IMPROVING THE DESIGN OF PNEUMATIC MUSCLES: SIMULATION AND ANALYSIS OF THE DYNAMIC BEHAVIOR OF THE SYSTEM

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INTRODUCTION

1.1 Past Experiences

The earliest pneumatic muscles, such as McKibben actuators, were developed in the 1950s. Over time, they have evolved with the use of synthetic balloons and elastic mesh materials.Modern designs focus on:1- Efficiency 2-Contraction strength3-Controllability

1.2 Theories Involved

- **Elasticity** – The ability of the inner bladder to stretch and recover.
- **Pressure Differential (Pressure Jump)** – The transformation of internal air pressure into mechanical deformation.
- **Stress and Strain** – The mechanical response of materials under load.

1.3 Necessity

While electric motors are safer and heavier, pneumatic muscles offer a lightweight and flexible alternative. Our objective is to develop a more human-like actuation system by: 1.Using advanced mesh and balloon materials 2. Designing a reliable, controllable contraction mechanism for robotic limbs

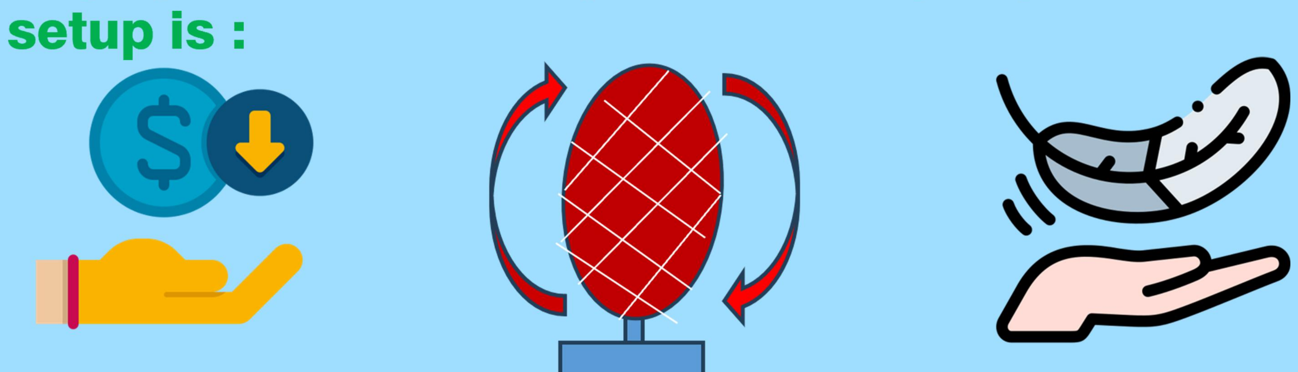
PROBLEM REVIEW

Pneumatic muscles are soft, light actuators that contract when pressurized air enters them. While light and mimicking living movement, there are certain fundamental limitations on their long-term reliability, control, and maintenance — especially in wearable technology and robotics.

Why it matters:

- Traditional muscles are non-repeatability, asymmetric, and imprecise.
- Low mesh elasticity prevents full relaxation.
- Existing systems are complex and very expensive.

But our setup is :



What this project will do:

- Improve the symmetry of contraction using hyperelastic balloons
- Test various netting materials like polyethylene
- Reproduce natural muscle conditions (isotonic, isometric, isokinetic)
- Create a controlled timing and pressure system for repeatable performance

PRODUCTION PROCESS

3-1-Idea-

Design a prosthetic-like actuator that inflates and deflates automatically with a timer-controlled solenoid valve and compressor system.

