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Design and Development of a Low-Cost Multi-Channel Re-Programmable Electro-Pneumatic Actuator Kit

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ABSTRACT

The objective of the research is to develop a low-cost, multi-channel electro-pneumatic actuator kit that would be conveniently accessible for students' learning experiences, trainings, and research at the individual and academic level. The essential feature of this kit is the inclusion of multi-channel outputs, which implies that the student may not only examine the behavior of basic pneumatic actuators but also train their minds to operate complicated actuation systems. With this electro-pneumatic actuation kit, a student can build and utilize it in a variety of research areas, as well as regulate a system synchronously or asynchronously with greater efficiency. The device remains portable, inexpensive, and simple to use. It has a power source of 12 VDC for the electrical circuit and is able to provide a maximum pressure of 90 kPa as well as vacuum of -40 kPa. Relays are being integrated to satisfy the smooth automation of the kit. It features the MPX700 differential pressure sensor, which allows the user to measure and manage the needed pressure. All of the components are controlled by the Arduino Board, which is affordable and can be programmable to do the required function. With this research, academic institutions will have the capability to create their own kits for their students, allowing them to discover numerous new inventive concepts.

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1. INTRODUCTION

The need for pneumatic actuators has been steadily as industrialization has progressed. For engineering students, understanding pneumatic actuation system is essential for anything from robotics to space exploration. Electro pneumatics have been successfully employed in many domains of industrial automation. Worldwide, electro-pneumatic control systems power the fabrication, assembling, and production plants. In addition to technological advances, the expansion of needs has a substantial influence on the physical appearance of controls [1],[2] and [3]. In the signal control segment, relays have been gradually replaced by microcontrollers to suit the growing demand for greater flexibility. To satisfy the demands of modern industrial processes, modern electro pneumatic controls typically combine innovative ideas from the power sector [6] and [822]. Pneumatic actuators offer several advantages due to their energy source. They have a simple design with very high safety ratings when compared to hydraulic and electronic counterparts because they use air to power the system [8],[9]. Due to the high cost of expensive kits, most universities in developing countries cannot afford them for their students. As a result, brilliant minds who want to work in fields such as soft robotics and traditional robotics as briefly discussed in [11],[12],[13] and [14] may feel disappointed because

their design requires an actuation system. The creator of this unique kit aims to promote learning innovation by focusing on the design and implementation of a multi-channel electro pneumatic actuator kit for students in order to offer students with the essential access for research and to improve the quality of learning results.
The primary goal of this investigation is to introduce researchers to a low-cost multi-channel electro-pneumatic actuator kit. The kit's operating voltage is 12V DC. This electro-pneumatic system is divided into two stages. In the first stage, a Micro-Controller and a Motor Driver are used to control the entire process. Furthermore, this stage includes two 12V DC air pumps as well as two 12V DC solenoid valves. The first stage produces a single-channel pneumatic output. This output is given to the input of the second stage that is a slave stage which consists of multiple relays and solenoid valves that accept input from the Master Controller and, depending on the state, provide the required output to the user. There is a feedback sensor that provides output pressure readings in Kpa. The output of this study consists of five channels. Developing and constructing a low-cost multi-channel electro-pneumatic kit for use as an educational and individual research tool, since it's an incredibly viable device to be employed inside the automation and instrumentation system training as a demonstration unit for simulating the learners' actual work. Because laboratory apparatus is expensive, the low-cost electro-pneumatic kit is employed in order to resolve the problem of limited training facilities at academic institutions. This low-cost electro-pneumatic kit provides better education in the automation and instrumentation laboratory courses while requiring no productive capacity or generally available instruments. Students from deprived backgrounds might conduct study on pneumatic controlled systems such as pneumatic-robots to better comprehend the control systems. This electro-pneumatic kit is designed to be compact, lightweight, and portable, allowing it to be easily transported from one location to another. By performing the experiments on the electro-pneumatic actuator kit, students were capable of understanding and learn additional information regarding it.

