Product Design and Development

Ideation Project Report
On Bio-Mechanical Shape Shifting Gripper

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Contents

Introduction

A bio-mechanical shape-shifting gripper is a robotic gripper that changes its shape to accommodate varying object sizes and forms based on bio-inspired and soft robotics concepts. Unlike rigid grippers, it incorporates flexible materials, including soft polymers and shape-memory alloys, enabling it to dynamically conform to objects. Powered by mechanisms such as pneumatics, hydraulics, or smart materials, it gives accurate, flexible, and delicate gripping, making it well-suited for use in industrial automation, healthcare, and robotics.

- Robot grippers have developed greatly, and now there are bio-mechanical shape-shifting grippers that can accommodate all sorts of object shapes and sizes.
- Conventional robotic grippers use stiff structures and pre-programmed paths of motion, which prevent them from grasping irregular or delicate objects.

-Bio-mechanical grippers combine aspects of:

- **Soft robotics –** allowing flexible, adaptive motion.
- **Bio-inspired design –** emulating biological mechanisms for grasping like human fingers and octopus tentacles.
- **Shape-shifting materials –** to enable real-time adaptation to object geometry

Mission Statement

Product Description:

Our Bio- Mechanical Shape Shifting Gripper is an advanced gripping system that dynamically adjusts its shape, texture, and stiffness to handle objects of varying sizes, materials, and fragility, use of materials or mechanisms that can switch between soft and rigid states.

Benefit Proposition:

It removes the necessity for multiple specialized grippers and thereby increases efficiency, precision, and cost-effectiveness, with a reduction in downtime and operation costs.

Key Business Goals:

- Development of Product & Patent Core Technology
- Lightweight, more strong composite material.
- Commercialization & Market Entry Scalability & Customization.
- Sustainability & Energy Efficiency Global Expansion

Primary Market:

- Industrial Automation & Robotics
- Logistics & Warehousing

Secondary Market:

- Medical Robotics & Prosthetics
- Food Processing & Agriculture
- Defense & Space Exploration

Assumptions & Constraints:

Assumptions:

- Industries are shifting towards automation and require versatile gripping solutions.
- Smart materials technology will continue to grow and reduce in cost.

- AI and sensor integration will improve real-time object recognition and adaptability.

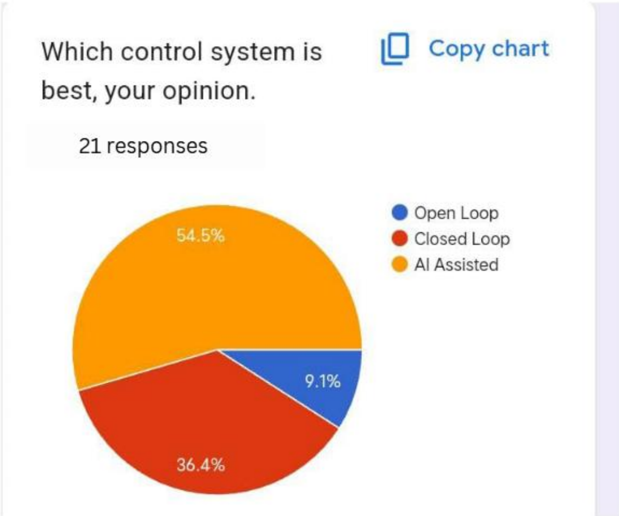
Constraints:

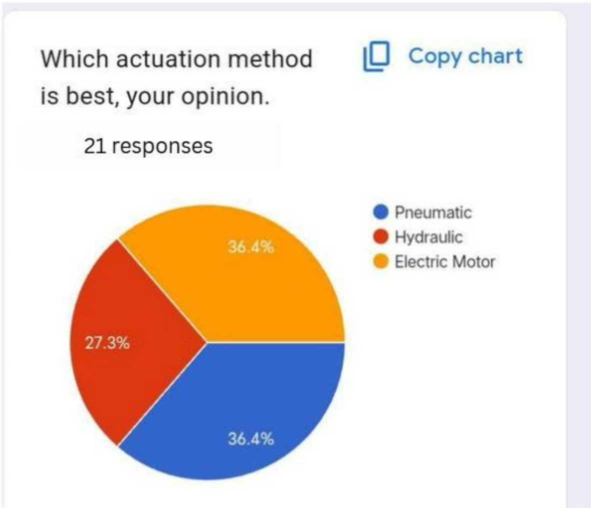
- Initial R&D costs and technology maturity timeline.
- Manufacturing scalability and supply chain dependency on smart materials.
- Regulatory approvals in medical and aerospace applications.

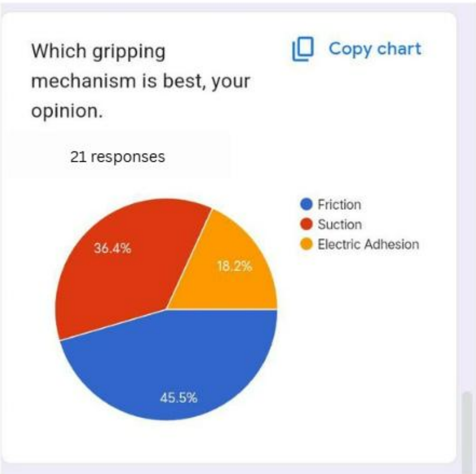
Stakeholders:

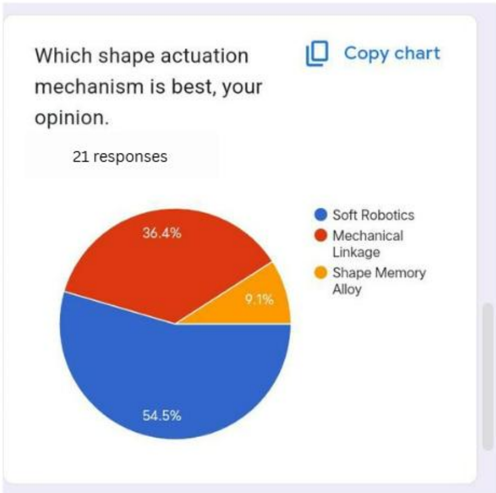
- Investors –Funding for R&D and market expansion.
- Manufacturing Partners – Industrial automation firms, robotic gripper manufacturers.
- Regulatory Bodies – Compliance with safety and industry standards (ISO, FDA, FAA).

