DESIGN METHODOLOGY FOR A SOFT ROBOTIC INNOVATION: ADVANCING KITCHEN INDEPENDENCE AMONG INDIVIDUALS WITH FINE MOTOR DISABILITIES

An Engineering Research and Development Project

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1. Research Problem

1.1. Describes a practical need or problem to be solved in light of prior solutions

Independence is an important part of adult life. As people get older, being independent becomes more difficult due to the effects of aging. Similarly, people with a disability define being independent as their key need in life. Independence is empowering and important for physical and mental health long-term. This project strives to enable people to obtain independence, allowing individuals to remain in their home environment by being able to prepare food at home, which is a core element to being independent.

Preparing and cooking food can be a significant challenge for many individuals who face difficulties with fine motor control, despite the availability of accessible cooking options. The process of preparing a healthy meal often involves precise and delicate slicing of various ingredients, each presenting unique challenges based on their texture and hardness, whether they are slippery, hard, small, or soft. Consequently, individuals with limited fine motor skills, or those with amputations that clearly result in a complete lack of fine motor control in one limb, often encounter obstacles that hinder their ability to prepare food in a manner similar to that of able-bodied individuals. See examples of conditions that can significantly affect someone's independence on the right.

Figure 1: Rheumatoid arthiritis of the hands on an elderly individual

Figure 2: Finger amputation due to accident

At present, many national populations around the world are aging. This means that in the future the number of people requiring assistance due to age-related illnesses is likely to increase. This has far-reaching implications and will require more assistive technology to be developed so people can continue to live on their own and not rely on carers through governmental social welfare (as there will be too many people making it unsustainable). A demographic pyramid of Australia's asymmetrical aging population is below.

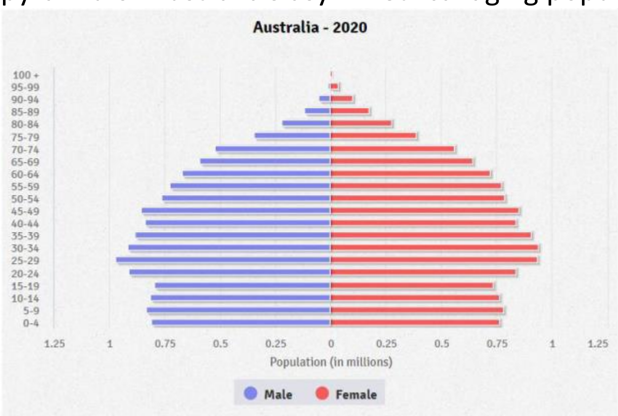

Figure 4: Australian Demographics Data[1]

Figure 3: Hand spasticity

[1] Australia Age structure - Demographics (indexmundi.com)

An inability to prepare healthy and nutritious food (i.e., not being able to chop, slice fruit or vegetables) can have detrimental effects on diet and an individual's sense of independence. Research on individuals who don't (or cannot) cook for themselves demonstrates that, *"Those eating home cooked meals more than five times, compared with less than three times per week, consumed 62.3 g more fruit (99% CI 43.2 to 81.5) and 97.8 g more vegetables (99% CI 84.4 to 111.2) daily. More freque nt consumption of home cooked meals was associated with greater likelihood of having normal range BMI and normal percentage body fat. … Those consuming home cooked meals more than five times, compared with less than three times per week, were 28% less likely to have overweight BMI (99% CI 8 to 43%), and 24% less likely to have excess percentage body fat (99% CI 5 to 40%)."*[2]

It is well established that having a healthy and nutritious diet affects long term physical and mental health and is an important way of staying healthy for everyone[3]. People with a disability are at a much higher risk of being affected by a poor diet[4], *"Based on self-reported data, around half (47%) of people aged 2 and over with disability eat less than the recommended serves of fruit and less than the recommended serves of vegetables each day, and are more likely than people without disability (41%) to not meet the guidelines"*[5][6]. This is a problem which endemically impacts, *"Younger adults with disability are more likely than older adults with disability not to eat enough fruit or vegetables each day. Around half (53%) of younger adults (aged 18–64) with disability eat less than the recommended serves of fruit or vegetables each day, compared with 39% of older people [aged over 65] with disability."*[7]

At present, the market offers limited solutions to address the challenge of preparing fresh produce for individuals with fine motor control difficulties, and unfortunately, accessibility remains a significant concern. These existing solutions, with the notable exception of food processors, predominantly consist of passive devices like spikes and flexible clamps. However, their applicability is far from universal, as they often fall short in effectively accommodating the diverse array of culinary tasks and the wide range of fruits and vegetables encountered in daily meal preparation. Additionally, many of the existing devices require the use of sharp spikes, or other guides which require the knife to be close to the hand, increasing risk of injury. There is limited academic research The need for an innovative and comprehensive solution that caters to a broader spectrum of disabilities and culinary needs becomes apparent in this context.

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[2] Mills S, Brown H, Wrieden W, White M, Adams J. Frequency of eating home cooked meals and potential benefits for diet and health: cross-sectional analysis of a population-based cohort study. Int J Behav Nutr Phys Act. 201.

[3] Siefert, K., Heflin, C. M., Corcoran, M. E., & Williams, D. R. (2004). Food Insufficiency and Physical and Mental Health in a Longitudinal Survey of Welfare Recipients. Journal of Health and Social Behavior, 45(2), 171–186.

[4] "People with Disability in Australia, Health Risk Factors and Behaviours," Australian Institute of Health and Welfare, July 5, 2022.

[5] ABS (Australian Bureau of Statistics) (2018a) *National Health Survey: first results, 2017–18, ABS cat. no. 4324.0.55.001*, ABS.

[6] ABS (2018b) *ABS sources of disability information, 2012–2016, ABS cat. no. 4431.0.55.002*, ABS.

[7] ABS (2019) *Microdata: National Health Survey, 2017–18, ABS cat. no. 4364.0.55.001*, ABS, AIHW analysis of the main unit record file (MURF).

Aside from the clear social significance of my need, the device also contributes to current research on soft robotics by providing a comparison with a rigid robotic system (the clamp) and a soft system. My invention also provides yet another effective use case, with a clear methodology for others to follow. Soft robotics is a new field that integrates compliant and flexible materials into the design and fabrication of robots, offering advantages in safety[8], adaptability, and versatility[9]. An example of a soft robot is seen in *Figure 5* below. These characteristics align perfectly with the requirements of my project, which seeks to provide a user-friendly, adaptable, and effective solution for individuals with disabilities that gives them independence to prepare food. By incorporating soft robotics principles, I aim to create a gripper that not only enhances accessibility but also contributes to the evolving landscape of assistive technology, particularly in applying these technologies to improve the quality of life for individuals with disabilities.

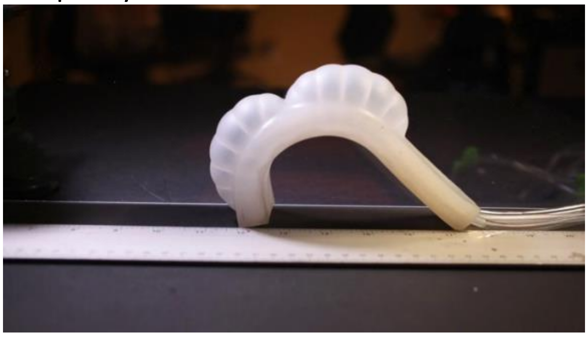

Figure 5: Soft robot

1.1.1. Design Situation

Many individuals with limited fine motor skills or amputations face difficulties when cooking and preparing food in the kitchen, especially to do with the chopping/slicing of fresh produce. Having a fine motor disability also greatly increases the risk of an accident in the kitchen because their grip on objects is often unstable or insufficient. This also impacts people with arm or hand amputations. It is important that people with a disability have access to tools which allow them to be independent and cook healthy, homemade food themselves.

Figure 6: An individual with lower arm amputations making a salad. Source: YouTube

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[8] Haider Abidi and Matteo Cianchetti, "On Intrinsic Safety of Soft Robots," Frontiers in Robotics and AI 4 (February 20, 2017).

[9] Jun Shintake et al., "Soft Robotic Grippers," *Advanced Materials* 30, no. 29 (May 7, 2018): 1707035.

1.1.2. Design Brief

Design a product which assist people with a fine motor disability to hold their fresh produce for chopping or slicing, aiming to enhance the user's independence and effectiveness in food preparation, ensuring their safety.

1.2. Explored existing ideas and alternatives

1.2.1. Existing Product Research

To analyse existing products and solutions, I decided to research the products in categories, and ignore any duplicated products with similar conceptual design implications.

Solution 1: Safety Chopping Board Tool

- Requires two hands to use, still needs 1 hand to close the boards holding the vegetable.
- Vegetable can still move in device (based on how hard the user is holding)
+ Very safe, well-protected
+ Easy to clean
+ Aesthetically unexciting

Target Market: elderly, those with Parkinson's, people with limited strength, want safety.

Figure 7: Safety Chopping Board, Source: Pinterest

Solution 2: Adaptive Cutting Board- Multiple devices

- Effective at holding soft objects, difficult for harder objects.
- Spikes dangerous for user
+ Good adjustability but requires some fine motor skills to move.
+ Holds most sizes of objects
+ Good modularity for future tools
+ Well planned aesthetically

Target Market: Very open to all disabilities, or people with issues prepping food. Less advertised to non-disabled audience.

Figure 8: Adaptive Cutting Board

Solution 3: Food Slicer Assistant- prongs

- Rounded, small diameter handle – is it able to be gripped even with a fine motor condition?
- Potential safety issue of sharp prongs
- Hard to push into the vegetable
- Only applicable to a small range of fruit/vegetables
+ Can cut between prongs and close to prongs, allowing finer slicers with safety issues
+ Very stable, little risk of fruit, hand slipping.
+ Cheap (can be found for less than $10)

Target Market: Open to the non-disabled audience, maybe chefs, or cooks generally not as good at cutting.

Figure 9: Food Slicer Assistant, Source: AliExpress.com

Solution 4: Food Processor

Figure 10: Common Food Processor

- Difficult to detach bowl with lid from processor
- Blades spin fast, are a little dangerous to change, clean, and put food in if you have limited fine motor
- Limited ability to slice food to a specified size.
- Decreases independence as it does it all for you
+ Handle (accessible)
+ Easy to turn on and slice
+ Does not require strength to chop (does it for you)

Target Market: Broadly accessible to all who want to get kitchen tasks done faster, and the ability to automate chopping tasks (when the user doesn't care about precision in cutting).

Solution 5: Chopping 'Pegboard' Prototype

Figure 11: Chopping Board 'Pegboard', Source: Yanko designs

- Cannot hold with much force, only rest vegetables against
- Difficult to clean inside pegs.
- Requires decent fine motor skills to put in 'pegs'.
+ Adjustability for many use cases
+ Knife, utensil storage

Solution 6: Prototype 'Gear' Cutting Board

Figure 12: One-Handed Chopping Board (with gears)

- Not much ability to hold harder vegetables like carrot.
- Product does not use a material that is easily gripped
- Cleaning is difficult.
+ Great for herbs, leafy greens as they are pushed with gears.
+ Operation of gears can be done with body (not hand)

1.2.2. Summary of market research

There are a few products which have been designed to assist people with the preparation of food. The current best option for people to hold while they cut vegetables is **Solution 2**. The solution allows individuals to use the device one handed, but it still requires a decent amount of dexterity to set up. Most user's who require this product are going to have limited dexterity. However, this solution is not able to cater to a very large range of sizes of fruits and vegetables as well as hardness. This might mean that larger vegetables such as capsicum can't be cut. Other solutions often necessitate the use of a second hand to use or to set up. This means that the device is not accessible for people with amputations to an arm, or stroke victims who cannot use an arm.
On the whole, the market while offering some solutions does not offer a clear solution that is adaptable to the larger target market. Furthermore, individuals with more severe fine motor disabilities are still disadvantaged significantly with most of the solutions as the operation of the device requires dexterity.

1.3. Identifies the significance of a solution for society

From section 1.1, it is clear that difficulties with fine motor skills have far-reaching repercussions on people with a disability's lives because it has a big impact on their diet and health. The impact of a solution for the problem would be in improving health for a vulnerable and disadvantaged group in society, and therefore bettering social welfare. A solution that is effective would mean that people with a fine motor impairment or another disability could be independent. Socially, independence is likely to manifest in more independent housing, moving away from necessitating costly service providers in the context of 'in home support'. An example of this is the cost of the [Australian] National Disability Insurance Scheme (NDIS) which is in place to support people with a disability. The cost per individual for in home support which might involve the preparing of meals or the assistance of preparing meals is an average of approx. $350,000 per year, per individual, across Australia. [10]

The device also contributes to the soft robotic field by adding further application of soft robotic grippers to work in conjunction with people with a disability. The dual actuator design of the device also offers a point of comparison between pneumatic rigid systems and soft robotic systems, demonstrating how both systems can work together to deliver safe and effective independent living.

1.4. Defines the criteria for a proposed solution

1.4.1. Factors Affecting Design:

1. Safety – How can I make the device safe to use? What are some potential hazards to the user? Are there any potential dangers during production of device?
2. Function – What key functions must the device fulfill? How powerful does the device need to be to be useful? What are the limitations for the device functionally?
3. Accessibility – How can the device be easy to use? Can I make the controls intuitive for the target market? What would make it difficult for the user group to use the product? Are there are any disabilities that the target market might have such as vision etc.? Who are the users and what are their disabilities (stroke, arthritis, Parkinson's etc)
4. Food safety – How can you make the product easy to clean? What materials are safe to use around food? How can you make the device hygienic?
5. Function/adaptability – What is the variety of vegetables that could be cut? How much variance is there in the size and softness is there?
6. Integration with Situation – What characterises a kitchen and kitchen devices? How can I design something which works well in the kitchen?
7. Durability – How can the device survive many uses? What materials and construction are most durable?
8. Cost – What is the price range the user group are willing to pay? How can costs of material be reduced? How can labour time be reduced? What is my budget for the project?
9. Aesthetic – What aesthetic is most appealing to the user group? How can the device look well-produced?
10. Material – What materials can be used? What materials are most durable, easy to access, food safe? Will there be any restrictions on material sources?

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[10] **The National Disability Insurance Scheme, "Transcript for National Quarterly Performance Dashboard as at 31 March 2022" p.9**

11. Maintenance – How can the components be easily replaceable? What components are most likely to fail, and how can that be mitigated? Who might repair the device?
12. Ease of use – Who is controlling the device? How will commands be inputted into the device? How will the user know how to operate the device?

1.4.2. Criteria for Success

1. Safety – The device must be safe to use. (electricity, hygiene)
2. Function – The devices should be able to hold different types of vegetables securely.
3. Accessibility – The device must be usable for people with some sight and severe motor difficulties.
4. Food safety – The device must pose no risk to food safety and should be easy to clean.
5. Function/adaptability – Most common vegetables should be able to be held by the device, and it offers some adaptability for oddly shaped vegetables.
6. Integration with Situation – The device should fit into the situation of a kitchen.
7. Durability – The device must be able to withstand 100 uses without damage.
8. Cost – The cost should be competitive and able to be bought by the user group – possibly go onto the NDIS funding.
9. Aesthetic – The design should be aesthetically pleasing and have a good finish.
10. Material – The material choices must be durable, food safe, fit the condition and be ecologically friendly.
11. Maintenance – Parts in the device must be replaceable. Parts that might often break should be easy to maintain.
12. Ease of use – The device must be intuitive with various input/control methods.

1.4.3. Target Market Definition

The target market of this assistive device is people who have difficulty with fine motor skills (limited or no control of fingers) in one or both hands.

Individual

It is hard to characterise a specific individual with fine motor difficulties, but some individuals that have conditions that affect their fine motor skills include: elderly (often have weaker muscles, and disabilities such as Parkinson's which limit motor control), Cerebral Palsy (issues with muscular coordination), amputees (difficulties in using and holding objects when needing two hands), stroke survivors (loss of movement/paralysis of muscles), arthritis (causes pain in joints, limited hand mobility), Duchenne Muscular Dystrophy (muscle degeneration and weakness makes holding, preparing vegetables difficult). This device appeals to their individual needs to live an independent life and cook healthy food. See characterising images in Figure 1-3, 6, 13.

Figure 13: Elderly person with parkinson's

Social

The social market for this device is one centred around welfare and equity, ensuring that people who have a disability affecting fine motor can still have autonomy and independence. On a wider scale, society appreciates assistive devices as they make the lives of people with a disability better, which advocacy groups campaign for and are also useful for non-disabled people. From a government perspective, the NDIS scheme would be able to provide the funding for this device. This would be beneficial as this would overtime reduce the amount of carers necessary as people can live independently. Hence reducing the NDIS burden on the nation (and on individual taxpayers).

Environmental

From an environmental perspective, getting more people to cook their own food and be independent leads to less food waste, healthier food (for those using the device), and reduces a harmful reliance on processed food.

2. Design and Methodology

2.1. Exhibits a well-constructed plan to address the need or problem

See design situation and design brief in section 1.1.1 and 1.1.2. The design brief guides the rest of the project's intention, so that every step of the project I am moving towards achieving an effective solution to the design situation. Furthermore, a time/action plan was made to keep track of progress. The format was a Gantt chart.