2. OBJECTIVE AND UNIQUENESS OF RESEARCH

The primary goal of this study is to create a low-cost multi-channel electro-pneumatic kit to address the lack of pneumatic instruments at educational institutions and provide students with hands-on learning. The goal of this project is to provide students hands-on experience with a pneumatic system and to enable them to build and control larger models for their own research. Another goal is to improve the quality of directions in the actuation of a system such as a soft robot at a low cost with this electro-pneumatic kit. This kit attempted to boost reliability by reducing the number of mechanical elements that required movement or were vulnerable to deterioration over time. The additional goal of the electro-pneumatic actuator kit is to reduce planning and installation work and cost, particularly for complicated controls. Another purpose of this kit is to reduce installation time, especially when using more modern, compact assembly.
This kit's distinctiveness lies in its own right. The kit is re-programmable, which means that the user can programme it multiple times to achieve the desired goal of learning. Other uniqueness lies in the fact that the user can get output from multiple channels synchronously as well as asynchronously. Students will be able to control a system utilizing PWM, time-control, and Continuous feedback method. Furthermore, with this kit, students will be able to have hands-on experience with real-time control systems that use feedback loops, which will improve their grasp of programming and control system skills.

3. MATERIALS AND METHADOLOGY

This study utilized the developmental type of research. The design of Electro-Pneumatic Actuation kit is to enable it to run in actual the program from Arduino IDE software. After the program is loaded to the Arduino UNO, the desired output corresponds to the given input values. The required components employed in this research are shown in [Table 1]. The desired quantity and its related rating are specified.

Table 1 : Components Specification of Electro-Pneumatic Kit

Components	Quantity	Individual Rating
Power Supply	1	12V,5A
Arduino UNO	1	5V
VNH2SP30 Motor Driver	1	12V, 5A
Air Pumps	2	12V, 2A
Air Solenoid Valves	7	12V, 200mA
Relays	5	5V,100mA
MPX700 Pressure Sensor	2	5V

The electrical circuit is powered by the electro-pneumatic control kit 12VDC. [Figure 1] shows the detailed overview of the components of the electro-pneumatic control kit. The entire system is controlled by the Arduino UNO (1) microcontroller board. Then comes the Motor Diver Board (2) from which two DC Air Pumps (3) and (4) are derived, each of which operates at 12V and 2A. Each pump has its own set of tasks. When one pump is activated, it simply produces pressure, while the other produces vacuum. In addition, each Air pump has its own solenoid valve (5) and (6). Each solenoid acts as an air flow gate. In between (7) is a pressure sensor that provides pressure and vacuum readings in Kpa. (8) shows the base of the electro-pneumatic actuator kit which is made of foam. The reason for using this material is that the vibration produced from the DC pumps needs to be minimized as it will affect the stability of the system. (9) shows the silicone tubing's as they carry the air from the Pump to the load. (10) shows the output of the Electro-pneumatic kit. The output of the Arduino Serial Monitor is used to record all of the pressure sensor information.

