TheraBuddy

Design Report

Group Members: Amna Askari, Jonathan Campbell, Karthik Chellappan, Yomna Genena

Table of Contents:

Abstract/Summary

TheraBuddy is a device that essentially integrates resistance band based physical therapy with an interactive interface in the form of a video game. Currently, resistance band based physical therapy is widely used to increase muscle strength and control for patients of various neurodegenerative diseases. However, exercises are not done frequently enough and patients are unable to view and track their progress. TheraBuddy allows the patient to visualize and participate in their unique training and healing process in an exciting manner. Given the restricted timeframe for the project, it was decided that the design for our prototype would be centered on the following considerations:

- Therapy would be specifically for those recovering from stroke who possess a mild degree of movement i.e. aren't completely immobile.
- The focus would be on one general movement targeted at recovering function from a particular muscle group – we decided on an extension of the forearm and rotation of the wrist
- We would only create one video game which is a racing game, although more game ideas have been discussed in detail and are a promising development for the future

Note: The name TheraBuddy is derived from the term Thera-Band™ which is the name of the most commonly used resistance band product in physical therapy

Clinical Relevance/Need

Neuropathology of stroke

Stroke is a devastating neurodegenerative condition that is the leading cause of serious, long-term adult disability [1]. It is caused by the restriction or loss of blood flow in the brain. This is owing to either formation of clots, weakening or rupture of blood vessels that supply the brain with oxygen and other nutrients. When this supply is reduced or eliminated, the brain is devoid of essential elements needed for its operation and therefore experiences functional losses in several regions. Stroke can result in immediate death, speech impairments other cognitive issues but our device is targeted towards assisting and healing stroke survivors that primarily experience motor disabilities.

As the brain is a crucial unit of the central nervous system, this loss in function results in severe discontinuities in nervous impulse transmission, especially to muscles. Therefore, stroke results in muscle weakness, spasticity, atrophy and paralysis that lead to loss in stability, movement and control. (These are essentially the three areas of improvement that we are focusing on)

Spasticity refers to the continuous contraction of muscles, which leads to spasms, stiffness and difficulty in movement. An example of this is a stroke patient having very shaky hands and not being able to grip onto things properly. Atrophy is the loss in muscle mass owing to reduced amount of signals sent to the muscles that activate them. Atrophy, paralysis and weakness mean that stroke patients struggle a lot with using their muscles. The loss of abilities that follow a stroke depend on the area of the brain that has been damaged by stroke. [2] Stroke is often characterised by hemiparesis, which is when weakness exists primarily on one side of the body. Due to this deterioration in motor command and ability, stroke survivors find great difficulty in locomotion and execution of day-to-day tasks like dressing, eating or going to the toilet. Aside from the physical aspect, stroke patients experience a high degree of mental health issues including depression, anxiety and lack of motivation. Hence a big hurdle in recovery is getting the patient on board and enthusiastic about getting better.

Some relevant stroke statistics

- About 40% of stroke survivors have serious falls within a year of their strokes.
- A stroke happens nearly every 5 minutes in the UK
- Stroke is the leading cause of adult disability in the US and UK and second leading cause of disability worldwide
- There are currently 1.1 million stroke survivors in the UK