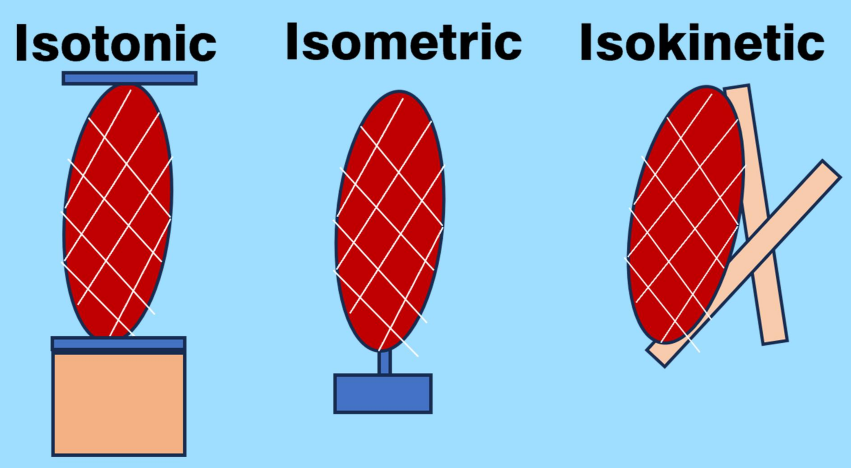
3-2-Device Design-

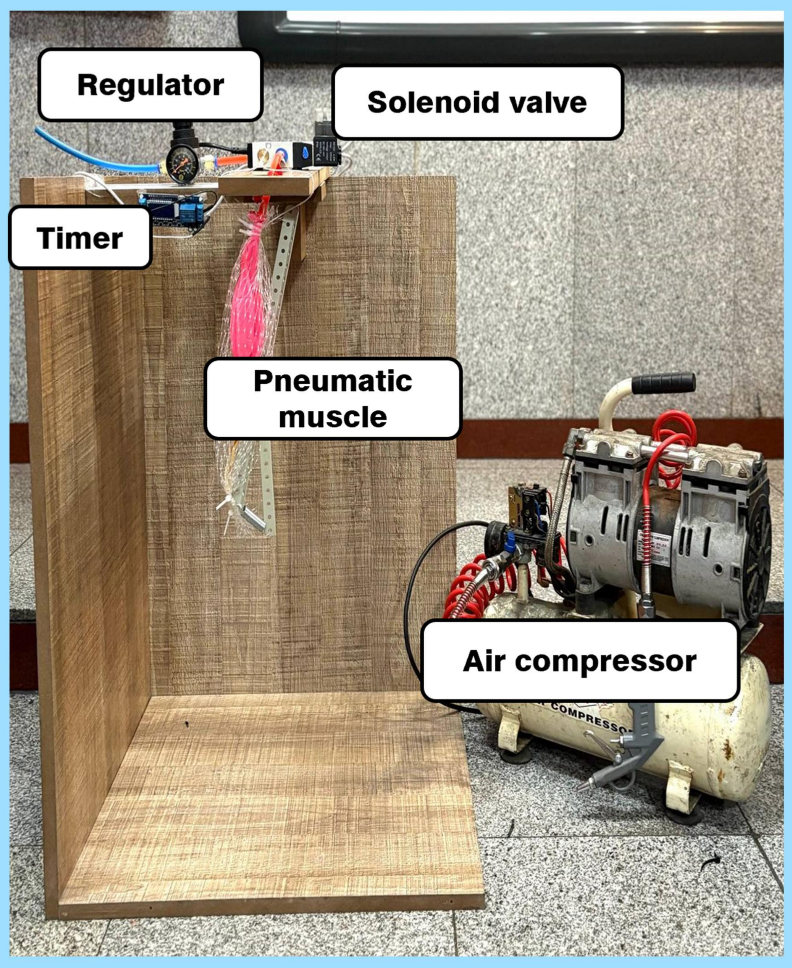
Balloon (hyperelastic, 11")-Mesh (polyethylene, 23 cm)-Solenoid valve-Timer (XY-J02)- Regulator and pressure gauge-Air compressor -12V adapter

3-3-Circuit Operation-

First step : Timer opens valve for 3 seconds → Air inflates balloon → Muscle contracts

Second step : Valve closes → Balloon deflates → Muscle returns to rest



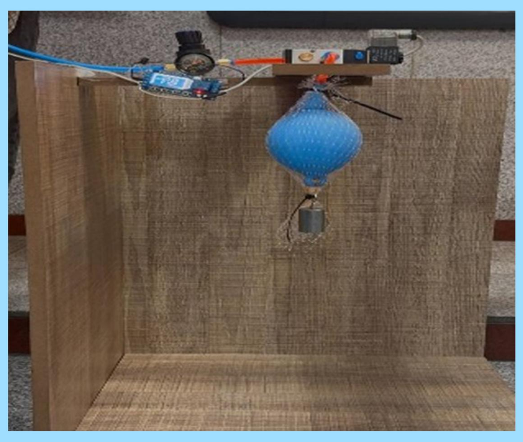


RESULTS AND DISCUSSION

In General: a more elastic mesh like polyethylene improves contraction characteristics and in result, muscle performance. The nozzle's angle affects pressure distribution, with uniform distribution at 0 degrees. A higher secondary ratio increases contraction force and elasticity, which causes greater work done and improved efficiency.