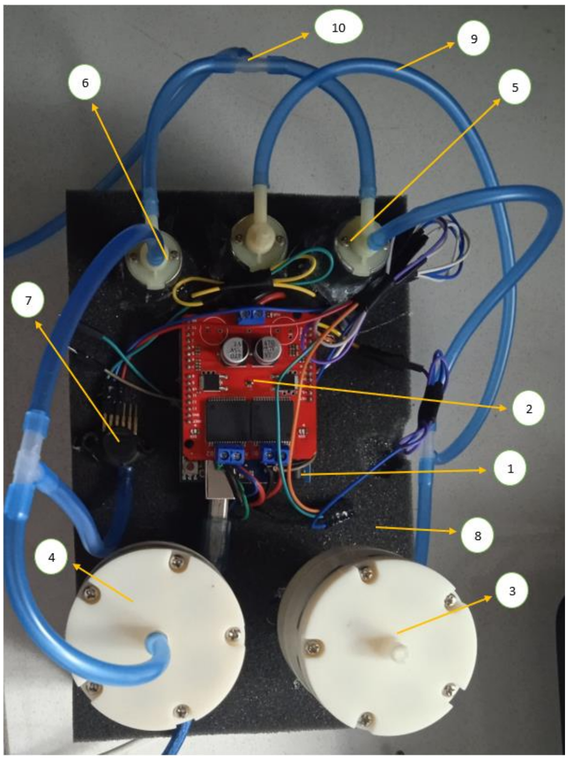

Figure 1 Pneumatic Actuator Kit

[Figure 2] shows the overview of the second stage of the electro-pneumatic kit. The pneumatic output from the first stage is fed to the second stage where it is distributed with the combinations of relays. The relays control the channel depending upon the instructions given to the Microcontroller. These relays are directly controlled by the Arduino itself. The relays control the triggering of multiple Pneumatic Solenoid valves. Each solenoid valve is called a Channel. This research proposes a Five-Channel Pneumatic Output.

[Figure 3] shows the process flow of the actual working of the electro-pneumatic kit. The user gives input to the Arduino UNO which then gives a signal to the Motor Driver. The Motor Driver then reads whether it has to turn ON the Pressure Air Pump or Vacuum Air pump. After reading the desired data by the Motor Driver, it will turn on the required Air Pump.

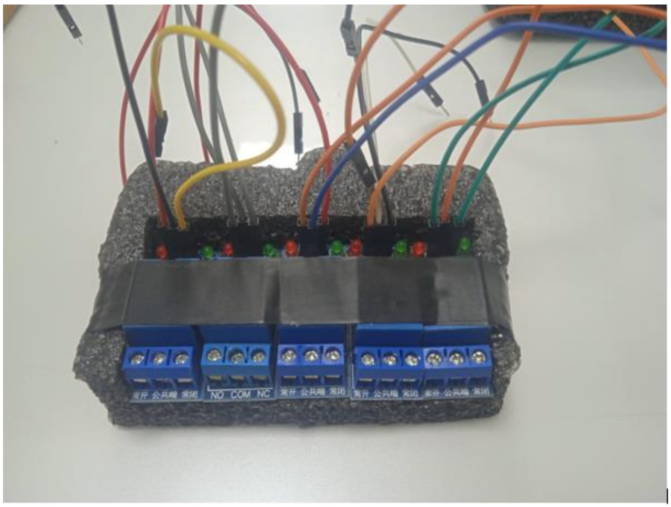

Figure 2 Second Stage of Pneumatic Actuator Kit

In the second stage of the electro-pneumatic kit, the output from the first stage, which is a single pneumatic output, is transmitted to the second stage for further processing and control. This single pneumatic output serves as the primary source of compressed air, and its flow is continuously monitored by the Pressure Sensor to ensure precise regulation.Within the second stage, the pneumatic output undergoes a series of actions through multiple relays and solenoid valves. These components act as control switches, determining the distribution and routing of the pneumatic output to different channels within the system. Each channel corresponds to a specific solenoid valve that can be independently triggered by the Arduino, enabling selective control over the pneumatic output's direction. For instance, if the user desires to use only one channel at a time, they can activate the corresponding solenoid valve (e.g., Channel 1 solenoid valve) using the Arduino. This activation allows the pneumatic output to be directed to the specific load or actuator associated with that channel, while the other channels remain closed. Consequently, the user can effectively control and manipulate different actuators or devices within the system using the single Pneumatic Controlled Output.

The main advantage and uniqueness of this kit lie in its capability to function as both an open-loop and closed-loop system. The user can configure the system to operate in an open-loop fashion, where the pneumatic output is directed to specific channels without any feedback control. Alternatively, it can be transformed into a closed-loop system, wherein feedback from sensors, such as the Pressure Sensor, is utilized to adjust and regulate the pneumatic output based on real-time conditions and requirements.