Resistance band based strength training for stroke patients

Having looked closely at what exactly happens in a stroke and what the patient goes through, it is now important to discuss relevant therapy options. Regularly administered physical therapy is widely used with stroke patients as it helps them regain muscle strength, and in some cases function. Our device is based on resistance band (Thera-Band™) based strength training, as it is widely recommended by all therapists and is something that is accessible and easy to use. There is a lot of relevant literature that discusses the success of strength training in the recovery journey for stroke patients. As part of a collaborative research project called LEAPS in 2007, researchers from many prestigious universities in the U.S. like Duke, UCLA, and USC carried out a large stroke survivor study on approximately 400 patients. They investigated the difference in effectiveness of robot assisted treadmill therapy versus home-based physical therapy exercises, including those with Thera-Band™ on the ability to walk independently. They concluded that home-based physical therapy is less expensive and pretty much as effective as robot-assisted therapy. The lead investigator of the study, Dr. Pamela Duncan had carried out another study on comparing the effectiveness of a structured and progressive Thera-Band assisted strength-training program to usual and spontaneous care of stroke patients. Her team found that the test group i.e. those that used Thera-Band had improved gains in endurance, balance and mobility. [3] Another project funded by the Canadian Institute of Health Research found that strength training with the usage of resistance bands statistically improves muscle strength in patients significantly. [4]Increasing recognition of the importance of muscle strength in stroke recovery is based, in part, on studies that have demonstrated a relationship between muscle strength and function in persons with stroke. [5] The hypothesis is that as one gets stronger, one is more able to carry out basic every day tasks like wearing clothes, walking and eating. We confirmed this after a detailed discussion with Dr Sarah Guy, who works closely with stroke patients. Therefore, one overarching aim of our product was to integrate strength training with practicing functional day-to-day tasks.

Problems with the status quo - Why TheraBuddy is different

There are various issues with the current administration of Thera-Band™ based therapy. Firstly, the success of this kind of therapy is based on the frequency of practicing the exercises and adding tougher resistances accordingly; it is an ongoing journey. Usually after visiting the therapist first time, patients may purchase the Thera-Band™ equipment and practice a couple of times but it is quite boring and dull to constantly do this everyday without being able to see how well you are doing. Secondly, even if the patient practices the exercises regularly and reports back to the therapist, current stroke assessment measures like the Fugal Meyer assessment are rudimentary and not specific to personal requirements and progress. Thirdly, a regularly available therapist is not an option for everyone: people have to wait in long lines or travel far distances multiple times to get the right kind of therapy. In fact, in most developing countries, people don’t even have access to a therapist.

TheraBuddy attempts to solve those problems and has unique added advantages. As the device integrates with a reward based video game, it suddenly makes bland Thera-Band™ exercises a lot more exciting. The patient is more involved with his/her therapy and can actually see how well they did at the end of the game, and place that against how well they need to do or how well they want to do. The game has an easy to use and colorful interface so that patients are more inclined on using it. Patients’ results can be sent to the therapist in real time (this is a future software development goal), so constant visits aren’t required and everything can be done independently. More importantly, the video game is a form of visual feedback that has proven to be beneficial in therapy. The Stroke Rehabilitation Evidence-Based Review (SREBR) is a collaborative research project between experts at various universities and research centers including Mcgill university in Canada and St. Joseph’s Healthcare in London. It reviews techniques, therapies, devices, procedures and medications associated with stroke rehabilitation. They state in their report that there is strong evidence that biofeedback methods that use either auditory or visual feedback can be used to improve gait and balance. [6]

Design

Design brief

At the beginning of the design stage, we formulated a succinct design brief to follow:
"Our goal is to design a device to help stroke rehabilitation patients regain strength in their upper limbs, while also assessing progress and promoting motivation. It must be portable, cheap, and easy to install and use. We would like to make the device interact with a therapeutic game, and give feedback to motivate the patient."

Mechanical

Therabuddy has been designed as two separate components, the tension meter and the wrist brace. Figure x shows the tension meter as a complete assembly. A set of nuts and bolts are used to lock the assembly together. The pink cap contains a wire loop that secures the theraband while the orange cap secures the tension meter to the desk via an universal mount. This arrangement improves both flexibility during use and the accuracy of force measurement by ensuring that the tension meter can pivot to the line of applied force.

When the band is pulled the green and pink parts act as one rigid body and the blue, yellow and orange parts act as another rigid body providing the support needed for the load cell. This arrangement is a cost effective way of replacing an expensive tension load cell with an affordable compression load cell. The compression spring in the device generates a preload on the load cell. Choosing a sufficiently stiff spring then allows both tension as well as compression to be measured. Compressing the device decreases the force acting through the load cell while pulling the device increases the force acting on the load cell. Both these changes in force magnitude are measured and conditioned using electronic circuits described in Section x.

For the second component we obtained a medical grade Neo G wrist brace to which a 3D printed anchor for the resistance band was attached. This allows quick yet secure attachment of the resistance band between the two components (wrist brace and tension meter) via an aluminium carabiner, which can be done with one hand.

