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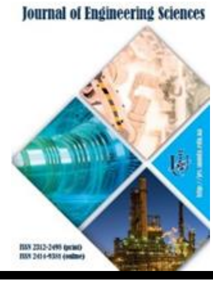

Movement Monitoring System for a Pneumatic Muscle Actuator

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Abstract. Recent advancements in soft pneumatic robot research have demonstrated these robots' capability to interact with the environment and humans in various ways. Their ability to move over rough terrain and grasp objects of irregular shape, regardless of position, has garnered significant interest in developing new pneumatic soft robots. Integrating industrial design with related technologies holds great promise for the future, potentially bringing about a new lifestyle and revolutionizing the industry. As robots become increasingly practical, there is a growing need for sensitivity, robustness, and efficiency improvements. It is anticipated that the development of these intelligent pneumatic soft robots will play a critical role in serving the needs of society and production shortly. The present article is concerned with developing a system for monitoring a pneumatic robot's parameters, including a spatial coordinate system. The focus is on utilizing the relationship between the coordinates and pressure to model the movement of the soft robot within the MATLAB simulation environment.

Keywords: soft robotics, process innovation, pneumatic manipulator, monitoring system.

1 Introduction

Researchers continue to mimic living things and their materials, morphology, and movements to create robots capable of performing complex tasks in unstructured environments. Soft robotic arms have generated considerable interest over the past few years due to their wide range of potential applications. This is due to their ability to adapt to their surroundings, move dexterously, and manipulate objects of a wide variety of sizes using whole-hand manipulation. In this case, the manipulators can lengthen, contract, and bend at any point in their structure. This allows them to access highly confined spaces and follows complex trajectories. They have unique features compared to rigid-body robots, such as smooth bending, inherent compliance, lighter weight, and increased resiliency [1, 2].

Soft robots and traditional complex robots use different mechanisms to achieve dexterously. Soft robots have distributed deformation, allowing them to have a hyper-redundant configuration space where they can reach any point in the three-dimensional workspace with infinite shapes or configurations. This is in contrast to hard robots, which have a limited number of degrees of freedom (DOF). Additionally, soft robots generate little resistance to compressive forces, allowing them to conform to obstacles and handle soft and fragile payloads without causing damage. They can also use large strain deformation to squeeze through openings smaller than their nominal dimensions, making them suitable for applications such as personal robots that interact with humans without causing injury, service and painting robots that need high dexterity to access confined spaces, medical robots for use in surgery, and defense and rescue robots that operate in unstructured environments [3].

2 Literature Review

The McKibben artificial muscle was Japan's first pneumatic muscle developed in the 1960s. These advantages are high power, low weight, softness, and compliance in terms of material and motion. The McKibben pneumatic artificial muscle is a device that consists of a chemical-fiber sleeve yarn and a rubber tube. When air is introduced into the muscle, the rubber tube expands radially while contracting axially. This deformation process ceases when the braid angle reaches its limiting value. In practical applications, the artificial muscle is secured at one end by a knot, while the other is connected to an air supply and fixed using a large connector and adhesive. By adjusting the internal air pressure, the actuator contracts and produces a contraction force that is used to power the motion of a manipulator [4]. This paper also contains research on improving a manipulator's mechanical properties based on McKibben's muscles and increasing its wear resistance and strength. This research is based on the similarity of pneumatic artificial and natural muscles [5]. It served as a further development, expanding the scope of the manipulator to industrial applications.

The field of continuum manipulator robots has a history dating back to the 1960s, but more formal research on their design and control began in the 1990s. These robots represent a shift in manipulator design from discrete rigid links to mechanisms with elastic structures that can bend continuously along their entire length. These elastic structures, or "continuum" elements, enable a wide range of motion and conformability, making them suitable for tasks requiring high dexterity and the ability to access confined spaces. [6]

There has been ongoing research to improve and modify pneumatic muscles using pressurized air to generate motion.