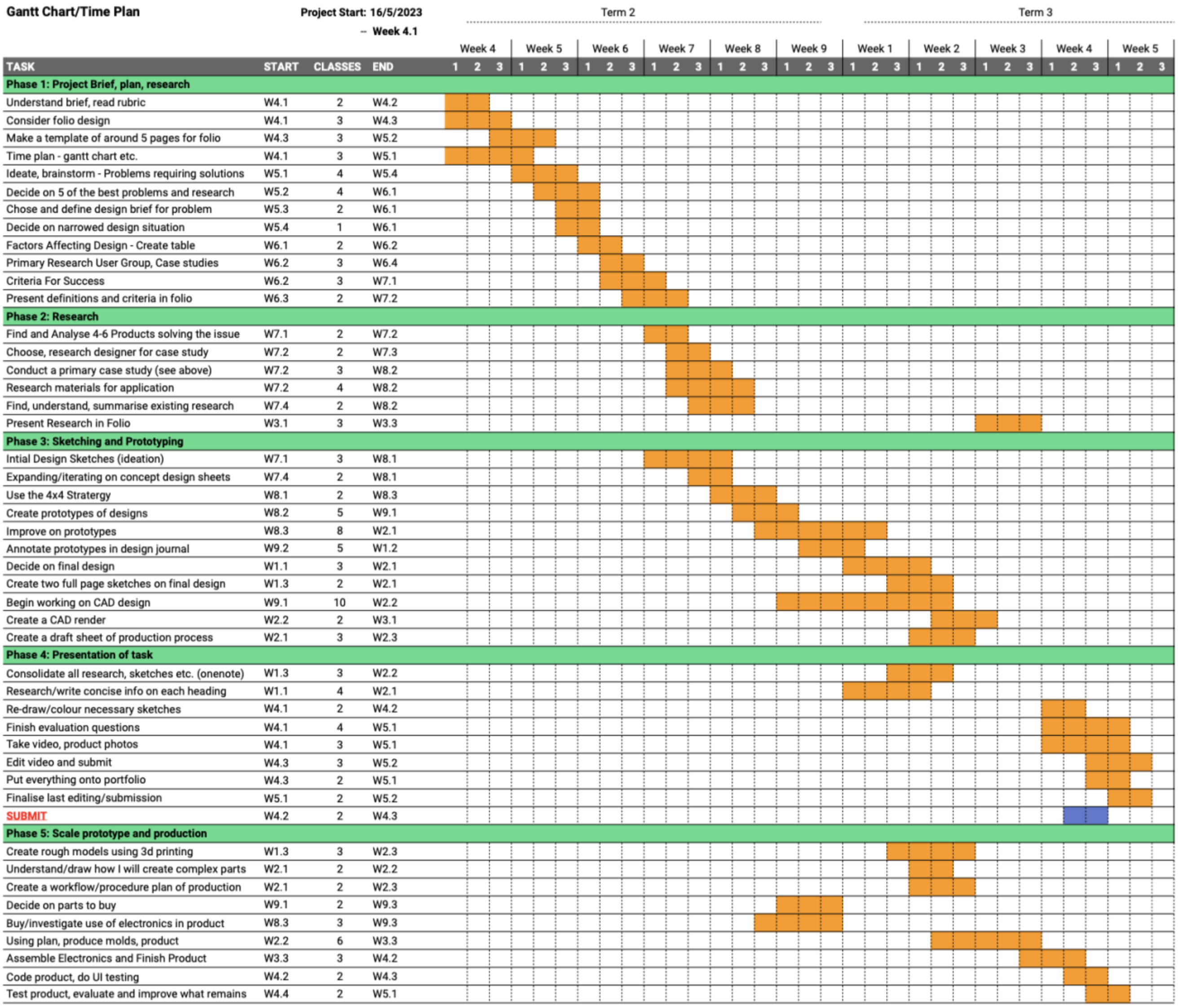


Figure 14: Project Gantt Chart

2.2. Justifies the choice of materials and technologies selected

The material I chose to make the soft robotic parts from was based on academic research which investigated mechanisms of compliance in gripping designs. Silicon is most often used and can stretch considerably while maintaining a relatively low level of hardness. For my application as a stretchable and compliant gripping device, silicon has other added benefits such as its food safety and resistance to high temperatures.

Additionally, because I chose pneumatics as the method of actuation (vs. string etc.) the best material to create the device is silicon elastomer. Silicon elastomer comes in many different hardness's and is sold at a few mould-making vendors. I want the gripper to be flexible against soft food, so I chose a lower hardness silicon, at about 30 Shore A (standard for this soft robotics application).

For the main body of the chopping board, the ideal material selection would be wood (aesthetics and durability), but for the prototype, I will settle for a PLA 3D Print.

Figure 15: A Translucent Silicon Elastomer similar to the material used in product

Silicon Elastomer Properties: Elongation at break: 600%; Colour: translucent; Shore Hardness A: 28; Tear Strength: 20kN/m; Tensile Strength 7.5 MPa; Mix Ratio 10:1

2.2.1. Cost

Part Description	*Vendor*	*QTY*	*Total Cost*
Silicon Elastomer RTV3428	Barnes	1; 500g	$65, per unit $13
Arduino Uno	School	1	$25
Jumper Wires, Connectors	Jaycar	2	$24
12V 1A Power Supply	School	1	$10
Pump (one for vacuum and one for air inflation)	eBay	2	$31
Pressure Sensor	RS-Components	1	$30
Force Sensor	RS-Components	2	$20
Nokia 5110a Screen	eBay	1	$7
Rotary Encoder	eBay	1	$5
Solenoid valves	School	2	$80
Pneumatic Tubing	School	N/A	$10
3d printing filament	School	N/A	Approx. $10
Syringes	School	2	$10

Part Description	*Vendor*	*QTY*	*Total Cost*
Screws to hold down electronics, double sides tape	N/A	N/A	$3
Wooden Chopping Board Base	Ikea	1	$5

Figure 16: Bill of Materials (BoM)/Cost analysis table

Total Cost = $274

The cost of labour and other materials for this project would likely mean that one unit with all accessories would cost between $200 to $300. The cost would significantly decrease as buying in bulk for tubing and electronics would mean that postage and the unit cost would decrease.

The project relied heavily on 3D printed parts (printed in PLA filament), but the parts and moulds could all be produced in other filaments such as ABS. PLA was chosen because it is food safe, stable and cheap. It would be very difficult to reproduce or make the PneuNet designs without 3D printing technology, but some parts could easily be made out of wood or other materials (such as the chopping board). The cost of PLA filament is low and accessible for most.

The microcontroller can be changed for other similar or custom microcontrollers, but the Arduino platform is fairly cost-effective and easy to prototype. The LCD screen can be changed for another other screen tech such as OLED or a different size of LCD (or without backlight). The control of the system can be achieved through just using a laptop for prototyping or altering the code. The use of pressure sensors are necessary, and any IC pressure sensor can be used. The force sensors are non-essential and offer only a little more control. The material of pneumatic tubing can be anything that fits into 3/8” quick connect fittings, or other joinery. The transformer/power supply can be any specifications of 12V 0.5A or above DC power.

2.3. Describes a proposed prototype or model to demonstrate the solution

2.3.1. Movement Analysis (of chopping vegetables) with user group

The first stage of research to optimise the device's function was analysing the motion and movements required for gripping/chopping fresh produce and what someone with a fine motor disability struggles with. This included video analysis, determining the most popular ways to chop vegetables and testing with user group (as a case study). The vegetables and types of chopping that I investigated included an onion, carrot, pumpkin and potato. I gathered quantitative data on the movements and the most importance of certain motions.

Results

Vegetable	*Motion*	*Grip*	*Comments of User Group Performance*
Onion (diced)	1: halving (cutting lengthwise).	Holding both sides of onion	Fairly safe motion, knife had tendency to slip
	2: Cutting/slicing into slivers	Claw grip or fingertip grip on top of onion	Confident with 75% of onion. Very difficult last 25% (fingers slipped because not enough strength to grip.
	3: Dicing/second direction	Not holding at all or flat palm	Easy with long knife on board, thumb stuck out (safety concern)
Carrot (cut in sticks, diced)	1: Halves (cutting lengthwise x2)	Clamp/pincer grip on both sides	Determined too dangerous for user group to test (knife can easily slip off carrot) Difficulties with strength
	2: Cutting into chunks	Hold flat, flat hand on board	Easy to hold, no safety issues. Found sizing difficult
Pumpkin (diced)	" (same process as carrot)	"	Easy to hold, stiff, well-shaped with a less slippery texture
Potato (diced)	"	"	Large size, easy to cut in half and dice (strength/pressure) was difficult for user group

Conclusion

After analysing grip techniques required for chopping some of the most common vegetables, I have shown that there are two key movements to cutting most vegetables, no matter shape or hardness. These are:

1. Chopping the vegetable in half (using a clamp or over knife grip)
2. Slicing/dicing the vegetable in a second direction

Therefore, my design should be optimised for the above two movements.
The hardest movement was slicing the onion - especially the end of the onion (as there was little space to grip) and required much more precision. Additionally, the halving of harder vegetables like

carrots and pumpkins was challenging due to strength issues and the tendency of the knife to 'slip off' the centre. Hence, I will try to design a device which can assist with these tasks as they are the most limiting.

2.3.2. Chosen Prototype System to Solve Problem

After ideation, research and testing, I determined that the project could be split into two central components/systems which perform two important functions of chopping/slicing vegetables. The first is a system for holding more delicate vegetables to be sliced and is completely compliant. It is based on the Harvard PneuNet design and imitates the function of a claw style grip when chopping vegetables. The second is a mostly rigid pneumatic system which has some soft robotic elements to provide compliance and mirrors the function of a clamp grip (ie. Holding both sides of a vegetable to chop in half). The control system is a 3d printed box with a screen and accessible rotary knob for both rotary and press input. Inside the box are the two pumps (vacuum and compressor), the microcontroller, the pressure sensors (receiving data from the air tubing), and valves which are used to select the device and whether to vacuum/pump.

Figure 17: Final device: See rigid clamp design on left and soft robotic actuator on right.

The manufacture and required tools are further detailed in the Fabrication/Design Process section, but the production of the device requires a 3D printer, a precise scale for measuring amounts of elastomer, cups and stirring tools for mixing, soldering tools, wires etc. and tools for pneumatic tubing such as tube cutters.

2.3.3. System 1: Soft Robotic PneuNet Gripper (biomimetic of finger)

The material that the PneuNet device is made from is silicon elastomer. Silicon elastomer is sold in varying degrees of hardness and is usually food grade. About 150g of elastomer is necessary to manufacture the device. The bending actuator is inside of a 3d printed mount which holds it in position and is slotted into a keyhole mechanism that allows the actuator to move in one axis (forward and back). This allows for securing mounting but also so that the actuator can be removed for cleaning easily and changed position for different shapes and sizes of fresh produce. The mount is 3D printed in PLA filament. The chopping board that the mount sits on can be either 3d printed (with grooves to hold vegetable in place) or can be made from a wooden chopping board. The device is supplied air pressure through silicon or polyurethane tubing. The actuator is embedded with a flexible force sensitive resistor (measuring compression force acting on sensor). The base of the actuator was designed to limit the slipping of the fruit through adding bumps and a textured base which meant that the fruit slips less when it is being cut.

The parameters for the size and design of the PneuNet actuator was determined through testing and prototyping various sizes of actuator. This allowed me to evaluate the weaknesses in the actuators and design custom 3d printed moulds to produce better results.

Figure 18: Testing of larger sized actuator (compared to smaller, final design)

Figure 19: Final 'finger' PneuNet actuator on 3DP mount

2.3.4. System 2: Mostly rigid ‘clamp’ with compliant cushioning

The clamp system is made from small syringes which act as pneumatic cylinders to provide uniform and controlled linear motion. The syringes have 10mL capacity and can be bought from some pharmacies or online. The two pneumatic cylinders (syringes) are clipped into a 3d printed bracket, which is screwed into the chopping board that holds them at a constant position with minimal/no play. The pneumatics are then attached to a 3d printed ‘jaw’ which is coated with silicon elastomer for easier cleaning and some compliance. The jaw holds both the cylinders at the same axis, so that they both extend the same amount and are not lop-sided. The other ‘jaw’ is mounted with a bracket to the chopping board and has a variation on a silicon PneuNet actuator (made in a similar method to the gripper in System 1) that adjusts the amount of compliance to not bruise the fruit and to increase the system’s safety. The jaws of the clamp also have embedded force sensitive resistors for an understanding of the forces acting on the fruit. The device’s purpose is to allow the user to cut vegetables accurately and easily in half (especially vegetables that are hard or slippery) with one hand, or without posing any risk of cutting themselves that might ordinarily occur. While fully soft robotic linear extension actuators were tested such as origami extending actuators, the devices were unsuccessful at providing sufficient force and were not as useful for this project.

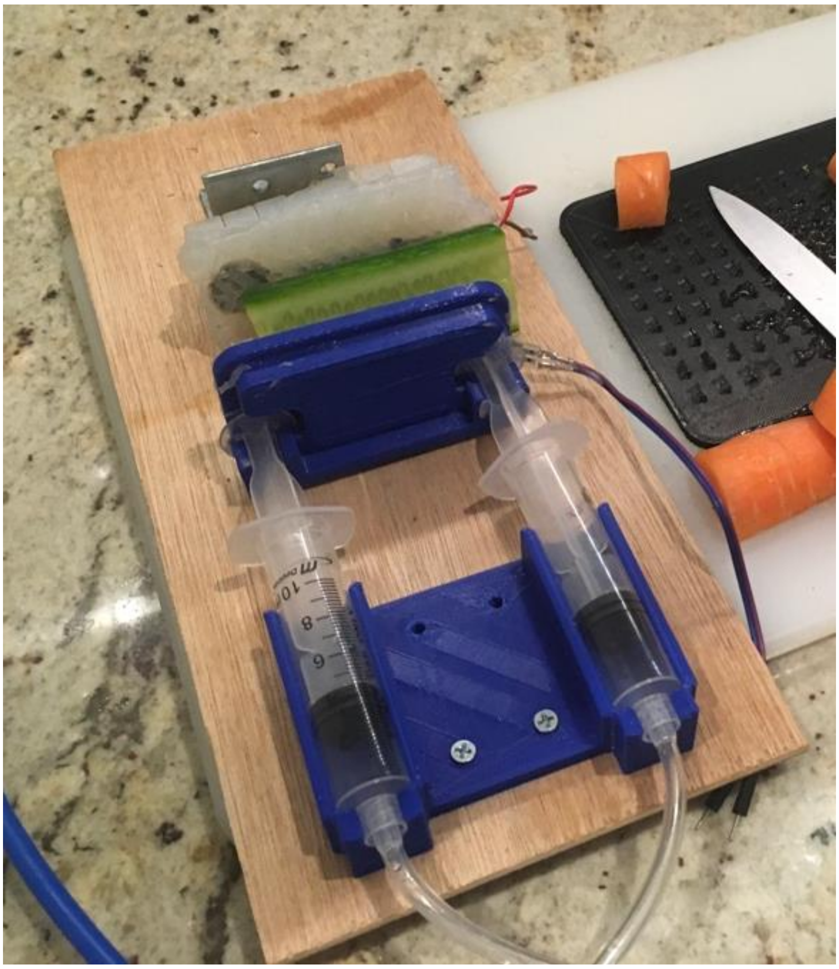


Figure 20: Final clamp device (using syringes, 3DP mount). Note wires for force sensors

2.3.5. System 3: Control System

The housing of the control system is a 3D printed box, around the size of a piece of a piece of printer paper. The box was 3d printed so that custom additions to fit certain electronic components such as the screen and encoder in the lid could be easily made. The power is supplied through a singular DC in power transformer from mains which supplies 12V 1A electricity in a singular pin on the box's exterior. There are also ports for debugging and software updating the Arduino. Along the side of the box there are two output connectors for the finger and clamp air tubes to be quickly connected and disconnected. As previously mentioned, the control of the device is done through a singular Arduino microcontroller. A breadboard is used to connect the pressure sensor, force sensors and screen to the Arduino. The small LCD screen on the box's exterior has a GUI interface of a scrolling menu, controlled through the large and accessible rotary encoder knob. The GUI can display pressure values, force values, switch to manual vs preset mode, set the preset value and power off/on the device. This interface has been tested with individuals with limited fine motor and with individuals with an intellectual disability.

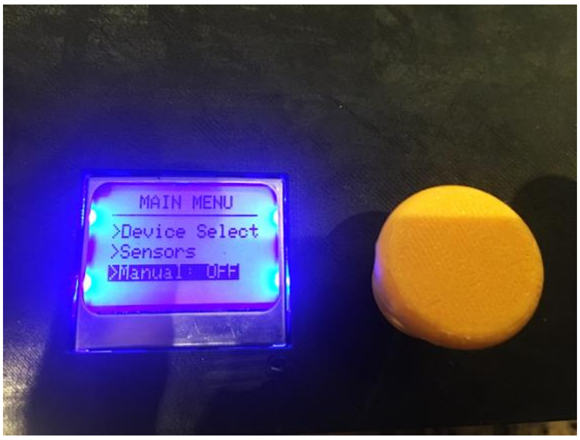


Figure 21: Control box LCD Screen and rotary knob, top view

2.4. Demonstrates depth of understanding of technological methodology used. Relevant technical concepts related to project design and methodology referenced in project:

2.4.1. Compliance

Compliance, a fundamental engineering concept, underpins this device's functionality. Compliance allows a mechanical system to deform or yield under external forces while preserving its structural integrity. In this device, compliance is achieved through a combination of material selection and mechanical design. Flexible materials, like silicone elastomers, are strategically incorporated to enable controlled deformation when exposed to external forces, enhancing the device's adaptability and precision. Additionally, the use of pneumatic systems utilises the innate compressibility of a low-pressure gas (air) as opposed to hydraulic systems which are non-compressible.