Benefits of mechanical design
To keep costs reasonably low, design for manufacture and assembly have been given careful consideration, even for this prototype design. The cylindrical sliding design of the device lends itself easily to standard turning and injection moulding processes and the universal mount was purchased from a mass supplier for about £15.

The same design configuration also focuses on usability and gives additional value for performing other rehabilitation exercises. This is achieved by allowing different grades of therapy bands to be swapped easily and by allowing different mounting arrangements in the home such as tables, doors, chairs etc. Some of the mounting locations could even allow the device to be used in an active assistive manner. For example mounting the universal mount on the top edge of a door frame would assist the patient with upper limb rehabilitation.

The locking mechanism of the orange and pink end caps (See Figure x) are symmetrical, allowing the configuration to be changed easily for bilateral training by having wire loops (two pink ends) on both sides of the tension meter. The locking mechanism for the end caps was inspired by the design of the canon slr camera lens mount.[ref] A similar click and twist mechanism will be needed for production ready versions of the product to ensure that patients with reduced physical mobility can still install the device in the desired configurations.

Electrical

There are two electrical components to the TheraBuddy system.
The force exerted by the user is measured using a load cell. The small signal generated from the load cell is amplified using a circuit with an INA125P[1] instrumentation amplifier, which outputs a larger voltage to be read by an analog input pin on a microcontroller. This voltage output is conditioned to account for temperature drift within the amplifier.
The advantage in using the INA125P is that the gain of the amplifier can be controlled using a 20kΩ potentiometer, which was useful for calibration and testing of the device.
To measure the angle of the user's wrist, we used an Adafruit IMU, which is a combination of a gyroscope, accelerometer and magnetometer. The output from this is read by the analog input pin on another microcontroller.
The microcontrollers we are using are two Adafruit Feather 32u4 Bluefruits, which are small microcontrollers with built in Bluetooth functionality. The Feather is powered by a battery, which can be recharged by connecting the Feather via a micro-USB cable to a power source.
Both electrical devices are housed in a small 3D printed casing for protection. Device power can be toggled with a micro switch, helping to conserve battery.

