Dataglove with soft contact interface to provide contact sensing capabilities to robot and human hands

By

Zain Ali Mohamed

150314510

Electrical and Electronic Engineering

School of Electronic Engineering and Computer Science

Queen Mary, University of London

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Dr Lorenzo Jamone

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Abstract:

This report looks at the possible idea of how to effectively design and create a data glove that is able to accurately record forces applied to objects from a user's hand. The idea is to have some sensors on a glove which can record the forces applied and store this information to be used later. This project is important, not only for artificial means but for human interactions, as there is a large number of people without proper use of their hands or their sense of touch. This project would be ideal to record data and convey it to a possible user, either by creating some sort of feedback to a person or to give precise information about the force requirements to interact with the object to artificial limbs. To do this, hall effect sensors are used that react to fluctuations in the magnetic fields close by, giving out different voltage responses. As the magnet embedded onto a soft silicone mould gets closer to the sensors which are attached to the glove, the greater the potential difference is across the sensor, which the microprocessor Arduino based bored translates into the force applied. This information is conveyed to the user in real time through the means of a 0.96 inch OLED display, where the user can see how much force they applying to objects and change their actions accordingly. For greater results, this information is also stored onto a 32 GB micro SD card which can hold up to approximately 40 years' worth of continuous information from the glove. All of the information is filed into a table format, ready to be exported into a suitable excel document for further manipulation. After several tests, this glove is seen to perform as outlined by the project requirements, proving that it does indeed correctly record the amount of force exerted by the user's hand. As the results need to be used for further projects, having all of the recorded information presented in an organised and informative method makes future manipulation of the data easier to work from. Overall, the design meets all of the design criteria outlined through the report and can be said to work as effectively and reliably.

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1. Introduction:

Human skin is a sensitive barrier that covers the entire body, made of several different layers and a multitude of nerves running through it. One square inch of skin contains a minimum of 1,400 nerve endings (Faber, n.d.), all responding to stimuli from the outside world. Hands are tools which human use the most that interact with the surrounding world and without them or even a loss in their full ability, humans are at a significant loss in their ability to communicate. Within the last 30 years, technology has advanced to the stage where many devices to replicate the functions of a regular hand are available. Many companies have tried to produce devices which could possibly be used to achieve this effect, such as Tekscan with their FlexiForce (Tekscan, 2018) load sensors, SingleTact with their Capacitive (Cool Components, 2018) force sensor and Johns Hopkins University with their E-Dermis (Osborn et al., 2018). Nevertheless, many of these companies construct designs which record absolute and discrete values, whereas natural nerves record information at a continuous rate.

2. Aim:

The aim of this project is to create a data glove that is able to accurately measure pressure from external stimuli and store this information for use by a robotic or a human hand. The results should be able to mimic realistic responses from the hand and detect all variables that would be required for daily and technical use, depending on their eventual purpose, use by a human hand or a robotic hand, respectively. The dataglove consists of a glove that placed on a hand, given that the hand consists of the traditional human shape regardless of size, some type of sensors that will be able to detect the forces applied to external objects and a method of conveying this information to the user. As this device needs to be versatile and ideally completely fitting on the hand and arm, the components should not weigh so much as to cause strain to the user after continuous use. As such, the device should be able to work off a power supply ranging between 3-volts to 9-volts, reducing both the overall weight of the product and the ease of replacing the power supply. The target audience, in part, is for people with a decreased use of their hand and so should be simple enough to control with one hand. Therefore, the design should not be inherently complex to increase the ease of use and to reduce the risk of errors emerging. As there is a possibility of this project being mass-produced, the total costs, including the cost of all the materials, components and manufacturing, need to be within a £100 limit. Lastly, the glove should have the capability to function for any hand size. Human and robotic hands come in all sizes and so the device should easily able to change its dimensions. This would require the sensors to have a modular design, with positions at any desired location on the glove. This also makes it useful for robotic hands, as they are traditionally larger than human hands and so there will be a greater distance between the sensors. The housing for the sensors should consist of a flexible material so an excess of force is not required for the product to work, but instead rely on the natural force enacted by the user.

3. Background:

3.1. Reason:

Measuring the quantity of force applied to objects of different sizes and shapes is a major aspect in everyday human life, evolving into technological life through machines with hand-like appendages. As technology has evolved, so has the need to produce a large number of devices in a small amount of time. Human capabilities are not able to keep up with the demand, and as such, mechanical robotic utilities share the work. It is ideal that the robotic devices used have the same functionality and precision of an organic human had, so to limit the risk of errors occurring. Therefore, a series of readings need obtaining so the 'hand' knows the correct amount of force to apply to the object it is handling. I will be looking at some of the different designs to develop a dataglove that will effectively achieve my goal.

3.2. Software:

All of the projects that I have looked at use different programming languages to reach their purpose. These languages all have their positives and negatives, and the basis of which I choose to use depends on the overall ease of use and how well it will work towards my target. The language needs to be such that it is easy to understand, as well as easy to work with for others to reproduce similar results.

3.2.1. Python:

Python is a high-level programming language used for general-purpose programming. Its simplicity emphasises codes readability, notably using significant whitespaces as memory blocks, thus reducing the amount of memory space/storage required. It is extremely useful for allowing users to interface with electronic devices through graphical and visual indicators, as well as having text-based navigation (Python.org, 2018). With the application of Python, users can translate the information obtained into a graphical format, making it easier to visualise all aspects of the project. With the large amount of information that is going to eventually be processed, having the base language a graphical friendly one makes eventual use of the data much easier. Even through its simplicity, Python is able to handle vastly complex numeracy and scientific functions, providing an ideal environment for any functions requiring handling of ample amount of data.

3.2.2. Arduino IDE:

Arduino is not necessarily a programing language but an integrated development environment, which uses the C and C++ languages to handle the interface between the sensors and the data banks. C and C++ is a highly intelligent object-orientated based language that facilitates for memory manipulation at a low level, making it ideal for all users from beginner level to those of an intermediate level. Using Arduino, the process of coding simplifies as it has a user-friendly interface to work with, as well as a form of coding which requires minimal experience (Banzi et al., 2018). Arduino also has the added benefit that is it both a software and hardware environment, reducing issues arising from incompatible software and hardware. Arduino also has one of the largest libraries available for any programming languages, due to it being open sourced for anyone to access. This reduces the experience needed as any function required already has a basic format that all users can manipulate for their selected desires. The access to libraries also reduces the amount of memory space required, as the functions do not need to be hard-coded within the code, but instead use the ones pre-stored within the libraries. Arduino is not only a software language but also produces hardware boards similar to the Raspberry Pi systems available, significantly reducing issues regarding incompatibility.

3.3. Materials:

With the objective of reading and storing information based on the pressure applied to external items, the material used to house the sensors is very important. This material needs to be non-conductive, so that if the connections between the sensors cross they do not short each other out. The material also needs to be soft enough that it can be compressed with as much force as the user gives out, but strong enough to withstand breaking apart under such forces whilst still returning to its original form.

3.3.1. Silicone Rubber:

Silicone rubber is an elastomer consisting of silicone, carbon, oxygen and hydrogen. It is a soft material that is versatile in its uses, having applications in; voltage insulators, baking, medical equipment and electronics. It has a temperature range of −55°C to 300°C, is able to resist extreme environments and is non-reactive. This makes the material highly useful as it can mould to any shape, is hypoallergenic so useful for people with skin ailments and, as it is non-conductive, be worked with exposed wiring and/or connections running through it. Silicone rubber is also the main material used for most projects of the like. Reasons behind this are that even over the smallest of surface areas, it is able to retain its structural integrity and has a high impact resistance before reaching its elastic yield (En.wikipedia.org, 2018).

3.3.2. Fibrils:

Fibrils are rod-like structures composed of linear biopolymers found within almost all organic organisms. These are nanoscopic in size and regarded for their high length-to-diameter ratio (Sunde et al., 2018). They are semiconductors, meaning that they are able to carry an electrical current, giving them similar properties of copper wires; however, they are smaller and able to hold their own electric field. Therefore, a lattice can be made of them to give material conductive properties. As such, many of these are found bound together in organic matter, as shown in Figure 1 (Knowles and Mezzenga, 2016). Within this project, fibrils or fibril like objects could be used within any soft, elastic material to provide connections. This would reduce the need to custom make any mould but also gives the secondary use of reducing any wirings with their conductive property.

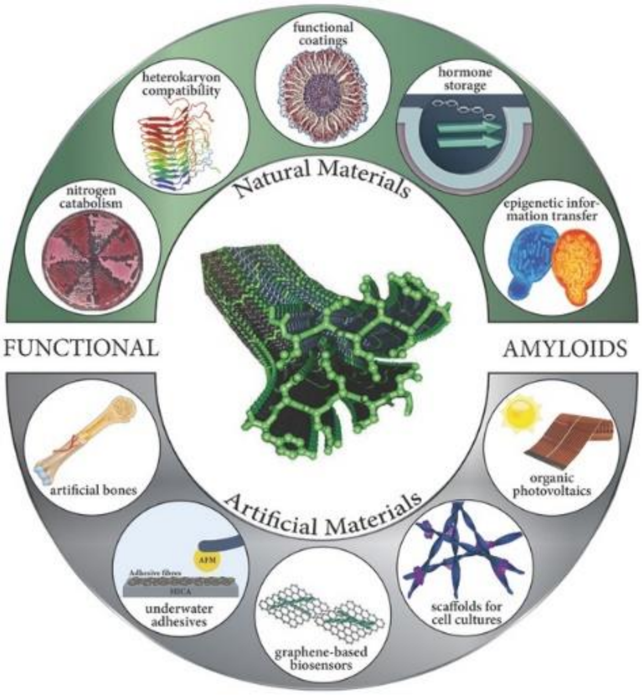


Figure 1: Roadmap to the diversity in functions in amyloids-based materials. Above image shows the uses of both natural and fabricated fibrils, including structural reinforcements

3.4. Design:

Data gloves are interactive devices that facilitate the tactile sensing and fine motion control for a robotic hand. With this project, the data glove will be primarily worm by a user, I, to store information about pressure applied to external objects. These types of devices are very valuable as they allow the advancement of robotic systems to improve their precision with interaction and support applicants who require help to interface with objects. The design of the glove will need to account for the use required and the placement of the sensors to provide the most accurate information.

3.4.1. Fingertips:

One of the main aspects relating to the function of gripping an object is due to the fingertips, or more specifically the finger pads (Ncbi.nlm.nih.gov, 2019). These cause the greatest amount of friction within a hand, even though they account for the smallest surface area. The conclusion made from this is that the fingertips then have the greatest pressure-to-surface area ratio. Having only pressure sensors upon the finger pads reduces the complexity of the overall design, as fewer sensors and wires will be required; alleviating the cost of the entire build with fewer materials and resources will be required. However, with this design, the quality of hysteresis increases as each sensor is confined to its own mould. As each mould is separately manufactured, the will be a slight tolerance to their elasticity due to factors including, but not limited to, the viscosity of the primary material and the number of air pockets within the materials. Together and independently, these factors reduce the efficiency of the design. This increases the time it takes for the sensors to return to their original value and setting, which would become disastrous if the function of the glove is for rapidly changing forces.

One method that is seen using the fingertip method is by Dr L. Jamone and Co. (Jamone et al., 2015), who used one magnet placed adjacent to the finger pads across the phalanges and a second magnet placed adjacent to the fingertip of their test subject. They also provided a small air gap between the magnet and the sensor, providing a lower amount of particles that could interact with the magnetic field from the silicon. This design provides a robust idea that can easily be replicated and worked upon, as well as providing accurate readings to the user. However, this designs downside is the build time. With the material they used, a silicon elastomer SYLGARD 186 from Dow Corning (Ellsworth Adhesives, 2019), a time of approximately 30 hours is required for the mould to set, even with the use of an oven. This would not be ideal, as this would increase the time needed to spend on the project whilst waiting for the mould cure, and increase the time needed to correct any mistakes in the likelihood of any errors discovered during this process.