3.1 Pneumatic Controlling Methods:

3.1.1. Time sequential through hit and trial Method:

The time sequential through hit and trial method represents a standard approach to controlling pneumatic actuation. Unlike utilizing a pressure sensor for feedback, this method allows the user to directly control the pneumatic output through a systematic process of experimentation and observation. To begin, the user collects various pneumatic output readings while correlating them with the corresponding load requirements. These readings serve as valuable data points to understand how the pneumatic system interacts with different loads. Based on these insights, the user proceeds to design a time sequence that governs specific operations within a pre-defined time limit, as set by the user. For instance, consider a scenario where a pneumatic soft robot is designed to withstand a maximum pressure of 30kPa. By setting specific inflation and deflation time periods for the soft robot, the user can ensure that the pneumatic actuation reaches its maximum potential without exceeding the desired pressure limit. In this manner, the pneumatic kit will provide the required pressure for a limited duration before automatically shutting down.
This method proves particularly beneficial for users seeking to streamline the functionality and reduce the overall cost of the pneumatic kit by minimizing the reliance on pressure sensors. While it offers a viable alternative, it requires a careful calibration of the time sequence based on empirical data and performance evaluations to achieve optimal results.

Table 2: Results of Open-Loop Time Sequential Through Hit and Trial Method for Pneumatic Soft Robot Actuation with Various Loads

Time Interval (Inflation)	Time Interval (Deflation)	Load Applied	Pneumatic Soft Robot Pressure (kPa)	Result
10 seconds	5 seconds	Load A	25.4 kPa	Successful Actuation within safe limit
15 seconds	7 seconds	Load B	32.8 kPa	Pressure exceeds safe limit, requires adjustment
8 seconds	4 seconds	Load C	28.1 kPa	Successful Actuation within safe limit
12 seconds	6 seconds	Load D	31.3 kPa	Pressure exceeds safe limit, requires adjustment
9 seconds	4 seconds	Load E	26.9 kPa	Successful Actuation within safe limit

In [Table 2], the user conducted multiple experiments with different time intervals for inflation and deflation. The results show the corresponding pneumatic soft robot pressures during each actuation attempt. The goal was to achieve successful actuation within the safe pressure limit of 30 kPa. Based on the results, the user could fine-tune the time intervals through iterative adjustments until the pneumatic soft robot consistently achieves successful actuation within the desired pressure range without exceeding safety limits. The Time Sequential Through Hit and Trial method offers a practical way to control the pneumatic actuation process without relying on pressure sensors, making it a cost-effective option for specific applications.

3.1.2. Feedback Controlling:

The Feedback Controlling method offers increased accuracy and reliability in managing the pneumatic actuation process, thereby ensuring the safety of the load attached to the electro-pneumatic kit. By incorporating a pressure sensor as a feedback system, real-time data is continuously obtained, allowing for precise monitoring and regulation of the pneumatic output. The feedback mechanism enables the system to detect and respond to any fluctuations or anomalies in the pneumatic pressure, promptly adjusting the actuation process to maintain safe operating conditions. This dynamic control mechanism prevents excessive pressure buildup, minimizing the risk of overload or damage to the load attached to the kit. Furthermore, the ability to customize the actuation parameters through re-programming the electro-pneumatic kit with the Arduino IDE empowers users to tailor the system to suit the specific requirements of the load. This flexibility ensures that the pneumatic actuation remains within the safe limits of the load, avoiding potential hazards associated with overloading. By regulating the pressure and vacuum of the air pumps using Pulse Width Modulation (PWM), the Feedback Controlling method facilitates controlled and gradual changes in the pneumatic output. This smooth and controlled actuation process contributes to the overall safety of the load and prevents abrupt or erratic movements that could compromise the load's stability.