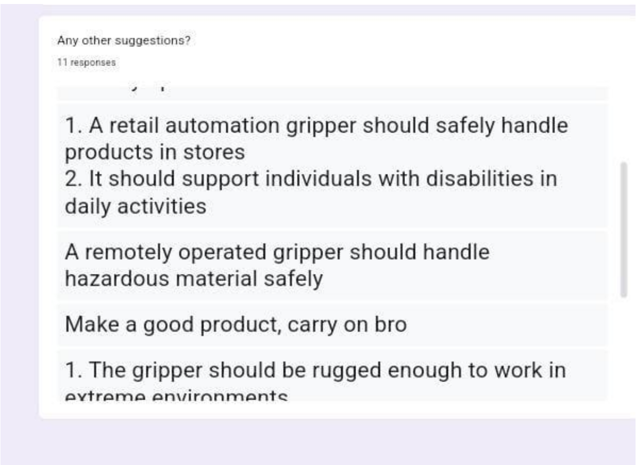
Customer Response Form and their Responses










Any other suggestions?
11 responses

1. A retail automation gripper should safely handle products in stores
2. It should support individuals with disabilities in daily activities

A remotely operated gripper should handle hazardous material safely

Make a good product, carry on bro

1. The gripper should be rugged enough to work in extreme environments

Name *

Your answer

Which shape actuation mechanism is best, your opinion. *

- ◯ Soft Robotics
- ◯ Mechanical Linkage
- ◯ Shape Memory Alloy
- ◯ Other:

Which gripping mechanism is best, your opinion. *

- ◯ Friction
- ◯ Suction
- ◯ Electric Adhesion
- ◯ Other:

Which actuation method is best, your opinion. *

- ◯ Pneumatic
- ◯ Hydraulic
- ◯ Electric Motor
- ◯ Other:

Which control system is best, your opinion. *

- ◯ Open Loop
- ◯ Closed Loop
- ◯ AI Assisted
- ◯ Other:

Any other suggestions? *

Your answer

Customer Need Statements

Customer Statement	Need Statement
"We need a gripper that can handle different materials without causing damage."	The gripper provides adaptive grip strength for various materials.
"Our production line requires precise and delicate handling for small components."	The gripper handles small and fragile components with precision.
"The gripper should be able to manipulate soft and flexible materials without deformation."	The gripper applies gentle pressure to avoid material deformation.
"A food-safe gripper is required for handling consumables hygienically."	The gripper uses materials that comply with food safety regulations.
"We need a high-speed, sterile gripper for medical and pharmaceutical applications."	The gripper enables sterile handling and operates at high speeds.
"The gripper should be able to sort and handle objects of varying shapes and sizes."	The gripper adapts to different object geometries automatically.
"A gentle gripping mechanism is required for handling fragile and delicate items."	The gripper ensures soft yet firm control to prevent damage.
"The gripper should have a secure grip without damaging sensitive components."	The gripper maintains stability while ensuring non-damaging contact.
"It should adapt to different product sizes and weights without requiring manual adjustments."	The gripper self-adjusts to various object dimensions.
"The gripper should efficiently identify and sort different types of objects."	The gripper recognizes and classifies objects automatically.
"A precise and dexterous grip is needed for surgical and medical procedures."	The gripper provides controlled movement for surgical tasks.
"An adaptive design is required for prosthetics and assistive robotics."	The gripper mimics natural hand movements.
"The gripper should assist users in grasping and releasing objects for rehabilitation."	The gripper supports grasp-and-release exercises.
"A contamination-free gripper is required for handling pharmaceuticals and lab samples."	The gripper minimizes contamination risks in sensitive environments.

Customer statements	Need statements
"The gripper should be easy to clean and resistant to contamination."	The gripper withstands sterilization and cleaning processes.
"A user-friendly gripper should help individuals with limited mobility in daily tasks."	The gripper is ergonomically designed for easy use.
"The gripper should hold and pass objects securely in robotic-assisted operations."	The gripper provides secure object handling during automation.
"A stable and precise grip is needed for handling diagnostic and medical tools."	The gripper ensures a steady hold for precision tasks.
"It should integrate into assistive robotic suits for enhanced mobility."	The gripper functions smoothly within wearable robotics.
"The gripper should function in zero gravity and handle fragile space equipment."	The gripper works efficiently in low-gravity environments.
"A durable and flexible gripper is needed for handling a variety of materials in space."	The gripper withstands extreme conditions and adapts to different objects.
"The gripper should be rugged enough to work in extreme environments."	The gripper resists mechanical stress and harsh conditions.
"A lightweight and efficient gripper should assist in drone-based delivery operations."	The gripper is compact and energy-efficient for aerial use.
"The gripper should support precision assembly in industrial and aerospace applications."	The gripper enables precise placement of components.
"It should be waterproof and resistant to corrosion for underwater applications."	The gripper functions reliably in wet and underwater conditions.
"A remotely operated gripper should handle hazardous materials safely."	The gripper ensures safe handling of dangerous substances.
"The gripper should function reliably in harsh environmental conditions."	The gripper is designed for extreme weather and terrain.
"An automated gripper should assist in efficient harvesting and sorting."	The gripper efficiently picks and sorts objects in agriculture.
"The gripper should optimize warehouse automation and logistics handling."	The gripper handles objects in automated storage and retrieval systems.
"A household-friendly gripper should help with everyday chores."	The gripper is easy to use for daily household tasks.
"A retail automation gripper should safely handle products in stores."	The gripper manages retail logistics smoothly.
"A responsive gripper should provide realistic tactile feedback for virtual applications."	The gripper offers tactile feedback for immersive experiences.
"A human-friendly gripper should support individuals with disabilities in daily activities."	The gripper is accessible and safe for assistive use.
"A programmable gripper should be designed for educational and research purposes."	The gripper supports hands-on learning and experimentation.
"An automated checkout gripper should scan and pack products efficiently."	The gripper facilitates self-checkout processes.

