# DESIGN AND DEVELOPMENT OF MULTIFUNCTIONAL SOFT ROBOTIC SYSTEM
# (MIMICKING OCTOPUS MOTION)

## 21MHP302L MINOR PROJECT

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*In Partial fulfilment for the degree*

*of*

**BACHELOR OF TECHNOLOGY**

in

**MECHATRONICS ENGINEERING**

of

**COLLEGE OF ENGINEERING & TECHNOLOGY**

SRM
INSTITUTE OF SCIENCE & TECHNOLOGY
(Deemed to be University u/s 3 of UGC Act, 1956)

S.R.M. Nagar, Kattankulathur, Kancheepuram District

**May 2025**

**SRM INSTITUTE OF SCIENCE AND TECHNOLOGY**
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# BONAFIDE CERTIFICATE

Certified that this project report titled **"Design and Development of Multifunctional Soft Robotic System"** is the Bonafide work of **U Aditya[RA2211018010022]**,and **Anugrah Samuel Frank [RA2211018010042],** who carried out the project work under my supervision. Certified further, that to the best of my knowledge the work reported here is based on which a degree or award was conferred on an earlier occasion on this or any other candidate.

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# ABSTRACT

This project explores the design and production of an octopus arm-mimetic soft robotic gripper for agricultural use with multifunctional capability. The aim is to create a system that can pick fragile fruits and vegetables without inflicting mechanical damage. The suggested design is six soft, pneumatically actuated silicone arms with suction cups to facilitate adaptive gripping and flexibility. The project overcomes the limitations of rigid grippers in dealing with fragile produce by embracing the principles of soft robotics and bioinspired engineering.

During the project, significant effort was spent on fabrication and design. The original 3D models were made in SolidWorks, and further mould preparation and design for silicone casting were carried out. Moulding tests were also conducted using clay and tape as a seal for the moulds, but repeated silicone leakage made it difficult to achieve clean, usable casts. One finger was successfully made, though it did not have good enough performance for strong grip. At the same time, finite element simulations were conducted in ANSYS on the original design to calculate stress, strain, deformation, and safety margins. The simulation results were used to calculate mechanical points of weakness, and this resulted in redesigning the gripper structure.

Unfortunately, because of time and resource constraints, the new design could not be physically prototyped. The results of the fabrication experiments revealed both the strengths and weaknesses of the design. While no functional and assembled gripper was the result of this phase, the project proved successful in providing proof-of-concept feasibility and a solid comprehension of the materials, geometry, and mechanics of soft robotic systems. This will serve as the foundation upon which to base future improvements and develop a soft robotic gripper optimized for application in agricultural environments.

Keywords—Soft robotics, Silicone gripper, Finite element analysis (FEA), Agricultural robotics, Octopus-inspired gripper, Pneumatic actuators

# ACKNOWLEDGEMENTS

It has been a great honor and privilege to undergo **B. Tech** in **MECHATRONICS** at **SRM Institute of Science and Technology**. We are very much thankful to the **Department of Mechatronics, SRM Institute of Science and Technology** for providing all facilities and support to meet our project requirements.

We would like to thank our Head of Department **D.T.MUTHURAMALINGAM, M.E., Ph.D** and our project guide **Dr. Ranjith Pillai R, M.E., Ph.D.** for their invaluable mentorship, continuous encouragement, and constructive feedback during every phase of the project.

We are also thankful to the **Department of MECHATRONICS** for providing the necessary resources, laboratory facilities, and technical support that made this work possible.

We acknowledge the support of our peers and colleagues who assisted us during the fabrication, simulation, and analysis processes, especially during critical troubleshooting stages.

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# ABBREVIATIONS

| Abbreviation | Full Form |
|---|---|
| CAD | Computer-Aided Design. |
| FEA | Finite Element Analysis |
| ANSYS | American engineering simulation software developer |
| FOS | Factor of safety |
| PLA | Polylactic acid |

# CHAPTER 1

# INTRODUCTION

The evolution of robotics has led to a growing interest in systems that can mimic the flexibility and adaptability of biological organisms. Soft robotics represents a allows for dynamic deformation under various forces. This capability is especially useful in fields like agriculture, where sensitive produce must be harvested and handled with care.

This project focuses on developing a multifunctional soft robotic system specifically aimed at addressing the limitations of conventional agricultural grippers.

## 1.1 Background

The theoretical significant advancement in robotic design by enabling robots to interact safely with their environment and handle delicate objects without causing damage. Unlike traditional rigid robots, soft robots are constructed using highly elastic materials such as silicone, which background for soft robotics is drawn from nature in the forms of organisms like octopuses, starfish, and elephant trunks—all of which demonstrate remarkable flexibility and environmental compatibility. Over recent years, the paradigm of soft robotics has been coming of age through advances in material science, pneumatic actuation, and additive manufacturing. As opposed to traditional robots with predefined joints and sections, soft robots tend to use fluid or pneumatic activation, which is achieved by swelling or shrinking silicon chambers to achieve motion. Through this, they can fit different types of tasks such as gripping, crawling, as well as fitting themselves around items of different dimensions and textures.

Automation in farming has, up until now, used mechanical grippers and mechanical arms to do harvesting and sorting. Nonetheless, these systems tend to be too rigid and may bruise or crush sensitive produce. The adoption of soft robotic systems in agriculture presents an attractive solution to such an issue by presenting compliant manipulation ability. **Fig 1.1** shows the potential of soft robotics in handling fragile objects. However, regardless of their potential, soft robotic grippers continue to have several major challenges regarding design reliability, fabrication consistency, and sealing of materials. **Figure 1.2** shows the design of soft robotic design mimicking its crawling capabilities. Such issues provide the foundation for this project's exploration and experimental development.

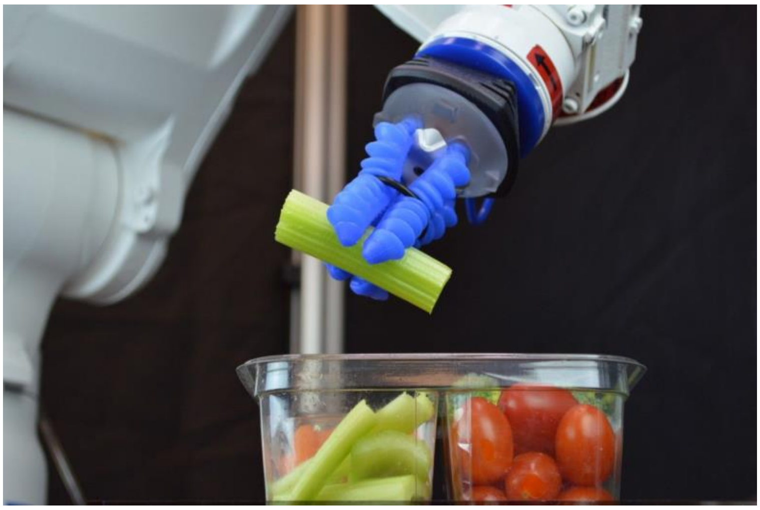

***Figure 1.1 Application of Soft Gripper in Agriculture***

***Figure 1.2 Crawling Application of Soft Robot***

## 1.2 Challenges in Existing Systems

Conventional robotic systems employed in industrial automation are mostly constructed using stiff mechanical parts. **Figure 1.3** shows the difference between soft robots and rigid (hard) robots. Although these systems work well for structured environments and repetitive tasks, they have several limitations when applied to unstructured and delicate areas such as agriculture. **Figure 1.4** shows the soft robotics are characterized by flexibility and safe interaction, whereas rigid robotics, known for durability and precise control, highlight their respective material usage and applications .The main issues in current robotic grippers and manipulators for agricultural applications are:

- Lack of Compliance

Traditional robotic grippers are stiff and do not have the flexibility to adapt to irregular shapes, hence not appropriate for dealing with fragile crops like fruits and vegetables. This tends to result in damage of the produce during harvesting or sorting operations.