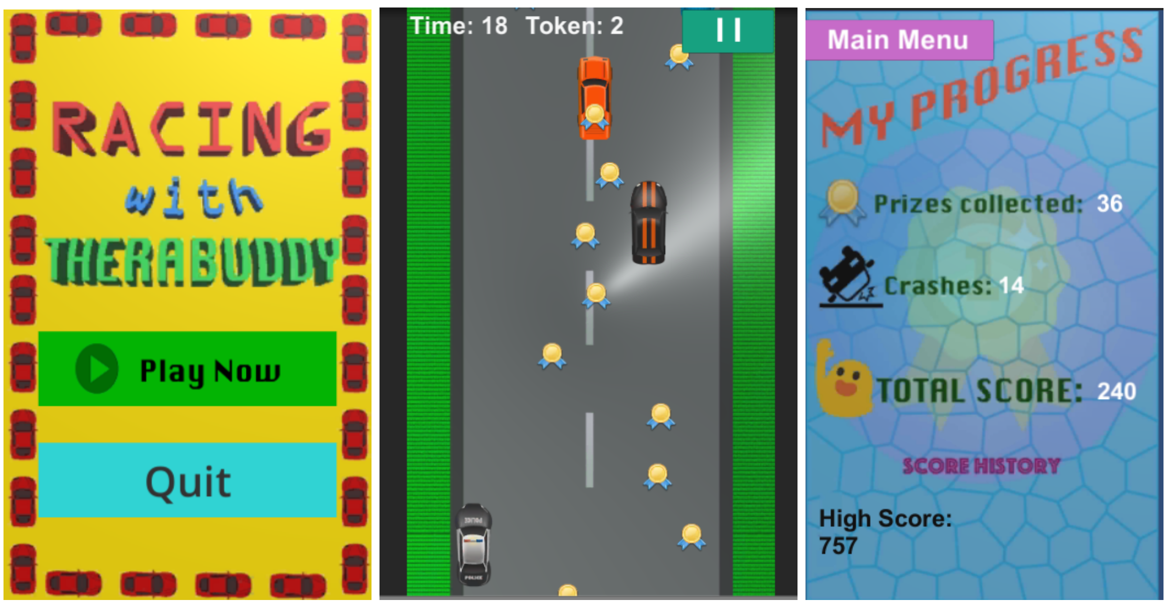
Programming

We have programmed our microcontrollers to act as a human interface device, specifically a keyboard, for the purpose of controlling our video game. The force that a user exerts is quantified to 10 discrete levels. Once the user reaches a new level, a Bluetooth command is sent which initiates a new key press to indicate to the game that a new level was reached. We found this to be a good way to bypass the complications of direct Bluetooth communication.
Our game is programmed using the Unity game engine.
Game specifics

[1] http://www.ti.com/lit/ds/symlink/ina125.pdf

Game Design

Our game was designed to encourage the patient to independently get involved in his/her own rehabilitation process. The game was designed to also give feedback in the form of a score that assesses how well the player can control specific hand movements: 1. Stretching the elbow and 2. Rotating the wrist. As the player stretches the elbow, a car speeds up and is surrounded by other cars and tokens. The player needs to avoid colliding with the other cars but collect as many tokens as possible. This is done through the wrist movements. A constant timer of 45 seconds is set, after which the number of cars crashed and tokens collected is counted and the score is set to be equal to $\frac{tokens\ collected}{cars\ crashed + 1} x100$



A high score is also stored in order to act as an encouraging factor to improve and to keep track of progress. Other than the score, the total number of tokens collected and cars crashed is also shown to the player after finishing the game. This can be used to assess a specific movement that might be weaker than the other. For example, if the elbow-stretching movement is weak then number of tokens collected tends to be very low because more tokens appear as the car moves faster, but if the wrist movement is weak, the number of cars crashed tends to be very high. Therefore, the player can assess which movement is hindering the score from rising.

Furthermore, two people can play the game, each controlling one specific movement. This can add more fun to the game while also allowing the patient to focus on one specific movements if controlling two at once is too challenging.
A potential addition to the game could be another interface that allows a doctor to add cars or tokens as the patient plays the game in order to communicate better and assess the specific movements. This feature could even be achieved remotely allowing physiotherapists to overcome funding and time constraints and to monitor patient progress on a more regular basis.

Testing

Once the components of the device were assembled, we entered the testing stage of the project. The sensors were calibrated for a range of realistic movements which patients would be able to achieve.

Final notes

We believe there are many possible applications for our device which can be explored. Bilateral movement training is a common rehabilitation exercise where a patient uses both their healthy and weakened limb in task related training, since many daily tasks require the coordinated use of both arms. (7) Repurposing our device for use with both arms could prove beneficial in bilateral arm training.

TheraBuddy is designed for arm extension exercises, however the device could be used in resistance band training for other parts of the body. For now the device is used while clamped to a sturdy tabletop or sideboard, and the user sits on a chair and faces away from the table. Different fixation points are possible, such as a door frame, but further testing and consultation would be needed. Another future goal is to allow the therapist to individually tailor the games difficulty for the patient, for example with the car game, the therapist could alter the track depending on how well the patient is doing.

References:

http://www.hygenicblog.com/2011/03/17/physical-therapist-led-home-exercise-programs-with-thera-band-bands-benefits-stroke-survivors/

http://www.strokeassociation.org/STROKEORG/LifeAfterStroke/RegainingIndependence/PhysicalChallenges/Weight-Training-After-Stroke_UCM_309780_Article.jsp#.VwFQ3mOleqB

---

[1] American Heart Association. Heart Disease and Stroke Statistics 2004 Update. Dallas, Texas: American Heart Association; 2003.
[2] https://www.stroke.org/sites/default/files/resources/NSA_Hemiparesis_brochure.pdf
[3] http://www.thera-bandacademy.com/resource/x-showResource.aspx?id=743
[4] http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3524263/#R1
[5] http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3524263/#R1
[6] http://www.ebrsr.com/sites/default/files/documents/executive-summary-srebr_final_16ed.pdf
[7] Bilateral arm training: Why and who benefits?
http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2953420/