The paper [7] presents a soft amphibious robot with three drive links in the legs and four drives in the body (Figure 2). The robot utilizes thin, soft McKibben actuators to achieve two types of bending: in the legs for movement and in the body for added mobility. The body's bending properties are achieved through the deformation of a plastic plate, which helps the robot mimic the locomotion of a salamander during walking. The authors also investigate the effect of changing specific parameters, such as frequency and input pressure, on the speed and stability of the walking movement. The research [8] explained the kinematics of rotation and bending features of the proposed robot arm and illustrated the direction of possible movements. The snake's movement in two directions became the prototype scheme for designing a double-bend pneumatic muscle actuator [9].

This will allow the development of larger underwater swimming robots in the future.

The authors of the work [10] discovered the following advantages of the Pneumatic Muscle Actuators (PMA): low cost, which is about 10 dollars, ease to manufacture, wide dimension grasping ability, safe to low stiffness objects, and it has low mass (0.18 kg). Its inertia is also low, which potentially makes it safer for operation around humans. Generally, the PMA is constructed from an inner rubber tube covered by a braided sleeve with two solid material terminals fixed firmly to ensure no air leakage occurs. One of the terminals has a small hole for the input and output of actuated air [11].

In the paper [12], a two-segment soft robot arm is constructed using simple retractors and extensor actuators. This allows it to expand, contract, and bend in multiple directions. The authors of the work [13] created a robot called "Octarm". Their prototype is the tentacles of an octopus. Pneumatic extensor muscles powered octarm Continuum robots.

Octarm robots have three independently actuated sections for 9 DOF. Each section is powered by three independently controlled pneumatic pressures fed to the extensor muscles. Therefore, the robot without pressure has a minimum length and continues to its maximum length as a function of actuation.

The research works [11, 16, 17-20] revealed limitations of the traditional soft drive.

These restrictions are:

– a pneumatic artificial muscle creates a contraction force only when pressed;

– the extension drive generates the extension force only when pressure is applied;

– each type of soft drive has a constant stiffness over a certain length.

Therefore, in the study [21], the design of a soft actuator is based on a starfish. The starfish is composed of elements such as connective tissue, calcite bone, and interosseous muscle, which allows it to regulate the structural stiffness of its body actively [22]. Since the movement of the elastic body of the actuator depends on the deformation of the tissue, especially the characteristics of the material used in its construction, this stage compensates for two anisotropic tissues (woven tissue and elastic tissue) and elastomer (silica gel) to develop a contractor and an extensor, respectively. Finally, they are combined into an inner and outer chamber structure and begin as an antagonistic actuator based on the extensors and contractors (ECFA) tissue. If both chambers are pressure controlled, a change in actuator stiffness can be achieved.

3 Research Methodology

The paper investigates controlling a soft robot with a pneumatic drive (Figure 1). Such a robot is a manipulator that makes it possible to grab soft objects and move them to specified locations.

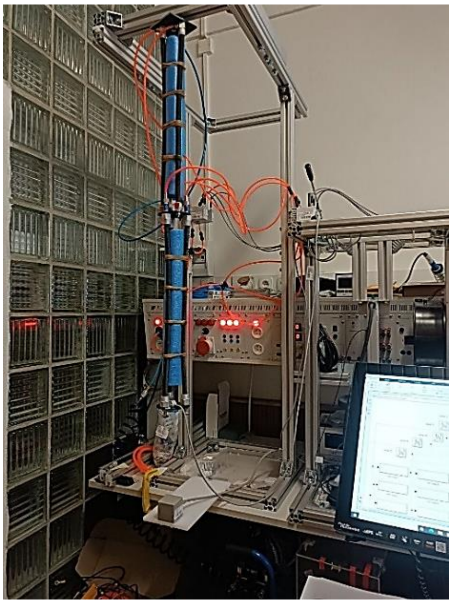


Figure 1 – Stand with the soft pneumatic robot

The movement of the manipulator is controlled by changing the air pressure in six pneumatic actuators. The compressed air source is a pump-compressor that creates an overpressure of 0 to 6 bar. Pressure gauges are used to measure the pressure in the pneumatic actuators, and position sensors are used to control the position. The robot's manipulator's movement is monitored using a computer with the Matlab simulation environment installed (Figure 2).