Figure 22: Joint and finger compliance example

2.4.2. Pneumatic Systems:

As already identified, pneumatic systems have an advantage over motorised and hydraulic alternatives as they are incompressible and hence not as safe, nor compliant and adaptable. In the context of pneumatic systems, higher pressure leads to gas compression, resulting in denser gas molecules and increased resistance to deformation. This gas behaviour functions as a spring-like element within the system, enhancing stiffness when subjected to external forces. This stands in contrast to hydraulic systems, where incompressible fluids maintain a constant volume under pressure, ensuring consistent stiffness levels regardless of pressure variations. See Figure on Boyle's Law.

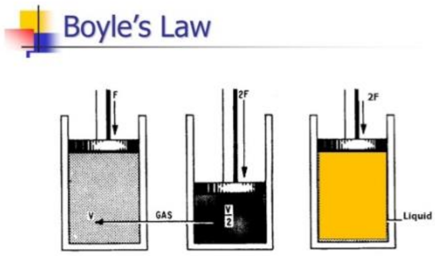


Figure 23: Boyle's Law diagram of load on cylinder

2.4.3. Feedback Controlled Systems:

Feedback control systems are a fundamental engineering concept that involves monitoring and adjusting a system's behaviour in response to changing conditions or disturbances. These systems use sensors to measure relevant parameters, compare them to a desired setpoint, and then adjust maintain the desired outcome. Feedback loops are crucial in achieving precision, stability, and reliability in various engineering applications. A feedback control system could be employed in my device to monitor and adjust factors like grip force or compliance based on real-time conditions. For instance, if the device is gripping a fragile fruit and the user has defined this, the system could use feedback from sensors to adjust grip force to prevent crushing and keep the system at a consistent hardness. This concept goes beyond compliance, as it involves dynamic, real-time control to optimize performance and adapt to changing situations. An example of a generic feedback loop is given below:

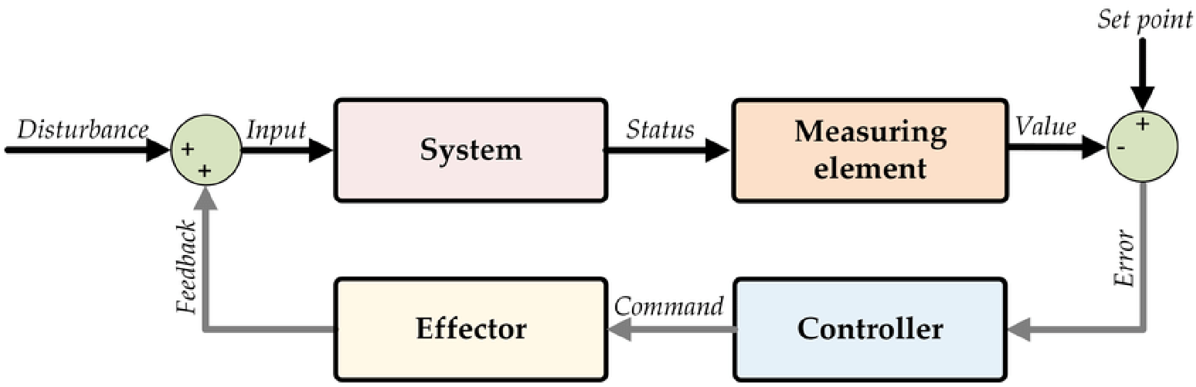


Figure 24: Feedback loop system flow chart

2.4.4. Human-Machine Interface (HMI) - Graphic User Interface

In software engineering, Human-Machine Interface (HMI) serves as the crucial way of receiving information from a user and translating this into usable information for the machine to run actions and algorithms from. In this context, the manual user input from a rotary encoder provides the ability to change different factors and menus which are designed to be intuitive and easy to learn. The combination of the programming enabling the menu to function graphically in a Graphic User Interface (GUI), the software input/reading from a rotary encoder and the programming which converts this into usable variables for the other processes to run off is the HMI system.

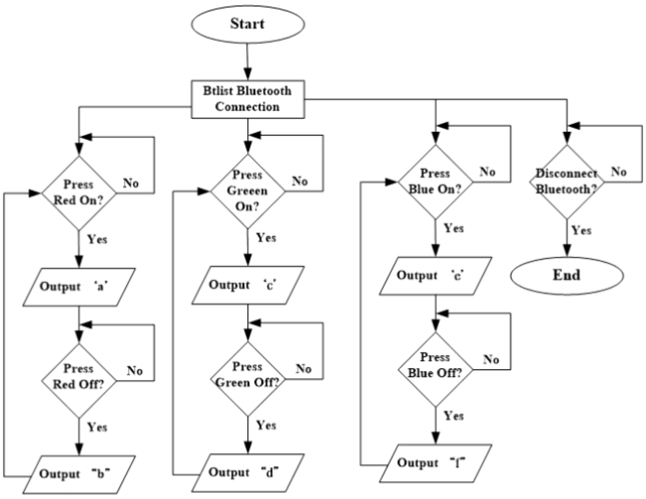


Figure 25: Example flow chart of HMI programming for a Bluetooth device

2.4.5. Soft Robotic PneuNet Actuators

An actuator is a device that can provide force or move. Bending soft robotic actuators utilise compliance to turn pneumatic pressure (or other forms of energy) into a bending motion or compression force (on an object) which can be used to grip it. As mentioned in section 2.3.1, a bending soft robotic actuator was chosen for the first component of the design (in order to grip softer and more fine objects). There are multiple types of bending soft robotic actuators. The chosen type of design for the project was a PneuNet class actuator. These were originally developed by the Whitesides Research Group at Harvard[11]. They consist of a series or pressurised channels which when inflated create motion. Because the underside of the actuator is inelastic, it does not stretch and therefore creates a bending motion when the top section becomes larger. The motion of the actuator can be adjusted through modifying the geometry of the chambers and channels of the actuator. Changing the inelastic, 'strain' limiting layer can restrict the amount of strain/motion that occurs.

The manufacture of the actuator is detailed in many research papers such as [9] from the Whitesides research group and Y. Sun's paper characterising the class of silicon rubber soft pneumatic actuators[12].

I followed very similar methodology as to the technical construction of each actuator, detailed further in section 3.

---

[11] Mosadegh, Bobak, Panagiotis Polygerinos, George M. Whitesides. et al 2014. "Pneumatic Networks for Soft Robotics That Actuate Rapidly." Advanced Functional Materials 24 (15) (January 10): 2163–2170.

[12] Y. Sun, Y. S. Song, and J. Paik, "[Characterization of silicone rubber based soft pneumatic actuators](#)," in Intelligent Robots and Systems (IROS), 2013 IEEE/RSJ International Conference on, 2013, pp. 4446–4453.

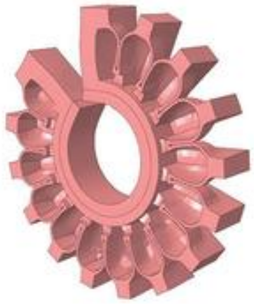


Figure 26: Diagram of PneuNet Actuator. Source: Harvard Soft Robotics Toolkit

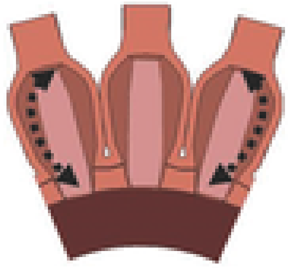


Figure 27: Section view of PneuNet Actuator. Source: Harvard Soft Robotics Toolkit

3. Execution: Construction and Testing of a Prototype

3.1. Exhibits good design and production skills

Prototyping, force tests with prototypes

3.1.1. System 1: Soft robotic PneuNet Actuator

First prototype was made with information from the *Soft Robotics Toolkit*'s website, made of silicon elastomer and some nylon pneumatic tubing. I 3D printed two different sized moulds downloaded from the internet and tested the breaking pressure and forces generated from the two differently sized actuators. I found that for the smaller actuator, I was able to produce approx. 1.96N down (measured with a scale) and this was at 7PSI (relative). At 8PSI, the force would remain constant, and the finger would bulge outward without producing any more force. This is evidenced in the image below.

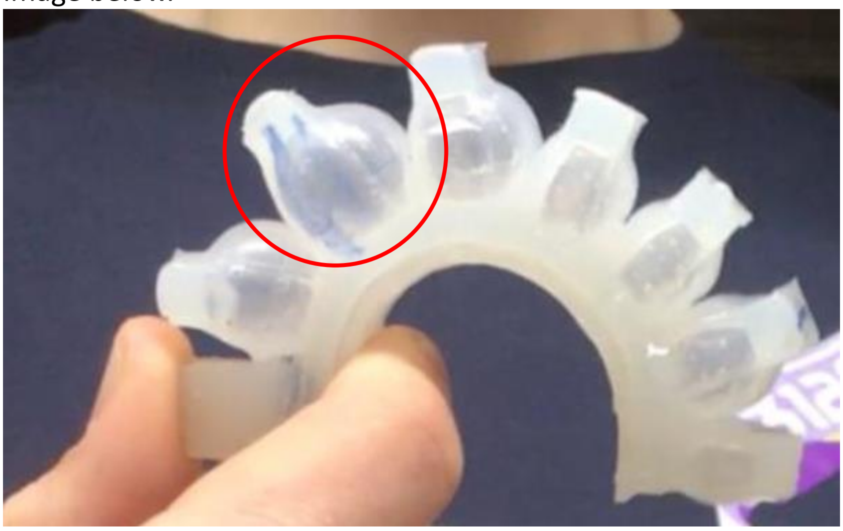


Figure 28: Inflated actuator, evidencing deformation of thin chambers (own work)

The larger actuator had a similar problem but at a higher pressure of 9PSI before it did not produce any additional force. At this peak, it produced approx. 2.75N of force down which was an improvement for my application. While testing this design, one of the actuators ‘bulged’ out as shown above and ruptured meaning that the prototype was no longer functional.

Design optimisation decisions:

- Reinforce the sides of the modules that inflate by increasing wall width.
- Programming: consider a ‘max pressure’ loop so that the actuator cannot burst at a high pressure
- Less length means that the actuator curls less and therefore produces a greater downward force (for this application)

3.1.2. System 2 Prototype: Soft Robotic Linear Origami Extending Actuator

Considering a method of linear extension that used soft robotics, I researched the possibilities of origami-based actuators which were based on cylindrical patterns encased in silicon. I used the principles and method from the paper “Elastomeric Origami: Programmable Paper- Elastomer Composites as Pneumatic Actuators” by Ramses Martinez et al. which included the Yoshimura origami pattern. I attempted this pattern, but found that I could not pore a mould which covered the whole paper in silicon, and the thick silicon impaired the bending of the folds and therefore caused the sides to cave in. If I chose to pursue this idea, I could investigate using a different type of paper and a thinner mould. Overall, however, this experiment led to me moving away from a soft robotic linear expansion to a hybrid pneumatic option, which has similar outcomes, but is much easier to manufacture and has great reliability.
See moulds and prototype actuator below:

Figure 30: Moulds for soft linear actuator (3D printed, own work)

Figure 29: Origami soft linear actuator prototype (with silicon covering)

3.1.3. Fruit/Vegetable Testing (force to break)

By testing the limits of certain common fruit/vegetables I determined some of the parameters for the max force that could be applied to a piece of fresh produce that is being cut before it deforms/bruises. This was tested by hand on a scale and force was derived from the mass readout. The data is to one significant figure.

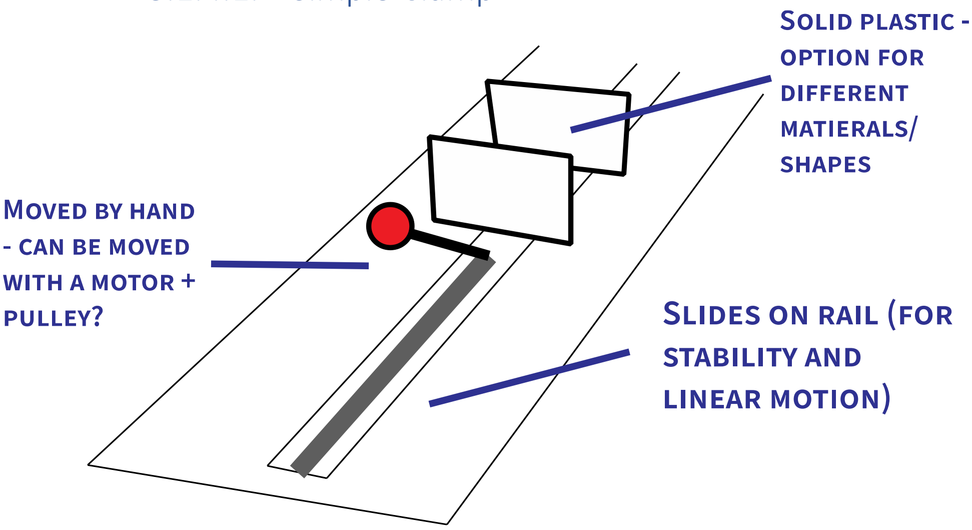
Results

Fresh Produce	Max Force Applied Before Deformation/Bruising (N)
Apple	700
Banana	30
Onion	200
Carrot	800
Pumpkin	200
Potato	200
Strawberry	10

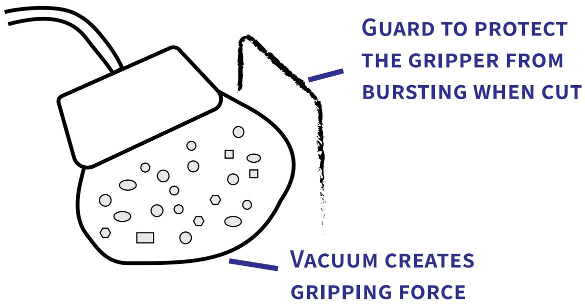
3.1.4. Design Process for Mechanisms: Mechanism/Conceptual Ideation

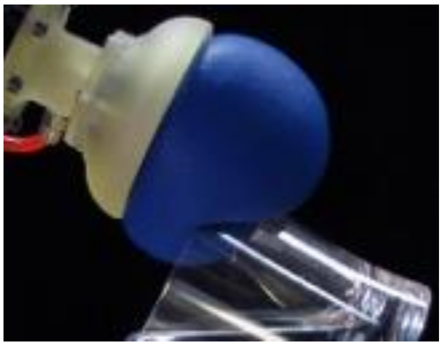
As part of my research and ideation for a solution, I sketched and analysed mechanisms that could be used to solve the problem I decided on.

3.1.4.1. Simple Clamp

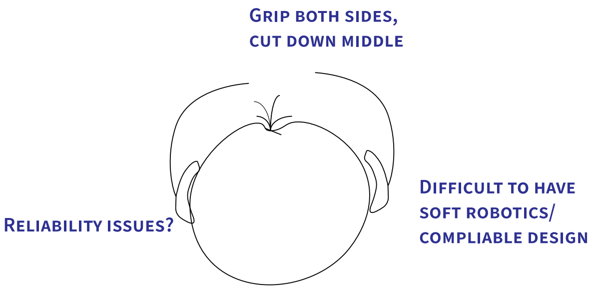


3.1.4.2. Granular Jamming Gripper- inspired by:

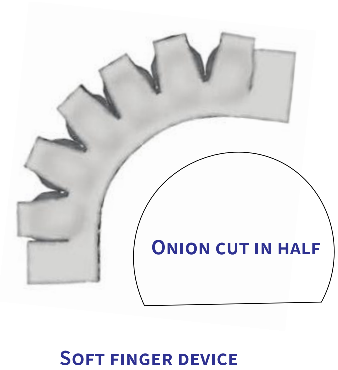




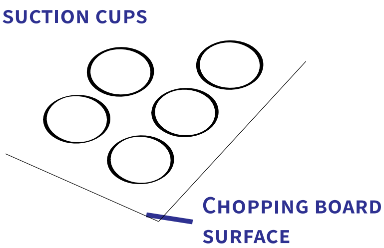
3.1.4.3. Horizontal/Pincer-style Gripper



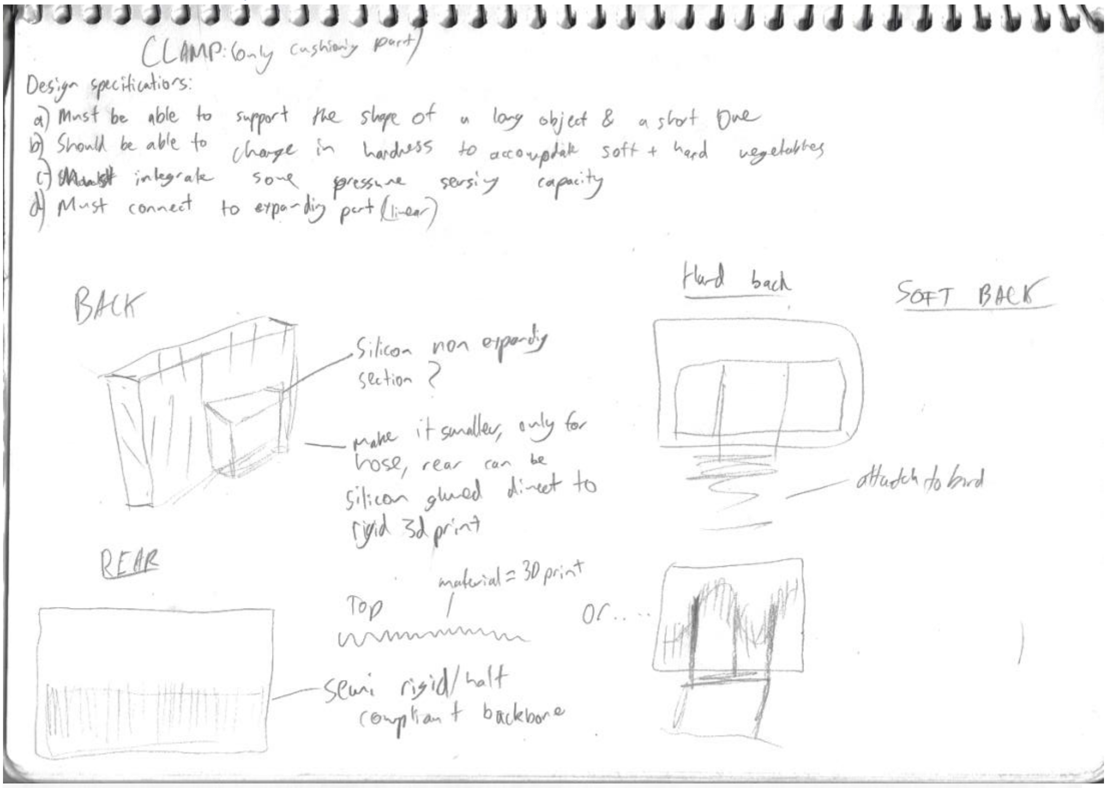
3.1.4.4. 'Top Pincer- Squashing from top