What's New

1. Smart Sensing and Feedback Mechanisms

- <u>Integrating Sensing-</u>
  - Use flexible, embedded sensors to detect pressure, texture, and object contours.
  - Materials: Piezoelectric films, capacitive touch sensors, or conductive polymers.
  - Innovation: Real-time force and texture feedback for adaptive gripping.

2. Self-Healing and Durable Materials

- <u>Self-Healing Polymers:</u>
  - Materials that can repair themselves after being punctured or cut.
  - Useful for maintaining gripper integrity during heavy-duty or abrasive tasks.
- <u>Fatigue-Resistant Actuators:</u>
  - Materials and structures that minimize wear and tear, even with repetitive motion

3. Energy-Efficient Actuation

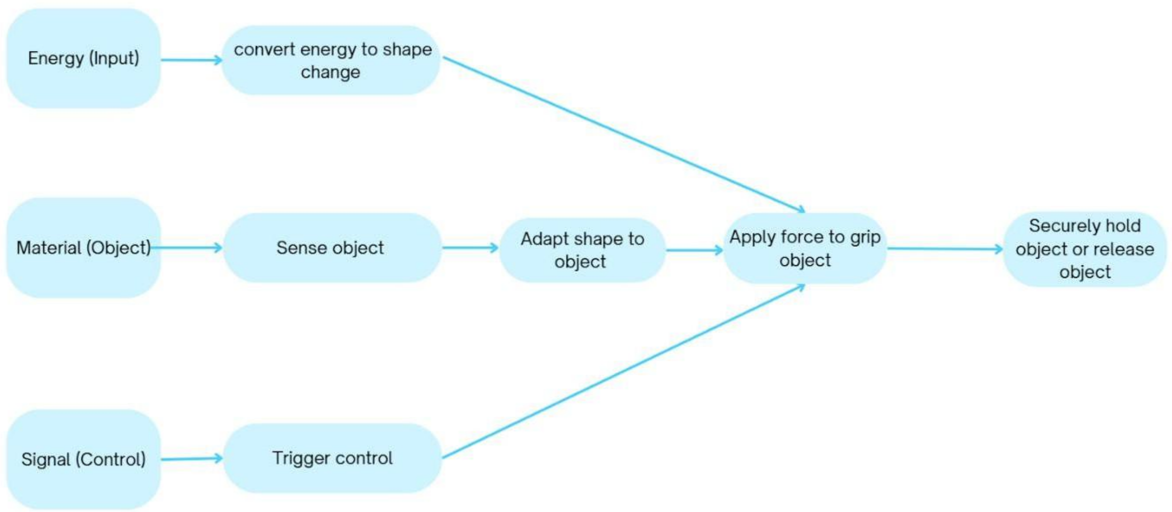
- <u>Passive Adaptive Grippers:</u>
  - Grippers that naturally adapt to an object's shape without active control.
  - Use compliant mechanisms and soft structures to minimize energy usage.

- <u>Pneumatic-Electric Hybrid Actuation:</u>
  - Combine the gentle touch of pneumatic systems with precise control from electric actuators