The set pressure in each of the six pneumatic actuators of the soft robot is set in the Matlab environment using blocks P1-P6. At the output of the circuit in Matlab, the movements of the robot manipulator in three coordinates (X, Y, Z) and three angles (θ, φ, and ψ), which are the angles of the rotation coming from the position sensors, are recorded. The experiment determined the dependence of each of the coordinates on the pressure in the pneumatic actuators.

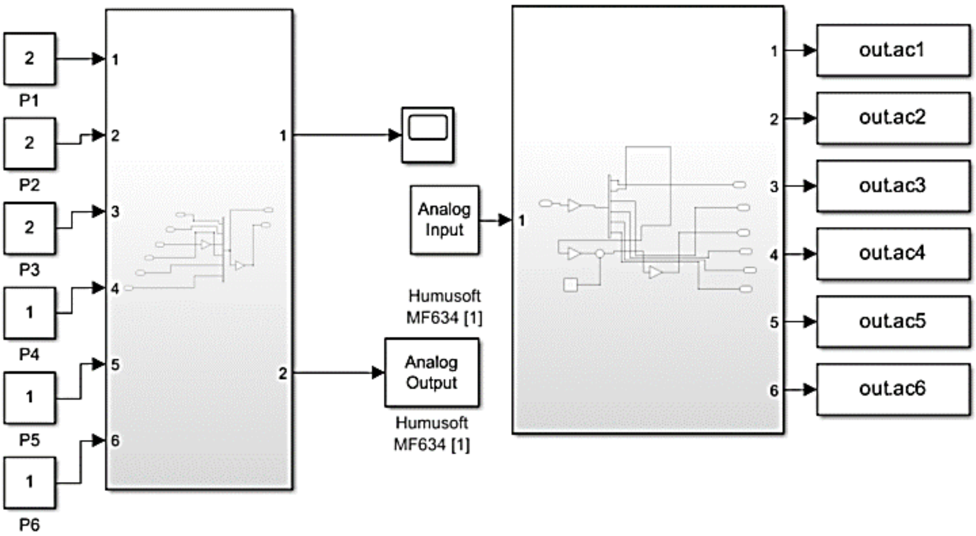
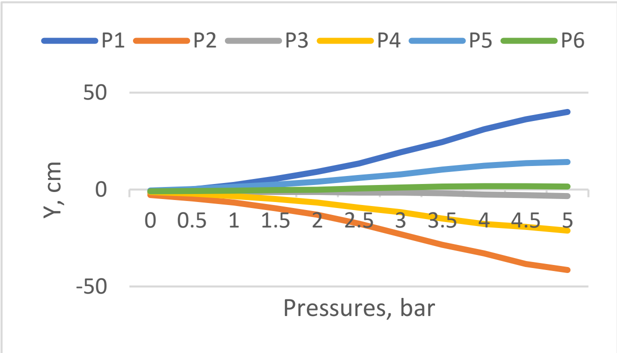


Figure 2 – Pneumatic robot parameters monitoring system

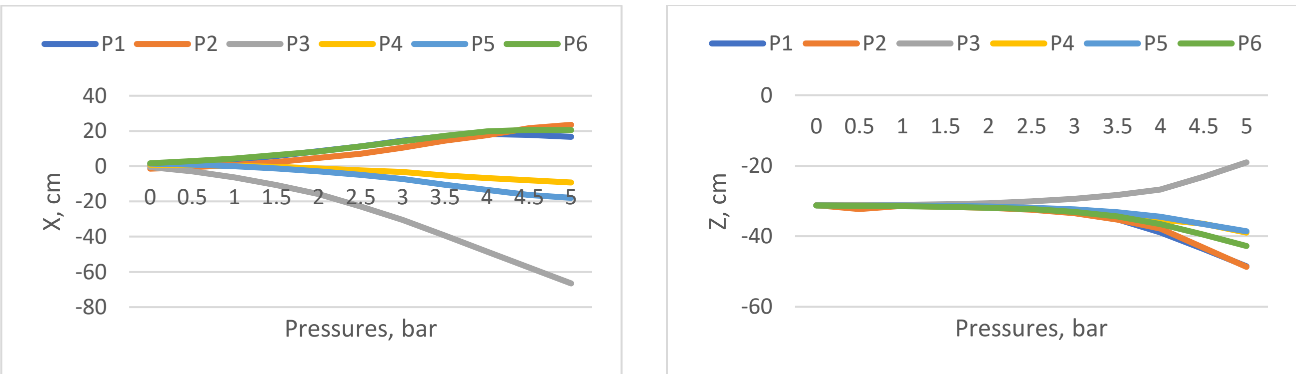
4 Results and Discussion

As a result of the experiment, dependencies were obtained that describe the kinematics of soft robot motion. Figure 3 shows a linear dependence up to a pressure value of 4 bar is observed.