Following on from the flow diagram, the user re-programs the electro-pneumatic kit using the Arduino IDE. The output channels have a maximum of five. Each solenoid valve utilizes in stage two controls the solenoid valves individually, and the relay is controlled by the Arduino. This pneumatic kit is simple and user-friendly, offering a new world of exploration for the students. Its design evolves from simple to complex architecture, allowing students to study and build in new ways. Its method of controlling the output synchronously implies that the user can get output from each channel at the same time, but what distinguishes it is that it is one of the low-cost pneumatic actuators that delivers output pressure and makes output vacuum asynchronously. This means that the user has gained the capacity to govern the system's flow in their own way. Users can regulate the pressure and vacuum of the air pumps using PWM. With PWM, the output can be delivered as needed with a time delay or as needed in less time. The power supply power is estimated to ensure that the demand and supply of each component work properly without interfering with their operation.

4. Estimated Price of the Electro-Pneumatic Kit:

The electro-pneumatic kit presented in this research offers a cost-effective solution for students and researchers seeking hands-on experience in pneumatic actuation systems. The estimated total cost of the kit, comprising all the components listed in Table 1, amounts to approximately 45 dollars. The affordability of the kit is a crucial factor, particularly for educational institutions and students in resource-constrained environments. By keeping the cost low, this kit provides greater accessibility and the opportunity for a wider audience to delve into the world of electro-pneumatic control.

It is essential to note that the estimated price considers the cost of individual components, excluding any additional expenses related to assembly and miscellaneous materials. Assembling the kit may require some basic technical skills, but the instructions provided in this paper aim to facilitate a smooth and straightforward assembly process. The low-cost nature of this electro-pneumatic kit makes it an attractive option for academic institutions, researchers, and students, fostering innovation and learning in the field of pneumatic actuation and control.