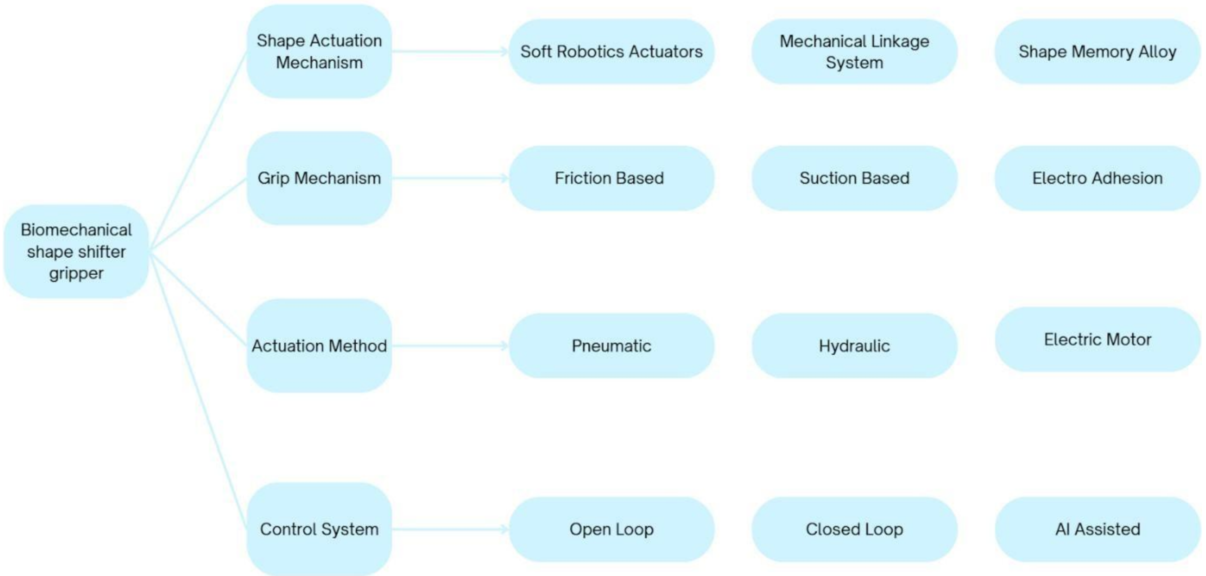
Specification

Specification	Metric	Target Value
Grip Strength	Newton	50–200 N
Shape Adaptation	% of object shape coverage	>95%
Response Time	Seconds	<2
Weight	Kilograms	<1
Material Cost	Rupee	<50,000
Operating Voltage	Volts	12–24
Energy Consumption	Watts	<50
Surface Pressure Control	kPa	Adjustable, <5 kPa for fragile objects
Sterilization Compatibility	Number of sterilization cycles	>500 cycles
Object Recognition Accuracy	% accuracy in sorting	>98%
Environmental Adaptability	Temperature range (°C)	-20 to 80°C
Dust & Water Resistance	IP Rating	IP67 or higher
Load Capacity	Kilograms	0.1–5 kg
Haptic Feedback Response	Milliseconds	<5 ms
Wireless Connectivity	Supported protocols	Bluetooth, Wi-Fi, or IoT-enabled
Automated Learning	AI Model Training Efficiency	Self-learning, adaptive to >100 object types
Safety Compliance	Certification Standards	CE, FDA (for food/medical applications)