- Safety and Interaction

Stiff robots are unsafe to operate in close contact with humans or soft biological tissue. Their inability to provide adaptive feedback makes them more prone to unintended collisions or over-force application, making them less appropriate for coexisting human-robot environments.

- Limited Adaptability

Most current robotic solutions are task- or object-geometry-specific. Agriculture, however, deals with a large range of shapes, sizes, and textures. Rigid systems have difficulty dynamically adapting to these fluctuating parameters without considerable reprogramming or mechanical realignment.

- High Cost and Complexity

Majority robotic systems with sensors and adaptive capabilities are costly and complicated to implement. For small-scale or low-income farmers, the cost and learning curve of such technologies can be prohibitive.

- Inefficiency in Unstructured Environments

Greenhouses and fields are unstructured and uncertain environments. Weather conditions, soil variability, and disparate plant geometries render it hard for stiff robots to act repeatedly without frequent human intervention and calibration.

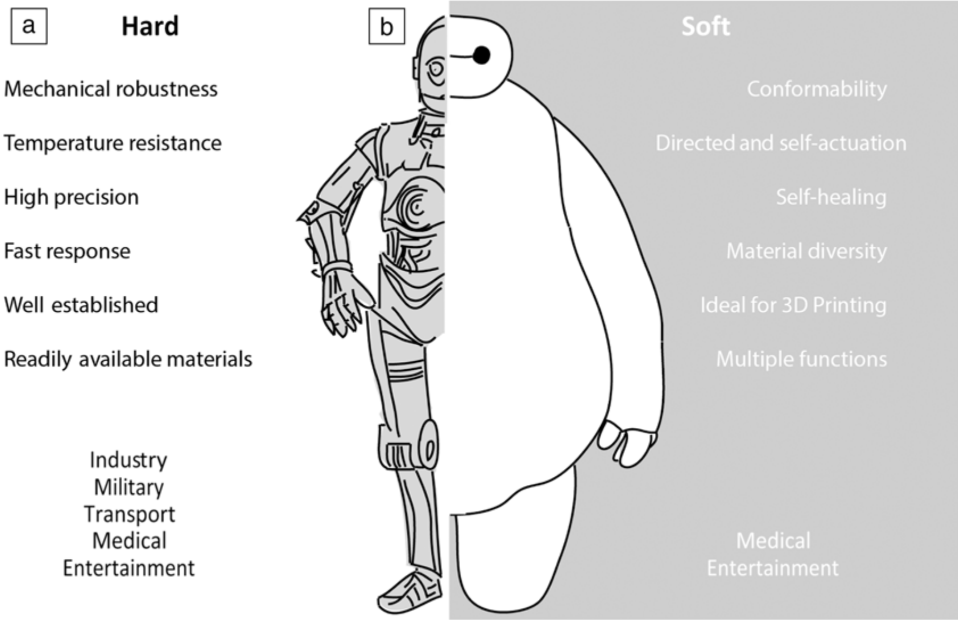


***Figure 1.3 Difference between Hard and Soft Robot***

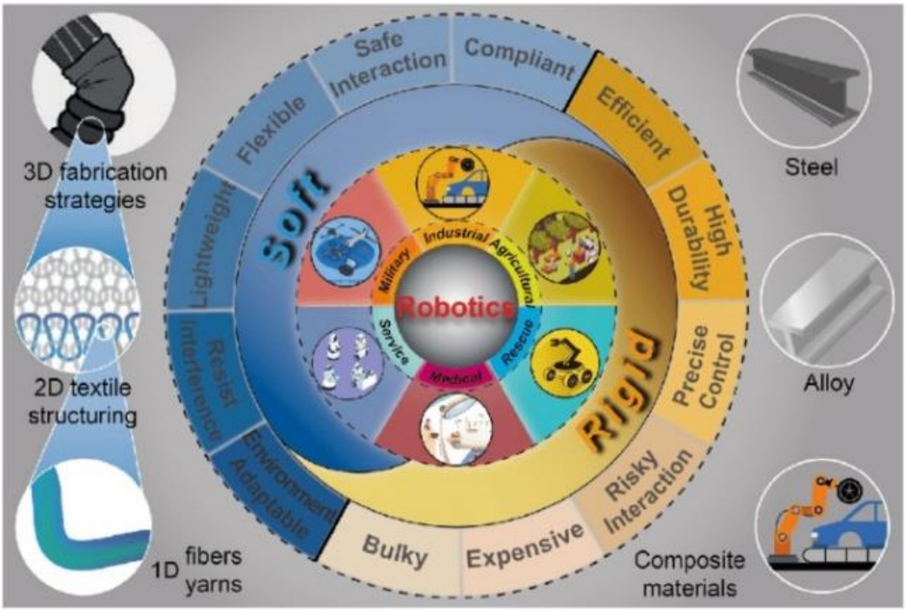


***Figure 1.4 Advantage of Soft Robots over Rigid Robot***

## 1.3 Applications

The designed soft robotic system with multifunctionality has widespread applications, particularly in the fields that demand flexibility, gentle handling, and safe human-machine interaction. **Figure 1.5** shows the gripping of fruits by soft robotic gripper in industrial level and **Figure 1.6** shows how soft robots are used for leg rehabilitation in the medical sector.The primary field of application is agriculture, but its design and functional principles also render it suitable to be transferred for application to other things.

- Soft Fruit and Vegetable Harvesting:

Its soft gripper can gently harvest soft produce such as tomatoes, strawberries, and grapes without bruising or mechanically harming them.

- Automated Sorting and Packaging

Its compliant fingers can be applied to produce shapes and sizes, facilitating post-harvest processing and packaging.

- Crop Inspection and Monitoring

With the integration of sensors, the robotic system can activate plants to help diagnose disease or monitor growth without harming the crops.

- Biomedical and Healthcare Rehabilitation Devices

The technology of soft actuation can be applied to therapeutic gloves or rehabilitation devices for mobility-restricted patients.

- Handling Fragile Objects

In manufacturing and logistics, soft robotics can assist in handling glassware, electronics, or other fragile components.

- Human-Robot Collaboration

The system's compliant nature makes it suitable for environments where humans and robots work together, reducing the risk of injury.

*Figure 1.5 Application of Soft Robot in Food Industry*


*Figure 1.6 Application of Soft Robot in Medical Sector*

## 1.4 Need for the Project

The increasing demand for automation in agriculture and other sensitive fields highlights the limitations of traditional rigid robotic systems.

These systems are often incapable of safely and effectively interacting with soft, fragile, or irregularly shaped objects. This project addresses a crucial need for a cost-effective, flexible, and safe robotic solution that can operate reliably in dynamic and unstructured environments.