Appendix

Mechanical Design

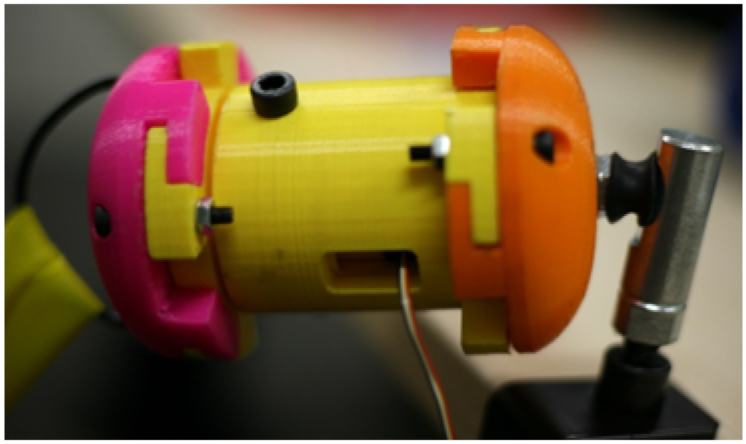


Figure x: Tension meter mounted in a table top configuration

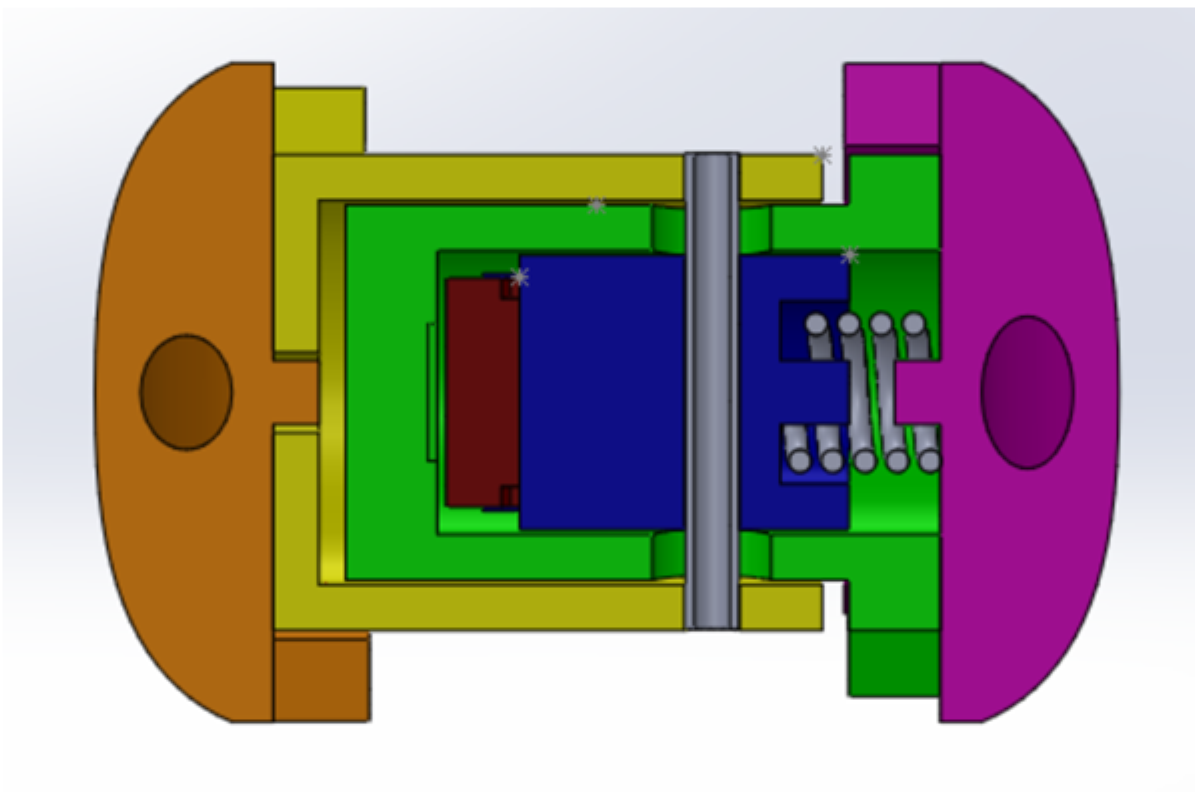


***Figure y**: A cross section of the tension meter shown in **Figure x** has been colour coded to distinguish the parts. (Red load cell, Blue load cell seat, Green inner sleeve, Yellow outer sleeve, Pink therapy band holder, Orange table clamp end.)*