Function Diagram

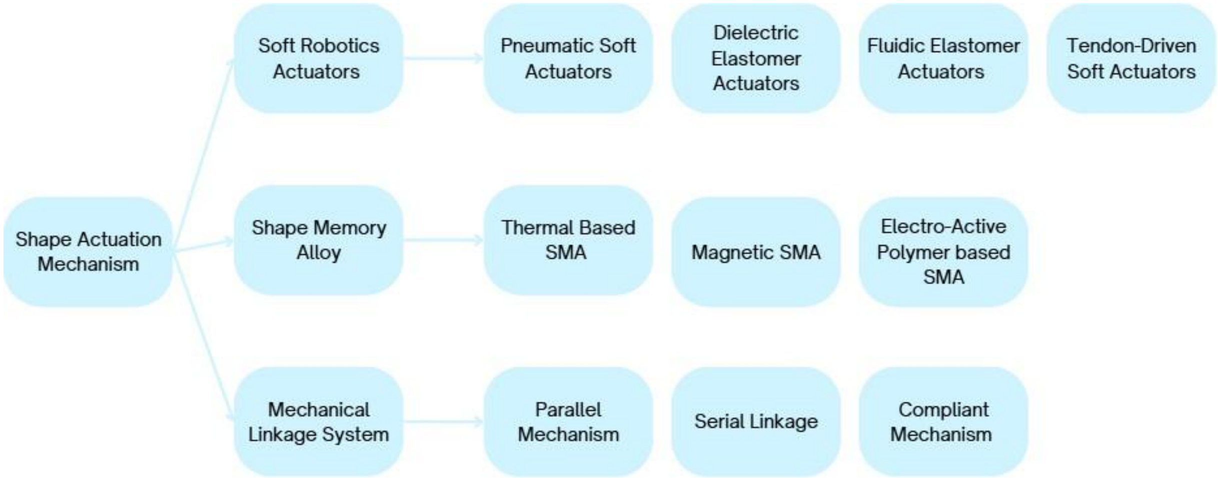


Concept Classification Tree

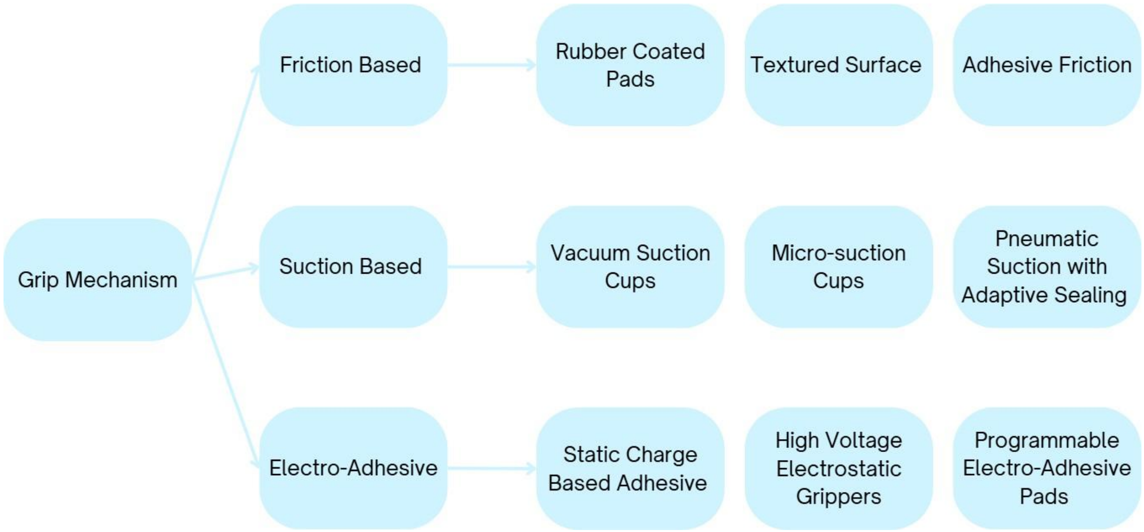


Breakdown of Concept Classification Tree

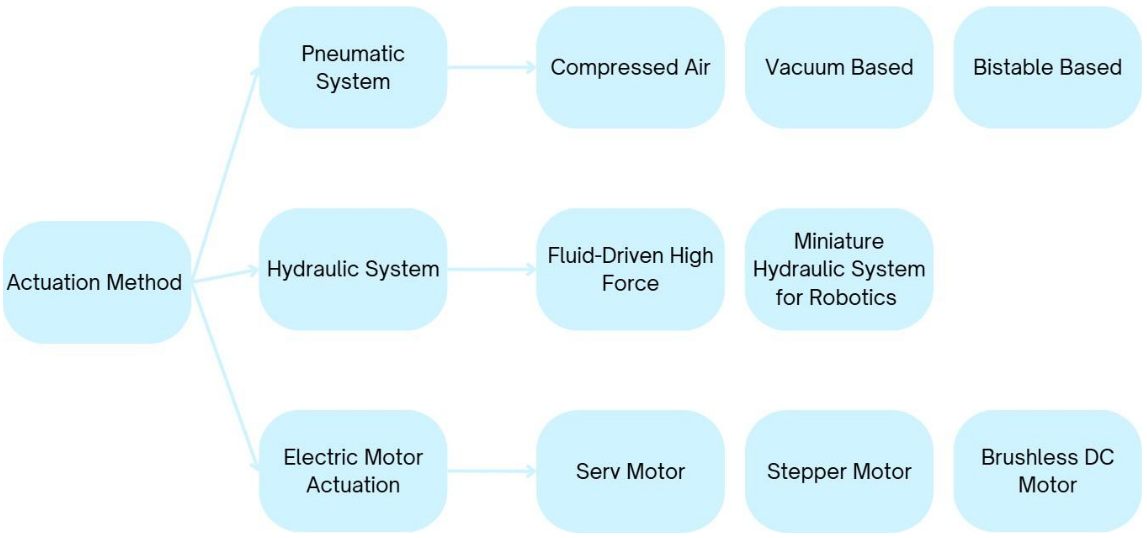
1. Shape Actuation Mechanism



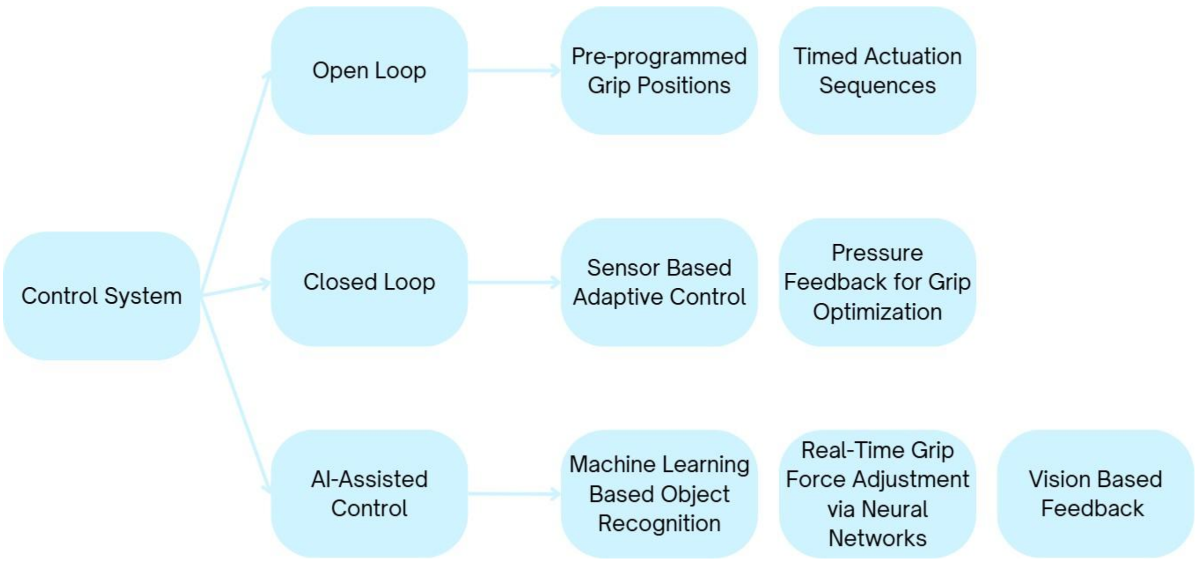
2. Grip Mechanism



3. Actuation Method



4. Control System



Concept Combination Table

Shape Actuation Mechanism	Soft Robotics Actuators	o Pneumatic Soft Actuators o Dielectric Elastomer Actuators o Fluidic Elastomer Actuators o Tendon-Driven Soft Actuators
	Shape Memory Alloy (SMA)	o Thermal-Based SMA Actuation o Magnetic SMA o Electro-Active Polymer (EAP)-Based SMA
	Mechanical Linkage System	o Parallel Mechanisms o Serial Linkages o Compliant Mechanisms (Flexure-Based)
Grip Mechanism	Friction-Based	o Rubber-Coated Pads o Textured Surface Grippers o Gecko-Inspired Adhesive Friction Grippers
	Suction-Based	o Vacuum Suction Cups o Micro-Suction Pads o Pneumatic Suction with Adaptive Sealing
	Electro-Adhesion	o Static Charge-Based Adhesion o High-Voltage Electrostatic Grippers o Programmable Electro-Adhesive Pads
Actuation Method	Pneumatic System	o Compressed Air Actuation o Vacuum-Based Actuation o Bistable Pneumatic Systems
	Hydraulic System	o Fluid-Driven High-Force Actuators o Miniature Hydraulic Systems for Robotics
	Electric Motor Actuation	o Servo Motors o Stepper Motors o Brushless DC Motors
Control System	Open-Loop Control	o Pre-Programmed Grip Positions o Timed Actuation Sequences
	Closed-Loop Control	o Sensor-Based Adaptive Control o Pressure Feedback for Grip Optimization
	AI-Assisted Control	o Machine Learning-Based Object Recognition o Real-Time Grip Force Adjustment via Neural Networks o Vision-Based Feedback Control

Detailed explanation of the Concept Classification Tree

1. Shape Actuation Mechanism

This section categorizes different ways robotic systems achieve movement, focusing on soft robotics actuators, shape memory alloys, and mechanical linkage systems.