Key reasons highlighting the need for this project include:

- <u>Handling Delicate Agricultural Produce</u>

Current robotic systems often damage crops due to their rigid structures. A soft robotic gripper mimics the natural compliance of human fingers, reducing damage during harvesting and handling.

- <u>Labor Shortage in Agriculture</u>

With a declining agricultural workforce, there is a strong push towards automation. However, most existing solutions are either too expensive or not adaptable to varying crop types and conditions.

- <u>Low-Cost and Scalable Solutions</u>

The proposed soft robotic system uses accessible materials and simple fabrication techniques, making it suitable for widespread use, even in small or medium-scale farms.

- <u>Advancements in Soft Robotics</u>

Recent research shows promise in soft robotics for applications that require adaptability and safety. However, there remains a gap in translating these developments into practical, field-ready tools. This project takes a step toward bridging that gap.

- Cross-Disciplinary Innovation:

By combining elements from biology, materials science, mechanical engineering, and robotics, this project serves as a platform for innovation in both academia and industry.

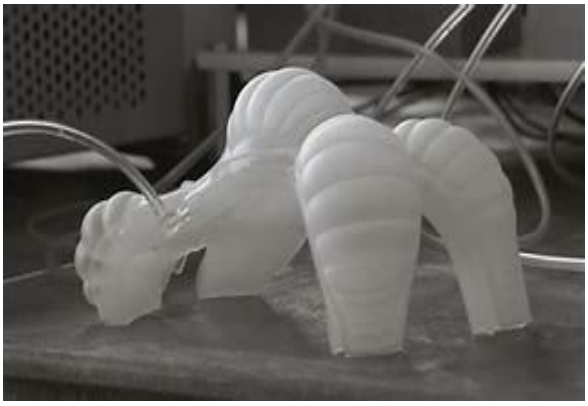

***Figure 1.7 Application of Soft Robot in Exploration***

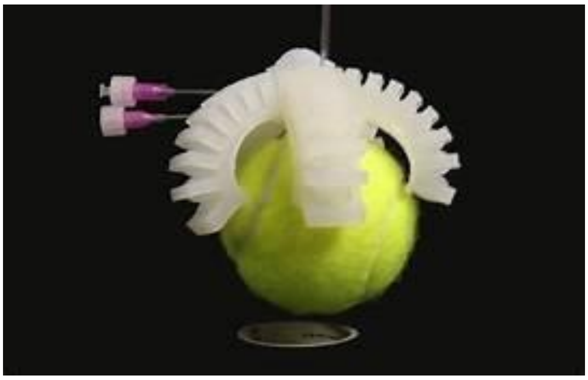

***Figure 1.8 Gripping Capability of Soft Robot***

## 1.5 Objectives of the Project

The specific objectives of the project are as follows:

- To explore the potential of soft robotics in agricultural handling tasks
- To design a bioinspired soft robotic gripper capable of gently grasping a variety of agricultural

products

- To validate the mechanical behaviour of the gripper using CAD modelling and structural analysis tools (SolidWorks and ANSYS)
- To fabricate a prototype using silicone moulding techniques and explore alternatives for sealing and material shaping
- To document the challenges encountered during moulding, sealing, and actuation trials
- To analyse the experimental results and suggest future directions for development and improvement

## 1.6 Methodology

**Figure 1.9** shows the methodology adopted for the design and development of the multifunctional soft robotic system followed a systematic and iterative approach. The overall process is illustrated in the flowchart and elaborated in the following steps:

- <u>Literature Review and Problem Framing</u>

The project commenced with a thorough literature review to investigate current trends, technologies, and limitations in soft robotics, particularly in agricultural applications. This phase helped in identifying research gaps and formulating a well-defined problem statement to be addressed by the proposed robotic system.

- <u>Conceptual Design and CAD Modelling</u>

A bio-inspired soft robotic finger was conceptually designed based on anatomical principles and application needs. CAD tools such as SolidWorks were used to model the soft actuator components. This visual representation served as the basis for structural analysis and physical prototyping.

- <u>Structural Analysis</u>

Finite Element Analysis (FEA) was conducted to study the stress distribution and deformation behaviour of the soft actuator under simulated loads. This analysis helped evaluate the design's structural integrity and informed necessary revisions before fabrication.

- Fabrication Trials

Multiple fabrication techniques were explored, including the use of clay moulds, silicone casting, and sealing with various tapes, to create the soft finger prototype. Due to challenges such as leakage and mould imperfections, several iterations were required. These trials were essential in developing a feasible and repeatable fabrication method.

- Testing and Evaluation

The fabricated prototype underwent basic functional testing to evaluate parameters like flexibility, durability, and gripping ability. While the initial finger was not perfect for effective gripping, these tests revealed design limitations and areas needing improvement.

- Decision Point

Based on evaluation results, a decision was made on whether to proceed with documentation or return to an earlier phase for redesign. Due to time constraints, the team chose not to perform additional 3D printing but instead documented design revisions and recommendations.

- Documentation and Future Recommendations

The methodology concluded with the preparation of detailed documentation summarizing all activities, findings, and challenges. Recommendations for future work included improved mould design, use of advanced sealing materials, and automated fabrication for scalability.