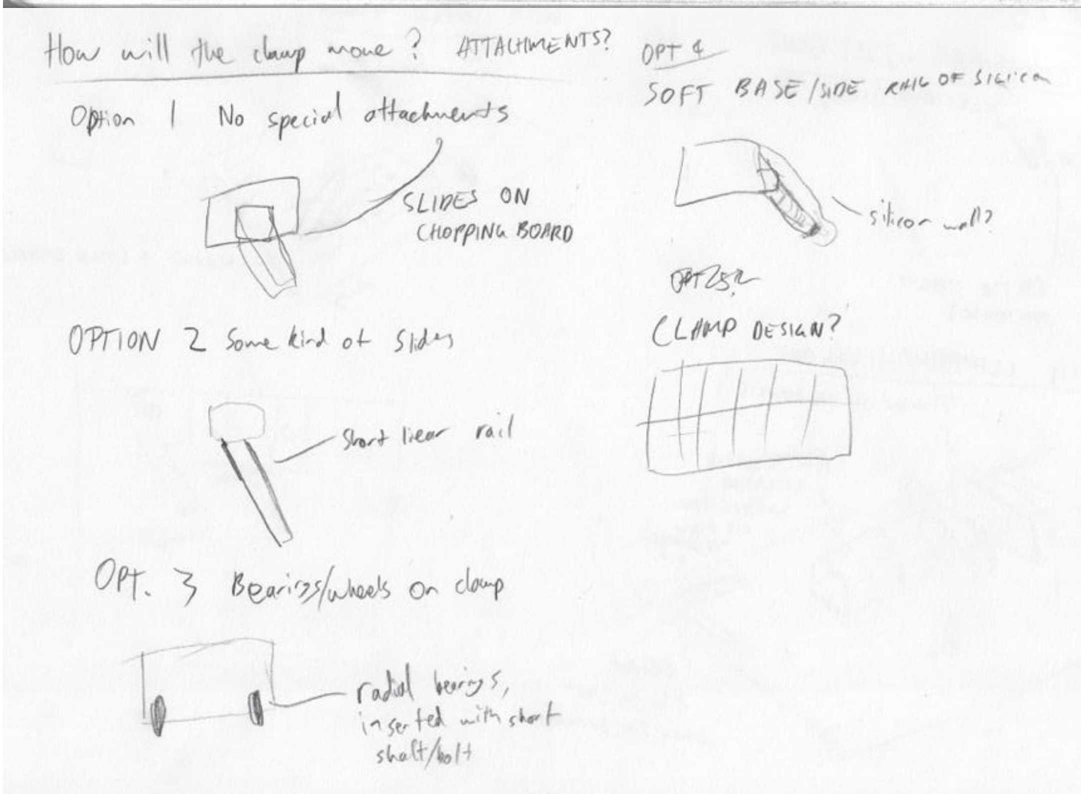


3.1.4.5. Suction Cup Chopping Board

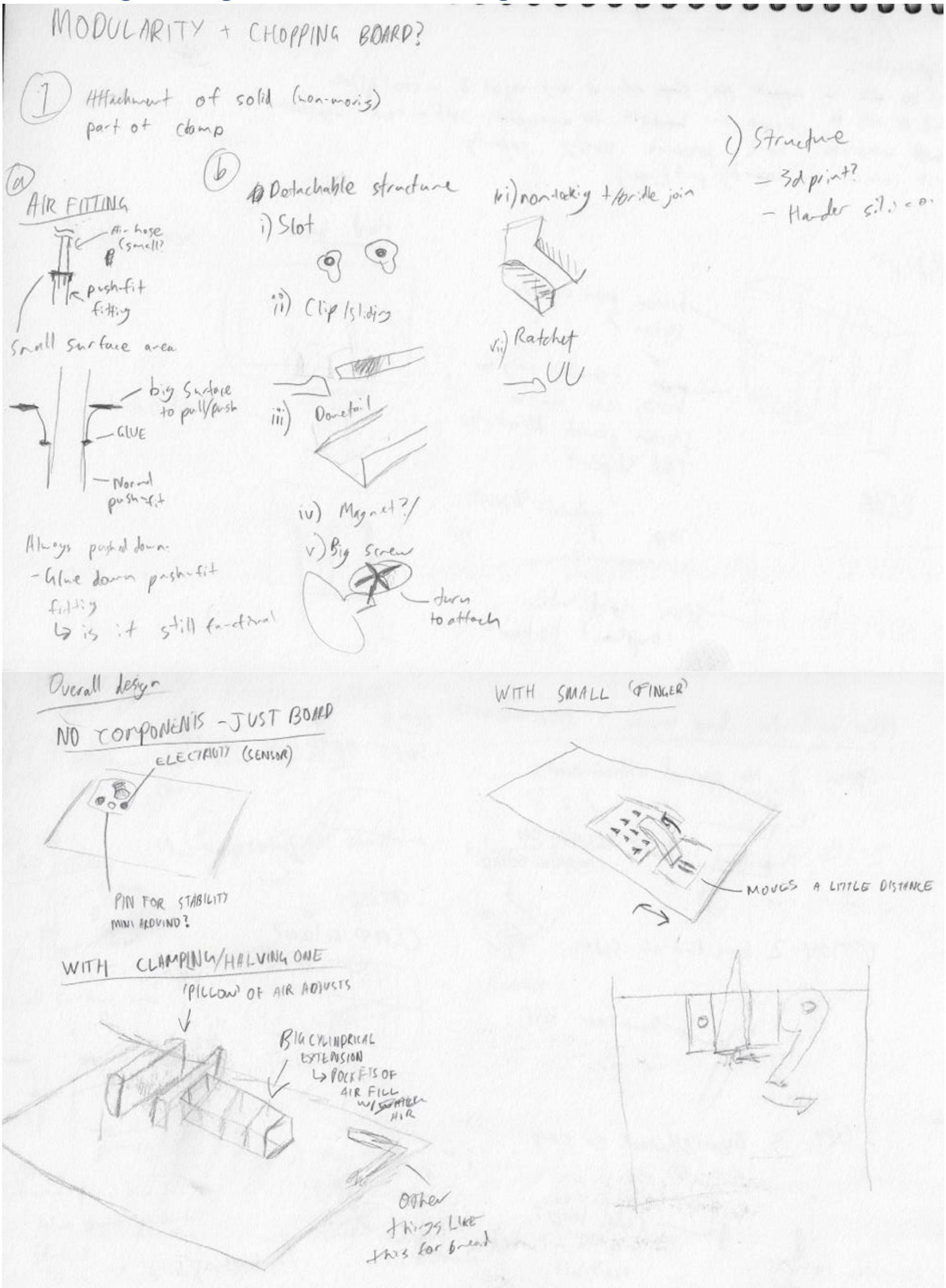


Clamp:


CLAMP: (only cushioning part)
Design specifications:
a) Must be able to support the shape of a long object & a short one
b) Should be able to change in hardness to accomodate soft + hard vegetables
c) ~~Must~~ integrate some pressure sensing capacity
d) Must connect to expanding part (linear)
BACK
Silicon non expanding section ?
make it smaller, only for hose, rear can be silicon glued direct to rigid 3d print
Hard back
SOFT BACK
attach to bird
REAR
material = 3D print
Top
or...
semi rigid/half compliant backbone


How will the clamp move ? ATTACHMENTS?
Option 1 No special attachments
SLIDES ON CHOPPING BOARD
OPTION 2 Some kind of slides
Short linear rail
OPT. 3 Bearings/wheels on clamp
radial bearings, inserted with short shaft/bolt
OPT 4
SOFT BASE/SIDE RAIL OF SILICON
silicon wall?
OPT 5
CLAMP DESIGN?

Finger Design, holistic device design:

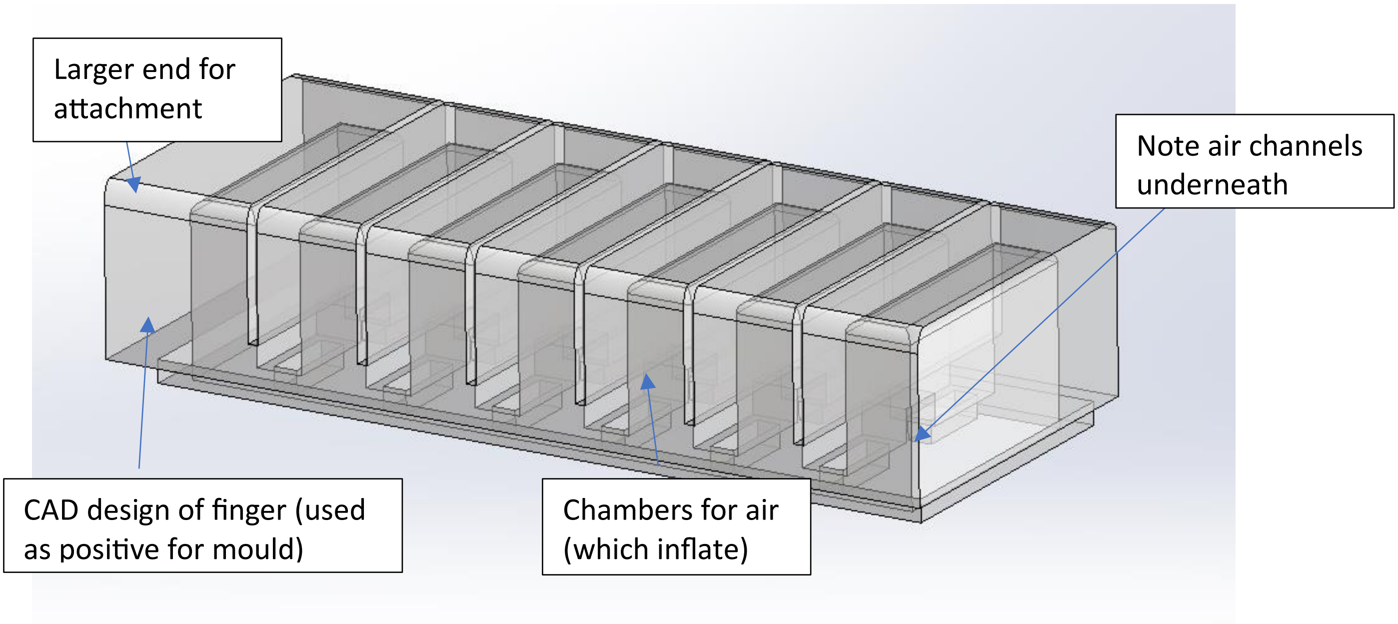


3.1.5. CAD modelling (mould parts, base printable)

https://github.com/timo-wilson24/Soft-robot-kitchen-assistant/tree/1f0e81280b5753aea2adc9df44ec5698dffbd508/Solidworks%20CAD%20files

Once sketches of design were complete, I used Computer Aided Design (CAD) modelling to make the mould and design the board and mount, which could then be printed.

For the mould of the finger, I first made each compartment which was patterned, added air channels to make the positive of the mould. Extruding around this shape and adding tabs for mould removal completed the CAD process. By changing the dimensions of the compartments or air channels, the characteristics of the device could be altered, which was effective for prototyping. See dimensions in engineering drawing at the bottom of this portfolio.