A. Soft Robotics Actuators

Soft actuators use flexible materials that mimic natural movement, providing compliance and adaptability.

- Pneumatic Soft Actuators:
  - Work using pressurized air or vacuum to create motion.
  - Common in soft grippers and biomimetic robots.
- Dielectric Elastomer Actuators (DEA):
  - Use electrostatic forces to deform elastomer materials.
  - High energy density and fast response.
- Fluidic Elastomer Actuators:
  - Contain internal fluid chambers that expand/contract to create motion.
  - Found in soft wearable robotics and artificial muscles.
- Tendon-Driven Soft Actuators:
  - Use cables/tendons to pull or push flexible structures.
  - Enable fine-tuned movement, similar to biological tendons.

B. Shape Memory Alloy (SMA) Actuation

Shape memory alloys (SMAs) change shape in response to temperature, magnetic fields, or electrical signals.

- Thermal-Based SMA Actuation:
  - Actuation occurs when heat is applied, causing the material to revert to a pre-set shape.
  - Used in minimally invasive surgical tools and robotic prosthetics.

- Magnetic SMA:
  - Activated by magnetic fields instead of heat, providing rapid and contactless actuation.
  - Used in high-speed micro-actuators.
- Electro-Active Polymer (EAP)-Based SMA:
  - Uses electrically conductive polymers to change shape.
  - Often used in artificial muscles and haptic feedback devices.

C. Mechanical Linkage Systems

Traditional rigid mechanisms that provide precise control over movement.

- Parallel Mechanisms:
  - Multiple actuators work together to provide stability and high precision.
  - Found in hexapods and robotic arms for machining.
- Serial Linkages:
  - Actuators are connected in a chain, allowing for large movement ranges.
  - Used in robotic arms and industrial automation.
- Compliant Mechanisms (Flexure-Based):
  - Flexible structures deform elastically to achieve motion without joints.
  - Common in precision instrumentation and bio-inspired robotics.

2. Grip Mechanism

This section categorizes the different ways robots can grasp and hold objects.

A. Friction-Based Grip

Gripping force is generated through friction between the gripper and object.

- Rubber-Coated Pads:
  - Use high-friction materials to improve grip.
  - Common in industrial grippers.

- Textured Surface Grippers:
    - Increase surface contact to enhance gripping strength.
    - Used in robotic hands and warehouse automation.
- Gecko-Inspired Adhesive Friction Grippers:
    - Use microstructures that mimic gecko feet to adhere to surfaces.
    - Can grip smooth and delicate objects without damage.

B. Suction-Based Grip

Uses vacuum pressure to hold objects.

- Vacuum Suction Cups:
    - A simple and effective way to lift and hold items.
    - Common in manufacturing automation.
- Micro-Suction Pads:
    - Use tiny air pockets to create adhesion without a vacuum pump.
    - Ideal for smooth and lightweight materials.
- Pneumatic Suction with Adaptive Sealing:
    - Uses soft seals to conform to irregular surfaces, improving grip stability.
    - Used in robotic end-effectors for varied objects.

C. Electro-Adhesion-Based Grip

Uses electrical charges to adhere to surfaces.

- Static Charge-Based Adhesion:
    - Relies on electrostatic forces to hold objects.
    - Used in semiconductor manufacturing.
- High-Voltage Electrostatic Grippers:
    - Generate stronger electrostatic forces for gripping heavier objects.
    - Found in space robotics.
- Programmable Electro-Adhesive Pads:
    - Can switch adhesion on/off for controlled gripping.
    - Used in robotic manipulation of fragile items.

3. Actuation Method

How the gripping system is powered and controlled.

A. Pneumatic System

Uses compressed air to generate movement.

- Compressed Air Actuation:
  - Delivers rapid force but requires air supply.
  - Common in industrial robotics.
- Vacuum-Based Actuation:
  - Uses suction to create movement.
  - Used in pick-and-place automation.
- Bistable Pneumatic Systems:
  - Stay in position even without continuous air pressure.
  - Found in energy-efficient robotic designs.

B. Hydraulic System

Uses fluid pressure for high-force applications.

- Fluid-Driven High-Force Actuators:
  - Suitable for heavy-duty robotics and construction machinery.
- Miniature Hydraulic Systems for Robotics:
  - Scaled-down hydraulics for precision movement.
  - Used in medical robotics and prosthetics.

C. Electric Motor Actuation

Uses electrical energy to drive motors.

- Servo Motors:
  - Provide precise position control.
  - Used in robotic arms and automation.
- Stepper Motors:
  - Rotate in precise increments.
  - Found in CNC machines and robotic 3D printers.

- Brushless DC Motors (BLDC):
  - Offer high efficiency and durability.
  - Used in drones and high-performance robots.

4. Control System

Defines how the gripping system operates and responds to external conditions.

A. Open-Loop Control

Pre-set instructions without feedback.

- Pre-Programmed Grip Positions:
  - Robot follows a fixed sequence of movements.
  - Used in repetitive industrial tasks.
- Timed Actuation Sequences:
  - Moves based on a set timer rather than sensors.
  - Found in simple automation.

B. Closed-Loop Control

Uses sensor feedback for precise control.

- Sensor-Based Adaptive Control:
  - Adjusts grip strength based on object properties.
  - Used in prosthetic hands and robotic manipulation.
- Pressure Feedback for Grip Optimization:
  - Measures grip force and adjusts accordingly.
  - Prevents damage to fragile objects.