3.4.2. Phalanges:

Another probable solution to the objective is to cover each finger with multiple sensors to get a greater accuracy of the forces applied by the user. This design accounts for all of the force applied across each finger, therefore reducing any losses in readings. By incorporating this design, the process of taking the results and using them to feed information to a robotic or human hand greatly increases in its reliability and accuracy.

One example of this design is seen in T. Paulino and Co.'s report with the use of such a design for the robot 'Vizzy' (Paulino et al., 2017). They use multiple sensors and magnets located along each phalange with 3-axis sensors, improving on the readings from basic two-dimensional readings to three-dimensional. This method not only provides immediate z-directional readings but also x- and y-directional readings. This increase in functionality produces a more lifelike response as this small sensor can now act as multiple. However, this design has a greater increase in price than the former, as well as increasing the complexity of the product as more sensors are required, thus more connections. This would possibly also increase the number of errors that could go wrong, as there is now more to go wrong.

3.4.3. Skin:

The last solution to achieve the objective that I will look at is to place sensors completely covering the hand, working as a synthetic 'skin'. By having multiple sensors at nearly every point on the hand, any force applied onto an object can be detected, thus giving the most accurate results and the most realistic representation of how the project would like to function. Whereas the previous designs fall to the effects of hysteresis, this design does not fall upon this as much. This is due to the magnitude of the sensors available, as whilst one sensor is returning to its original value, the sensors surrounding it could still accurately mark the value of the forces. Most versions of this project only apply their sensors to the phalanges, as these are the points where most people use to apply force to objects. However, a full coverage design would include the palm of the hand. This is the largest part of the hand and the strongest, and being such, it is able to apply the greatest amount of pressure to anything. As the force applied by the palm is not done by any specific part, it is overseen as a single appendage. However, through research carried out in the form of a questionnaire, I have seen that 80% of people feel that the palm plays an important part in pressure applied and so should be included(Figures 2, 3 and 4).

This is seen in the product developed by the people at the Harvard School of Engineering and Applied Sciences (Hammond, Mengüç and Wood, 2014), which have developed a glove that does not use sensors but instead opts for the use of a silicone elastomer substrate paired with a conductive liquid metal. This method measures the voltage flowing through the system. From ohms law (Hyperphysics.phy-astr.gsu.edu, 2019), as the resistance changes so do the currents as there is now a lower surface area for the electrons to flow through. As the hand applies more force, the more the liquid metal compresses, thus increasing the resistance of it. This works in place of the sensors as the distance from a magnetic field is no longer measured but instead the resistance at specific locations due to the relationship between resistance, voltage and current. However, this design comes with a multitude of downsides. This design becomes much more expensive than the traditional method as different materials are required which are not as commonly used. There is also a greater risk of error as to gain the most accurate readings the resistance needs to be constant throughout. If any point there is a greater density of conductive material than other points, the overall resistance would be less and so the results skew. However, as the surface area could cover more parts of the hand more easily, this would reduce the overall complexity as there will need to be less wiring.

3.5. Positions:

For the possibility that multiple miniature sensors are used to detect and record the forces applied, an investigation into the points on a hand that are used most in regards to applying force needs to be carried out to determine the optimal positions for the sensors. To investigate this factor, external testers are asked to interact with multiple objects. The points on their hand, which they feel applies the most relevant forces, will be recorded into a table for further use; Figures 2, 3 and 4 showing the points on the hands which will be considered.

After initial measures have been made, it has come to my conclusion that the main points to be put under investigation should be the tip of each finger, the three phalangeal points, the interphalangeal joins (not shown), the five metacarpal bones and the scaphoid and pisiform carpals. After numerous findings, I have concluded that the tip of each finger, as well as the interphalangeal joins, do not factor into the forces applied with most object interactions. Therefore, these points will not be considered for the final design. It should also be noted that only one of the metacarpals were seen to play a role in the interactions, this being the second metacarpal. Finally, only the pisiform carpal was recorded to be involved during the tests. All of these findings lead to the fact that these are the 16 points that need to be considered; on the chance, the final design will require multiple sensors.

	Thumb					Index						
Item	Tip	Distal	DIP	Proximal	MIP	Tip	Distal	DIP	Intermediate	PIP	Proximal	MIP
Can	0	25	0	19	0	0	25	0	25	0	4	12
Bottle	0	25	0	22	0	0	25	0	25	0	11	6
Hand	0	25	0	3	0	0	25	0	25	0	15	0
Knob	0	9	0	7	0	0	25	0	25	0	7	0
Handle	0	0	0	4	0	0	25	0	25	0	20	20
Wall Corner	0	25	0	25	0	0	25	0	25	0	18	16
Glass	0	25	0	25	0	0	25	0	25	0	25	6
Total	**0**	**134**	**0**	**105**	**0**	**0**	**175**	**0**	**175**	**0**	**100**	**60**

	Middle							Fore						
Item	Tip	Distal	DIP	Intermediate	PIP	Proximal	MIP	Tip	Distal	DIP	Intermediate	PIP	Proximal	MIP
Can	0	25	0	23	0	19	0	0	25	0	25	0	15	0
Bottle	0	25	0	25	0	25	0	0	25	0	10	0	25	0
Hand	0	25	0	25	0	25	0	0	25	0	25	0	25	0
Knob	0	25	0	22	0	3	0	0	25	0	23	0	25	0
Handle	0	25	0	18	0	24	0	0	25	0	7	0	22	0
Wall Corner	0	25	0	25	0	25	0	0	25	0	25	0	25	0
Glass	0	25	0	25	0	25	0	0	25	0	25	0	25	0
Total	**0**	**175**	**0**	**163**	**0**	**146**	**0**	**0**	**175**	**0**	**140**	**0**	**162**	**0**

	Pinky							Palm						
Item	Tip	Distal	DIP	Intermediate	PIP	Proximal	MIP	Scaphoid	Pisiform	First Metacarpal	Second Metacarpal	Third Metacarpal	Forth Metacarpal	Fifth Metacarpal
Can	0	25	0	16	0	14	0	0	7	0	25	0	0	0
Bottle	0	25	0	20	0	17	0	0	25	0	25	9	8	2
Hand	0	25	0	24	0	25	0	25	5	0	18	3	3	7
Knob	0	25	0	3	0	1	0	0	0	0	0	0	0	20
Handle	0	25	0	25	0	7	4	25	25	25	25	25	25	22
Wall Corner	0	25	0	25	0	25	0	25	25	0	25	0	0	25
Glass	0	25	0	25	0	25	0	12	25	0	25	0	0	23
Total	**0**	**175**	**0**	**138**	**0**	**114**	**4**	**87**	**112**	**25**	**143**	**37**	**36**	**99**

Figures 2, 3 and 4: The results from the questionnaire researching into the useful hand parts. The test subjects were a group of 25 who were asked, when given various items, what parts of their hand from the list they believed the used for the interaction. Only the parts that got more than 100 notices will be used.

4. State of the Art:

One of the better ideas that have been developed is the BioTac SP developed by SynTouch (SynTouch, 2019). This tactile mound, constructed using an elastic layer to replicate human skin, has 24 electrodes embedded into it. The mound is filled with a conductive liquid and as pressure is applied to the mound, the electrodes, here called 'taxels' detect the change in the impedance between the electronic core of the mound and the elastic 'skin' encasing the design. This is design to be fitted onto the phalanx of a robotic hand to amplify the ability to detect the amount of pressure required when interacting with objects. As pressure is applied, the fluid within becomes displaced, thus decreasing the resistance detected by the taxels. From prior configurations, the sensors are then able to acknowledge the quantity of pressure that is currently being applied to an object. With the use of 24 sensors embedded around each phalanx, this design has the capability of not only detecting the quantity of the force but the quality of the force by sensing the main direction on the finger where the majority of the force is originating from. This setup provides a better quality of information that can be processed. However, this design requires components and materials which are more costly than the alternatives available. With the use of multiple microscopic electronic sensors, the complexity of this build comes into consideration. Whilst this design idea considered a unique methodology, it has its negatives which would possibly yield issues when implementing this into the project.

An alternative means to reach the requirements is seen by the ‘E-Dermis’ developed by the people at John Hopkins University (E. Osborn et al., 2018); a thin multi-layered design that uses pressure across the surface area to detect the amount of force being applied, this design creates a more realistic model to answer the query. This design takes advantage of the conductive and piezoresistive properties of semiconductors and measures the change in electrical resistance when a mechanical force is applied to the sensor. The entire model is 4 mm thick, making the idea light but, with the semiconductors, effective at reading the information. They have also included time response graph, showing that within less than a second the sensor is able to detect and analyse the type of force present; whether it be sharp, dull or compressive. As most designs of this nature, silicone elastomer is used to hold the sensor together and provide a separation barrier between the layers, with a second property of providing a soft contact interface during its usage. With its small dimensions and elastic construction, this design proves to be one that is versatile in its workings yet, able to provide accurate readings. However, this is a single dimensional approach as it is only used to detect when a force is applied to the area covered, not where the force comes from. By decreasing the dimensions, they withdrew from complete functionality; this consideration is one that will need to be carried forward for the final design.

So far we have looked at large sensors which are costly but can detect force and direction. We have also looked at a sensor that is light, cheap, yet is only able to detect force. However, Stanford University has developed a glove containing sensors, detecting both qualities of force and direction. Similar to the ‘E-Dermis’, this ‘E-Skin’ uses multiple layers of conductive materials to respond to forces acting on it from objects. As the force applied to the glove by objects is equal to the force exerted by the user's hand onto it (Newton’s Third Law (Khan Academy, 2019)), the readings also indicate the force applied by the user. Similar to the SP, the lowest layer of the glove contains bumps and troughs and the other two layers act as the sensors, carrying a potential difference that, when approaching the third layer, pass on their energy that is then read by the receptors. The topmost and middle layers have connections running perpendicularly to each other along the same plane, effectively creating a larger matrix of connections available to be used. This is one of the more advanced designs available and takes advantage of physical properties to make the glove more realistic whilst still opening it to its full potential. A unique point about the glove is that it is not only used to detect the amount of force an object is detecting onto it, but has a smart system that accurately detects when the force acting on the item from the user (whether it be human or robot) exceeds the amount of force that it can withstand, and as such relays this information back to relieve some of the force. Ideas put forward by this design show the greatest reach in terms of the diversity of functions in response to the cost-effectiveness. This glove also has the function of being able to detect forces on ever part of the hand, hence the name E-Skin, with responses in the milliseconds. However, the technology being used for this glove is fairly new and many of the materials and components used are not widely available, making it currently expensive to reproduce a product of this calibre. At this point, I will take notes of design idea possibilities from this glove, but adjust parts to make it more fitting for the project at hand, staying within the scope of the requirements.

5. Specifications:

5.1. Requirements:

After carrying out the necessary research needed for this project, I have looked at possible solutions that I can work against, as well as looking at ideas that could work to build the design. I have looked at components that would work for the hardware, different software aspects that I can code in and previous projects around the idea of a force detecting data glove. Through thorough research into the possible methods of building this device and measuring them against the specification required, I have come to the following conclusions.

5.1.1. Sensor Requirements:

Multiple sensors are required to get the full spectrum of readings. There will need to be a minimum of 16 sensors, one on each phalange and two on the palm of the hand. This will meet the requirement of being able to sense as much force as possible without restricting hand movements. Each sensor also needs to be separate from each other in individual moulds. This will help with the flexibility and mobility when using the device as the modules can be placed in a way that they do not interact with each other, removing any restrictions with natural movements. Having all the sensors separate also lowers the risk of the magnets possibly affecting the other sensors and skewing the results by interacting with the other magnetic fields. As the total number of sensors seems high, the number of connections can be reduced by connecting all of the voltage source pins together and all of the grounding pins together. This will not interfere with any of the functions of the components, as they will all be systematically parallel to one another.