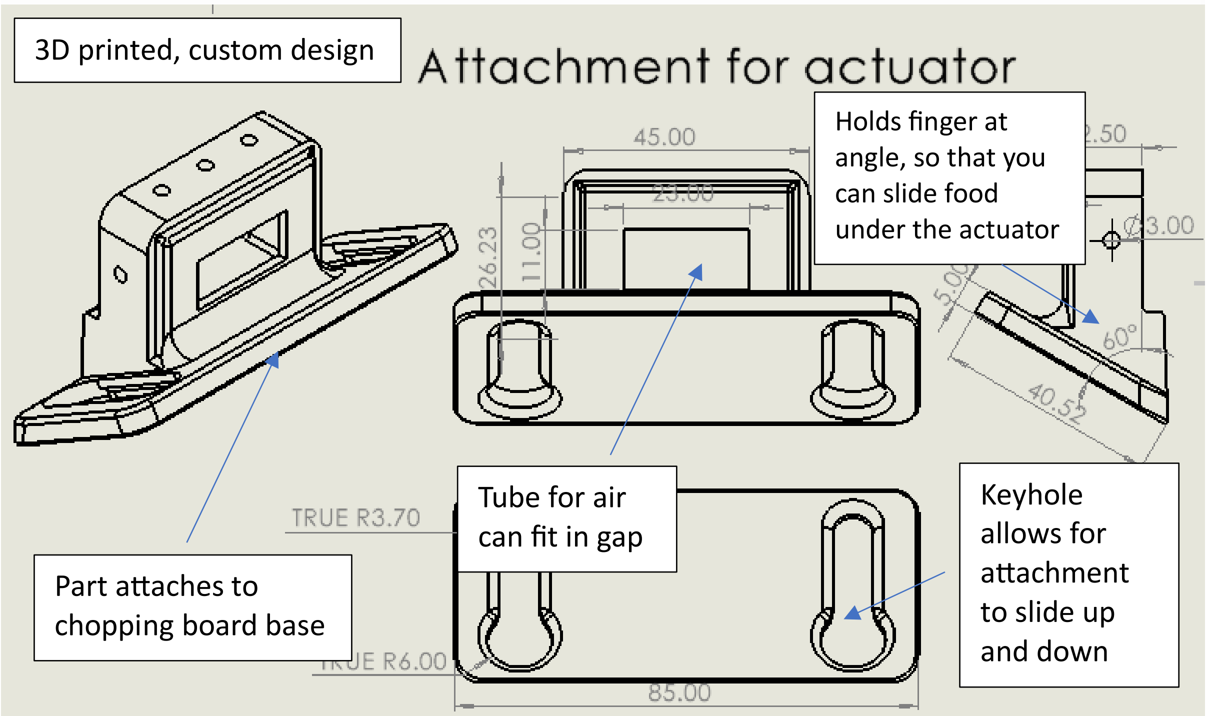


Figure 31: Engineering Drawing of soft actuator attachment

Accessible knob

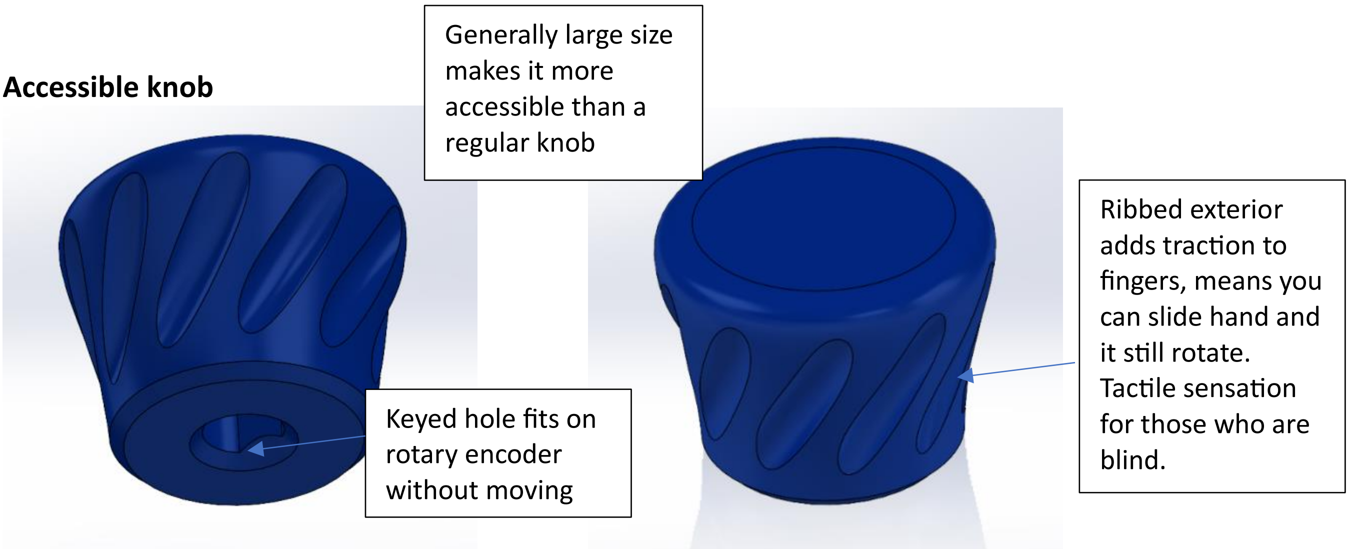
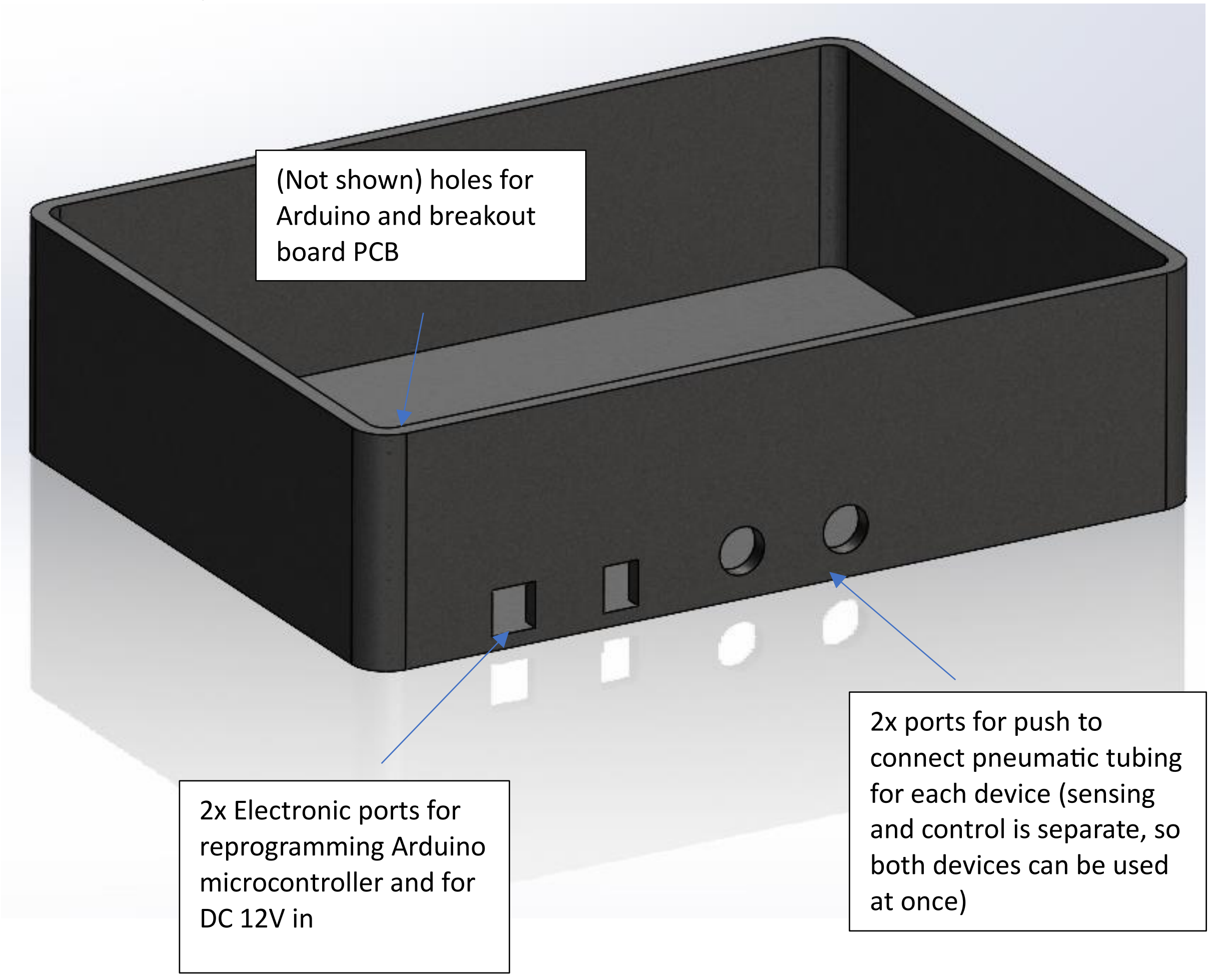
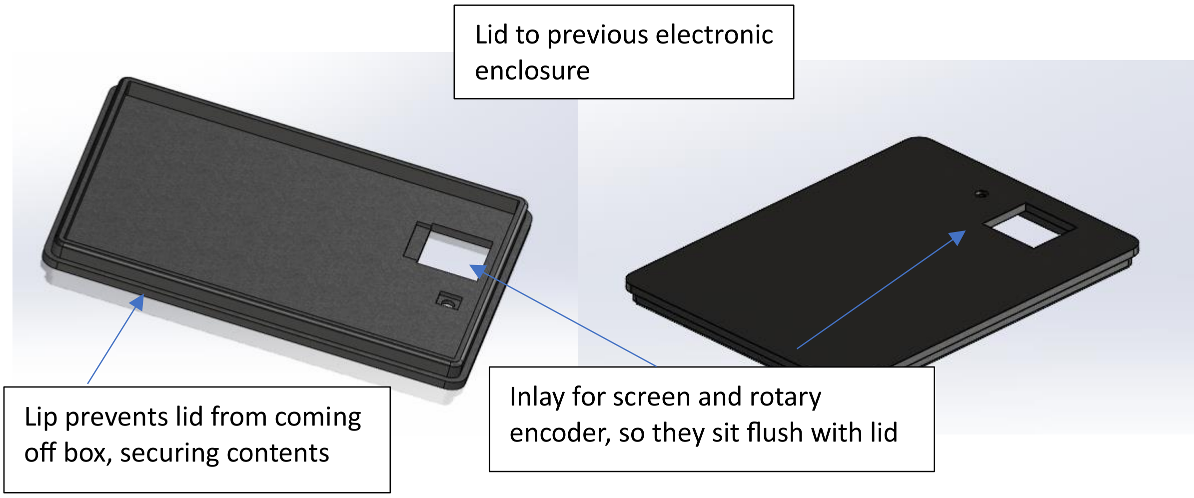


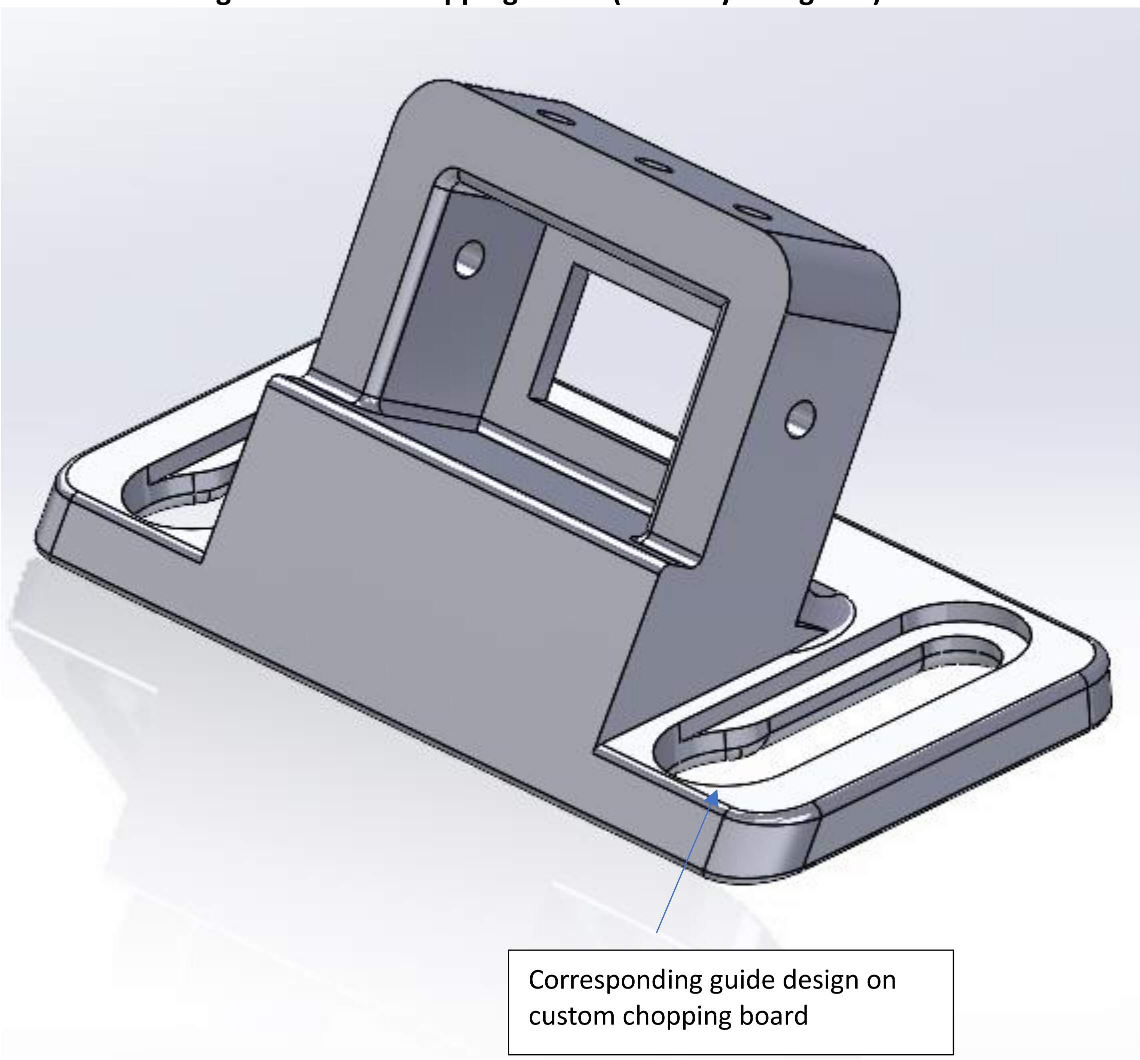
Figure 32: CAD design of custom accessible knob

Electronics Box/enclosure with lid

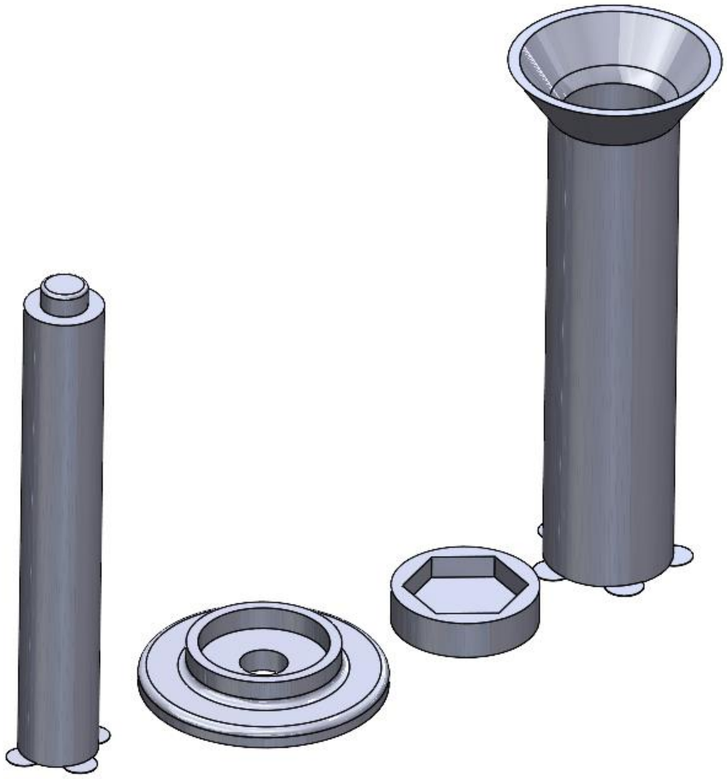




Part for attaching PneuNet to chopping board (with keyhole guide)



Prototype soft robotics linear extension moulds

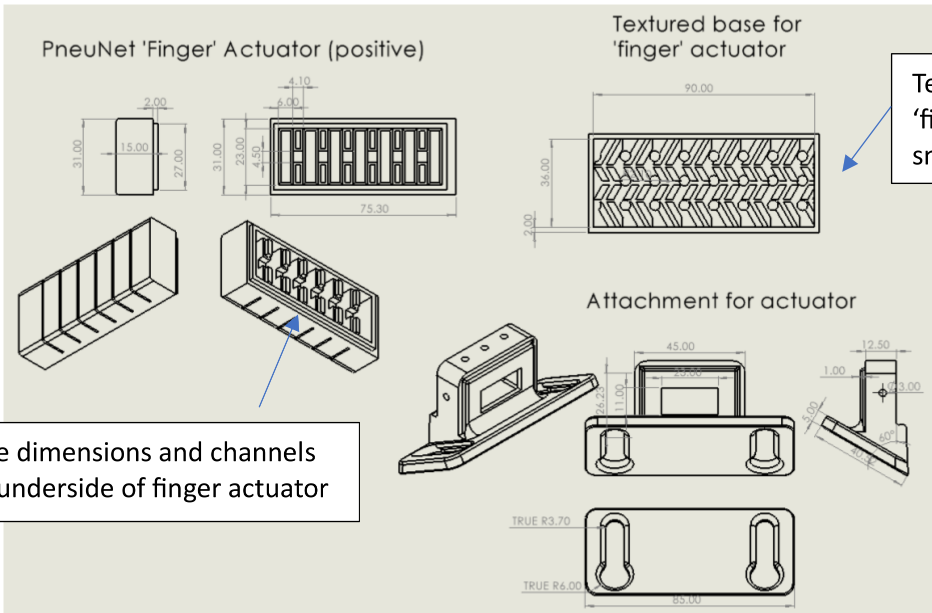


4 part mould that silicon is poured into to make custom tube for linear actuator

Have made all the design information open source for anyone wanting to replicate project

3.1.6. Engineering Drawings

https://github.com/timo-wilson24/Soft-robot-kitchen-assistant/tree/1f0e81280b5753aea2adc9df44ec5698dffbd508/Solidworks%20CAD%20files/Engineering%20Drawings



Textured base adds traction to ‘finger’ when grabbing more smooth vegetables/fruits

See dimensions and channels in underside of finger actuator

Figure 33: Engineering drawings of PneuNet Finger Actuator Mould and other components