C. AI-Assisted Control

Incorporates machine learning and computer vision.

- Machine Learning-Based Object Recognition:
  - Identifies and classifies objects for optimal gripping.
  - Used in robotic sorting and warehouse automation.
- Real-Time Grip Force Adjustment via Neural Networks:
  - AI learns from experience to refine gripping.
  - Found in autonomous robotic hands.

- Vision-Based Feedback Control:
  - Uses cameras to assess grip quality and adjust accordingly.
  - Applied in surgical robots and autonomous assembly.

Concept Combination Selection Table

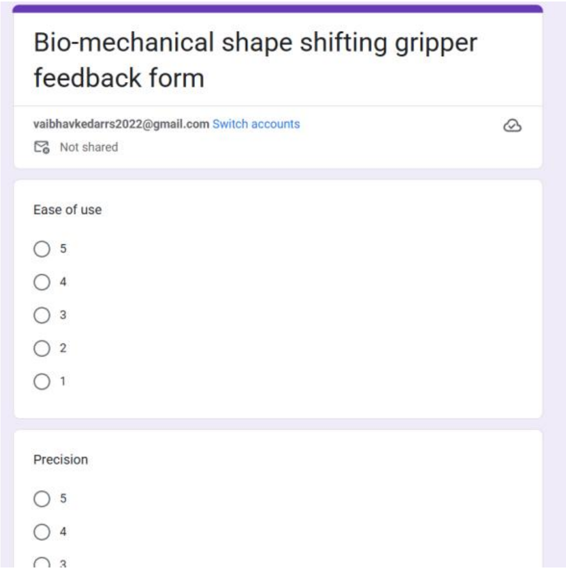
Combination No.	Shape Actuation Mechanism	Grip Mechanism	Actuation Method	Control System
1	Dielectric Elastomer Actuator (DEA)	Gecko-Inspired Adhesive Grip	Electric Motor (BLDC)	AI-Assisted Vision-Based Control
2	Fluidic Elastomer Actuator	Vacuum Suction Cups	Pneumatic System (Compressed Air)	Closed-Loop (Pressure Feedback)
3	Tendon-Driven Soft Actuator	Textured Surface Grippers	Servo Motor	Machine Learning-Based Object Recognition
4	Magnetic SMA Actuator	Programmable Electro-Adhesive Pads	Electro-Adhesion System	Sensor-Based Adaptive Control
5	Parallel Mechanism with SMA	Rubber-Coated Pads	Hydraulic Miniature System	Open-Loop Pre-Programmed Grip
6	Compliant Mechanism (Flexure-Based)	Static Charge-Based Adhesion	Bistable Pneumatic System	Real-Time Neural Network Grip Force Adjustment
7	Electro-Active Polymer (EAP)-Based SMA	Pneumatic Suction with Adaptive Sealing	Vacuum-Based Actuation	Closed-Loop (Pressure Feedback for Optimization)
8	Thermal-Based SMA	High-Voltage Electrostatic Grippers	Fluid-Driven Hydraulic Actuation	Timed Actuation Sequences (Open-Loop)
9	Dielectric Elastomer Actuator (DEA)	Micro-Suction Pads	Electric Stepper Motors	Vision-Based Feedback Control
10	Soft Pneumatic Actuator	Friction-Based Rubber-Coated Pads	Servo Motor	AI-Assisted Grip Force Adjustment

Concept Selection

Category	Number of Statements
Adaptive & Versatile Gripping	**9**
Precision & Control	**8**
Soft & Safe Handling	**6**
Structural & Material Innovation	**7**
Hygiene & Sterility Compliance	**6**
Total statements Categorized	**36**

Combination No.	Adaptability & Precision Handling	Soft & Safe Handling	Hygiene & Sterility Compliance	Structural & Material Innovation	Precision & control tech	
	25.00%	**16.67%**	**16.67%**	**19.45%**	**22.23%**	
Soft Pneumatic + Friction Rubber Pads + Servo + AI Force Adjustment	10	10	8	8	10	9.2796
Tendon-Driven + Textured Grip + Servo + Machine Learning	10	9	7	8	10	8.9462
Compliant Mechanism + Static Charge + Bistable Pneumatic + Neural Network	10	9	7	8	10	8.9462
DEA + Gecko Grip + Electric Motor + AI Control	9	9	7	8	10	8.6962
EAP-Based SMA + Pneumatic Suction + Vacuum Actuation + Closed-Loop	9	9	8	7	9	8.4461
Magnetic SMA + Electro-Adhesion + Sensor-Based Adaptive	9	7	6	9	10	8.3906
Fluidic Elastomer + Vacuum Suction + Pneumatic + Closed-Loop	9	8	8	7	9	8.2794
Thermal SMA + Electrostatic Grip + Hydraulic + Timed Actuation	8	7	7	10	8	8.0572
DEA + Micro-Suction + Stepper Motor + Vision-Based Feedback	9	7	6	8	9	7.9738
Parallel SMA + Rubber Pads + Hydraulic + Open-Loop	8	6	7	9	7	7.4737

