are the sensors displaying a number within a margin of 100 of each other, but within a margin of 3 points difference. There were also no SPI channels that displayed a constant 0 or 1023.

Next, I stepped onto the left side of the board and checked the output of the channels. Then I did the same, but shifting my weight to the right hand side of the board. When I did this, the channels on either side of the screen increased or decreased, showing that the sensors were reacting to the change in weight distribution. I then stepped off the board to test how it would react to force being applied to the sensors. The numbers changed from their positions down to 0, indicating that there was no force applied, and that the board can recognise when there isn't force being applied to it. I then turned off the device to check that the system continued to shutdown without errors. It did shutdown without any errors.

Program Diagnostics

Once the device was booted and onto the Desktop, I opened the Balance Board program, which presented me with various graphs for the boards total weight distribution, and the distribution chart for each axis, X and Y. I then stepped onto the board and tried to centre my weight as close to the centre of the board as possible.

When I stepped on the board, the program reacted as expected. The graphs changed to reflect the new force that was being applied to it and showed where the force was being applied the most. No errors were presented due to this change.

I then changed my posture to apply more force on one side of the board than the other, to replicate someone who had impaired balance as a result of ABI (Acquired Brain Injury) or because of a stroke. The graphs changed accordingly, showing that there was more pressure towards one side of the board, confirming that the software has the potential to be useful in measuring people's balance abilities.

Stepping off the board stopped the program, just as I designed it to do so that it wouldn't record minute changes, acting as a kind of threshold.

Evaluations

Timeline Evaluation

	Weeks											
Step	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Cut Layers												
Import Drawings into AutoCAD												
Place Materials onto Laser bed												
Plot and Cut layers												
Assemble Footpads												
Use template to mark puck places												
Score and glue pucks to footpads												
Construct Raspberry Pi Shield												
Cut board to size												
Solder components to board												
Create connections between components												
Cut unwanted connections												
Assemble Board and Sensors												
Embed Sensors												
Mount Raspberry Pi												
Connect Shield to Sensors												
Connect rubber feet to bolts												
Bolt Layers together												

The production of the system did end up falling well behind the planned schedule. Many factors have had roles to plan in this outcome, from the need to change sensors to unforseen circumstances in my personal life. I was also mildly sick during the time of production, which contributed to the delay in finishing. In conclusion, my product ended up being completed four weeks later than I had originally planned, but I did leave time for this to happen when I first planned the production timeline. However, in saying this, the product and folio was completed before the due date, everything was evaluated and tested too without the need to rush.

System Evaluation

Subsystem	**Evaluations**	**Weight**	**Awarded**
Sensors	How accurately can the sensors weight various amounts of weights?	7	7
	How accurate are the sensors over multiple uses?	5	4
Electronics	Are the components inside the system safe for a medical context?	5	3
Size and Safety	Does the product introduce any electrical hazards to its environment of use? (Yes = 0, No = 7)	7	7
	How well does the system accommodate for both with those of small stature to those with large stature?	7	7
	Can the physical product be used by people of a range of weights? (20kg - 140kg)	7	7
	Is the product safe to stand on? (Is it slippery? Is it unnecessarily high?)	7	5
Construction	Is the product made of high quality, high durability materials?	5	3
	Is the product predicted to need regular maintenance? (Yes = 0, No = 3)	3	3
Information	Does the information displayed help to make smarter medical decisions for balance rehabilitation?	7	5
Aesthetics	Does the product fit in with its surroundings?	3	3
Transportability	Can the product be safely transported by person?	5	5
Physical Size	Is the product small enough to store?	5	5
Availability	Is the product cost efficient?	5	4
	Does this product have a price that makes it widely accessible?	3	3
Totals		**86**	**78**

Overall, the system performed incredibly well is majority of the criteria areas. Though it did fall in some, a lot of the criteria was scored very high; some even scored full marks. I think this was a combination of planning and testing, but also my ability to set realistic goals and requirements for the product. Being able to set these goals allowed me to achieve what I set hoped to achieve, through the product, which was to make a device that medical professionals can use to measure and monitor patient's ability of balance.

Although it did score very highly, I would like to see in the next version more accurate sensors. This would come from using better quality and higher precision Analogue to Digital Converter Integrated Circuits, more accurate operational amplifiers and perhaps even different sensors; although the FSR sensors seemed to have no issues in this version when it came to accuracy.

Another area that didn't score top marks was the durability of the material. Although Acrylic is very strong, it is also prone to cracking if dropped from a height or dropped often. While this shouldn't present as too big of an issue, because of the context of the device, being used in a medical environment, I would like to see the next version made out of a more 'drop-friendly' material that will withstand a little beating.

Also, because of its strip board shield, there are some potentially hazardous wires within the Raspberry Pi slot. Though this doesn't present as an issue for the users of the board, both medical professional or patient, it could present as a hazard for someone trying to repair the board while the Raspberry Pi is still powered. For this reason, I would like to see a change to a professionally fabricated PCB with Molex connectors and a silkscreen; to help prevent injury like electrical shocks from occurring.

Process Evaluation

For a large portion of the project, the investigation that came from researching different existing products and systems helped give me a base point of research, and a place to go from. These leads that I found helped to continue on my research into more sophisticated and accurate system solutions that I ended up implementing into the final product, being the FSR sensors. While I did have to revaluate which sensor I was going to use, because of the limitations of QTC that I did not discover during the investigation phase, overall, I believe I did make more effective choices that has lead to a better overall product that aids to assist medical professionals and victims of balance impairment.