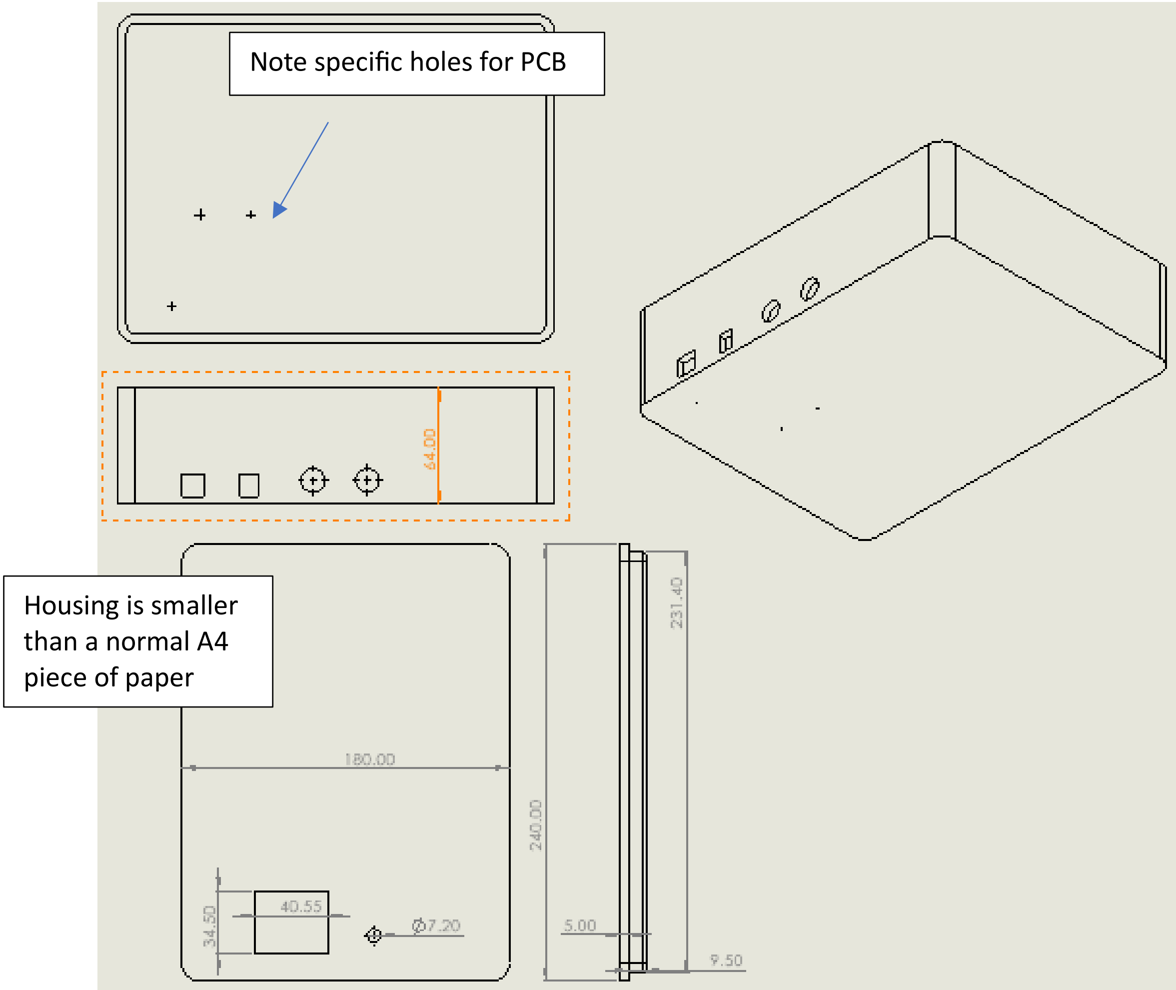


Figure 34: Engineering Drawings of electronic enclosure

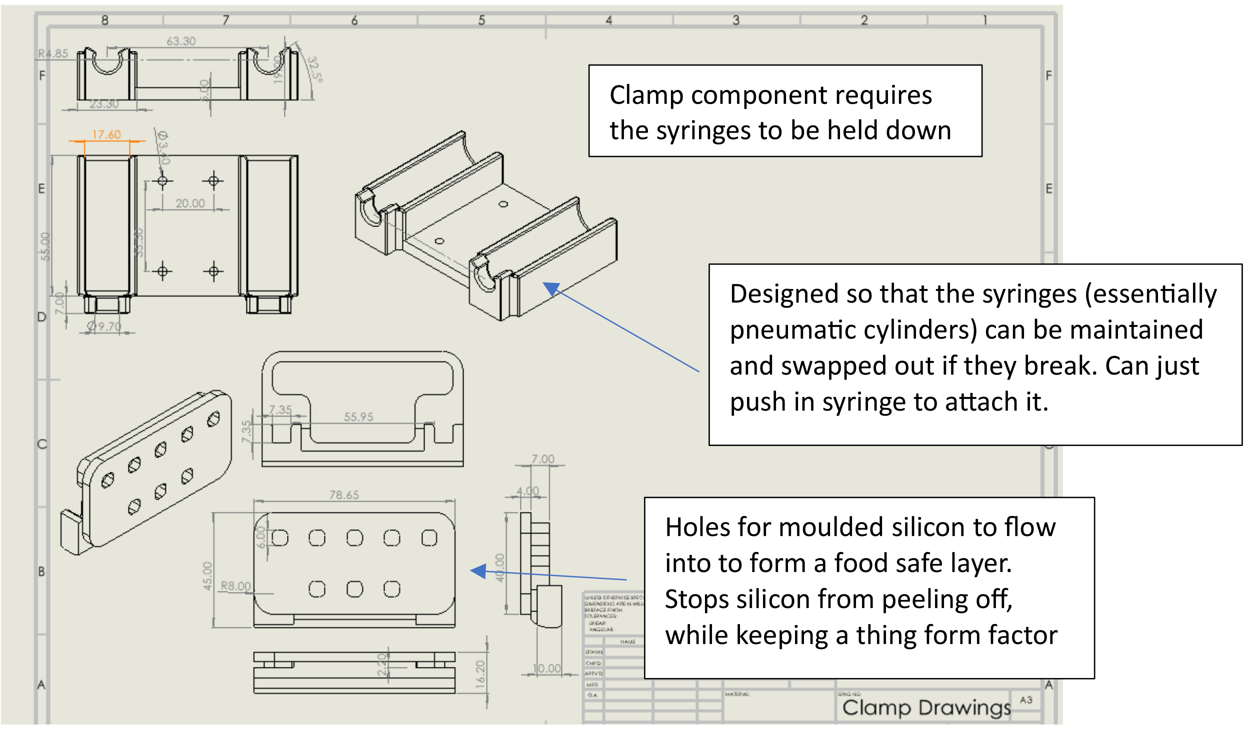


Figure 35: Engineering drawings of clamp components (housing for syringe cylinders)

3.1.7. Manufacture Process:

1. 3D printing of parts, assembly of mould

https://github.com/timo-wilson24/Soft-robot-kitchen-assistant/tree/1f0e81280b5753aea2adc9df44ec5698dffbd508/Printable%20files%20(STL) All my prototypes and final design utilise the process of 3D printing to create customisable and highly detailed moulds for silicon. The 3D printing process involves 3 steps: slice the 3D model in a slicer software (Ultimaker Cura 5.2) using settings which make the best print quality; transfer GCODE file to a printer (Anycubic Vyper) and press print; wait for print to complete then remove 3D print from print bed with a scraper and clean model of any support material.
Once the mould is printed, the top and bottom part can be placed together, ready for silicon to be poured.

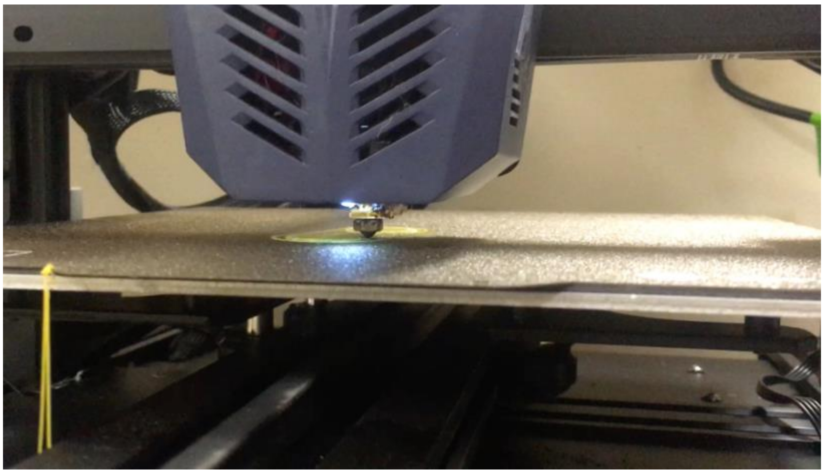


Figure 37: 3D printing mould (using Anycubic Vyper)

Figure 36: Mould for finger actuator (3D printed, PLA) see top and bottom part assembled, rear is base with traction marks

Figure 38: Mixing of silicon elastomer with scales

Figure 39: Pouring of silicon into base mould

2. Mixing of silicon elastomer, pouring of part 1 of mould

Mix the two parts of silicon elastomer according to the mass and the ratio given. Mix slowly and let to rest for 10 minutes to reduces air bubbles. If applicable, use a vacuum chamber to remove bubbles for mix. Pour the silicon generously into the mould.

3. Insertion of Strain-Limiting Material, Curing

So that the soft robotic actuator can bend, a material (fabric or paper) must be put inside the silicon to limit its flexibility on that surface. I determined that the best durability material for this application is fabric, as paper tends to fold and crack under repetitive and high loads. Paper can, however, be used as an alternative.
Cut a piece of non-elastic fabric to place on the base (flat part) of actuator. Place on the base/flat mould once the first layer (~2mm of silicon) along with a thin flexible force sensor. Ensure the wires are accessible (either have connections or easy solder points).

4. Demolding

Use a screwdriver or other prying tool to separate the top from bottom mould. The silicon can bend and stretch without snapping, just ensure not to puncture the walls or roof of the actuator. Once demolded, and the strain-limiting material is inserted, the top and flat part of the mould can be fused together (with more silicon), taking care as to not seal the air channels.

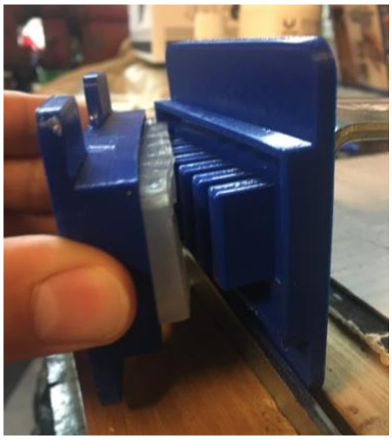


Figure 40: Demolding of final upper section

5. Curing

Leave parts on a flat surface for curing. Curing will take approx.. 15h. A faster curing can be achieved by leaving parts in an oven at about 50˚-70˚C.

6. Electronics and general assembly

Once the mechanical/soft robotic subsystems are finished, the electrical and pneumatic subsystems must be connected to the soft robotic parts. A tube must be glued into a hole punctuated in the soft robotic PneuNet device. This tube can attach to the quick connect fitting in the outside of the control box.

The pumps and solenoids (if necessary) need to be soldered so that they can be permanently tethered inside the box without reliability issues. The other side of the wires should be plugged into the MOSFET bank.

Connect all relevant pins to the Arduino, including the sensors. Connect the other end of the pins to the breadboard or relevant device. Solder any resistors onto the perforated circuit board.

Screw electrical components into enclosure so that they are secured.

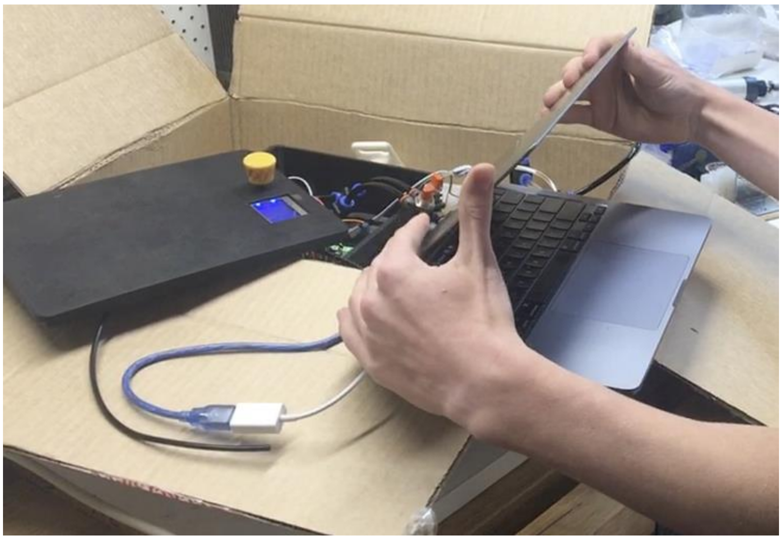


Figure 41: Assembly of electronics, programming of arduino in progress

Attach tubing to solenoids and pressure sensors. Attach tubing/anything else from the exterior (including the force sensor).

7. Programming of Arduino

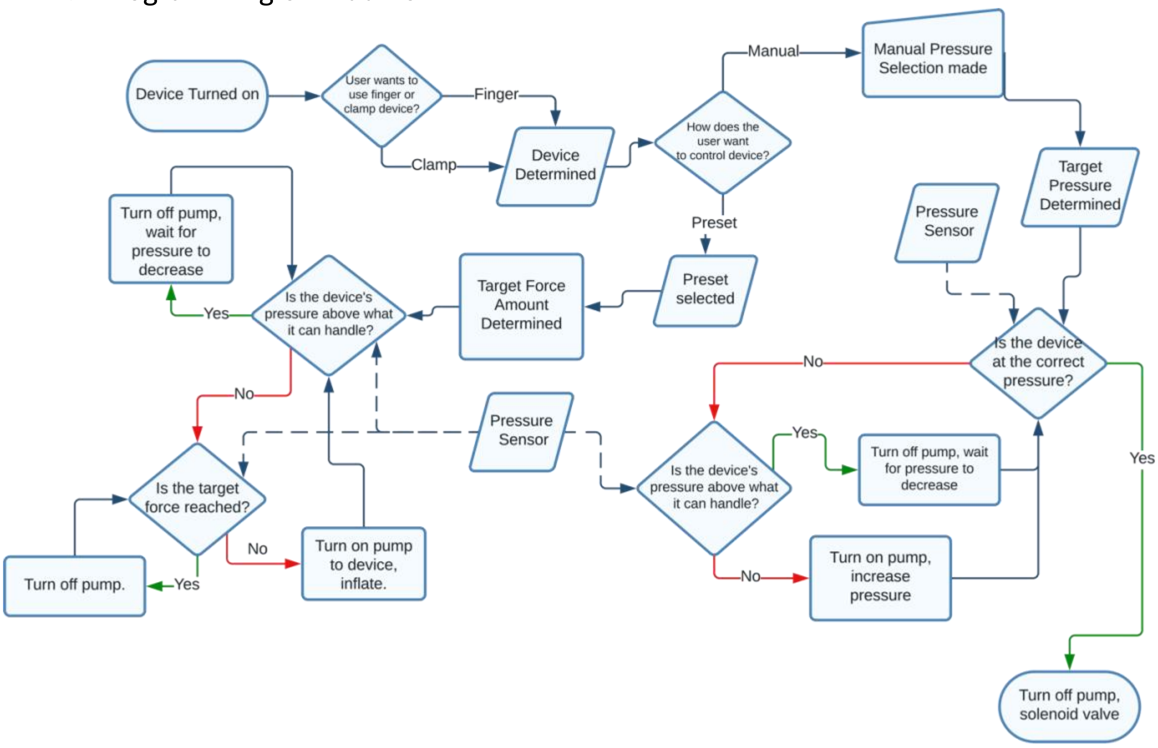


Figure 42: Flow chart of programming, feedback loops on Arduino microcontroller

https://github.com/timo-wilson24/Soft-robot-kitchen-assistant/blob/1f0e81280b5753aea2adc9df44ec5698dffbd508/Menu-screen-and-control-code.ino

I have open sourced all code I made in the

3.2. Has been tested in multiple conditions and or trials

3.2.1. Durability Experimentation

To optimise the durability of the device, I did a repetitive trial of the soft robotic 'finger' actuator. A program was used that counted cycles from 6PSI to 1PSI (relative) as this is about the working pressure of the device. I recorded 45 cycles for the larger device (first prototype) until a small air leak came from an air bubble in the silicon. Aside from the minor leakage, which was fixed with tape, there was some shape deformation over time which caused its rest position to be more inclined.

Factors to improve durability:

- Minimise air bubbles in manufacture of device
- Shape deformation -> vacuum feature of device to make actuator rigid and straight upright

Final product durability evaluation

The test was repeated for the final design, and 100 cycles (@1-6PSI) were recorded without any leaks (due to improved fabrication quality). There was some shape deformation, but it was still usable due to the vacuum feature which pulled device to horizontal. The pressure sensor had .8 PSI of offset which could be addressed by adding a reset button for the offset to the menu, but this amount is within the functional range of the device.
The clamp part of the device survived with no change for >100 cycles, likely because of its rigid design and limited complexity. The pump and motor also remained healthy, with no variation.

Results

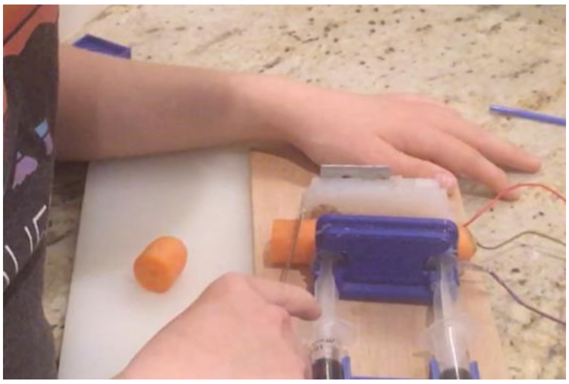
Devices	Cycles before issue or significant deformation (@6 PSI to 1 PSI)
Prototype (1st iteration) soft 'finger' actuator	45
Prototype (2nd iteration) soft 'finger' actuator	60
Final soft robotic 'finger' actuator	>100
Clamp device (rigid)	>100
Pressure Sensor	100
Pump	>100

Configuration of device for durability test

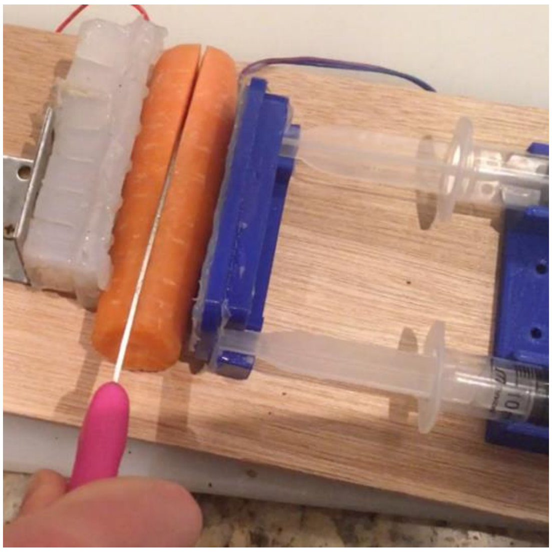
Figure 43: Durability test device configuration

3.2.2. Case Study 1: Grace (with Downs Syndrome)

The case study was performed with 'Grace' who has Downs Syndrome and so has decreased fine motor control in her fingers and an intellectual disability. I observed her cutting some vegetables to prepare a healthy pasta, including onion, carrot and potato. This revealed the difficulties faced by people with motor disabilities in preparing food (see full results in Section 2.3.1, especially relating to safety issues around the knife slipping into fingers and potentially causing injury).



After the product was fabricated, I conducted another observation experiment with Grace to test her improvements in using the device. I explained to Grace how to use the product and she seemed to understand how to operate the screen well and increase, decrease pressure. In using the clamp system, she attempted to prepare the same vegetables tried previously without the device. While using the clamp system, her grip and cutting was much more stable than previously. She had better control over her cuts because she could focus more on the movement hand that was cutting (rather than holding the vegetable). The only issue with the clamp device was that she instinctively felt that she had to hold the chopping board or hold the clamp to secure the device, so some suction cups should be added to the base to make it more stable.