5.1.2. Mould Requirements:

To hold the magnet in place at a set distance from the sensor, silicone elastomer will be used. This is sourced in its liquid form and poured into a mould designed by a 3D printer. Designing the mould using a 3D printer is a cost-effective but detailed method of making the small structure required (Figure []). The silicone used will be a liquid version of the material so any shape can be formed with it, yet it is viscous enough that, once poured to fill the desired mould, it will not expand out of shape.

As this is an elastomer, this has the property of being able to stretch whilst still being able to retain its original shape. This is an important factor to consider when designing a product like this as the main aspect is the sensor housing being compressed and expecting it to decompress back to its previous distance. Silicone elastomer gives the unique property of being able to be quite malleable and resilient whilst still being non-conductive and functional.

5.1.3. Display Requirements:

To inform the user about the forces they are applying to different objects, readings from the glove will be conveyed to the user using a display. This will give real-time results of the forces applied to each point, with all of the sensors clearly displayed to simplify the results into a concise and readable format. To ensure that the overall weight of the product does not increase to an undesirable weight, the display should be small and or thin, possibly using an LCD or OLED display, both of which are small in design and lightweight. It should be brought into consideration that, as the final design is aimed to be hand mounted, the chosen display should use the minimal amount of connections to both keep the complexity of the design down and lower the chances of any of the connections being interacted with in a way that they could break or become loose.

5.1.4. Build Requirements:

The final initial design choice that I have made is that each piece of the product will need to be modular. This data glove is required to be able to fit all sizes of hands and for the sensors to work at optimal performance, they need to be placed parallel to the finger pads as that is where the majority of the force is acted through. As the positions of these points are different for different hands, the sensor modules need to be able to move around to achieve a more efficient spot. Having the mould be modular also helps with improvements for the design, as if their locations are at points where the majority of the force is lacking; they can easily be moved to the optimal location.

5.2. Components and Materials:

5.2.1. Silicone Elastomer:

Smooth-On is a company that produces a vast range of different silicone based products. One of these products is EcoFlex 00-50, a two-part silicone elastomer. It is a viscous liquid which, when mixed together in equal parts by volume or by weight, forms an elastic solid that is able to retain its shape under strain. This product was considered for use for two main reasons; when cured this goes from being clear to being translucent. Being such, when the magnet and the sensors are placed within it, they can still be seen and if any errors occur (such as the magnet not being completely flat), it would be easier to correct such an issue.

The other reason is that this is a platinum-based elastomer. The platinum acts as a catalyst between the silicone hydride and the vinyl parts then reduces the curing time from 24-36 hours to an average of approximately 3 hours. As 16 moulds are required, based on the specification of the number of sensors, having such a low curing time increases the efficiency of the process, as the rest of the build can them be constructed sooner and any issues will not be that detrimental compared to non-platinum based elastomers.

Figure 5: Smooth-On EcoFlex 00-50. Shown is part A (left) and part B (right), which needs to be mixed in equal parts by mass or volume. Whilst sealed, each pot has a usable lifespan of 3 years.

5.2.2. Hall Effect Sensor:

As the magnet is going to be moving parallel to the sensor when in use, an appropriate sensor is required. The one chosen is the DRV5053OAQLPG Linear Hall Effect Sensor as it is an inexpensive component (£9.74 for the 16 sensors required) and the linear property makes it simpler for the output to be converted to the corresponding force. With 16 needed for the dataglove to function, wiring all the sensors is an issue that cannot be overlooked. However, the people at Texas Instruments, who produce the component, designed it in the simplest form where there are only three pins to use; the voltage source pin, the grounding pin and the output pin (Instruments, 2019).

With this simple design, the wiring to connect all of them has been made less complex as all of the voltage pins and the ground pins can be connected together (Appendix Figure []) as they will be parallel to each other. In accordance with Kirchhoff's first law (Isaac Physics, 2017) they will all carry the same amount of voltage as each other that is derived from the voltage source. Therefore, the only pin that will need independent wiring will be the output pin, individually connected to the board used. The sensor is pole sensitive and will function accordingly when in the presence of a southern magnetic field. If a northern magnetic field is acted upon it, the resistance increases and the output values drop.

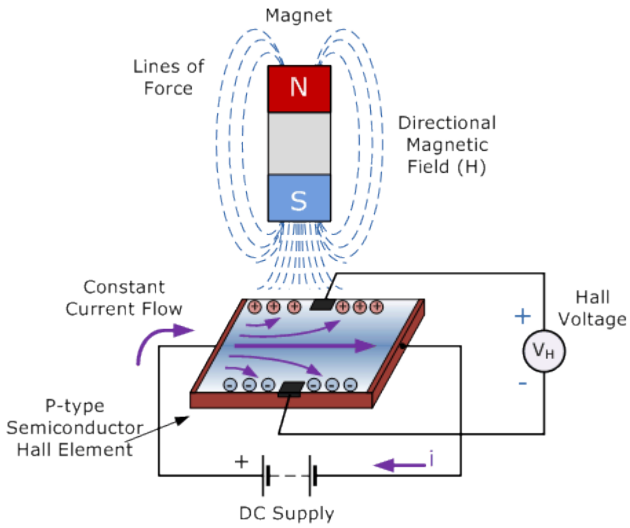


Figure 6: Internal working mechanics of a hall effect sensor. As the magnetic field come closer, the greater the change of change, creating a larger potential difference between the pins.

5.2.3. OLED Display:

Using a display would add significant weight to the build, so to overcome this issue a small OLED screen will be used, specifically the 0.96 inch OLED display by MakerHawk (Smile.amazon.co.uk, 2019). This weighs only 10 grams and runs on between 3 to 5 volts, all specifications that work in accordance with the design specifications. As this screen only uses four pins to function, it is inherently simple to interact with and as stated by the design requirements, this can be interfaced with only one hand. Using an OLED display also reduces the complexity of the coding, as both Python and C++ are compatible and the display chosen is designed for most microcontroller boards. This display also has the added benefit of being able to have the size of the characters on the screen changed to any size required. Therefore, if the user requires a larger font, this will be a minute change to make.

5.2.4. Conductive Thread:

To connect all of the sensors to the board, multicore wire was considered, as this is a relatively cheap utensil that can be procured from most electrical shops. This is made by bundling copper wires together within a laminated shell that helps to insulate them from other connections. However, due to the lamination being thick, this was seen to not be effective enough for the project, as flexibility is a key aspect in the design. Therefore, an alternative of conductive threading was chosen; stands of cotton have been individually coated with silver to give them conductive properties. Each stand has a maximum diameter of 10 micrometres, thus being much thinner than traditional multicore wires.

The specific thread chosen, Light Stitches Conductive Thread (Rapidonline.com, 2019), is coated in a slight lamination, which stops the thread from interacting with other signals, meaning that multiple connections can be crossed without any interference. As this is much thinner and consists of a cotton core, it is as flexible as the glove and thus will not cause any added resistance to the movements of the hand. This also has the added benefit that it was being sewn into the fabric, rather than having to be stuck on as traditional wirings would need to be done. This reduces the chances of any interference with the wiring or breaking due to interactions from external stimuli (such as catching on something).

5.2.5. Modules:

The final design requirement is that the sensors be modular so that they can be placed at different points on the glove, depending on the size of the user's hand, may it be human or artificial. To achieve this, small plates are constructed for the sensor and the housing moulds to rest on. These modules are then sewn to the glove in the desired places using general thread. This gives each module the property to be placed at any point in the glove, even changing the basic layout to one that is different from primarily thought. The plate is 3D printed and only 3 millimetres thick, so it is quick to produce and doesn't require a lot of material to form, keeping the costs as low as possible with still meeting its requirements. These modules will be placed at the centre of each finger pad, as well as the two palm locations discussed in section 3.5. When constructing the glove, if it is seen that the moulds interact with each other when the phalanges are curled, they can easily be adjusted to avoid this scenario.

6. Development and Implementation:

This project is based on two different sections, one being the hardware sections and the other being the software section. Both sections are important and require either part working to full efficiency to function correctly. This section will cover the two parts and how I implemented them into my design, as well as any improvements I made to my final project.

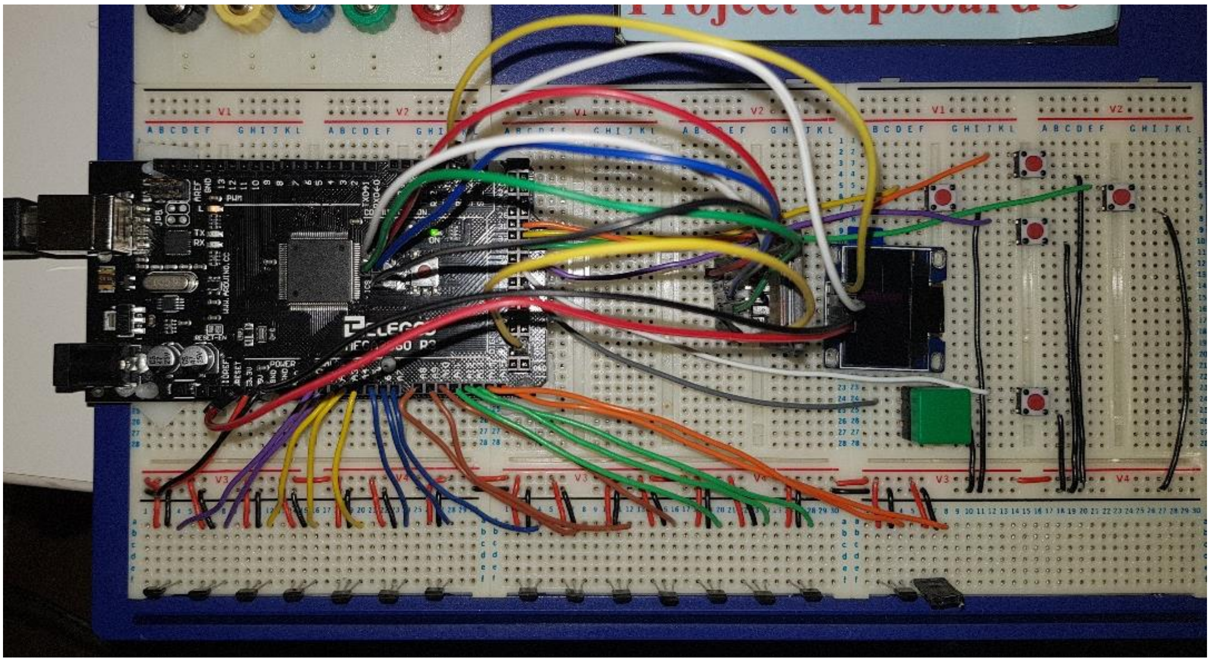


Figure 7: Breadboard Circuit. As seen in the image, the entire circuit has been completed on one breadboard. Starting at the top left and working clockwise, there is the ELEGOO MEGA 2560 board, the Micro SD Card module connected to the ICSP header pins, the display, the display control buttons and all 16 hall effect sensors.

6.1. Hardware - Breadboard:

The final design was created primarily on a breadboard, before being finally moved onto the glove in the final stages. This was done so that there would not be any need to make any fixed connection; rather DuPont jumper cables are used to bridge the connection between components and the board. These plug in easily into the holes of the breadboard and the sockets on the controller board used. They can be moved around easily and connections can be made and broken without any issues when using them. Figure 7 also shows the completed circuit consisting of the ELEGOO controller board, the 16 sensors, the display and a micro SD card module. This is the skeleton of the build, where at this point the circuit functions are desired. However, this still needs to be implemented into the final design to achieve all of the aims.

6.1.1. Language:

To connect all the inputs and outputs together and working, a controller board was required. It was decided that to make the coding simple to implements, as well as keeping the total memory capacity low, the programming language Arduino was selected to implement and run the code. This was chosen as it runs on the C++ language, which is credited for its memory manipulation to reduce the overall memory space used, and its feature of containing pre-built libraries reduces the level of complexity of the system and the expertise required to use. Arduino is not only a software hub but a hardware hub, with a vast line of microcontroller boards available to work on. As the programming environment and the hardware board are designed by the same company, issues arising from any incompatibility with the two platforms are made redundant.