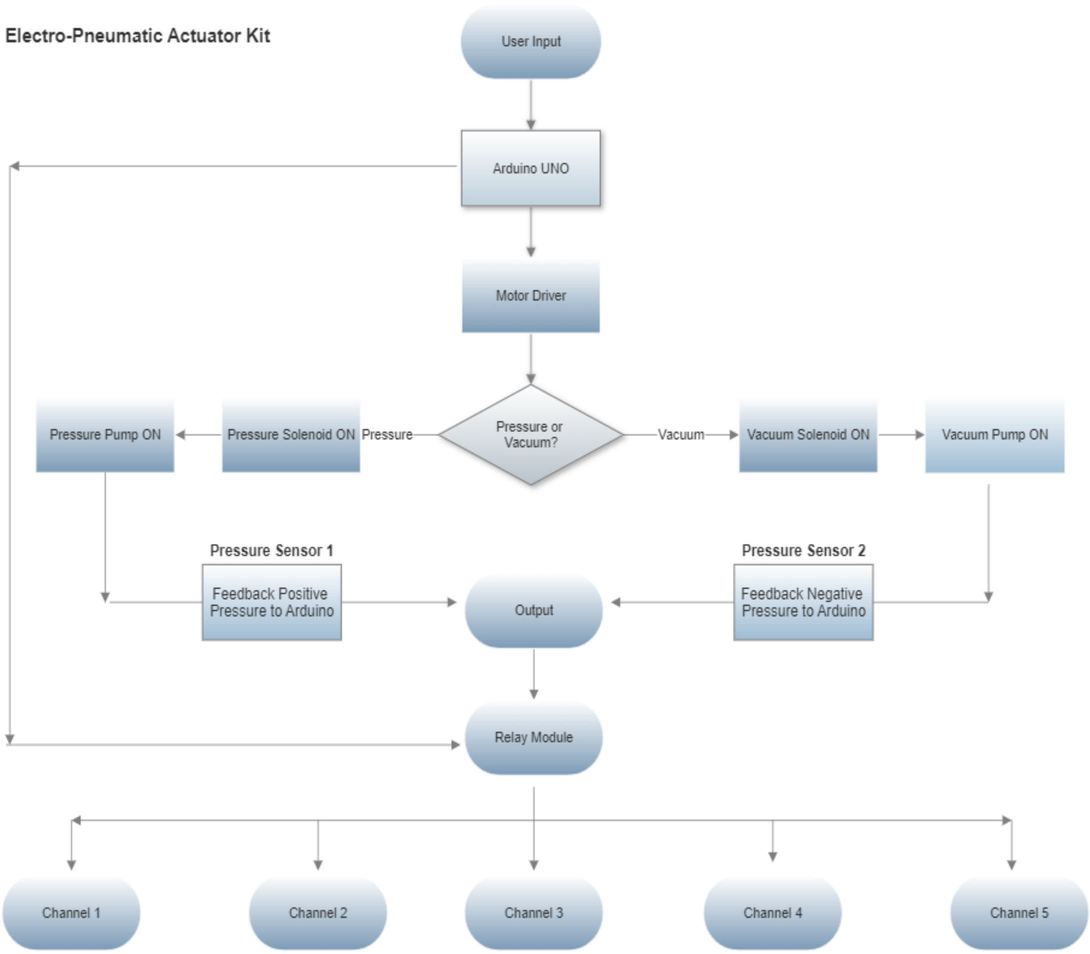

Figure 3 Process Flow Diagram of Electro-Pneumatic Kit

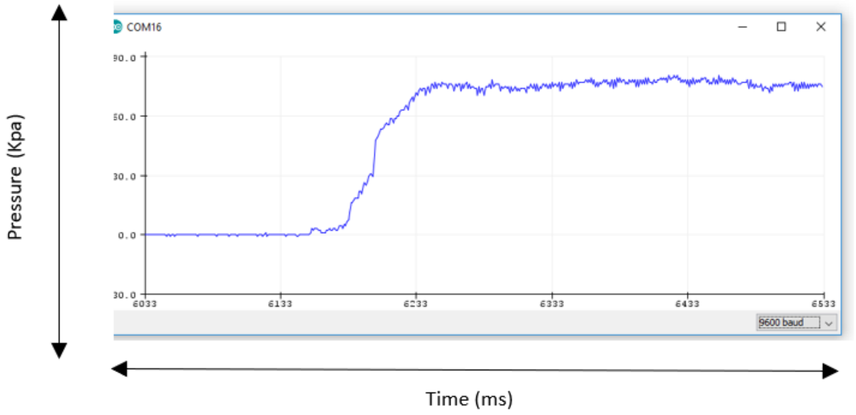

Figure 4 Maximum Positive Pressure of the Electro-Pneumatic Actuator Kit

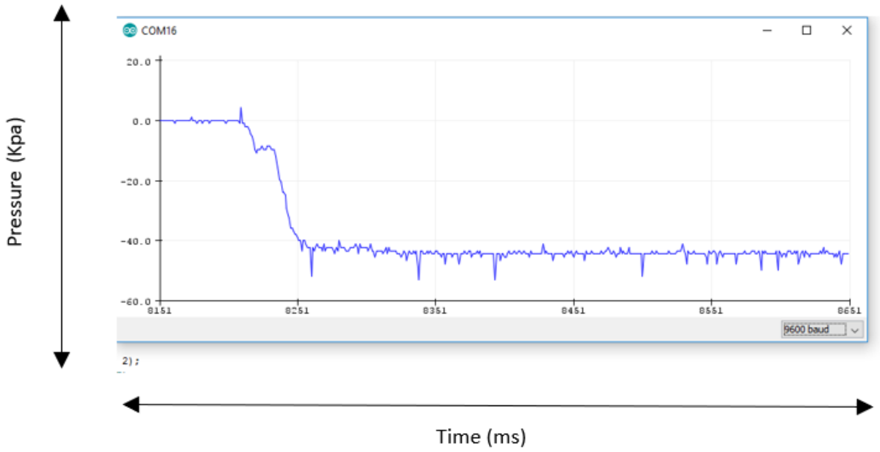

Figure 5 Maximum Negative Pressure (Vacuum) of the Electro-Pneumatic Actuator Kit