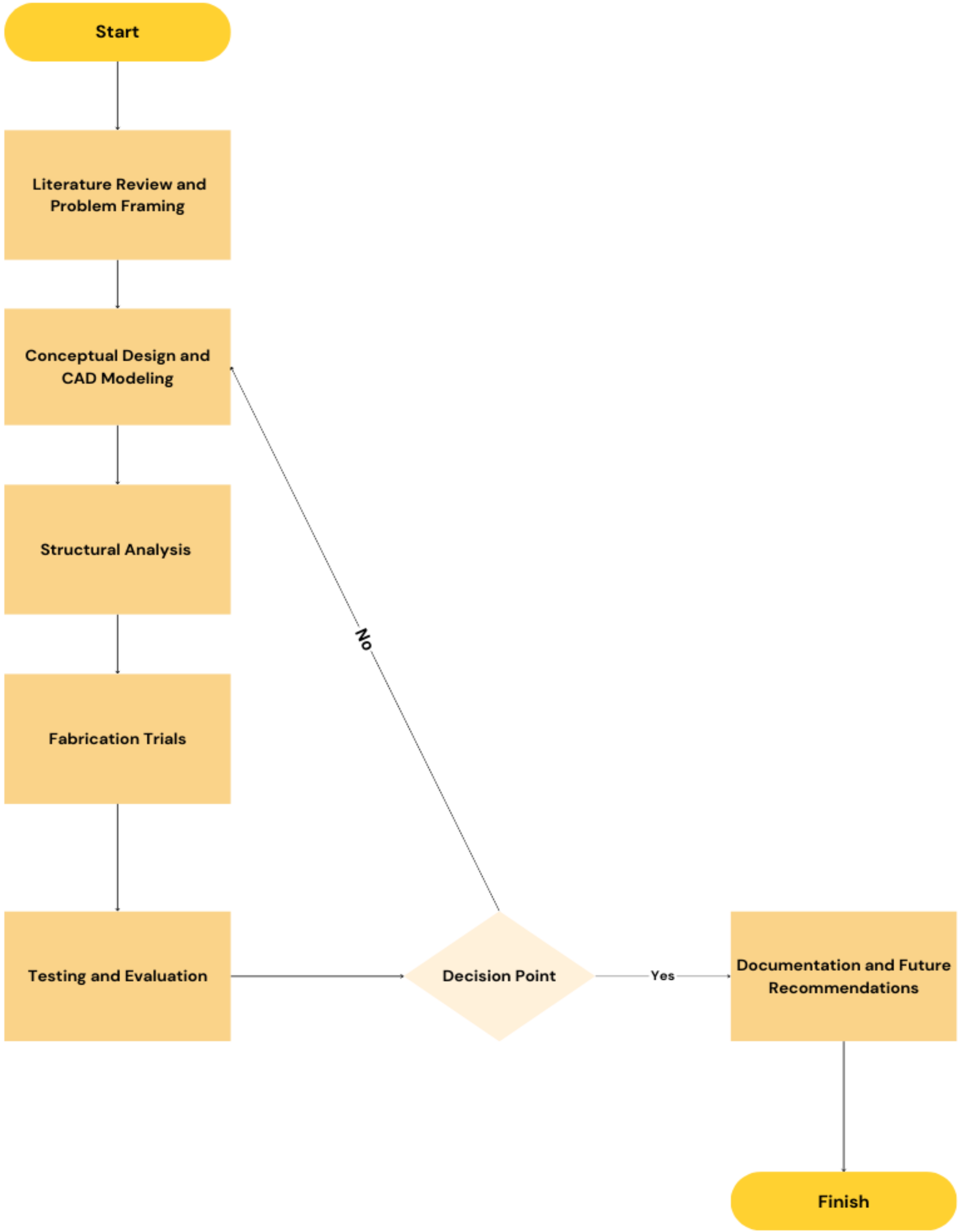


*Figure 1.9 Sequence of Operations Performed for developing Soft Robot*

# CHAPTER 2

# LITERATURE SURVEY

## 2.1 Survey 1

The focus of current robotics research is on creating systems with increased flexibility and adaptability, especially for interacting with delicate and unstructured environments. Traditional rigid robots often struggle with tasks requiring a combination of strength, precision, and adaptability, such as underwater exploration, agricultural automation, and medical surgery [1].

Researchers are increasingly drawing inspiration from biological systems to overcome the limitations of rigid structures. The octopus's arm, with its complex locomotion and manipulation capabilities, has become a particularly valuable model for soft robotic applications [1]. **Figure 2.1** shows the three-segment soft manipulator arm design element . Early research explored continuum robot arms inspired by cephalopods, and subsequent studies have demonstrated the potential of mimicking cephalopod morphology to enhance robotic flexibility and dexterity [1].

The development of new materials and actuation mechanisms has been crucial in advancing soft robotics. **Figure 2.2** shows the 3d printed molds employed in the fabrication of the soft manipulator arm: (a) linear chamber molds, (b) helical chambers molds. The integration of soft sensors within robotic systems and foundational work on the design and fabrication of soft robots have paved the way for robots capable of safely interacting with humans and delicate objects [1]. The creation of soft robotic fish with autonomous underwater navigation highlights the application-specific advantages of soft robotics in challenging environments [1].

Recent studies have focused on using new materials and structures to more closely replicate biological functions, enabling the creation of more versatile and safer robotic interactions across various fields, including healthcare and environmental monitoring [[1]]. **Figure 2.3** shows Series of frames from experiments involving (a) longitudinal extension, (b) whole-arm bending, and (c) S-shaped bending, of the three- segment soft arm.

Control strategies for soft robotic systems are also rapidly advancing, with a focus on integrating sensory feedback and biomimetic design principles. These advancements contribute to our understanding of how to design, control, and apply soft robotic systems in real-world scenarios with capabilities like those of biological systems [1].

- Advantages:
    - Enhanced compliance due to soft silicone material, beneficial for interacting with delicate environments.
    - Octopus-inspired design allows for versatile movements, including bending, elongation, and twisting.
    - Twisting capability expands the arm's potential applications (e.g., minimally invasive surgery).
    - Model-free closed-loop control using visual feedback for real-time shape and pose reconstruction.
- Disadvantages:
    - The paper primarily focuses on the design, development, and control of the soft arm. Detailed performance metrics like energy efficiency, actuation speed, and load capacity are not extensively discussed.
    - The complexity of the multi-segmented design and control system may present challenges in practical implementation and robustness.

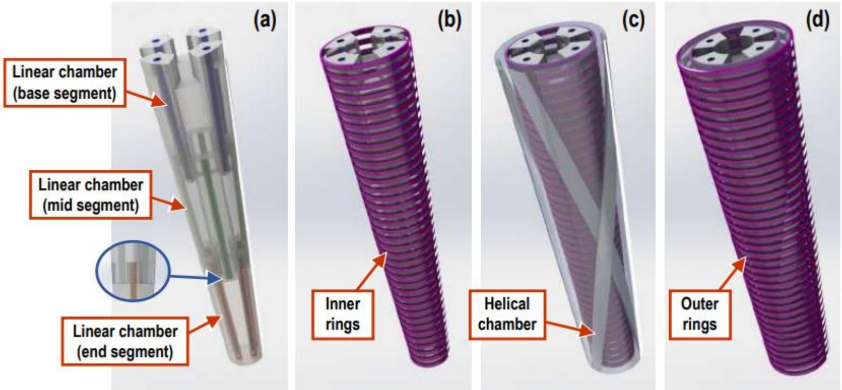


*Figure 2.1 Architecture 1 For making Octopus Mimicking Soft Robot*


*Figure 2.2 3D Printed Molds for Implementing Octopus Mimicking Robot*

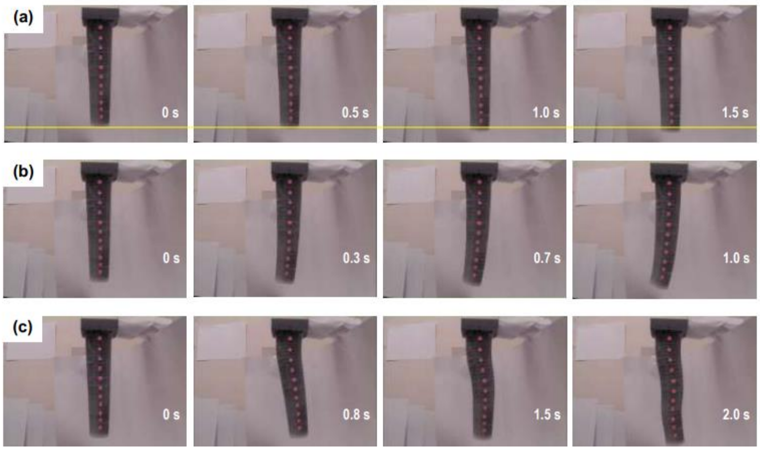


*Figure 2.3 Working and Performance of Soft Robot*

**Survey 2**

The ocean is a particularly challenging environment for robotic manipulation, with tasks like marine pollutant cleanup, fishing, and underwater archaeology being labour-intensive and often requiring robots to assist or replace humans [2]. Cephalopods such as octopuses, with their underwater multimodal motion and adaptive grasping abilities, are a popular animal model for the design of next-generation underwater grippers [2].

Traditional robotic grippers, often fixed to robotic arms, have limited workspace and struggle to grasp objects in confined underwater spaces. While soft grippers offer compliant interaction for adaptive grasping, they may have limitations in grasping stability and handling objects of varying sizes and shapes [2].