6.1.2. ELEGOO MEGA 2560:

A compatible hardware board is required to work with the Arduino software, and in this case, this was the MEGA 2560 R3 by ELEGOO. This is a reproduction of the Arduino Mega 2560 Rev 3, yet this board is implemented with secondary ICSP header pins, which makes the board more accessible when using serial off-board components. This board is of the same quality but is cheaper in price, thus helping to reduce the cost of the project as opposed to using the official board, with the former costing less than half the price of the latter.

Compared to the smaller and cheaper Uno and Nano models, this board comes equipped with 16 analogue input ports that are required to read the outputs from the hall effect sensors. If the idea of using a smaller board was implemented, the use of a multiplexer would be required to host all of the sensors, increasing the size and weight of the overall build, an increase in the cost and the significant exaggeration in the time taken to process all of the readings. By having all of the sensors given independent ports, they can be processed in parallel to each other, rather than a serial method when multiplexing which would introduce queuing to the system (a process of data having to wait for the previous packet to be completed before the next one can be acknowledged).

Figure 8: ELEGOO MEGA 2560 R3 microcontroller board. The larger version of the common Uno, this reproduction of the Arduino board accommodates all functions whilst costing significantly cheaper. All pins available are clearly labelled, making connecting components easier.

6.1.2.1. Sensor Setup:

If digital pins are used to read the sensors, the system will only show when the sensor output reads greater than 2.5 volts, as it has an output reading of between 2 and 5 volts. If the aim was to determine when the force acted upon an object by the user was greater than a specific value, this would be ideal as the ELEGOO Uno R3, a smaller version of the board, does indeed contains at least 16 digital input/output reading pins. However, as a continuous signal is required to be read, the Mega provides the simplest solution to the aim, without the use of added external components. As seen in Figure 9, all of the sensors are connected to their own ports, schematically parallel to each other. With this design, each sensor is read independently from the others so there can be no possibility of any of the data affecting anything else.

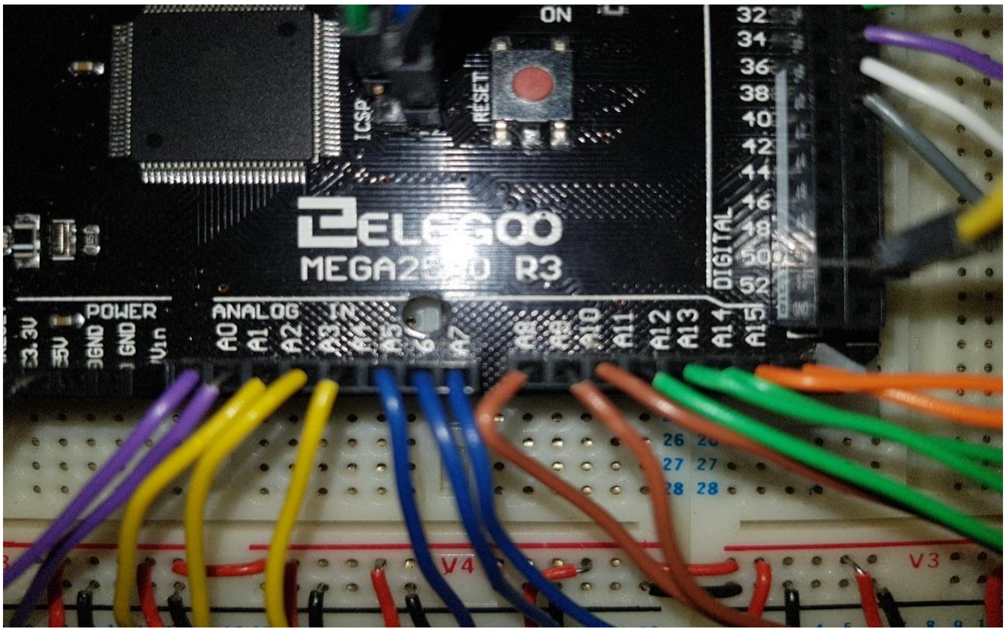


Figure 9: Sensor connection. There are 16 available analogue GPIO ports connected to all 16 of the sensors. Giving each sensor its own port allows for the data to be read simultaneously, avoiding queueing.

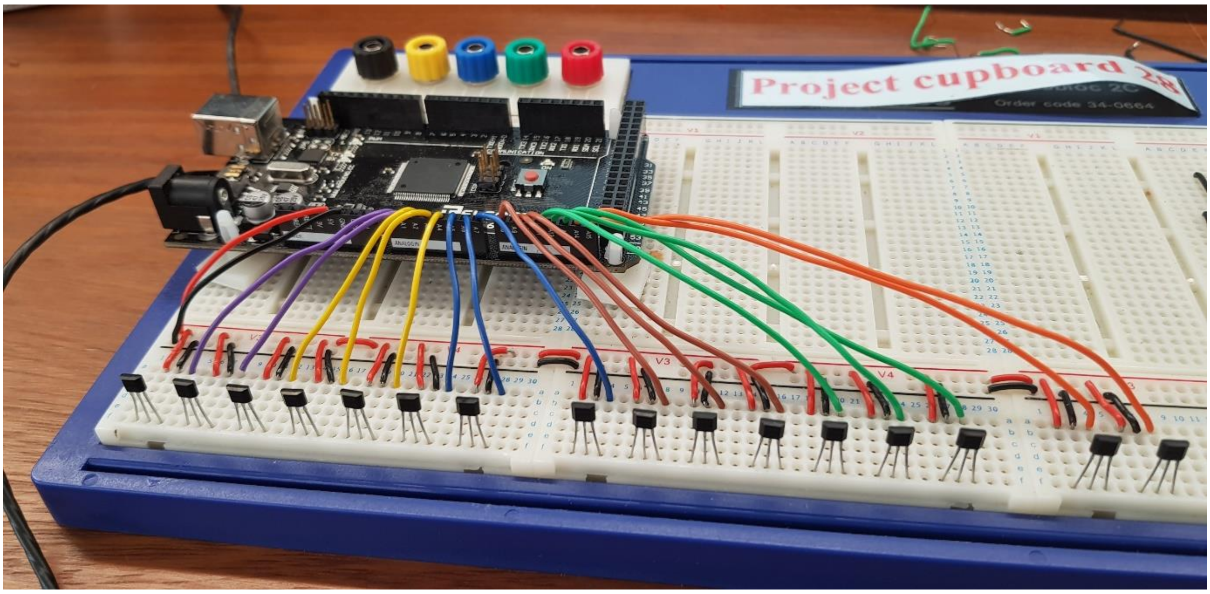


Figure 10: Sensor setup. On the breadboard, the 16 sensors are placed along in a line, where all of the voltage pins and ground pins are connected to the same rail. Using different coloured wires, the sensors corresponding to their hand placement are connected to the board.

Figure 10 shows how all 16 sensors are connected to the board which is placed onto a breadboard. It can be seen that all of the voltage source pins and the grounding pins are connected to their same rail respectively. There are no issues arisen from doing this, which aligns accordingly to the design requirement stated in section 5.2.2.

6.1.2.2. Magnet Test:

The sensors being used are south pole sensitive, meaning that they work accordingly when presented with a southern magnetic field. As a magnet is moved closer and further away from the sensor (Figures 1, 13 and 15) the output from Figures 12, 14 and 16 changes accordingly depending on the distance. However, as this a south pole sensitive sensor, when the magnet is flipped so that the northern pole is acting upon the sensor, the values reduce when the distance is decreased and increments when the distance increases.

Figure 11: Magnet Test 1. The magnet is place at a distance of 13 millimetres from the sensor. The face of the magnet is the southern pole, causing the sensor to active.

Figure 12: Magnet Test 1. The corresponding voltage level and analogRead() values are shown. To convert between the two values, the constant of 0.0049 is used.

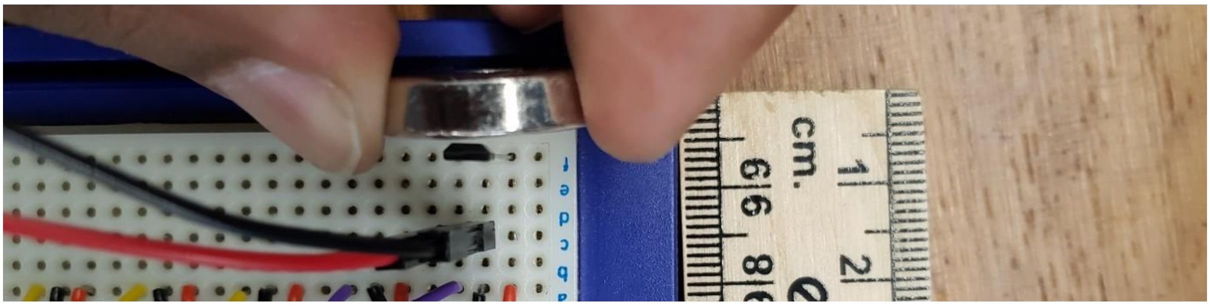


Figure 13: Magnet Test 2. The magnet is place at a distance of 2 millimetres from the sensor. The face of the magnet is the southern pole, causing the sensor to active.

Figure 14: Magnet Test 2. The corresponding voltage level and analogRead() values are shown. As the magnet has moved closed, the voltage across it has increased, increasing the level value corresponding to it.

Figure 15: Magnet Test 3. The magnet is place at a distance of 5 millimetres from the sensor. After multiple tests, this was seen as the distance that gave the steadiest value

Figure 16: Magnet Test 3. The corresponding voltage level and analogRead() values are shown. At this distance, the value on both screens did not fluctuate, thus showing the benefits of having the magnet fixed at this starting point.

6.1.3. Display:

The display used comes with four pins at the top; voltage source, ground, serial clock: used to refresh and update the screen, and serial data: used to send information to the screen to display information (Figure 15). The board comes with two pins which are premade to connect these pins, so wiring them to the board requires no extra coding or connections to be made. As stated in section 5.1.3, having the minimal amount of connections is imperative with this type of hand mounted project, as the main idea is to keep the weight as low as possible. Even though the weight of a wire can be seen as being negligible, the combined weight of the many wires used will eventually add up. Therefore, this display only requiring four connections, and thus four wires, to work properly keeps the total weight down. Compared to using an LCD (Appendix Figure 3), they require the use of sixteen pins compared to the four currently being used. They are also significantly bulkier and heavier, adding further reinforcement to using the OLED display.

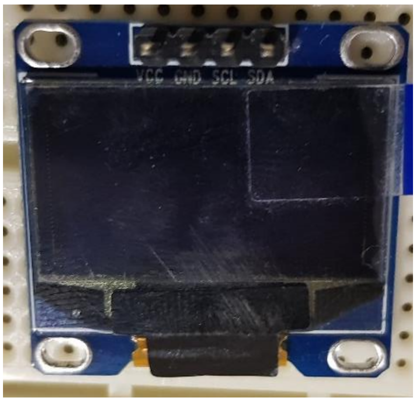


Figure 17: Display Pins: At the top of the module, the 4 header pins are displayed, each with their function labelled underneath. The ELEGOO board comes with premade SCL and SDA pins.