After 4 bars, a non-linear dependency is observed. This relation between the displacement of the soft robot and the pressure is due to the material's properties used to manufacture the soft robot's pneumatic muscles.



b



a

c

Figure 3 – Dependencies of X (a), Y (b), and Z (c) coordinates on pressure

These dependencies can be used to describe the motion model of the pneumatic muscle in three-dimensional space.

These dependencies can be used to describe the motion model of the pneumatic muscle in three-dimensional space, as shown in Figure 4.

One of the biggest problems of pneumatic soft robots is the search for methods and models that would most accurately describe the experimental values. The given graphs (Figures 3, 4) allow for defining the dynamic movements of soft robotics and finding its position at any moment in time.

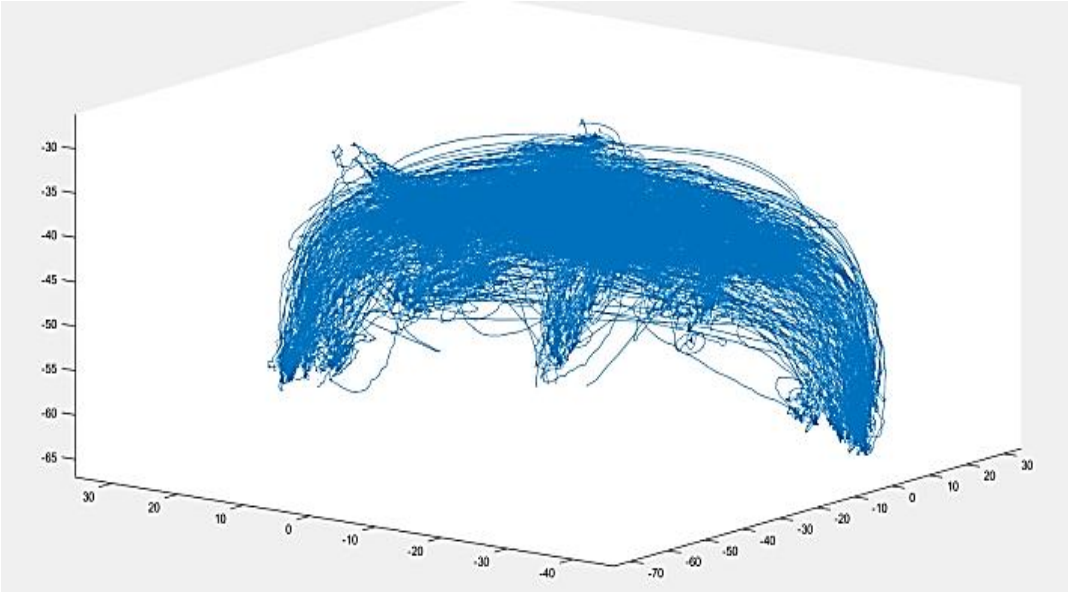


Figure 4 – Simulation model of pneumatic robot movement

5 Conclusions

Modern research on pneumatic soft robots has proven that they can interact with people and the environment in various ways, move over unknown terrain, and grasping irregularly shaped objects, regardless of their position.

These basic operations open the door to applications where robots work closely with humans. Therefore, there has been a growing interest in developing new types of pneumatic soft robots in recent decades.

As robots become more practical, sensitivity, robustness, and efficiency improvements become increasingly important. It is believed that shortly, by integrating industrial design with related technologies, advances in this field will create a new lifestyle and change in the industry, enabling intelligent pneumatic soft robots to serve all aspects of society and production.

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