Electronic Schematics

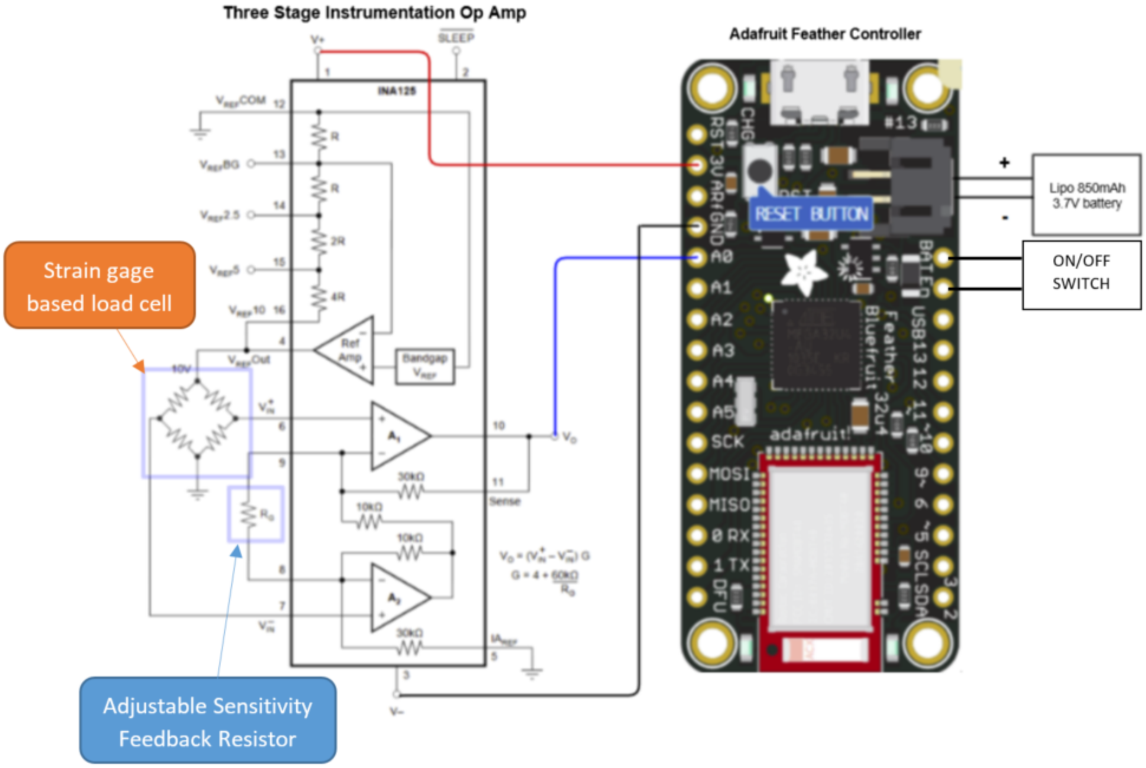


Figure z: Tension meter electronics schematic

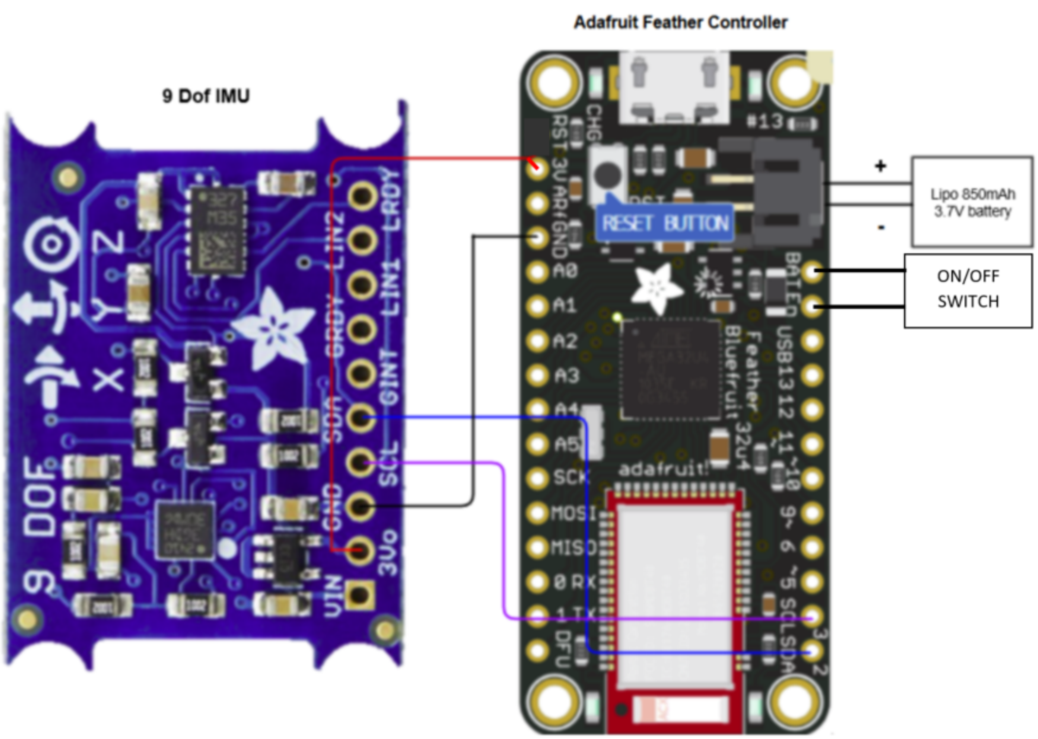


Figure zz: Wristband Angle Sensor Electronics

Cost

Item	Cost per piece	Units	Multiplied Cost	Link	Supplier
110mAh Lithium polymer battery (On trunk device)	5.38	1	5.38	https://proto-pic.co.uk/polymer-lithium-ion-batteries-110mah/ - £5.38	Protopic
Adafruit Feather Bluefruit Controller	28	2	56	http://www.ebay.co.uk/itm/Adafruit-Feather-32u4-Bluefruit-LE-ADA2829-/161974621983?hash=item25b670971f:g:INYAAOSwQYZWu65A	Ebay
Accelerometer (On wrist band)	13.32	1	13.32	http://www.mouser.co.uk/ProductDetail/Adafruit/1714/?qs=GURawfaeGuCEKVdhBFmMZQ%3d%3d	Mouser
Instrumentation Op-amp (INA125P)	4.04	1	4.04	http://www.mouser.co.uk/ProductDetail/Texas-Instruments/INA125P/?qs=sGAEpiMZZMsE1dKaA2ImUPh%2fgv48%2feoePbaebgHtKUQ%3d	Mouser
Strain Gage Based Force Sensor (0-200lbf) chosen 25lbf	21.56	1	21.56	http://www.mouser.co.uk/ProductDetail/Measurement-Specialties/FX1900-0000-0025-L/?qs=sGAEpiMZZMvDU9HV27FC0cEKlUF0yobiTU6lSg4APp9%2fPKqlW5Sn9A%3d%3d	Mouser
Ball link joint	6.05	1	6.05	http://www.ebay.co.uk/itm/191584366554	Ebay
Desk clamp	10.55	1	10.55	http://www.amazon.co.uk/gp/product/B000NU2V7W?psc=1&redirect=true&ref_=oh_aui_detailpage_o00_s00	Amazon
NG wrist support brace	16	1	16	http://www.boots.com/en/Neo-G-Wrist-Support-Universal-Size_1311225/	Boots
VAT on mouser.co.uk purchases	7.78	1	7.78		
Total	**£140.68**				