The design phase allowed me to play with ideas, and make different combinations of features. Having 3D models, developed in Autodesk Fusion 360 definitely aided me in choosing the final design because it gave the ability to have a visual representation of what the final product may look like. Also, because of the investigation done previously, information from the Journal of Neuroengineering and Rehabilitation and factors from the design brief helped to develop an evaluation criterion that ended up evaluating the most suitable design option to build.

The planning stages of the project were mostly beneficial, barring the fact that I had to modify the end design to fit different sensor types, FSR rather than QTC. Because the previous design was made in CAD software, this change was easy and it was quick to cut the modified layer.

This wouldn't have been as easy and quick to accomplish if I was using a different program, such as Adobe Illustrator.

The overall production of the product was fairly efficient, when I was focused on it. Unfortunately, throughout the production phase I was distracted by other matters, but due to the straightforward nature of the plan, when I became focused on the production once more, it was easy to accomplish lots in a short amount of time.

The major difficulties that I faced during the project was the previously mentioned change in design and side-tracking. In terms of the change in design, because of the prior research done on the Force Sensitive Resistors, it was easy to accommodate for them in the design, having the datasheet that mapped out the working drawings of the physical sensors. As for the side-tracking, this wasn't a pressing issue because of the planning done prior to starting the production. Once ready to continue with the project, it was only a matter or refereeing to the folio and checking what the next step was on the road to completing the product. Keeping all of my material, both finished and fabricated allowed me to have a visual space to keep track of my progress – what still needed doing and what was already done. This saved me from fabricating the same object twice, and assisted in maintaining a mental list of what still needed doing.

Evaluation of the Products Suitability

The system adheres to the majority of the system factors, including Function, User Needs and Requirements, Environment of Use, Waste, Size and Maintenance. The investigation into subsystems and existing systems aided in the design of the final system to follow the requirements necessary to create a solution to the problem.

For example, the Size factor indicated that the system should be small and light enough to be portable. The final system is light enough and small enough to accomplish this. For the User Needs and Requirements, the system accommodates to a range of people; small to large, light to heavy. The Environment of Use factor can be seen throughout the design phase, with high importance set on the physical design and properties that would otherwise damage the systems end effectiveness.

Though successful is the majority of the factors, others the product fell short in. Factors such as Materials and Components, Safety, Quality Standards, Styling and Appearance and Performance and Durability weren't given enough importance during the research and development phase of the Systems Engineering Process.

As outlined previously, the materials used may not be the most suitable for the systems context of use, because of its tendency to crack when dropped. Also, for areas like Safety, I would like to have given higher importance to the industry standards and ISOs available for products like this, then develop design options and systems options around the constraints attached to the standards.

Overall though, the system does show evidence all of the factors. While not displaying every point listed in the Design Brief, it does show evidence for every factor, and most are well developed in the board.

Potential Modifications

If I was to design the board again, I would consider using QTC sheets in a board that is specifically for younger children and lighter adults. It would be interesting to design a board that used a heat map approach to measuring balance. It would be fascinating to observe the changes in balance on a much more detailed level, and test it in real-world scenarios to compare the effectiveness of this product, compared to one like that.

If I had extra time and / or access to machinery that had the ability to do so, I would like to replace the strip board Raspberry Pi Shield with a professionally fabricated PCB one. This would help to ensure quality and consistency if the product was to be made several more times.

I would have also liked to create the program responsible for displaying and graphing the data into a web / cloud based application. This would have allowed medical professionals to access patient records online, which could have opened up the possibility of remote diagnosis and rehabilitation plan design.

Another change I would potentially add would be giving the board the ability to move and change its angle. I could add hydraulics to each side of the board, which would allow medical professionals the ability to observe how patients react to changes in the ground they stand on and how well they are able to accommodate to this change through their posture.

I would have liked to experiment with new and upcoming processes like SLA and MJF 3D printing; also possibly injection moulding. It would have been interesting to see if either of these processes would have helped bring the cost of the overall system down, making it more affordable and available to institutions looking for this type of product but don’t necessarily have the funds for it. Also, it would have been interesting to see if I could have made the product more rugged through the employment of either, or both, of these processes.

In terms of the production of the product, I believe that I would plan ahead more as to finish the system quicker. This would afford me more time in testing the product and also to more time to spend on my folio. A lot of the processes were left to the few weeks because of the distractions of other subjects, etc. I will definitely take this into the future for when I develop future systems and products.

Thorough explanation of areas for improvement to the finished system and management of the stages of the Systems Engineering Process.

Conclusions

Overall, I feel that the system has given a solution to the problem I outlined at the start of the project. I am extremely content with the outcome of the device, thought I am aware of several changes I would make I were to make it again – all of which I have outlined in previous sections of the folio; mainly in the ‘Potential Modifications’ section. I would like to call this system the first version of the overall solution.

Bibliography

- https://www.adafruit.com/
- https://learn.adafruit.com
- https://www.sparkfun.com/
- https://www.learn.sparkfun.com/
- http://matplotlib.org/
- https://pimylifeup.com/
- http://askubuntu.com/
- http://pastebin.com/
- http://stackoverflow.com/
- https://www.youtube.com/
- https://www.peratech.com/
- http://www.cl.cam.ac.uk/
- https://www.raspberrypi.org
- http://www.scipy.org/
- https://github.com/ruecksticss
- https://au.element14.com
- https://pypi.python.org
- http://ww1.microchip.com/
- https://pinout.xyz/pinout
- http://electronics.stackexchange.com/
- http://abyz.co.uk/
- https://www.tekscan.com/
- http://www.farnell.com/
- https://wiltronics.com.au/
- https://projects.drogon.net
- http://elinux.org/RPi_SPI
- http://au.mathworks.com/
- *Gil-Gómez, Lloréns, Alcañiz, & Colomer, Effectiveness of a Wii balance board-based system (eBaViR) for balance rehabilitation, 2011)*