Key Results:

- Increased contraction in isotonic mode
- Polyethylene mesh improved performance
- 36 cm^3 air volume and 0° nozzle angle ensured maximum efficiency
- Consistent contraction with softer balloon



SWOT Analysis

	Pneumatic muscle	Project muscle		Pneumatic muscle	Project muscle
Strength	High precision - Fast response - human-like motion	Low-cost – lightweight-elastic - easy to modify	Weaknesses	Needs compressed air -bulky -high cost -Don't have constant pressure distribution	Low durability-environment-sensitive-Not used for heavy industries

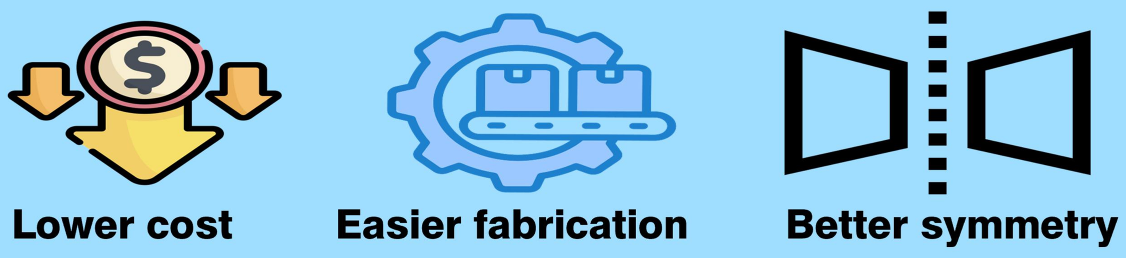
	Pneumatic muscle	Project muscle		Pneumatic muscle	Project muscle
opportunities	Applications in medicine-Rehabilitation robotics	Suitable for prototyping -eco-friendly materials-Usable for soft robotics	Threats	Pressure-related risks -high energy use-competing actuators-High costs	Unreliable for long-term heavy use -high competition

SWOT stands for Strengths, Weaknesses, Opportunities, and Threats. It is a strategic analysis tool used to evaluate the internal and external factors that can impact a project, product, or organization.

CONCLUSION

A pneumatic muscle constructed using a balloon and a braided net achieved a contraction of approximately 15–20% upon inflation. It demonstrated rapid responsiveness (under 1 second), successfully lifted loads up to 1000 grams, and maintained reliable performance over more than 100 actuation cycles. Compared to elastic alternatives, the braided net ensured smooth, symmetrical, and stable motion.

Compared to traditional pillow-type muscles, it had:



LCA(Life Cycle Analysis)

LCA evaluates the environmental impact of a product from raw materials to end-of-life disposal, including manufacturing, use, and recycling stages. To evaluate the total environmental impact of pneumatic muscles from material sourcing to disposal, guiding more sustainable actuator design.

	Pneumatic muscle	Project muscle
Energy consumption	Compressor and air pressure gauge	Compressor and air pressure gauge
life cycle	Durable, repairable	Shorter life, repairable
recycling	Requires disassembly	Some non-recyclable components
Environmental effect	consumption + manufacturing complexity) High (energy	Low (simple materials + low consumption)

Sustainable Development Goals:

SUSTAINABLE DEVELOPMENT GOALS

3th goal — Educational uses in teaching robotic to pupils in lower price

4th goal — Can be used in simple prostheses for patients with lower price

9th goal — Experimental and simple robotic uses

FUTURE PLAN

Building on the strengths and opportunities identified in the SWOT analysis, this project demonstrates considerable potential for integration into soft robotics, low-cost prosthetic devices, and educational platforms, offering advantages in affordability, efficiency, and environmental sustainability. To address current limitations and mitigate potential risks, future iterations will focus on replacing the air bladder with materials that maintain high elasticity while providing superior environmental resistance, such as RTV (Room Temperature Vulcanizing) silicone or medical-grade catheter balloons. Furthermore, with strategic dissemination and targeted marketing, the improved actuator design could achieve broader adoption and establish a competitive position in both academic and commercial markets.

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REFERENCES