5. RESULTS AND DISCUSSIONS

Large applications are typically handled by electro-pneumatic control, which combines electrical and pneumatic systems. The signaling channel in electro-pneumatics is an electrical signal with a direct DC supply. DC Air Pumps serve as the working medium, providing pressure and creating vacuum as needed to produce the desired output. Upon the completion of this research, it must have been established that the relays function as a sequential order bridge between the pneumatic solenoid valves and the Microcontroller. After installing pneumatic solenoid valves and other required components, as well as making electrical connections, this electro-pneumatic actuator kit can regulate positive pressures of up to 90Kpa and vacuums of up to -40Kpa from a reference pressure of 0Kpa, as shown in the [Figure 4] and [Figure 5]. No instances of prone to failures observed in any of the electrical wirings throughout operation.

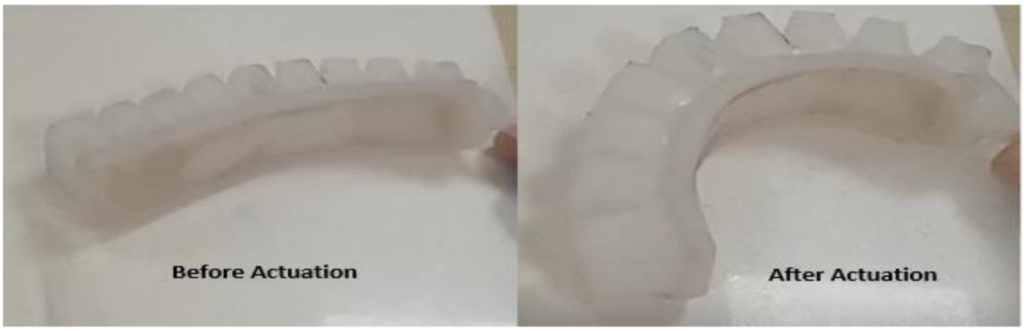

Figure 6 Pneumatic Soft Finger Actuation using the Electro-Pneumatic Actuator Kit