Feedback Form



Bio-mechanical shape shifting gripper feedback form

vaibhavkedarrs2022@gmail.com Switch accounts

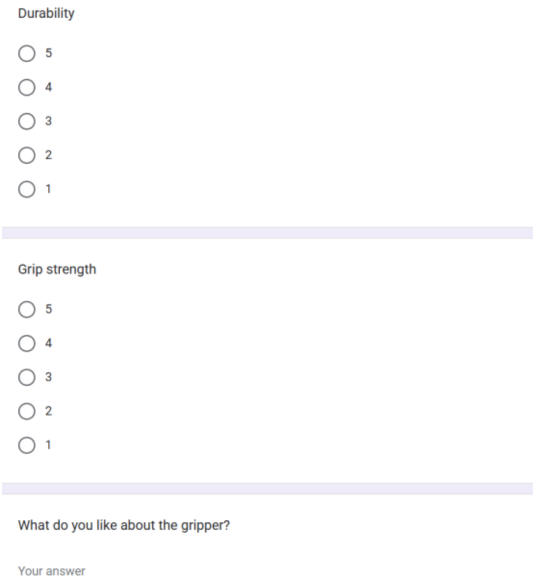
Not shared

Ease of use

5
4
3
2
1

Precision

5
4
3



Durability

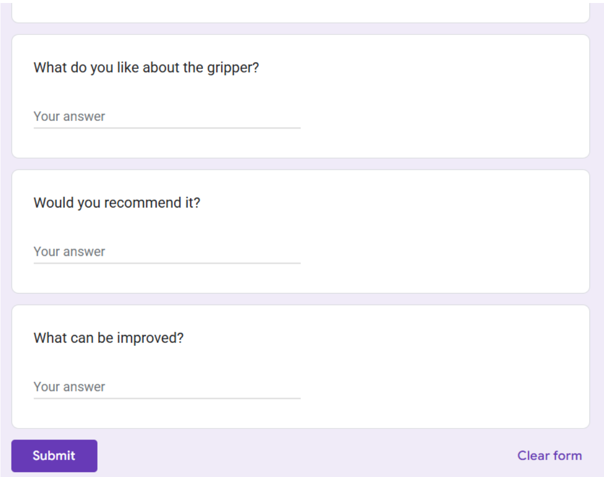
5
4
3
2
1

Grip strength

5
4
3
2
1

What do you like about the gripper?

Your answer



What do you like about the gripper?

Your answer

Would you recommend it?

Your answer

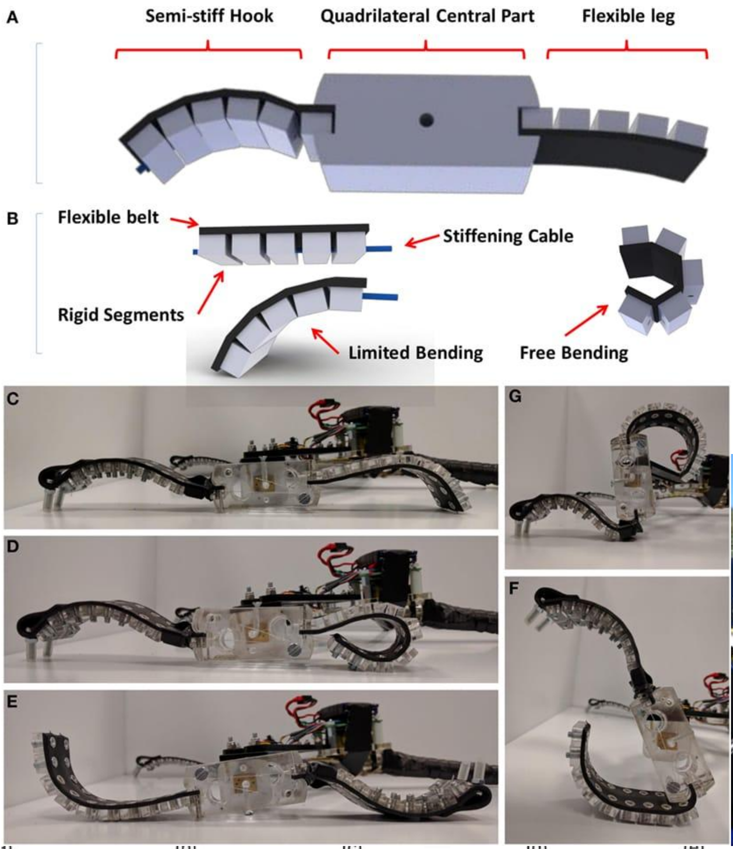
What can be improved?

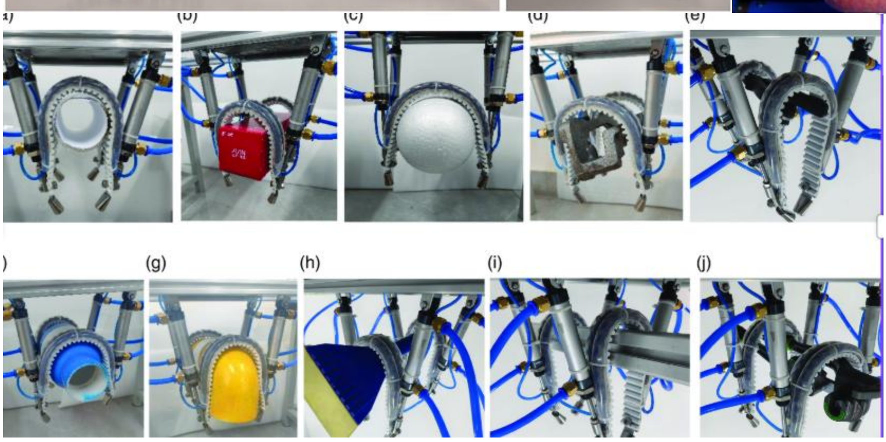
Your answer

Submit

Clear form

Concept Communication





Conclusion

After applying product design and development methodology and doing research, understanding market, customer needs, talking with them, and according to our product we come to the end of ideation process following:

- Lightweight, energy efficient, better grip, composite material, and cost effectiveness are the main focus of our product development process.
- We are going to use Soft Pneumatic Actuation as a shape actuation mechanism.
- Friction Rubber Pads for gripping mechanism.
- Servo motor as a actuation system.
- AI Force Adjustment as a control system.

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