To address these challenges, researchers have developed octopus-inspired soft grippers with multiple arms, capable of both grasping and underwater movement. These grippers integrate functionalities like omnidirectional crawling and 3D swimming, enabling dexterous manipulation in unstructured underwater environments [2]. The development of soft actuators and the incorporation of twisting motions in soft robotic arms further enhance their versatility and functionality, allowing for more complex and efficient interactions with objects and environments [1].

- Advantages:
    - Multifunctional soft robotic gripper with integrated capabilities: grasping, omnidirectional crawling, and 3D swimming.
    - Octopus-inspired design enables diverse grasping actions for various object shapes and sizes in unstructured underwater environments.
    - The gripper can operate independently of a robotic arm, expanding its application space in confined underwater areas.
- Disadvantages:
    - The paper mentions that soft grippers have limitations in grasping stability and handling objects of varying sizes and shapes.
    - The application of suction-based grippers is limited to objects with flat or nearly flat surfaces.
    - Long-term durability and reliability of the soft gripper in harsh underwater environments may need further investigation.

Our project aims to develop a multifunctional soft robotic system that mimics octopus's motion, specifically for picking, placing, this involves designing soft arms with suckers, a pneumatic actuation system, and a control architecture. **Figure 2.4** shows a depiction of the mission profile and design of the octopus-inspired underwater soft gripper system. The gripper integrates adaptive grasping, omnidirectional crawling, and 3D swimming capabilities. The design incorporates six soft arms made of liquid silicone, each with five suckers, and a ventral membrane to enhance object wrapping and stability. Pneumatic actuation is used for arm bending and sucker activation, with separate control channels for each. The system also involves mould design and finite element analysis to optimize the mechanical structure [3].

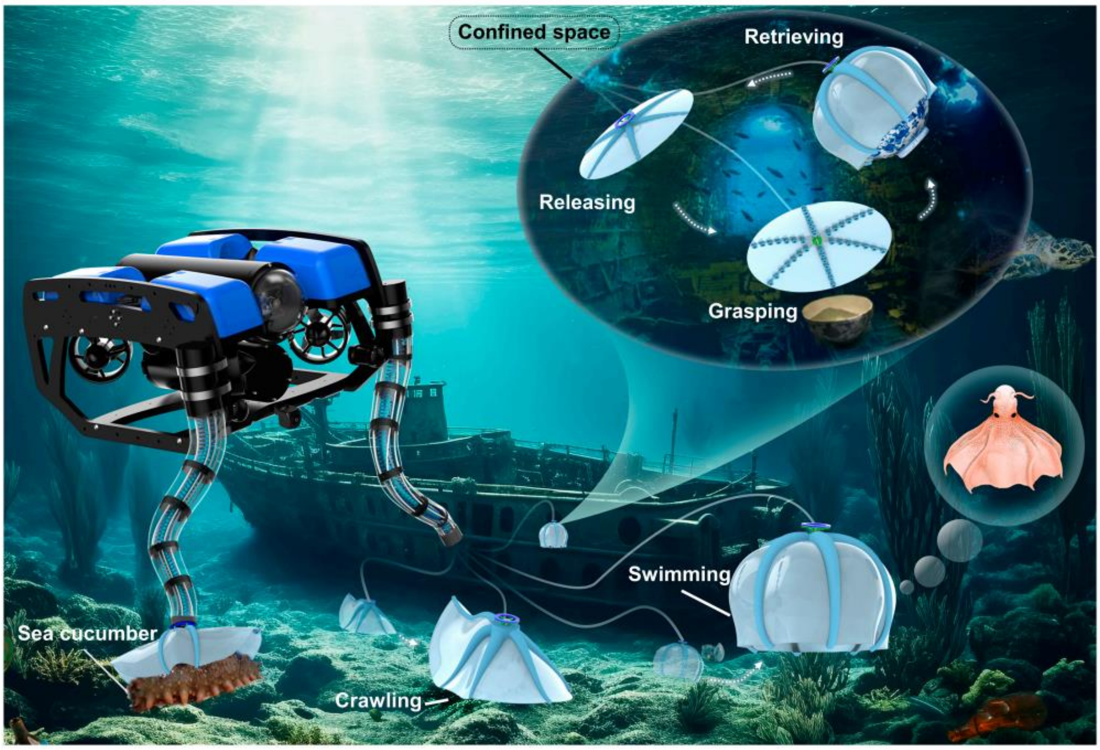


*Figure 2.4 Operations performing Boy Octopus Inspired Robot*

# CHAPTER 3
# SYSTEM DESIGN AND DEVELOPMENT

## 3.1 Conceptual Design

The conceptual design of the multifunctional soft robotic system was inspired by the anatomical structure of the Octopus. Recognizing the need for adaptability and gentle interaction in agricultural applications, the team pursued a bioinspired soft gripper capable of conforming to varied object geometries. The concept revolved around soft pneumatic actuation—where inflation drives motion—selected for its simplicity, safety, and ease of fabrication.

Key initial objectives for the design included:

- Multi-finger configuration for stable grip.
- Pneumatically driven flexion mimicking finger bending.
- Modular structure to allow ease of replacement or scaling.
- Lightweight and low-pressure operation for field use.

Brainstorming sessions were conducted to explore various finger configurations (3-finger, 4-finger, claw-style, etc.), and rough sketches were iteratively refined based on expected grip coverage and flexibility.

## 3.2 Design of the Robotic Gripper

The gripper was structured with three soft fingers arranged in a circular layout around a central hub. Each finger was designed to inflate using embedded air channels that would induce bending when pressurized. Finger geometry was based on a semicircular cross-section to promote uniform curling under pressure.

Each finger was subdivided into flexible chambers to optimize bending angle while minimizing energy loss. Air inlet positions, inner radius, and wall thickness were iteratively adjusted to ensure predictable deformation. The base of the gripper included a common manifold for controlled air distribution to all fingers.

A simplified initial design was selected for prototyping, allowing for manual actuation testing before full system integration. Challenges with finger curvature and air sealing during inflation prompted minor redesigns mid-process.

### 3.3 CAD Modelling using SolidWorks.

CAD modelling was conducted using **SolidWorks** to visualize the design and prepare for simulation and fabrication. The steps included:

- Creating 3D models of individual fingers with internal channels.
- Assembling the complete gripper system with proper constraints.
- Adding air inlet geometry for interfacing with tubing and valves.
- Ensuring manufacturability by simplifying complex features.

These models served multiple purposes:

- Design validation and visual inspection.
- Export to ANSYS for finite element analysis (FEA).
- Preparing moulds for 3D printing, though fabrication constraints limited actual printing to initial stages.

Test functionality, cross-sectional views and exploded diagrams were prepared, which helped the team understand internal geometries and actuation pathways.

*Figure 3.1 Inner Mould*

*Figure 3.2 Outer Mould*

*Figure 3.3 Top and Bottom Mould*

*Figure 3.4 Complete Mould Assembly*

**Figure 3.1** shows outer mould and **Figure 3.2** shows inner mould and **Figure 3.3** (a) (b) shows upper and lower lids and (c) shows cup slots and **Figure 3.4**

### 3.4 Selection of Materials

Material selection was informed by prior literature, project budget, and accessibility. After evaluating various elastomers and flexible polymers, silicone rubber (e.g., Eco flex )**(Figure 3.4)**was chosen due to:

- High elasticity and tear resistance.
- Biocompatibility and safety for agricultural handling.
- Proven record in soft robotics applications.