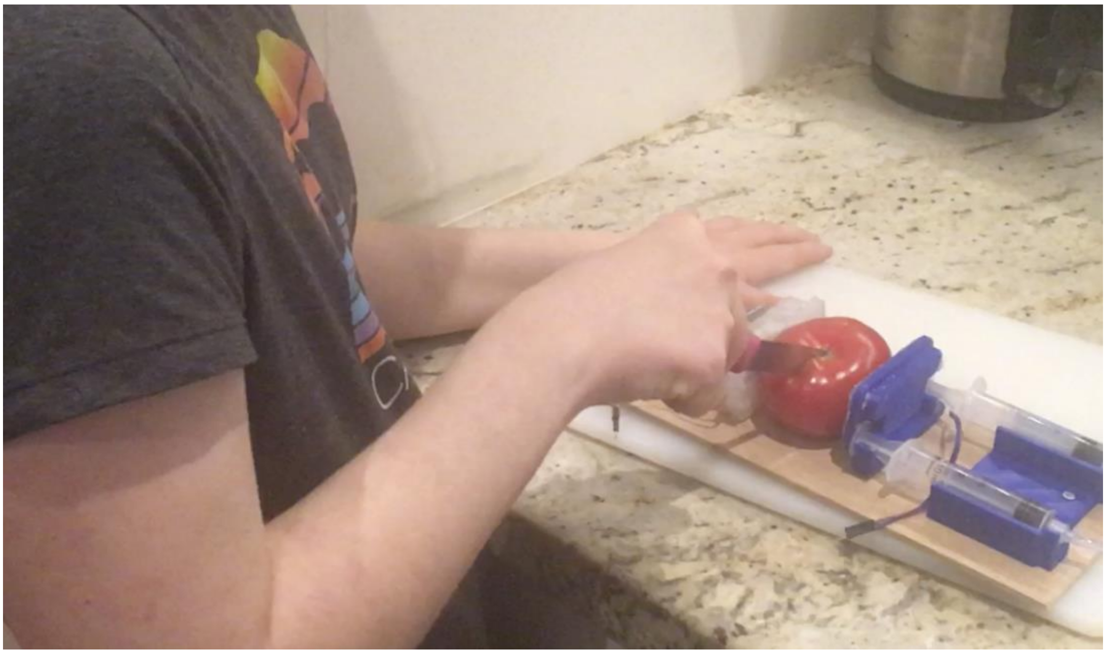
The device held the carrot very securely and had no movement of the carrot when slicing horizontally to slice it into pieces. It was noted that having a very high pressure on the device made it difficult for the user to chop the vegetable as it compressed the vegetable onto the knife. A lower pressure was preferred for vegetables that could be held at a high force even though it might create some minimal movement. The clamp was also good for slicing perpendicular to the carrot to dice the carrot (if necessary). The prototype used for this test was mounted on a small chopping board which made the use of the device a little clumsy, and a larger chopping board was used for the final prototype.

The slicing of the onion in the clamp device was effective and easy for the user. The removal of the vegetable to chop it into quarters was simple as all it required was the turning of the accessible knob. Similarly, to the carrot, a higher pressure made it difficult to chop the onion in half, so a moderate pressure was preferred. It was still sometimes difficult for Grace to cut directly down the middle, so a moving guide might be considered for another prototype/future improvement.

The cutting of a more delicate fruit – a tomato – was performed to test the device's effectiveness at all types of fresh produce The finger device was used to finely chop a tomato and it was mostly effective. It had a quite secure grip on the tomato, but it would occasionally slip. The not perfectly ideal compression force is because the curling of the 'finger' pulled the tomato towards the actuator base and reduced the force holding the tomato in place. The finger had to be used at close to its max operating

pressure to generate enough force to hold the tomato securely. The last section of the tomato was difficult to cut as the actuator slightly covered the last part of the fruit. This allowed Grace to finely slice the tomato for a healthy meal!

This was also trailed with the clamp device which worked fine on a low pressure and did not squash the tomato. As the tomato was easy to slice into, it was not hard to use in this setting. There were no safety concerns. Cutting the tomato with the soft actuator was effective as the device was more effective at a lower pressure.



3.2.3. Case Study 2: Telma (eldery person with fine motor difficulty and severe macular degeneration, also have arthritis)

Before doing any observational work with Telma, I conducted an interview to hear from her as to her issues. Here are some of the answers (paraphrased) that she provided about her experiences with fine motor and sight difficulties in the kitchen and how it has impacted her.

- I am 94 and have quite a bit of pain with my arms and shoulder. I cannot raise my shoulder, so everything in my kitchen needs to be low. It hurts to push too hard into vegetables as the shoulder is in pain. [I presume she has a form of arthritis in her shoulder, though this was not mentioned].
- I often cut myself when making food as my fingers are not so good. Because it is hard for me to see, I can't tell where the knife is and what size I am cutting. [She showed me the cuts on fingers].
- I make a lot of vegetables and mostly cook for myself, but it is still very hard to do sometimes. I have carers who help me out with other things, but they aren't here long enough to cook everything for me. Recently some simpler meals like porridge have been better as they are easier.
- I want to continue living on my own and I like living independently and on my own.

While with her, I asked her to cut some of the vegetables that she would normally prepare. This included a carrot, a cucumber, an onion and some beans. The video of her cutting in seen in my final video, see section 7.1. She used a very small knife with a small blade as it was easiest for her to hold as she had arthritis in her fingers. As she could not see the knife, her slices were quite random, and were often very large or quite thin. This also meant that she would cut very close to her holding hand without realising. More than once did she touch the knife to her 'gripping' hand and very nearly cut herself. This was compounded with the fact that she would sometimes shake a bit when trying to hold something carefully. Note her cutting style on the right. She was not able to cut through the carrot horizontally to make smaller carrot sticks as she was not strong enough and the knife wouldn't cover the whole carrot, so it would slip off. This was also a challenge with the cucumber.

Figure 44: Telma cutting a carrot (very close to her fingers!)

The cutting of the carrot was significantly easier with the device. This was because both hands could be used to guide and push down with the knife, so her strength improved. This also caused less pain on her part, as her right shoulder did not have to bear all the strain. Because of her poor eyesight, the sizing of pieces was still not very consistent, but it was easier for her to manage the knife and cut. In terms of safety, there was a vast and consequential improvement by using the device. It meant that even if the knife didn't cut close to the end, it did not risk cutting her hand as it had before. She was confident to cut without her hand close to the knife. There were no safety risk as she removed the chopped vegetable from the device also.

Despite being unable to cut the carrot horizontally before, by having the carrot in the clamp device, she was able to cut through it and was very proud of herself. She was able to use a larger knife as she could use both hands, and the device held it much sturdier than she had previously when attempting to cut it herself. The cucumber was also significantly easier and she made an almost perfect cut down the middle. This was helped by using the side 'jaw' of the clamp device as a guide for her hand so that she cut straight.

3.3. Uses an appropriate application of mathematical and scientific methods

Used of scientific experimentation throughout the project, such as in section 3.2.1, 3.1.2, 3.1.3. The device also used a feedback loop control system to effectively monitor and determine …
The use of mapping in the programming of the device meant that the pressure and force sensors were mathematically scaled to a linear graph, so that they are in a useful range and gradient. The mapping uses a function determined through the C++ code. An example of this is:

```
FSRval1 = map(FSR_value, FSRminForce, 1024, 0, (FSRmax + 1));
```

The above example maps the value for the force sensor, 'FSR_value', where the domain is between the variable 'FSRminForce' and the max for the sensor which is the largest 10 bit no. 1023 (1 is added to make 1024 as the domain is exclusive). The range of the function is defined as between 0 and the variable FSRmax (again 1 is added as the range is exclusive). The resulting FSRval1 is then a mapped value that is going to always be less than 'FSRmax', essentially constructing a function to return all values in that domain to be in a corresponding linear range based on the defined limits.

Utilizing the Harvard Design Process, I began by outlining the problem, drawing on scientific and mathematical data for a comprehensive analysis. This data-driven approach informed the ideation phase, where I employed mathematical models and scientific methods to generate and refine potential solutions. Throughout the iterative process, I consistently applied mathematical reasoning and scientific methodologies, ensuring a robust framework for problem-solving. Ultimately, this methodical approach resulted in a solution that effectively addressed the problem while demonstrating the practical application of mathematical and scientific methods in this project.

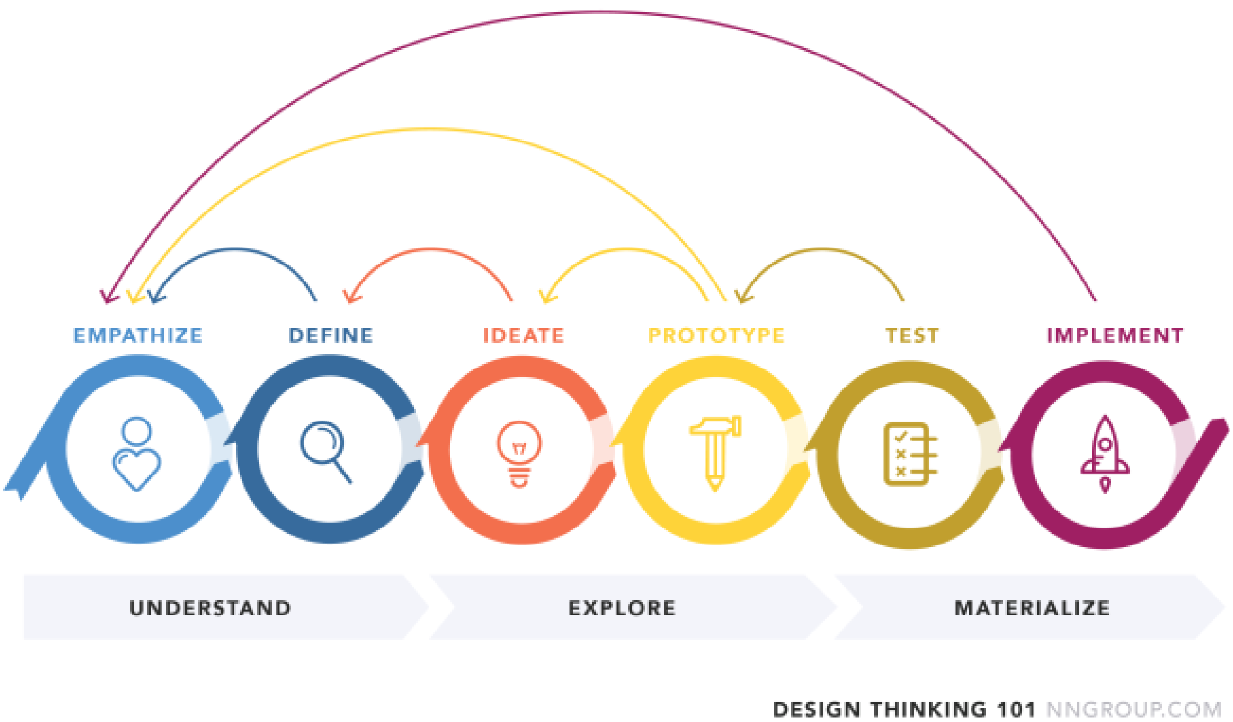


Figure 45: Harvard Design thinking process

3.4. Demonstrates engineering skill to develop a reliable and functional solution

The use of CAD, 3D printing, mould making and programming evidence engineering skill that makes this project an effective and functional solution. Furthermore, the improvement of the design through continuous experimentation also demonstrates engineering skill, especially given that the final product has improved on many of the factors originally designed for. The reliability of the solution is seen in section 3.2.1 and the functionality is both seen in the video (see section 7.1) and in the case study trials. The use of prototyping and testing of novel and innovative engineering design in the soft robotic components of the project is representative of significant engineering skill. The manufacturing process which produced a very functional solution is seen in section 3.1.

4. Creativity or Innovation

Significant creativity and or innovation shown in one or more of the aspects of the project

4.1.1. Individuality in Design Situation

Accessible devices is a large sector of the disability product market, and is popular among people with a disability as they help cater to their specific needs, also helping them to function independently. Despite this, not much care has been taken to reconsider the approach of the commercial sector. This leaves many people with a disability with minimal options. This problem is equally poor if not worse in the academic field where there is a greater bias towards disability rehabilitation, but less focus towards designing tools to assist people with their current living conditions. Elderly people are most affected by this, as there is often very little chance of their rehabilitation of disabilities. This is because most affecting disabilities worsen with age such as arthritis, macular degeneration etc.

Therefore, people with fine motor difficulties in the kitchen often do not have access or do not know about any solutions that they can access to help them. Additionally, there are rarely solutions that cater to their individual needs.

As a result of this, my project is unique and innovative as it addresses a problem not commonly thought about, researched or reapproached. By solving a problem that is less addressed and unique to a specific group of people, my project is much more likely to have a lasting and more meaningful affect on society and the individuals affected.

4.1.2. Unique design choices

The choice of mechanisms and overall design that I have solved this problem with has made for an innovative and successful solution in a way that has not been done before. There are no existing solutions for this exact issue which solve the problem by using robotic gripping technology of any kind. The use of a 'clamp' mechanism is common, but it is mostly moved by hand and locked by closing the device. By making it fully automatic by using pneumatic cylinders, the device can hold food much stronger and with great ease for people with strength. This is important as it means that the device can be more effective for a wider audience.

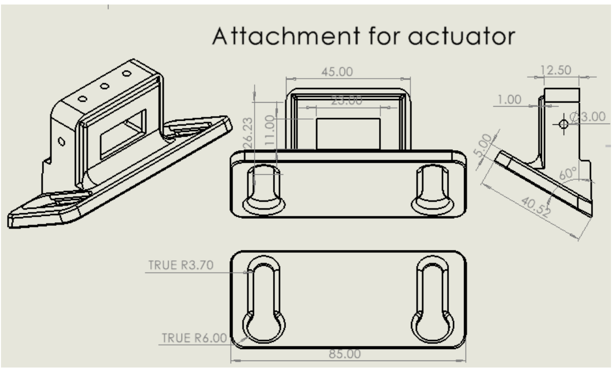
Another unique feature of my chosen solution is the soft robotic gripping finger. Soft robotics is commonly used for finger rehabilitation, and for industrial grippers, but used less with accessibility as soft robotics is an emerging field. The solution is not just unique but innovative because it solves the problem more effectively than current solutions. There are limited solutions which hold the fruit 'top down', and even more limited are solutions which are soft and therefore pose very limited risk of injury for the user. The biomimicry of a human finger means that it is also more intuitive to use. This is relevant for individuals in the target market who also have an intellectual disability, as making something simple and intuitive will make it easier for them to understand how it works.

Figure 46: Evidence of device's biomimicry (source: EurekAlert!)

The programming and GUI is unique and provides an easy-to-use menu for the user. There are little solutions for scrollable menus with a rotary encoder in Arduino, so much of the code was self-made. By making an interface on a small LCD screen, the user has an interface which is viewable and can change many aspects of the design. There includes function in the menu such as: preset, mode, device switching, manual mode, reset all controls, backlight and sleep mode.

The ability to use my device completely one-handed makes it very unique compared to existing solutions which often require two hands to adjust or operate.

Furthermore, by making all the key mounting parts for both devices removable the device is much easier to clean. The finger device has a unique keyhole feature which means it can be securely fastened and not move but can be removed by sliding it towards one end. By making this unique mounting, I have made the device easier to operate and maintain and overall, a better solution. See the design on the right.



4.1.3. Creativity in design process (to solve problems)

Throughout the design and production of the process, I encountered many problems which required creativity and lateral thinking to overcome. The first of which was the mechanical design of the clamp component. Originally, I had planned to make the clamp device also fully soft. While prototyping a soft linear extension, I ran into problems with the folding of the actuator not functioning correctly. After doing some more trials evidenced in section 3.1.2, I decided that it was not within the scope of my project for me to design and produce the soft extension. Therefore, I decided to investigate how I could integrate and make a rigid actuator safe.

I sourced some syringes and realised their potential as the actuator. To use the syringes, I designed a holder which was snap to fit, so it needed no screws or bolts

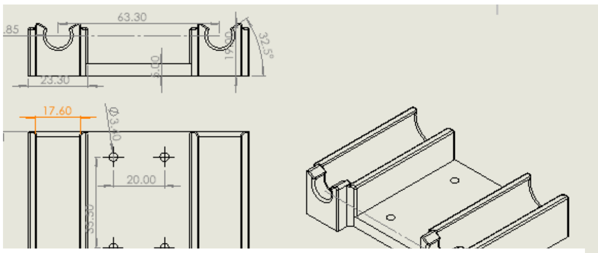


Figure 47: Close up of clamp device engineering drawing

to assemble. This vastly reduced prototype time and makes it much easier to assemble. See design on the right.


Figure 48: Close-up of clamp device

To make this safe for the user and so that the fruit/vegetable would not get damaged in the use of the device, I made another soft silicon 'jaw' which was attached to the chopping board base. See Figure 41.

To integrate sensing into the actuators, so that I could monitor and control the amount of pressure applied to the fresh produce, I inlayed the sensor in the silicon actuator. This was unique as it also allowed the sensor to double as a strain-resistant layer. This is not a process commonly used for sensing on soft actuator devices.

5. Conclusion and Discussion

5.1. Evaluates the potential impact of the prototype or model for engineering, applied science and/or for society

5.1.1. For Engineering, applied science

The development of this project contributes valuable insights and practical applications to the field of soft robotics, particularly in the context of assistive technology.
The integration of rigid and compliant systems, particularly in the mounting of the soft ‘finger’ actuator and the ‘jaws’ of the clamp are effective demonstrations of how soft robotics can be used to enhance rigid and more conventional robotic systems. It also offers a point of comparison between pneumatic rigid systems and compliant systems, demonstrating how both systems can be used concurrently in a solution to deliver safe independent living. In doing so, the device will meaningfully encourage other research into more modular/movable mounting for the commercial application of soft robotics.
The research and development to the PneuNet ‘finger’ actuator and rigid clamp are now open sourced, so anyone looking to prototype similar solutions or looking into optimise the PneuNet model for similar or different applications have a knowledge base and CAD files which can be used to reproduce the project.