6.1.3.1. Item Entry Buttons:

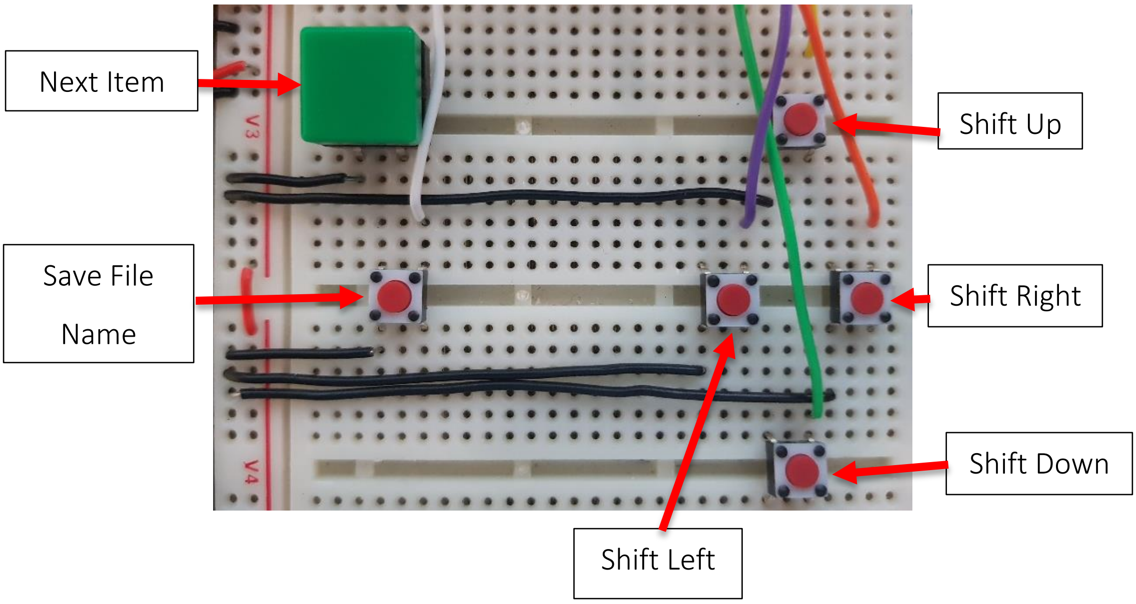


Figure 18: Button Setup. As shown above, the buttons are separated on the board according to their function, with the item entry controlling button on the right, the enter item button on the bottom left and the next item button above it.

As the purpose of this glove is to measure to forces acted on different objects, it would make sense that all of this information is made clear to differentiate between different objects. To serve this purpose, four buttons have been implemented to input the name of the object currently being interacted with by the user. These buttons are used to cycle through an array of variables that hold the letters of the alphabet, from A to Z. The up and down buttons increment and decrement through the array, which is programmed to work as a closed loop where once the up button is pressed when the displayed value is Z, the display loops back to A and the same happens when the down button is pressed with A being displayed.

The left and right buttons are used to control the position of the cursor for the word, so any mistakes in the entry can be amended. The button functions have been designed in this way as to make using the data glove as simple as possible. If only one button was used to shift through the array, the user would then be required to loop around back to the same position if any mistakes were made. Additionally, if only one button was used to change the position of the current character, the user would be required to complete the current entry mode, even if there has been an error made. By using two additional buttons, using the glove has been simplified to be used by anyone.

6.1.3.2. Save File Name Button:

A fifth button, Figure 18, is added to enter and save the entry to the SD card as a new file (more in section 5.3.2) and if it was successfully opened, the display screen would confirm this. This is a single use button, as if this is pressed during the measurements stage there will be no function, but if pressed accidentally during the item entry stage then the current entry will be saved. To correct this, the current process will need to be stopped and the correct name will need to be entered. The only way to erase the accidental file would be to insert the micro SD card into a pc device and delete it manually.

6.1.3.3. Next Item Button:

Another button is added to the circuit that is used to end the current measurements and to restart the system, waiting for a new entry. This button does not serve any function when pressed during the item entry button. However, if the system is in the measuring stage, the measuring will be halted and a new item will be prompted to be entered. The user can enter the same item again and this will be covered at a later stage.

6.1.3.4. Button Issues:

The reason the next item and the item entry functions are not linked to the same button is to ensure that either functions do not occur accidentally. The functions of the buttons are designed to work cyclically, so the next item button will not be read until the item entry button has been pressed, and the item entry button will not work whilst the system is still in the measurements stage. This reduces the chances of errors forming with the end result of multiple empty files being stored on the SD card.

6.1.4. Micro SD Card:

6.1.4.1. On Board Storage:

The memory space of the microcontroller board is approximately 256 kilobytes of flash memory for storing code, 8 kilobytes of SRAM and 4 kilobytes of EEPROM, where the data from the sensors can be stored. However, this seems insignificant to hold all of the data required for the device, as multiple object readings are ideally going to be recorded with a continuous data stream.

6.1.4.2. SD Card Module:

To amend this, a micro SD card module has been added, Figure 19, that has a capacity of up to 32 gigabytes, around four million times more storage than if only using the onboard storage. This also means that there can be more information about the objects stored without the circuit heating up too quickly due to stress on the memory. If at any point the capacity becomes full, it would also be easy to change the storage device to a new one. Therefore, new data can be recorded whilst the old is being processed for some other functions.

Figure 19: Micro SD Card Module. Only 2 inches in length, this module has the ability to extend the board memory u to 32 gigabytes. At the bottom, all of the pins are labelled to show their function and where to connect them.

6.1.4.3. Module Connections:

Most Arduino board have separate ICSP header pins which are designated for use with serial reading and writing. The module uses the pins SCK, MISO, MOSI, +VCC and GND, all of which are found on the ICSP header pins. The only pin which is not in these header pins is the CS pin, which can be coded to work with any digital pin. The CS pin is important as its definition within the code determines how the microcontroller will communicate with it. If the CS pin is not defined, the module will remain idle and will not serve any function to the overall circuit.

Figure 20: ICSP Pin Connections. This is the order where ICSP devices can connect to the board. On the MEGA, pins 50, 51, 52 and 53 carry the same functions. However, if the need to be reassigned for another use, these header pins allow for serial communication to still occur.

6.2. Hardware - Glove:

Once the circuit was found to be functioning to complete its desired functions, the next step was to move this from the breadboard onto a glove. The glove in question needed to be one that was tight fitting, so that when force was applied to an object there would be minimum movement of the module on the finger. The glove also needed to be one that was hypoallergenic, as to not cause any allergic reactions to be used by everyone, and flexible to avoid any restrictions to the regular movements of the hand. This is not one of the main requirements of the design, but one which will need to be considered for future uses. As this specification will not create issues with the main functions of the glove, it is considered to be something that can be accommodated at this stage.

6.2.1. Glove Selection:

It became apparent that a glove that conformed to all of these requirements was a sports one. These are made from a blend of polyester and elastin, giving the glove flexible and stretchy properties. With the addition of the elastin, the glove will easily form too many hand sizes whilst still retaining its form and flexibility. The one being used, a pair of SuperDry

Running Gloves (TRADEINN RETAIL SERVICES, 2019), is an affordable set which comes in for both left and right hands. These have been designed to be used as active wear, and as such are very pliable. However, this is then coated in a layer of silver nanoparticles which remove the chances of any allergic skin reactions, making the gloves friendlier for people with skin ailments.

Figure 21: SuperDry Running Gloves. These are a pair of sports active wear gloves, made of 93% polyester, 7% elastin, and then coated in a layer of silver oxide.

As seen in Figure 21, each finger of the glove is covered in an additional layer of fabric. This makes the process of applying the modules to the glove easier, as the modules can be sewn or glued on in such a way that it will not make using the dataglove uncomfortable to wear and use. Each module will be placed directly on the middle of each phalange, parallel to the finger pads. The ones on the palm of the hand will be placed on the second metacarpal and the pisiform, as concluded from the table in Figures 2, 3 and 4.

6.2.2. Mould Formation:

The silicone elastomer is a two-part solution, parts A and B. Both parts are transparent and have a low viscosity. However, when mixed together, the colour of the solution becomes translucent as the solution starts to become more solid. The pot life of the mixture is approximately four minutes before it can no longer be poured. The volume of the solution required was calculating the volume of one of the moulds, and then multiplying this value by 16. The dimensions of the inside of the moulds are 7mm x 7mm x 10mm, equating to a total volume of 490 mm3, or 0.049 millilitres. Therefore, the total volume of substance required is 7.84 millilitres, which will be rounded up to 10 millilitres to give an excess of material that will be lost due to residue left within the mixing pot.

6.2.2.1. Filling Moulds:

Using a syringe, each mould is filled with a base layer of the elastomer. A small, 2 mm magnet is then inserted at the bottom of the mould, held in place by a second magnet on the outside of the mould. This secondary magnet helps to keep the internal magnet secure whilst the rest of the silicone is poured in so that it does not move about. The rest of the mould is filled to the brim with the mixture. This needs to be done quickly so the mixture does not reach its pot life. Once this is done, these will need to be left for at least four hours too completely cure, where it will resemble what is shown in Figure 23.

Figure 22: Plastic Syringe. There have a large nozzle at the entry where the viscous fluid can easily be sucked into and pushed out of. As the total capacity of the syringe used is 100 millilitres, the entire 10 millilitres of fluid can be contained without issue.

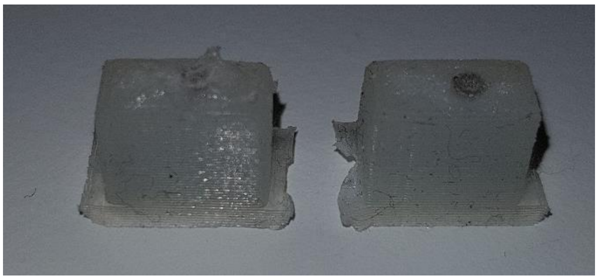


Figure 23: Silicone Moulds. Image shows the finish silicone mould, complete with secured magnet embedded at the top.

These will then be placed onto the plate using an adhesive compound, which will require a certain amount of force so that the entire base surface of the silicone moulding makes constant contact. In between the plate and the silicone, the hall effect sensor is inserted and held in place with the adhesive. This will not cause any issues as the plastic casing of the sensor and the metallic legs do not react with the adhesive, but instead the adhesive coats the sensor in place. This process is then repeated for each plate.

6.2.2.2. Placing Moulds:

When designing the plates for the modules, consideration was needed to be taken for how they will be placed onto the glove. To account for this eventuality, the length of the plates was extended by 2 millimetres. Small holes were then added to the design, approximately 1 millimetre in diameter. These holes are used to thread the plates onto the gloves, with one hole at each corner of the glove. This helps to give stability to the module on each finger pad, as well as giving additional security to how they are placed. The modules are then sewn directly to the glove, as shown in Figure 24, where all of the threads lead back to the board.

Figure 23: Glove with Sensor Modules. All 16 sensors have been placed on the glove, giving the first real look of how it will function.

The legs of each of the sensors measures to approximately half an inch in length each. As these are placed sideways (Figure 23) on each phalange, they are cut down to 8 millimetres so they do not protrude too much off each finger. This length gives enough room for the conductive thread to be tied around each leg, with a length of heat shrink covering each leg to insulate it from the other connections.

Using a needle, the thread connecting to the output pin is then sewn through the glove until it exits at the wrist of the glove, where is then connected to the header pins on the board. All of the exposed pins are covered with the heat shrink, both to hold the connections in place and to reduce the chances of any interference from the other signals. The voltage source pins of each sensor and the ground pins are then sewn to a common point on the opisthenar where this will then be connected to the VCC and GND pins of the board. Doing this reducing the overall complexity of the design as fewer connections are needed that go from the glove to the band.

6.2.3. Board Connections:

To ensure too great of weight is not acting on the hand, the board will be mounted on the forearm. To hold it in place, this will be sewn onto a generic store bought armband. The board, as well as the power supply, makes up the majority of the weight of the project, therefore removing the force it would be applying to the hand will help to reduce the strain on the user, as well as making the project easier to work with as there is now more space between each section, making the construction process clearer and any issues easy to amend.

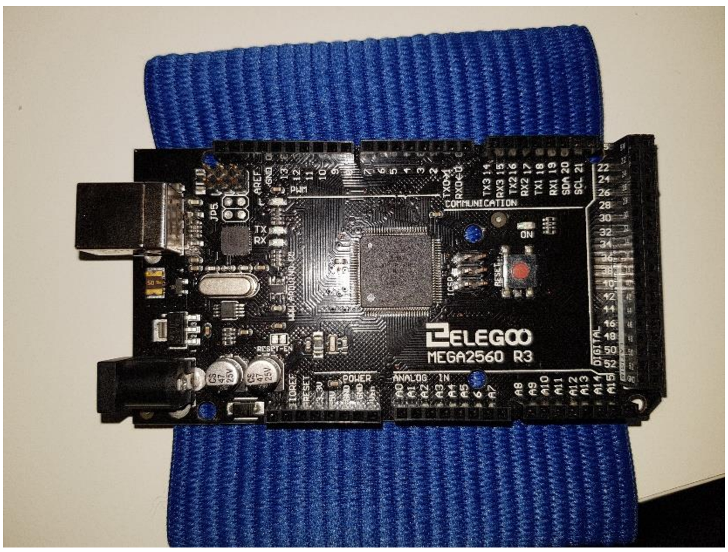


Figure 24: Board on Arm Band. The board sits comfortably on the arm band, with only the power supply port and serial port hanging off the edge.