For mould construction, clay was initially used due to its ease of manipulation. However, due to its lack of reusability and the challenges of precision shaping, further iterations explored alternatives such as using double-layered tape, flexible tubing, and pre-cast acrylic pieces.

Sealing remained a persistent issue**(Figure 3.5).** Tape-based sealing, although quick and low-cost, often failed during curing. This led to consideration of mould redesign for tighter fittings and better pressure resistance in future work.


***Figure 3.5 TINFLIX TLS-105 Liquid Silicone Rubber***

## 3.5  Moulding Techniques and Challenges

Multiple moulding techniques were trailed throughout the fabrication phase. The most significant challenges encountered were:

- Silicone leakage during curing, especially at joints and seams**(Figure 3.6)** .
- Air entrapment inside the mould, causing bubbles and deformation.
- Difficulty in maintaining consistent wall thickness of the fingers.
- Time constraints limiting the ability to reprint corrected moulds.

Approaches tried included:

- Clay moulds shaped manually around preformed templates.
- Taping moulds tightly to avoid silicone escape.
- Using prefabricated tubes **(Figure 3.8)** inserted as cores within silicone.

Despite many attempts, a fully functional gripper was not achieved due to fabrication imperfections and pressure inconsistencies. However, a single soft finger was successfully produced and partially tested.


***Figure 3.6 Leaking of Liquid Silicon From Mould***

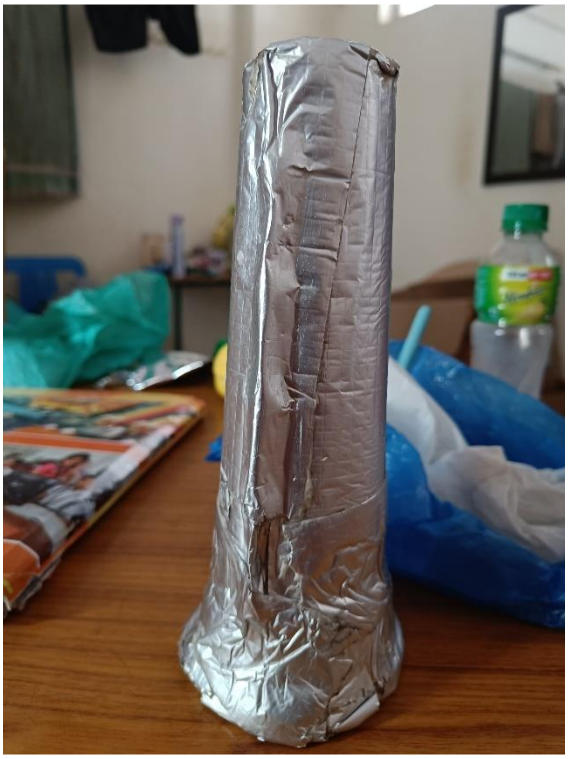

***Figure 3.7 Using Duct Tape to Prevent Leakage***

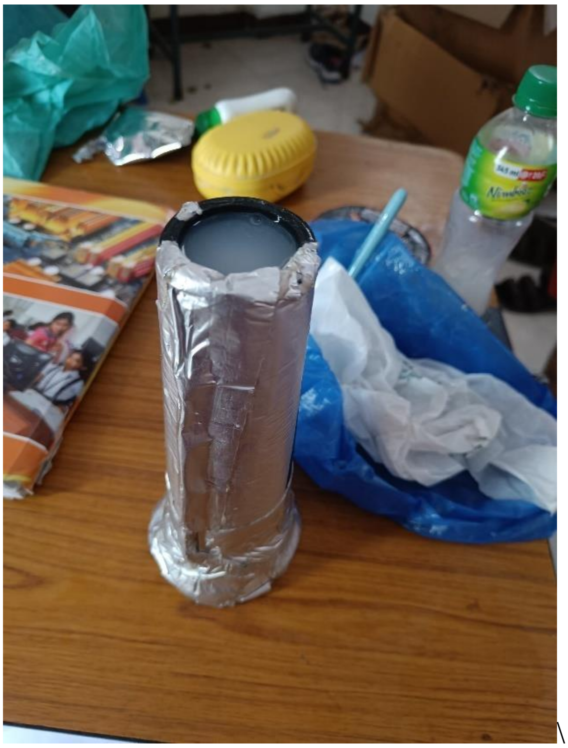

***Figure 3.8 Using Duct Tape to Prevent Leakage***

# CHAPTER 4

# SIMULATION AND ANALYSIS

## 4.1 Introduction to ANSYS

To evaluate the structural performance and mechanical feasibility of the soft robotic gripper design, simulations were conducted using ANSYS Workbench, a powerful tool for finite element analysis (FEA). The objective was to assess stress distribution, deformation behavior, and determine the factor of safety (FoS) for the materials and structure under operational loads. As physical testing was constrained by prototyping issues, simulation played a vital role in predicting the design's reliability.

## 4.2 Simulation Setup

The CAD model of the soft finger, designed in SolidWorks, was imported into ANSYS for simulation. The simulation involved the following steps:

- <u>Material Definition</u>

Silicone rubber was modelled using a hyper elastic material model, incorporating experimentally sourced or literature-based properties (Young’s Modulus ≈ 200 kPa, Poisson’s ratio ≈ 0.49).

- <u>Meshing</u>

A fine mesh was generated with tetrahedral elements to capture complex geometries and internal channel effects.

- <u>Boundary Conditions</u>
    - The base of the finger was fixed to simulate attachment to the actuator hub.
    - A uniform internal pressure (0.3–0.5 bar) was applied inside the embedded air chambers to mimic pneumatic inflation.

- <u>Contact Conditions</u>

No-slip boundary conditions were assumed for internal interfaces, and inflation was modelled as quasi-static to simplify analysis.

### 4.3 Stress and Strain Analysis

The simulation revealed the distribution of von Mises stress, principal strains, and total deformation throughout the structure:

- Maximum stresses were observed near the inner walls of the air chambers and at the junction between the finger and base.
- The outer arc of the finger exhibited higher tensile strain, consistent with bending mechanics under inflation.
- Overall deformation matched expectations, with a curling pattern similar to that seen in soft robotic actuators from existing studies.

This analysis helped identify stress hotspots that could potentially lead to material fatigue or rupture in long-term use.

### 4.4 Factor of Safety Evaluation

The factor of safety (FoS) was calculated by comparing the maximum allowable stress of the silicone with the peak stress values from simulation:

- For a typical silicone with a tensile strength of ~3 MPa, and simulation results showing maximum stress < 0.6 MPa, the calculated FoS was approximately 5, indicating a safe operational range.
- Some regions near sharp transitions in geometry showed reduced FoS (~2.5), suggesting a need for geometric smoothing or reinforcement.

This validated that the design was safe under intended pressure loads, but improvements in design could further enhance durability.

### 4.5 Interpretation of Results

The simulation served as a crucial step in understanding and validating the soft gripper's mechanical behaviour:

- Confirmed functional deformation matching the gripping motion concept.

- Identified regions of high stress that need design revision.
- Demonstrated that material selection (silicone rubber) was mechanically sufficient for the task.
- Provided insights to guide mould redesign for improved fabrication and real-world testing.