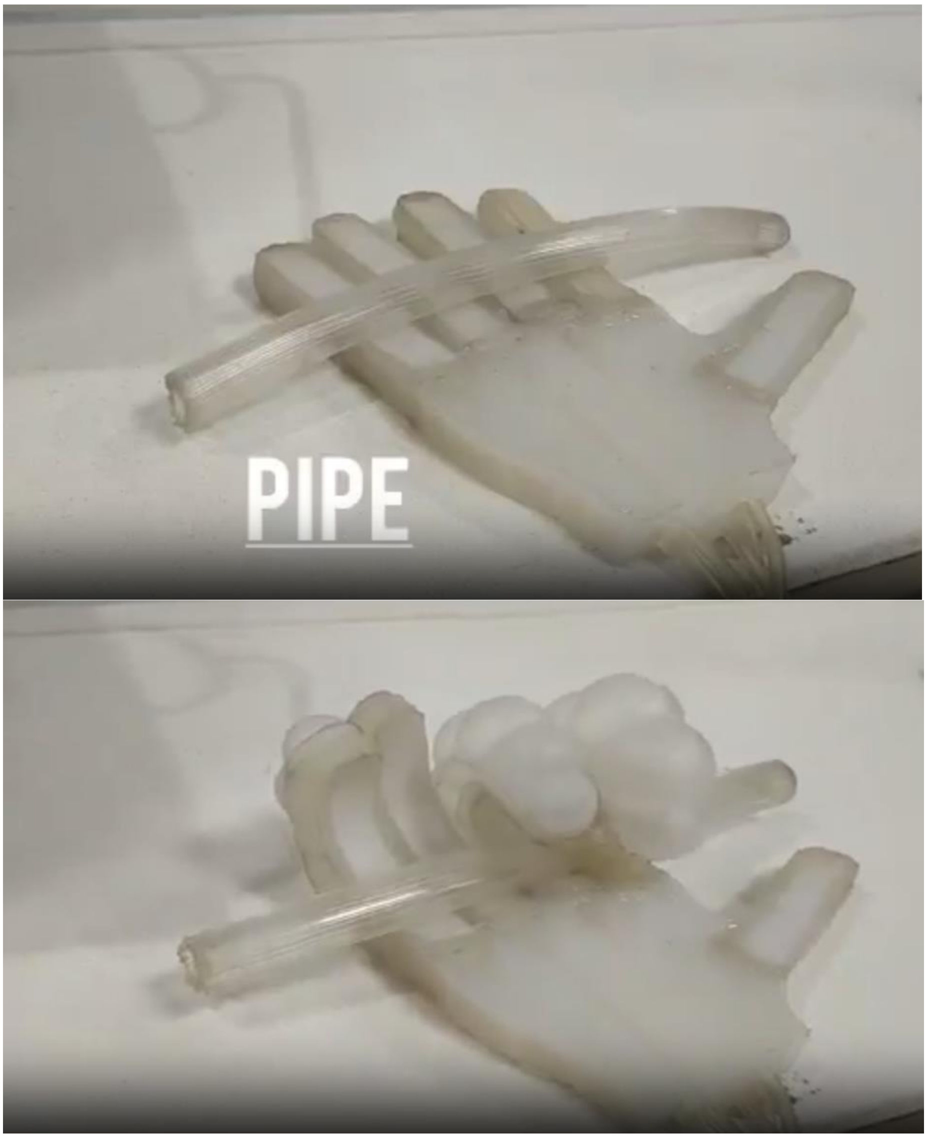

Figure 7 Pneumatic Soft Hand Actuation using the Electro-Pneumatic Actuator Kit

The operating voltages are 12 volts direct current. The kit was successfully tested on the actuation of soft robots, demonstrating their maximal bending ability that is used to grip various things as demonstrated in [Figure 6] and [Figure 7]. The electro-pneumatic system is controlled by a relay combination. Signal input from Digital Pins of Arduino UNO is converted to the desired amount of output signals using relays. Ultimately, the output signals are delivered to solenoids, which trigger the final control valves, controlling the actuation of the load. The aforementioned Pneumatic Kit can carry out all of the actions associated with the real-world automation business.

6. CONCLUSION

In conclusion, this research successfully developed a Low-Cost Multi-Channel Pneumatic Kit, which was tested and proven effective for actuating soft robots. The kit's synchronous and asynchronous capabilities allow for diverse applications, providing students with valuable hands-on experience. By working with pneumatic systems, students gain practical insights into the specific topic of pneumatic actuation while also acquiring fundamental knowledge in the vast domain of industrial automation technology. While working with pneumatic systems, students learn how to design, construct, and operate complex pneumatic circuits, thereby honing their problem-solving and critical-thinking skills. By delving into pneumatic technologies, students acquire valuable knowledge applicable to a vast array of industrial automation processes. They become familiar with concepts like energy efficiency, load handling, and safety considerations that are essential in industrial settings. By gaining comprehensive knowledge about pneumatic systems and their application, students can transfer these skills to different automation technologies, such as hydraulic systems, programmable logic controllers (PLCs), and mechatronics. This interdisciplinary understanding empowers them to analyze and optimize complex automation processes, contributing to advancements in various industries. On the whole, the Electro Pneumatic Automation Training Kit not only equips students with the expertise to develop low-cost multi-channel pneumatic systems but also provides them with a solid foundation in industrial automation technology. Through hands-on experimentation with pneumatic actuators, valves, and sensors, students are primed to excel in the vast domain of automation technology, fostering their potential to become skilled and adaptable professionals in the field of industrial automation.

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