6.2.4. Display and Controls:

Following the point of reducing the complexity, the display, as well as its controlling buttons, will be placed on the back of the palm. This section provides ample space for all the necessary components to be placed with enough room so that the function of each button can be made clear. Apart from the sensor modules, these will be the only parts of the circuit which will be based on the hand, with the power supply, microcontroller board and SD card module all placed on the armband.

The buttons that interact with the letter array are placed in a diamond formation directly underneath the display. This pattern clearly defines the function of each button, with the up and down buttons being placed above and below the left and right shift buttons, where they are placed both to the left and right, respectively, of the other buttons. The item entry button is placed adjacent to these four buttons, but still in line with them. This button is the same as the rest, therefore indicating that its function corresponds to the item entry. The only button that is separated from the rest is the next item button, as this function is not connected to the other buttons. Placing this button away from the rest also makes it distinct so that its function is clear to the user. Whereas the other buttons have black buttons, this one has a red one, further distinguishing it from the rest, decreasing the likelihood that it would be mistaken for another one.

Figure 25: Display and Controls. As explained above, the buttons are placed in a diamond formation around the display, which sit on the middle of the opisthenar

When attaching the buttons to the glove, it would be undesirable for the legs to be sticking out, making the design not look professional. To handle this issue, the legs of the switches which are not required have been cut off to keep the area clear. This only leaves the output signal legs left, which will then directly be connected to the board. As this section of the design is on the opisthenar (back area of the hand), the conductive thread does not need to be used as this area moves less than the fingers. Multicore wire can be used to fulfil the purpose of the connections as it is flexible enough for the function and comes laminated, helping to prevent any interference from the other connections. With this replacement, the total cost of the build has been reduced as the multicore wire is significantly cheaper than the conductive thread (£0.34 and £0.42 respectively), something that would add up when mass produced. As this connection will be crossing from the hand to the forearm, having a flimsy wire would increase the chances of it being caught on part of the glove and thus breaking the connection. However, as multicore wire is much sturdier, this issue can be avoided.

6.2.5. Storage:

As stated previously, the board will be attached to an armband wrapped around the forearm. This will be sewn into place using thread, as this provides a stable option, but also one that is easy to replace if any issues arise in the future. On the underside of the mount, the micro SD card module is placed, chosen to be here as to keep the main section less cluttered. As the module needs ease of access on the occasion the SD card needs to be replaced or used, placing it away from the main section will help to meet this aim whilst still keeping it on the armband so no additional section or material will be required. The sensors on the hand are all grouped together on one side of the board; therefore the connections for the module can be wired around the other side. As the module is fixed in place, there will not be a need for any wiring which is too flexible. Therefore, DuPont jumper cables will be used to connect the two sections as these are relatively inexpensive and their standard length is long enough to cover the required distance. As the ones being used are female-to-male cables, these can be attached to both components without the need for any further materials or utensils.

6.2.6. Power:

Currently, the board is powered using the serial cable which plugs into the USB Type B port. This provides both serial communication and power to the board. However, as this project is designed to be hand and arm mounted, a lengthy cable connected to a PC is not warranted. The boards' solution is to also implement an external power supply port. A 9-volt battery can be used to power the board as it is small and light in weight, as well as being compatible due to the voltage regulator inbuilt into the board. Using a 9-volt battery snap to barrel connector, the battery can be connected directly into the board. This batter will also be held on the armband, but instead of being sewn in it will be held in place using double sided tape, which at this stage in the design will be effective enough as this design is a prototype version of a finalised device.

6.3. Software:

This project is a two-part project. Part one is based on hardware, where physical devices are used to measure information and to interact with external stimuli. The second part is the software, where coding is used to control the hardware and to process the information received from the hardware. The code needs to read the output from the hall effect sensors, convert this value into its corresponding force, and then display this value to the user on the display, saving the value onto the micro SD card simultaneously. So that each item is defined, the code also needs to process the item the user enters and save this as the file name onto the card, at the same time informing the user of any issues that arise during the entire process. This section will detail the evolution of the code and how it works hand-in-hand with the hardware.

6.3.1. Basic Functions:

To start, the basic functions of the circuit first needed to be considered. At its premise, the software needed to read the outputs of the sensors. Although more functions have been discussed in section 5.3.1 and 5.3.2, many of these are additional functions that have been added to make the system easier for the user to interact with. The use of the sensors and the method of processing this data is the main idea around this project, and what section 5.3.1 will look into.

6.3.1.1. Initialise Sensors:

As the coding platform being used was Arduino, this was made much simpler. The first step was to initialise all of the sensors. To do this, it was required that all of the pins the sensors were going to feed their information into were assigned the correct data type, in this instance being integers as the information being read will be continuous integers as opposed to characters or strings. Line 48 shows how this is done at the beginning of the code. At this stage, no additional libraries are required (pre-defined functions they allow the user to carry out functions without the need for extra code to be written) as the initialisation process is a simple method that all C and C++ languages use.

This is done outside of any of the other methods as this information needs to be available for the entire scope (the landscape of code which can be seen by the machine), being able to be used at any point within the code. The next step is to define the hall effect sensors as being inputs. This is done within the setup method, as this is where definitions of variables are made to be understood by the Arduino platform. As all of the sensors are going to be similarly defined as inputs, using a for loop all the sensors can be defined as such. The loop will continuously set the current sensor (as they are all in an array) to inputs until the last position of the array is reached.

6.3.1.2. Initialise SD Card Module:

Once the sensors have been declared and initialised, the SD card module needs to be initialised to work with the hardware so that the process of reading the sensors and saving their values can be initiated. To do this, certain libraries are required, such as the Serial Peripheral Interface (SPI) library which helps with communicating with external devices which are hardwired to the board, and the SD library, which contains specific functions when using SD card modules, such as the micro SD card module or the Arduino Ethernet Shield. These are header files which need to be included at the beginning of the code, declared as

Arduino boards also come with a selective pin, Slave Select (SS) or Chip Select (CS), which determines when the peripheral can be used. The board uses this pin to control when the external device can be allowed to transmit or receive information and can be specified in the code using Line 24.

For this part, the name of the file was fixed to “file.txt”, which creates a text file on the SD card named 'file' to be written to and read from, with the extension “.txt” denoting the file to be a readable text file format. Using the analogRead() function with the specific port within the parenthesis, the value of the voltage across the external sensor can be read and manipulated within the code. Without further coding, this function presents the voltage in millivolts, which can then be stored if the read function is used in combination with a storing integer variable. However, presenting the value as such is redundant, as it does not explicitly define the amount of force present. To do this, the line of code shown in Line 618 demonstrates how the value is converted from a voltage to a force. This algebraic equation was concluded from the tests expressed in section 7. This is the value that will be manipulated through the code, both being displayed to the user through the display and serial monitor, and being saved onto the SD card.

6.3.1.3. Initialising Display:

Given the expected aims of the project, the information gathered from the hall effect sensors needs to be clearly conveyed to the user. One method was to save this information onto the SD; in combination for the same information being displayed onto the serial monitor (more on this in section 5.3.1.4) is a serial communication cable is used. Alternatively, with the addition of the OLED display gives another method for this information to be illustrated to the user, without the need for the SD card to be removed or a serial cable to be inserted.

So that the display works to its full effect, multiple libraries need to be imported into the scope. It is simpler to import these libraries, rather than coding in the lines manually as a vast amount of functions can be derived from including a simple line of code. Of the libraries available, the ones that a required include; ‘Wire.h’: allowing communication between the board and I2C devices, in this case, is the OLED display, ‘SSD1306.h’ and ‘splash.h’; both used to display information onto the display, as well as importing functions two control font size and colour, and ‘gfxfont.h’, ‘SPITFT.h’ and ‘SPITFT_Macros.h’, all which are used to create graphical designs in conjunction to the display, such as shapes, angles and a wider array of colours.

6.3.1.4. Designing File:

So that all of the information can be easily read from the file, it would be ideal to create a design for the file in the form of a table so that it would not be hard to determine which value corresponds to each sensor. To do this, strings consisting of '¦', '-', '+' and '|' symbols are stored to help organise the data by printing at specific places, that when the code is run work together to work a coherent table.

One the sensors have been connected and the system is running, the file on the SD card will look like. To save these strings, 'myFile.print()' is used which "prints" what is within the parenthesis, in this case being the table design, onto the SD card. This can be seen in real time as well by using the command 'Serial.print()', which performs the same function but instead to the serial monitor.

As can be seen, what is shown on the display and what is sown on the serial monitor, as well as the SD card, differ in their design. This is as the display is limited to a much smaller area of effect, causing severed considerations into what can be displayed (Figure 17). However, both devices managed to display all of the information, with the stored table being able to show the data retrieved in a more coherent method.

6.3.2. Advanced Functions:

The basic use of the design was to take readings of the forces applied to by the user upon certain items and display these results back to the user in a coherent method. However, certain aspects of the original design seem unsavoury and so needs to be evolved to better fit their purpose. Section 6.3.2 will look into the changes made to the display and how the SD card is used.

6.3.2.1. Designing Display:

Once it has been concluded that the sensors can be read correctly and all the information saved, it is time for the information to also be displayed to the user. The display is only 0.96 inches big, with pixel dimensions of 128 by 64 pixels; though it seems small, the display has a high definition of quality as well as a bright backlight which helps to show complex shapes easily. With this capability, all 16 sensors can be clearly defined upon the screen and their corresponding readings. Using a similar method as seen for the file, strings of characters can be used to form a table for the screen. However, the command to display this is 'display.print()' which "prints" the object onto the screen. The screen refreshes every machine cycle to display the new values, as the sensors take continuous readings and human hands do not create constant forces across their hands. However, this information can easily be manipulated later on to average out for the results to be used.

6.3.2.2. File Name:

From the preliminary requirement of the name of the file representing the object being interacted with, it would not be ideal if the file name was fixed within the code. As one of the eventual uses of the data glove is to help advance the precision of robotic hands in use within factories moving and placing components, unlabelled data would not be sufficient to assist them. To avoid this issue, the system will now allow the user to manually enter the name of the item that they are going to be interacting with. With the presence of the buttons available, the code can read these inputs and determine what to display. Same as when declaring the sensors, there is an array of letters at the beginning of the code.

6.3.2.3. Entry Buttons Setup:

The board actually contains miniature resistors connected to all of the input/output ports which can be activated to pull up the signal leading into the port. This is important as then the input to a specific port can be held high until a connection is made to create a path of lower resistance for the current. To do this, within the setup() method, all six of the buttons are declared as inputs as the signal they produce is being read by the board with pull up resistors activated for each of them (Figure []). This is done to both reduce the chances of switch bounce, a phenomenon caused when the contacts of the switch do not make a complete connection and multiple signals are sent to the board, and to make reading the switches more efficient, as all that is then required is for the board to detect when the voltage going into the specific ports drops.

Working with both the buttons and the letters array, the user can now enter the item they intend to interact with. Each button serves a specific function, with no button being able to be used until the process of the previous one has completed. This is done so that there are no errors made when trying to enter a new item, such as the next function being carried out unintentionally. As this is supposed to be used with one hand by the user, having each button only carry out one function also makes it less likely that there is any confusion between each use, as what is required for the moment has its own individual predefined button.