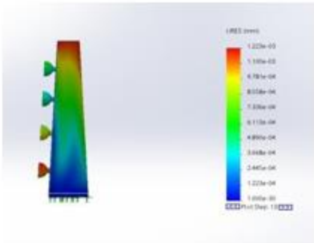

*Figure 4.1 Displacement Analysis*

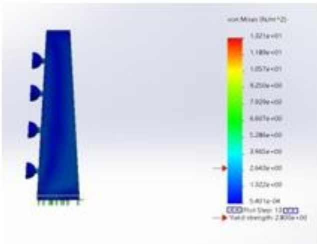

*Figure 4.2 Stress Analysis*

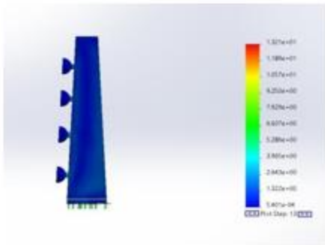

*Figure 4.3 Strain Analysis*

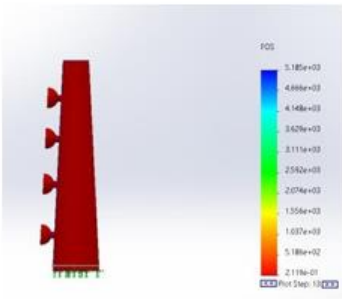

*Figure 4.4 Factor of Safety Analysis*

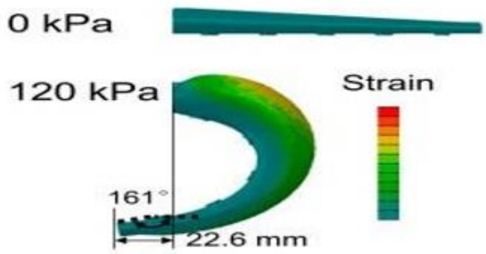


*Figure 4.5 Transversal Deformation Analysis*

**Figure 4.1** shows the Displacement Analysis, **Figure 4.2** shows the Stress Analysis, **Figure 4.3** shows the Strain Analysis, **Figure 4.4** shows the Factor of Safety Analysis and **Figure 4.5** Transversal Directional Deformation - Maximum Pressure Level=120kPa done in SolidWorks Analysis Study and Ansys

# CHAPTER 5

# FABRICATION PROCESS

## 5.1 Mould Fabrication Methods

To fabricate the soft robotic finger, multiple mould-making techniques were explored to create precise cavities for silicone casting. Initially, clay-based moulds were used due to their ease of shaping and accessibility. These moulds, however, lacked dimensional accuracy and repeatability. Subsequently, and sealing tapes was attempted. This allowed better control over internal channel geometry but introduced leakage issues during casting. A finalized mould could not be 3D printed due to time constraints, but the design was prepared in CAD for future iterations**.**

## 5.2 Silicone Casting Procedure

Silicone elastomer (Eco flex) was selected for its high flexibility, biocompatibility, and robustness. The casting steps(**Figure 5.1** ***)*** included:

- Mixing: The two-part silicone was thoroughly mixed in a 1:1 ratio by weight.
- Pouring: The silicone mixture was poured into the mould cavity in layers to avoid air pockets.
- Sealing: Different tapes, such as duct tape, were tried to seal the mould. These were only partially effective in preventing leakage.
- Curing: The mould was left undisturbed at room temperature for 4–6 hours for full curing.

## 5.3 Prototype Assembly

Once cured, the finger structure was de-molded carefully. A pneumatic inlet was added using flexible tubing and adhesive sealant. The gripper finger was connected to a basic pneumatic setup for initial inflation tests. Due to fabrication limitations, only one functional finger prototype was assembled. It demonstrated curling upon inflation but lacked enough gripping force and consistency for reliable performance**.**

## 5.4 Issues Encountered and Modifications

Throughout the fabrication phase, the team faced several practical challenges:

- Leakage in moulds due to poor sealing or dimensional misalignment.
- Non-uniform casting caused by air bubbles and improper pouring techniques.
- Design inaccuracies in mould geometry led to weak joints and deformation.
- Material waste and trial repetition due to frequent casting failures.

As a corrective measure, the CAD design was revised to simplify mould geometry and enhance internal channel definition. Although reprinting the mould was not possible due to schedule limitations, the updated design was preserved for future trials. The team also concluded that using professional-grade mould enclosures or 3D printed parts would significantly improve the quality of the prototype.


*Figure 5.1 Steps for Making Silicon Arm*

# CHAPTER 6
# ANALYSIS OF PROTOTYPE PERFORMANCE

## 6.1 Analysis of Prototype Performance

The developed soft robotic finger prototype was tested for its basic actuation and deformation using a manual pneumatic setup. The finger successfully curled upon inflation, demonstrating the working principle of a pneumatic soft actuator. However, the degree of curvature and repeatability of the actuation were suboptimal. Key observations included insufficient grip strength, structural instability, and minor air leakage—due to imperfections in the moulding process.

## 6.2 Comparison with Simulation Data

Finite Element Analysis (FEA) conducted in ANSYS revealed ideal deformation profiles and stress concentrations within safe limits, assuming uniform material distribution and precise channel geometry.The actual prototype performance deviated from this, with visible buckling in some sections and uneven deformation. This disparity is attributed to real-world factors such as:

- Non-uniform material thickness
- Air entrapment during casting
- Minor misalignments in mould geometry
- Manual sealing inadequacies

## 6.3 Insights and Lessons Learned

- Simulations are dependable for preliminary analysis but must be validated with physical tests.
- Material handling and curing conditions require strict control to minimize defects.
- Even a basic prototype can demonstrate core concepts, offering a valuable learning experience in rapid prototyping and iterative design.

# CHAPTER 7

# CONCLUSION AND FUTURE WORK

## 7.1 Summary of Project Outcomes

This project successfully addressed the initial stages of designing a bioinspired soft robotic finger tailored for agricultural applications. The work included a comprehensive literature review, conceptual CAD modelling, simulation through finite element analysis using ANSYS, and attempts at physical fabrication using silicone-based casting methods.

The final prototype, although not fully functional for practical deployment, exhibited basic pneumatic actuation, validating the underlying design principle. Simulation data offered valuable insights into the mechanical behaviour of the soft material under pressure, revealing predictable deformation patterns and stress concentrations. These results affirm the feasibility of using soft actuators for gentle handling tasks, such as fruit or crop harvesting, where traditional rigid grippers may cause damage.

## 7.2 Limitations

Despite the meaningful progress, the project encountered several limitations that impacted the completeness and performance of the prototype:

- <u>Fabrication Precision</u>

The primary challenge during physical prototyping was the leakage and poor alignment in manually fabricated clay moulds. These issues led to inconsistent silicone casting, resulting in non-uniform gripper fingers that failed to achieve the expected grip strength and flexibility.

- <u>Time Constraints</u>

The academic timeline restricted iterative refinement. Although an improved design was developed post-analysis, lack of time meant that it could not be fabricated using 3D printing or higher-fidelity mould fabrication techniques.

### 7.3 Future Scope

` To overcome the current challenges and enhance the design's applicability, the following recommendations are proposed:

- Adoption of 3D Printed Moulds

Replacing clay moulds with CAD-based 3D printed moulds will significantly improve geometric precision, repeatability, and sealing quality. This shift will help minimize casting defects and improve mechanical consistency across gripper fingers.