5.1.2. Social Impact

The social impact of my device is significant. It directly addresses the practical needs of individuals with fine motor disabilities, enhancing their independence and enabling them to participate more actively in daily life, particularly in culinary activities. This has a direct positive effect on their quality of life, providing them with a sense of autonomy and dignity. In my family directly, it has meant that my sister (who has Down Syndrome) can cut vegetables with confidence and participate more in the making of her meals, rather than being too afraid to cut, or there being safety issues in her chopping of fruit/vegetables.

A functional societal should care for and assist those most vulnerable, so when fine motors disabilities significantly affect the diet of this group of people, something must be done to address this. As the device makes it easy for people with a fine motor difficulty to prepare healthy meal options, widespread use of the device will improve public health and therefore better society. At present, limited solutions address the challenge of preparing fresh produce and accessibility remains a significant concern. These devices often fall short in effectively accommodating the diverse array of culinary tasks and the wide range of fruits and vegetables encountered in daily meal preparation. The need for an innovative and comprehensive solution that caters to a broader spectrum of disabilities and culinary needs becomes apparent in this context.

Moreover, this device has the capacity to challenge prevailing societal attitudes towards disability by demonstrating the competencies of individuals with fine motor disabilities. It can play a role in shaping a society that not only embraces diversity but actively promotes inclusivity and equal opportunities for everyone. In essence, the social impact of this device spans from immediate enhancements in users' lives to the prospect of enduring societal transformation and technological progress.

5.2. Demonstrates understanding, interpretation and limitations of the product/solution

5.2.1. Evaluation of limitations relating to criteria for success:

1. Safety: The clamp component/device is strong when on a high setting, so adding another failsafe to the control system such as a second button needing to be clicked to activate higher pressure might be a good idea. A new device mode restricting max pressure more could also be explored to improve overall safety.
2. Function: The function of the clamp device is effective, but it could be improved if the chopping board it was mounted to was secured to the kitchen bench. This problem is easily solved with suction cups or a clamp fixture to the bench. The soft robotic bending actuator does not have too much compressive power which can impact the device's performance on harder or more slippery vegetables. Making the finger apply the compressive force more uniformly downward would also assist in
3. Food Safety: There is some risk to food safety due to the open ports on the Arduino, which could get food in them and be impossible to remove. Covers should be considered. The actual device in contact with the food uses only food safe materials and has no issues.
4. Adaptability: Perhaps greater range adjustments for finger device, to make it more adaptable for taller vegetables, and for some flat vegetables such as asparagus.
5. Integration with Kitchen: Control box is quite large, so reducing the size would make it integrate more with the situation and be less intrusive
6. The cost of the production is quite high as I had to buy lots of wires, resistors etc. I think without labour costs, the product costs less than $100 which mostly fulfills my aim, but some cheaper materials should definitely be considered.
7. Aesthetics: No, the product doesn't look very aesthetically pleasing, and is instead a little obtrusive due to its current bulky size. The colour and mainly standard design means it is not 'loud'.
8. Material: the print material is about moderate quality and could be improved with some sanding. Happy with material selection for the soft actuator
9. Maintenance: Most of the design can be easily cleaned, but making the tubing easier to disconnect from the control box would make the maintenance and potential deep cleaning easier.
10. Ease of Use: currently no second input method which for people who are blind, or for people who have no way to control the rotary knob. Some users may require a different design to the control knob such as the addition of a lever that they could push rather than turn.

5.3. Demonstrates depth of understanding in relevant concepts, structures and processes

See technical explanations of concepts, components in section 2.3, 2.4. General understanding of scientific process evident in section 1-3 and the video as I explain the process and the case study. The understanding of scientific structures and design is seen in the experimentation of the project, with multiple case studies and experiments, see section 3.2 and section 2.1.

5.4. Suggests meaningful and relevant ideas for further research and development

5.4.1. Future Research

In the future, I hope to expand on the electronic control of the pneumatic system of the device. This might mean potentially using more solenoid valves, or more reliable solenoid valves, so that there is no need to rely on any manual valves for normal operation. I think using a harder silicon material would be more effective at holding down the fruit/vegetable when using the finger device, as there is a little bit of a force limitation from the soft material bulging. Additionally, it would be wonderful to see more research done into soft robotic linear actuation with origami, as it would be a safer alternative for my clamp device to have a completely soft system (across both devices!). Lastly, some future progress could be made in more user group testing with the appliance, identifying from their suggestions the best ways to move forward with further assistive innovations. This could include better designed controls for the interface system with a larger screen, or using different input methods. This could involve voice control, larger buttons, or even a joystick.

5.4.2. Other Applications of Design

The device can be used for plenty other user groups in the kitchen – for example it could make the chopping of vegetables in a professional kitchen more efficient or safer. For fast food restaurants where efficiency and safety of (often) not highly skilled workers is key, this device could be used to minimise risks of injury. It could also help with allowing the employment of people with a fine motor disability in the hospitality industry, making a big difference financially on their lives.

In other applications aside from the clear kitchen application, the device could be used in the workshop setting for automating the holding of fine parts. This could be for electronics, where clamps and soft holders are often needed to allow for steady soldering and the attachment of parts. Additionally, the device could be scaled up to a larger workshop setting and be used as an automated clamp and holder for woodworking for people with a motor disability.

6. Presentation and communication

6.1. Addresses purpose and audience

As of the purpose for the project, this is addressed in section 1.1, 1.3. The purpose academically is set out throughout this paper, as I have both open sourced the paper and my results as well as clearly explaining my methodology.

In terms of the audience of the paper, concise style of the paper, along with detailed explanations of decisions will enable future researchers to be able to replicate the project and use parts of the project for future research. Additionally, the open sourcing of the project's CAD and code allows other researchers to easily continue on my work.

The audience of the device is explained in section 1.1. To directly address those who might use or buy the device developed, there is an accompanying user manual:

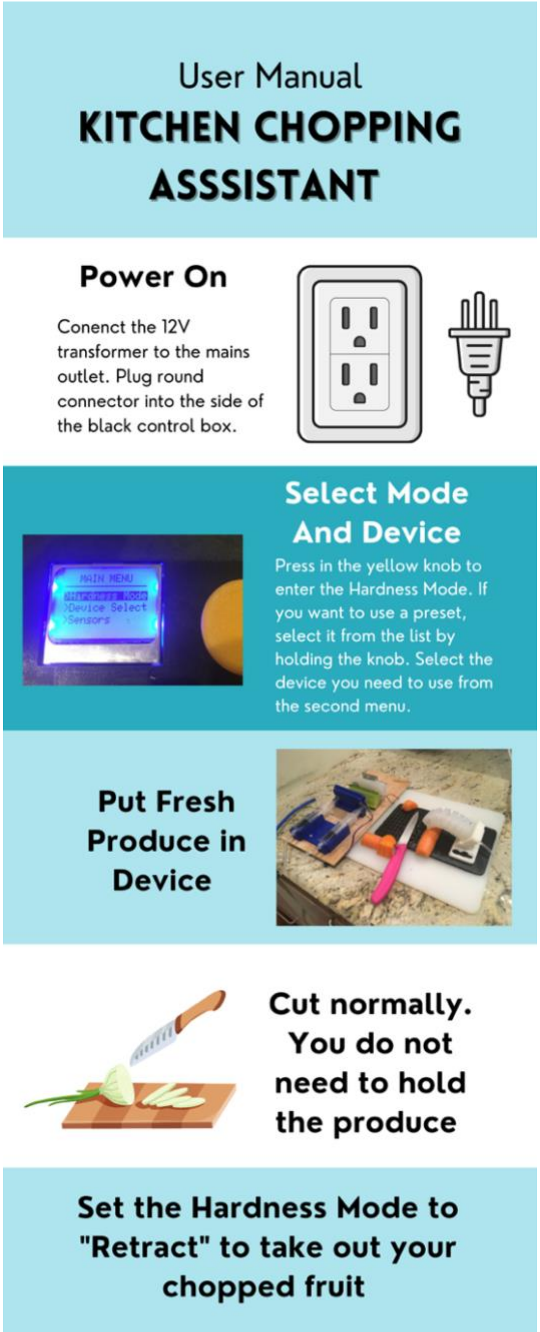


Figure 49: User Manual

6.2. Demonstrates logical organisation of material

Through the ordering of material, naming of figures, and the structure of this paper with clear sections, it is evident that I have logical material organisation. The material of this paper is roughly organised using the Harvard School's design thinking process of:

6.3. Has clearly illustrated initial ideas and all design stages to the final design

The progression of the design process is clearly detailed in the time planning and general ideation in section 2.1. Further illustration of the development of initial ideas is displayed in initial concept sketches which highlight my design thinking and early development in Section 3.1.4.

The decisions at each of the design stages are detailed and have continual evaluation in the process. This includes research (1.2-1.4, 2.4), material choice (2.2), time planning and general plans (2.1, 2.3), construction in section 3, and the evaluation of the final product through scientific experimentation and conclusion (3.3, section 5).

Further evidence of the prototype and design process are seen at the end of the video (see section 7.1).

6.4. Provides evidence of a high degree of independence of the student

The project was completed independently, this is clearly evidenced in:

- Videos made during the prototype stage (seen in the final video linked in …) . These show explanations of design process, challenges I faced and the reasons behind the final design choices.
- The research on topic (both primary and secondary) and clear explanations in other sections demonstrate understanding of concept, and display my individual and thorough design process.
- Explanation of methodology in section 2 detail a good understanding of topic and decisions.

Despite the project being completed largely on my own, I would like to thank the contributions of: my parents in helping with difficult parts of construction that required two people, in assisting filming parts of the video and for their help in funding their project; and my DT teacher for helping guide me on my project path.

7. Evidence of Project, Media of Final Product

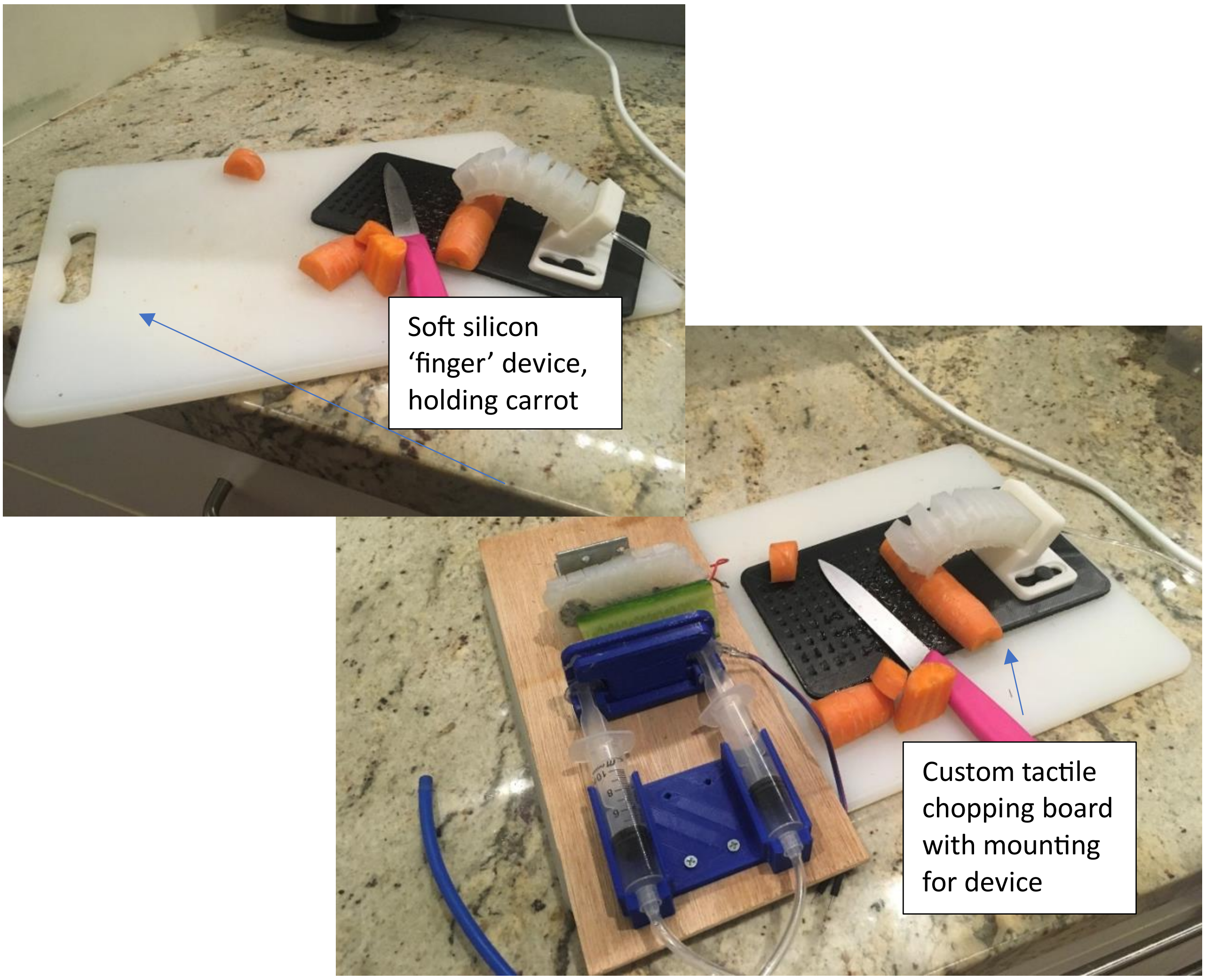
7.1. Video:

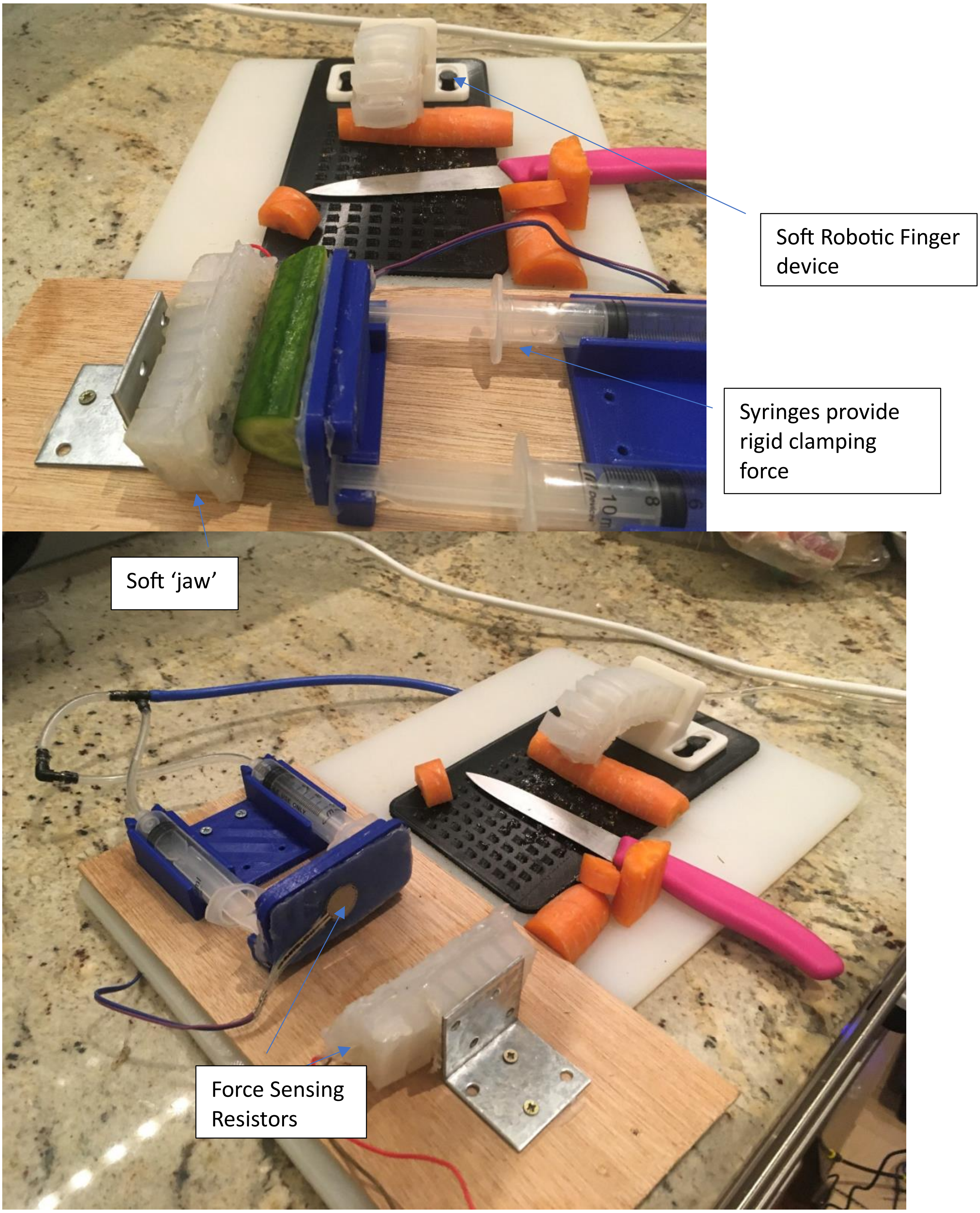
YouTube link:
https://youtu.be/T2KDRH2tRoQ

Google drive:
https://drive.google.com/drive/folders/1qww55SaSp3BqxEDuzN_p_HGzx8bOS1_8?usp=sharing

[In case YouTube link does not work]

7.2.Other Photos of Product:





Soft Robotic Finger device
Syringes provide rigid clamping force
Soft 'jaw'
Force Sensing Resistors

Device User Interface/menu

7.3. CAD, Engineering Drawings

See all CAD and engineering drawings of product in section 3.1.5

8. References

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