6.3.2.4. Fine Name Saved:

Once the user has finished entering the item name, they then press the enter button, which saves the name into the code. Using a combination of for loops and if statements, the entry is reduced down into one string, where it is saved into a variable called ‘file’, and another version with the extension ‘.txt’ is saved into the variable ‘filename’ so the system knows the file format.

After the name of the item has been entered, this name is then printed on the display and the table. If the connection between the SD card module and the board is secure and the file was able to be correctly opened or created, then the user is displayed with the message “File Open: Okay”, whereas if the file failed to open for any reason, the message “File Open: Fail”. If the latter scenario is seen, the user has then presented the item entry screen again. If the former scenario is seen, then the user is then presented with the readings being shown on the display. This display will be shown until the next item button is pressed, where the file will be saved, closed, and a new item will be asked to be entered.

6.3.2.5. File Checking:

When the user wants to add more data to a previous file, the table continues from the previous data file and the name of the item is not shown. However, if the user entered a new item, a new file is created and opened. This is shown on the serial monitor with the break line between the previous data and the current data, as well as the column headings being printed.

6.4. Improvements:

Whilst in the process of researching for components that can be used for this project, specific parts were found which would greatly improve the design as a whole. As it was imperative that the project is completed to its full effect, the aspects found from section 3 were used for the build. However, once the build was completed, consideration into further improvements was the next logical step. As the design functions as intended, only two small improvements were taken into regards.

6.4.1. MEGA 2560 Pro:

Currently, the board being used is the ELEGOO MEGO 2560. This is a 101.52 mm by 53.3 mm board, with a total weight of 37 grams. However, through thorough research, an alternative product has been found that provides the same functions as the ELEGOO, yet is smaller in size and weighs significantly less. This is the MEGA 2560 Pro, a custom made board manufactured in China by RoboDyn (RoboDyn, 2019) contains all of the same features as the official full-size board but compacts the design significantly. With dimensions of 38 mm by 54 mm, this is just over a third of the size of the ELEGOO and weighs less than half at 17 grams.

Following the point the project requiring to be as light as possible, using this board significantly helps to keep both the overall weight down, the total size small, all the whilst keeping all the functions and capabilities as provided by the former board. As shown in Figure 26 of the board, this is an unsoldered board where all of the pins are connected to pilot holes where, with the proper equipment (a soldering iron with solder wire), header pins can be attached for components to be connected to the board. However, as the sensors will be connected to the board with conductive thread, the process is now made easier by having half of the sensor threads tied through the holes. This reduces the complexity of constructing the glove, as tying the thread through a hole is far easier than tying one around a header pin. Nevertheless, all of these issues are not removed as the second set of sensors will still be required to be connected as previously stated by tying them around the header pins. This method adds the benefit of removing the chances of connections interfering with each other as they are now on two separate levels. To secure these connections even further, heat shrink will be used to cover the links so insulate all connections from each other.

With the reduction in the weight of the board, the amount of force being applied to the forearm has been lowered, thus increasing the usage time possible for the user. This reduction helps to alleviate the projects strain whilst being used so that a greater amount of information can be recorded with the extended period of usage time. From section 1, it was stated that one of the main uses of this glove it for people who have a reduced sensitivity of their extremities, in this case being their hands. As people will a lower amount of control over certain appendages require a greater amount of energy to function (Salim Göktepe et al., 2010), reducing the amount of energy required to control the glove benefits the user to continue using the data glove.

6.4.2. Battery Pack:

A can be seen in Figure 26, the Pro Mini board does not have a serial or power port, but opts to use a single micro USB port for both functions. This helps the board to save on space, but without anything else connected the total height is now also much lower. With this possibility, the idea of using a miniature portable battery pack was then considered. The one used, Figure 27, is a small pack just under double the length of the board and comes with an in-built micro USB cable attachment, reducing the need for any other components to be used. As the previous power supply was intended to be a 9-volt battery, this option matches the weight but increases the overall capacity, with a limit of 2500 mAh compared to the former 500 mAh. This increase in size allows for the unit to record data for longer periods of time before having to be recharged, where if the battery dies before the measuring is stopped then the data will not be saved and the information will be lost.

7. Testing:

Most aspects of the design have a very basic function, such as the board only being used to control the inputs and outputs, as well and receiving and transmitting data. The buttons used in conjunction with the system all have a single use function, so for these and the board, testing is not required. However, the other three families of devices used, the sensors, the micro SD card module, and the OLED, can be tested for their functionality. A number of tests can be carried out to determine their limitations and how well they within the scope of the project.

7.1. Sensors:

The sensors used are linear hall effect sensors. These have the property that when presented with a positive (south pole) magnetic field, they will generate a potential difference proportional to the strength of the field. Two tests are conducted to assess this property and to ensure that it can effectively function within the parameters for the design.

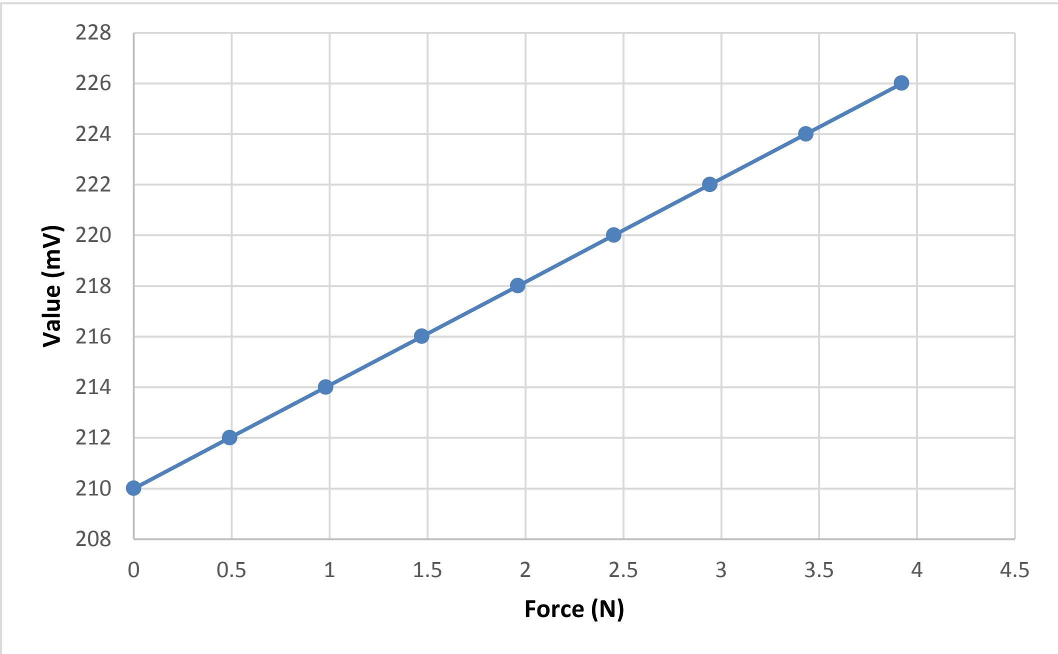
7.1.1. Magnet Distance:

The modules on the hand are designed to respond to forces acting upon then, through the means of the distance between the sensor and a miniature magnet fluctuating. To determine the correct position for the magnet to be kept at when at its initial stage, a test needs to be conducted to measure the optimal distance for the magnet to be placed. Using a moderately sized magnet (Figure 26), measurements were taken from set distances from the sensor and their corresponding output voltages were recorded in the table below, Figure [], as well as the value read by the board and displayed on the OLED display.

Figure 28: Magnet

G	Mass	Weight	Force	Value
9.80665	0	0	0	210
9.80665	50	0.05	0.490333	212
9.80665	100	0.1	0.980665	214
9.80665	150	0.15	1.470998	216
9.80665	200	0.2	1.96133	218
9.80665	250	0.25	2.451663	220
9.80665	300	0.3	2.941995	222
9.80665	350	0.35	3.432328	224
9.80665	400	0.4	3.92266	226

(Above) Figure 29: Force Calibration Test. Using a multitude of weights, the output given from the display is recorded. These values are then converted to Figure 30 (below), where the gradient is equal to the constant of proportionality.



When the information from the table above is extrapolated onto a graph, the linear properties of the sensor are easily definable. The graph also shows that the voltage output of the sensor is a non-zero value when not in the presence of an active magnetic field. This phenomenon is due to two reasons, one being the natural magnetic field due to the earth's core that affects the sensor minutely. Without the use of specialised equipment, the field effect cannot be negated and so, within the workings of the code, this force needs to be accounted for and the starting value for the glove should include the secondary magnetic field. The other reason is due to the manufacturing of the sensor, where the separation of the internal layers by the p-type semiconductor (material which is low in electrons) causes unwarranted charges to create a potential divide. Due to these issues, the code will need to accommodate these factors, where the initial value given by the sensors is recorded and taken as the zero value, where any value above that is accredited to the forces applied by the user.

7.1.2. Force Calibration:

Currently, the analogRead() function within the code reads the voltage output of the sensors and converts this value to a voltage value based on the resolution of the board. For the MEGA 2560 board being used, the maximum resolution is 10 bits, which translates to 1,024 voltage levels. 1 level read equates to 0.0049 volts or 4.9 millivolts. This factor will need to be used for the calibration of the readings for the correct corresponding forces.

To calibrate the sensors, weights of different masses will be balanced on a module so that all of the force is resting on the sensor and not supported by anything else. Using a basic analogRead() program to read the sensor and display it on the OLED, the corresponding level can be seen. The table below shows the procedure carried out to calibrate the sensors and to determine the multiplier needed to be used within the code.

Once all the results have been taken and the results have been rendered into a graphical format, the constant of proportionality can be derived. This value will be used to adjust the read value, multiplying with the sensor output to give the correct force being measured. The equation on Line 618 demonstrates how this will be implemented into the code, making the information that will be displayed and saved more understandable than showing the measured voltage.

7.2. Micro SD Card Module Operation Response:

The SD card module required for an appropriate SD card to be inserted to function, as well as all of the connections to be correctly made so that the communication between itself and the board work properly.

7.2.1. SD Card Size:

The specifications of the module state that it can only accommodate SD card sizes of up to 32 gigabytes. Through test runs of files, a file that has run for 5 minutes continuously only uses 4 kilobytes of memory space, allowing 8.2 million files of the same size to be stored. With this memory capacity, the device can record information relating to a multitude of items before the storage device is required to be exchanged.

7.2.2. Module Connections:

Both the datasheet of the device and the device itself states that the supply voltage the module requires is 3.3 volts. As this module is designed to work with Arduino boards, this can be connected directly to the 3.3-volt port without further components required. Using a meter, it was discovered that the module actually requires 4.5 volts to function correctly. When connected to 3.3 volts, the module card will turn on but malfunction when information is attempted to be written to it. During the writing process, a spike is seen on the meter before the voltage immediately drops to zero. To correct this issue, the module can be connected to the 5-volt power supply also found on the board. This change provides a stable supply without any issues, due to the on-board voltage regulator protecting the module from overload.

7.2.3. Missing SD Card:

When using the SD libraries in conjunction with the module, data is written directly to the card. However, before any manipulation of data with regards to the SD card can be initialised, the module checks to clarify if there is a compatible SD inserted. If the system discovered that this is not the case, the program halts all functions as the primary route for the data cannot be changed back to the board. This works as a safety precaution, as most systems that incorporate the use of such a module require a large amount of data to be stored. To protect the board from overheating or the data from being overwritten, no other processes can be made till the issue is rectified.

7.3. OLED Display User Compatibility:

The display being used is only 0.96 inches diagonally across, with overall screen dimensions of 20 mm by 27 mm. As half of the world's population is predicted to become short-sighted by 2050 (Crew, 2019), there is a possibility that many will find it difficult to view the display. It is then seen a necessary that further tests are carried out to evaluate the extensiveness of the display and how the information can be better presented.