- Automated and Vacuum-Assisted Casting

Implementing vacuum degassing during silicone mixing and automating the casting process can reduce air bubble formation and improve the integrity of the moulded parts. Controlled environments will also enhance curing consistency.

- Development of Multi-Finger Gripper Assembly

Future iterations should focus on assembling a multi-fingered gripper system, allowing the study of coordinated actuation and the ability to grasp objects of varying shapes and sizes more reliably.

- Sensor Integration for Feedback Control:

Incorporating soft or embedded sensors (e.g., pressure, stretch, or tactile sensors) will enable real-time feedback and closed-loop control. This will allow adaptive gripping based on object properties and positioning.

- Field Testing and Application-Specific Trials:

Prototypes should be evaluated in simulated agricultural environments or directly on field produce (e.g., tomatoes, strawberries). Such tests will assess durability, grip precision, and overall robustness in real-world conditions.

- Exploration of Alternate Materials:

Materials like Eco flex with different Shore hardness should be compared for improved elasticity and load-bearing characteristics. Hybrid materials may also offer better trade-offs between softness and strength.

Integration with Robotic Arms:

Mounting the gripper on a robotic manipulator with programmable control will offer end-to-end automation capability, essential for commercial-scale deployment.

‘

# APPENDIX

## APPENDIX A: PRESENT DESIGN DOCUMENTATION


*Figure A1: 3D CAD of current mould design (SolidWorks).*

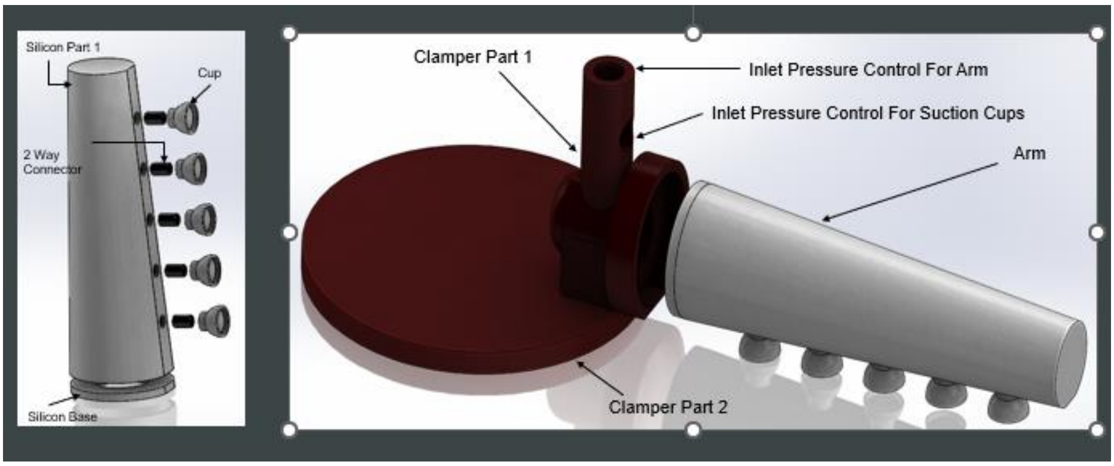


*Figure A2: 3D CAD of gripper with clamper plate (SolidWorks).*

## APPENDIX B: FUTURE DESIGN PROPOSALS

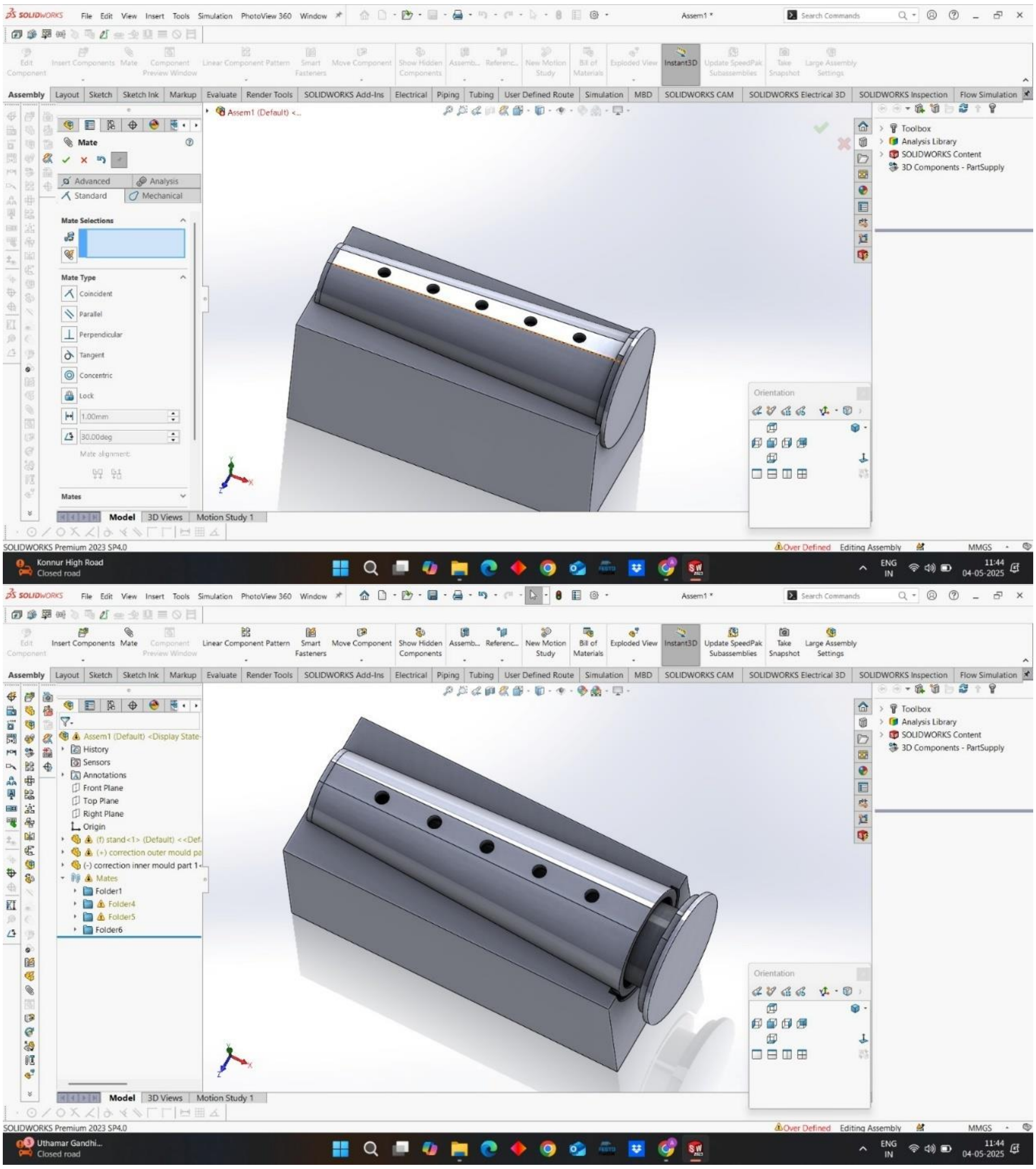


***Figure B1: Modified mould for 3D printing.***

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