Firstly, the distance the display can be read correctly needs to be measured to gain a better understanding of its limitations. This will be researched with external users with similar impairments to gain a vast range of results. As seen from the table below, Figure [], with the font size set to 1, measuring a pixel width of 1 pixel and a height of 5 pics, the information displayed can be accurately read from 2 meters away. When the font size is changed to size 2, with a width of 3 pixels and a height of 9 pixels, the distance increases to an average of 3 metres away, expected from the change in size. As the display will not be expected to be viewed at from further than 1 metre away from the user whilst on their hand, the display can be said to work at an effective enough level for all users.

8. Results:

The idea behind this project was to use hall effect sensors to measure the amount of force a user's hand applies to different objects. To translate the sensor readings into force readings, the value of proportionality needed to be calculated (as the sensors a directly linear). After multiple tests with different weights, the system was complete. With the same weights now being balanced on multiple sensors attached to the glove, the total of the readings was correctly equal to the total weight being used, showing that the glove meets the requirement of reading the forces acting on it. The glove also helpfully displays the data in a method that all users can understand, with each sensor reading clearly labelled. The tests carried out of viewing the screen from multiple distances, using volunteers with visual impairments, showed how clear the results (at font size 1) could be seen, and as the OLED display will only be at an arm's length, there will be no issues with being too far from the screen.

Overall, the tests carried out conclude how well the main functions of the glove perform and accurately meet their goal. Some additional tests, as in the OLED and SD module tests give further information into how useful these functions are to the system as a whole, whilst not being detrimental to the overall project. It can also be seen how useable the glove is, as the items used for concluding the positions of the sensors can still be used with the glove on the hand, giving what is inferred to be correct results. At this stage, it can be decided that the data glove works as intended.

9. Conclusion:

The aim of this project was to create a data glove with soft contact interface that can accurately measure the amount of force a user applies onto an object. The glove needed to use hall effect sensors to measure a magnetic field in some method, then to have this information stored to be extrapolated at a later date. Through research into past work and possible design methods, I have made a functioning prototype of a data glove that meets the requirements stated.

As this glove was designed to be hand and arm mounted, it needed to weigh as little as possible. Upon completion, the total net weight of the project was 132 grams. Users were tested with holding 200g weights, with most being able to withstand the mass for over 10 minutes. As this gloves' main aim was to take measurements, it is not expected to be used for longer than this time, and so it can be seen that the requirement was met.

Another main requirement was that the total cost of the build would amount to under £100. Including all of the components used, the materials and the resources, the total of the project culminated to £48.76, less than half the price limit. However, this cost also included the parts removed from the final design, such as the ELEGOO MEGA 2560. When removing the cost of all components that did not make it to the final design, the price significantly drops to £35.89, just over a third of the limit. As one aspect that needed to be considered was mass producing the product, the low price makes constructing the build on a wider scale more commercially viable.

Finally, the glove was required to measure the force acted onto an object by a user and to represent this information in a clear and legible format. From the tests done by using weights of different masses and from tests involving objects of different shapes and strengths, it was seen that accurate and reproducible results could be gathered. With the inclusion of the

OLED display, in combination with the formatting design of the files, all of the results were clearly displayed to the user, with the saved values easily being able to be used and manipulated.

Given the requirements and how the project has managed to attempt to meet them, it can be concluded that the prototype made correctly performs to the requirements and specifications stated earlier within the report. Given a longer period of time with access to higher quality materials and equipment, the project could be improved to work more effectively and to look more desirable. Nevertheless, the data glove made does indeed work and correctly served the desired purpose.

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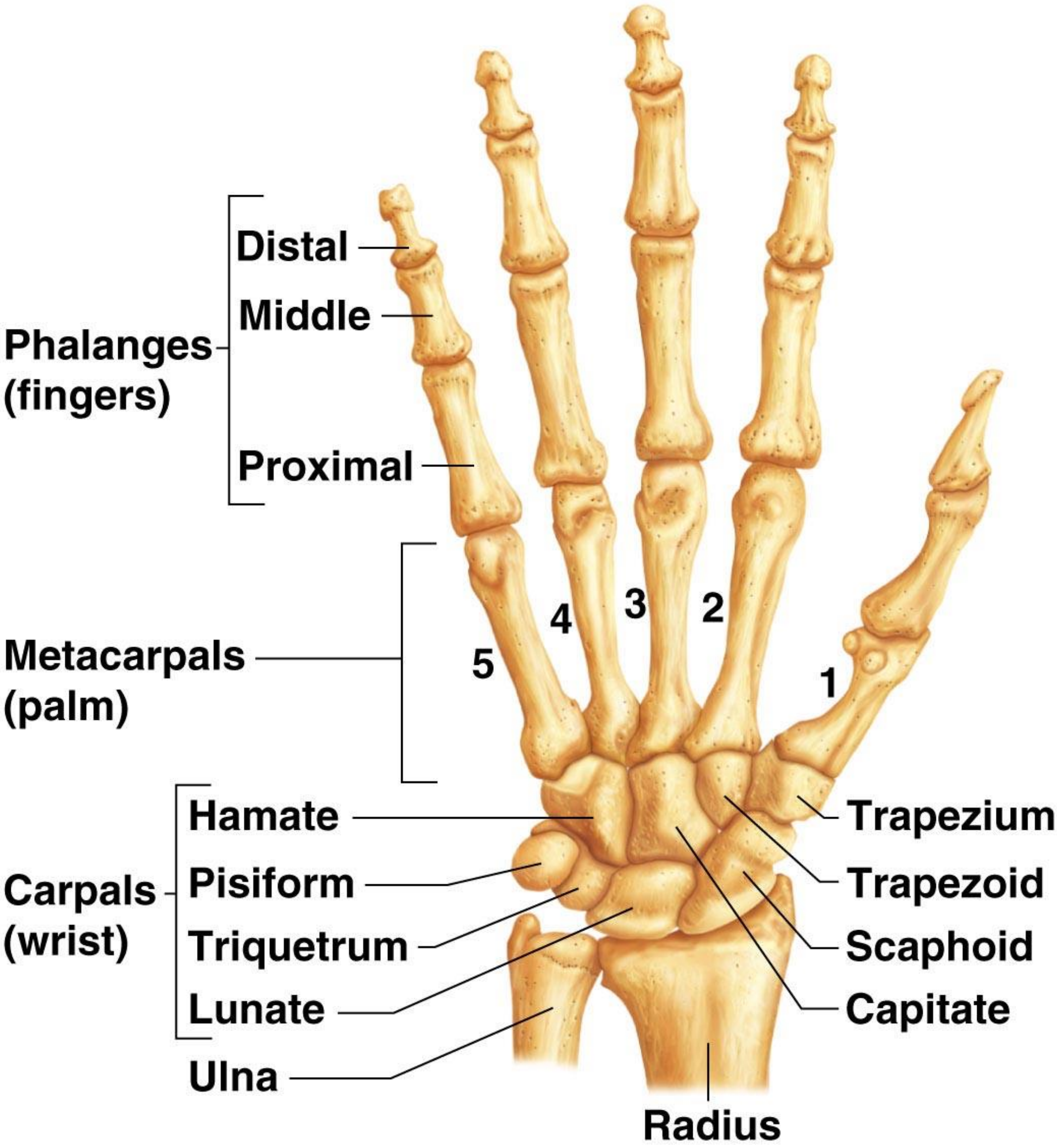
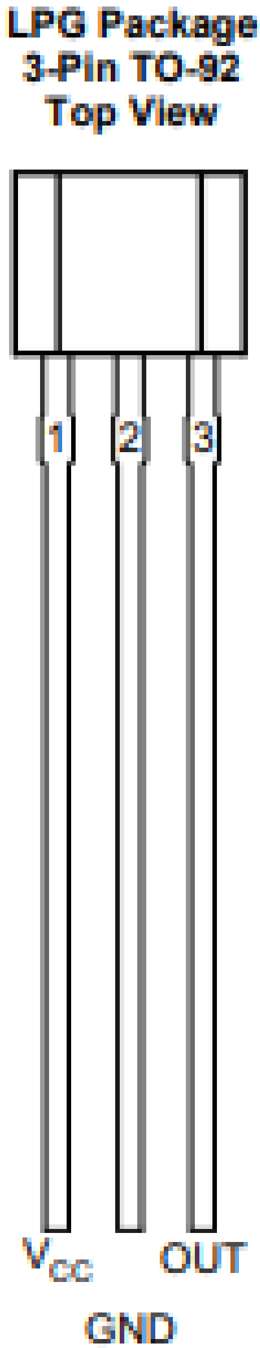
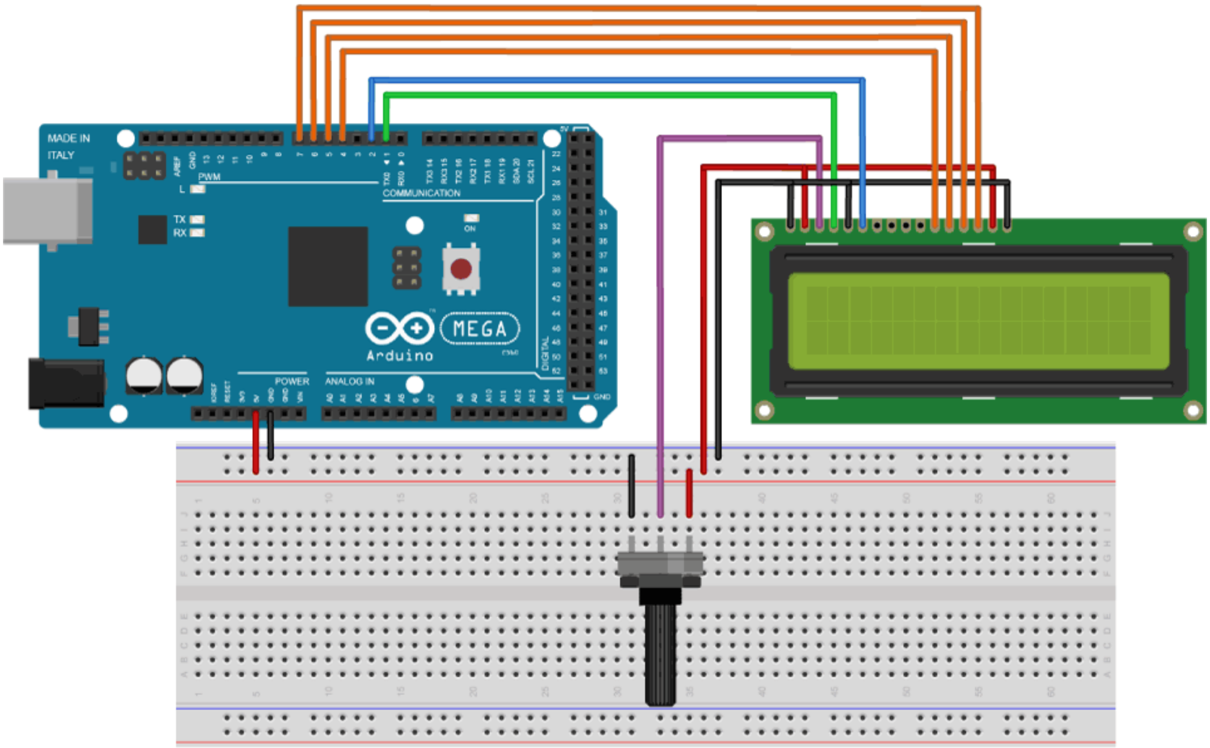
11. Appendix



Appendix Figure 1: Dissection of the hands' bones. This diagram shows all of the bones in a human hand, with clear labels. This was used to determine the positions for the sensors, in collaboration with the table in section 3.5. (ANATOMY BODY DIAGRAM, 2019)



Appendix Figure 2: Pinout diagram of the DRV5053OAQLPG Linear Hall Effect Sensor. With the voltage source (VCC) and the grounding (GND) pins placed next to each other, the sensor output pin can easily be accessible or placed in a way without any issues for the other pins. (DRV5053 Analog-Bipolar Hall Effect Sensor, 2014)



Appendix Figure 3: LCD to Arduino MEGA connections. This image illustrates the additional number of connections required to connect an LCD instead of the OLED display, 12 connections rather than 4. (HowToMechatronics, 2019)