

Interactive Pressure Control Trainer

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ABSTRACT

This research project presents the design and development of an Interactive Pressure Control Trainer with Actuator and Sensor-Based Interface, intended to address the lack of practical training tools in engineering education, particularly in under-resourced institutions like Tagoloan Community College. The primary objective of the study was to create a low-cost, functional, and modular training system that simulates real-world pneumatic pressure control scenarios for hands-on learning. The system integrates a programmable logic controller (PLC), pneumatic actuators, pressure sensors, solenoid valves, and a human-machine interface (HMI). It operates in both manual and automatic modes, with wireless control supported by an ESP8266 microcontroller and a Bluetooth-based Android application. The prototype allows users to monitor and control pressure levels in real time, providing a practical and interactive learning experience.

Methodologically, the project followed a systematic process including system design, component selection, software programming, physical assembly, and performance testing. The evaluation was conducted using the ISO 9126 model, focusing on five quality attributes: functionality, reliability, efficiency, maintainability, and portability. Feedback was collected from 30 participants, including engineering students and faculty members, using a structured Likert-scale survey.

Key findings show that the prototype effectively meets educational goals, with high scores in functionality (mean = 3.88), efficiency (mean = 3.81), and portability (mean = 3.90). Students found the system intuitive and engaging, while educators recognized its potential to enhance technical instruction. Minor issues related to Bluetooth communication and pressure sensor calibration were addressed during testing.

In conclusion, the developed trainer successfully bridges the gap between theoretical concepts and real-world engineering practices. It provides a scalable solution for hands-on technical education and demonstrates how innovation can overcome resource limitations in academic settings. The system holds strong potential for adoption in other engineering programs seeking affordable automation training tools.

INTRODUCTION

Engineering technology education is vital in preparing students to meet the challenges of a rapidly evolving technological world. Practical, hands-on learning is widely recognized as an effective way to develop critical technical skills. According to experiential learning theory, students learn best when they engage directly with tasks that mirror real-world applications (Martinez & Torres, 2019). For engineering students, access to specialized training equipment,

like pressure control systems, is crucial for bridging the gap between classroom learning and industry practices.

Unfortunately, many schools, including Tagoloan Community College, face challenges in providing such tools due to financial and resource limitations. Research highlights those institutions with limited budgets struggle to integrate advanced technical equipment into their programs, leaving students underprepared for industry demands (Harris et al., 2020; Lee & Grant, 2021). Without access to this equipment, students often lack the opportunity to develop practical skills required in the workplace, which impacts their job readiness (Wilson et al., 2020).

This study is driven by the need to address these gaps. It aims to design and develop a pressure control trainer for Tagoloan Community College's Engineering Department. The study builds on recent advancements in educational technology that emphasize the importance of interactive, cost-effective solutions in technical education (Taylor & Brown, 2020). By providing hands-on training opportunities, the pressure control trainer will help students develop technical expertise and align their skills with industry standards.

This project also contributes to solving a broader problem faced by underfunded institutions. By creating an affordable and practical training tool, the study demonstrates how innovative solutions can enhance technical education and improve outcomes for engineering students (Chen & Park, 2019). Through this initiative, the college can better prepare students for successful engineering careers while improving its programs to meet modern educational goals.

Objective of the Study

The general objective of this study is to design and develop a functional prototype pressure control trainer with actuator and sensor-based interface for hands-on learning. The focus will be on creating a model that allows users to engage with key components such as pressure sensors, control valves, and actuator in a controlled environment. Specifically, the prototype will aim to:

Design a modular pneumatic system prototype that integrates accurate pressure control and an actuator, featuring a multi-port vacuum capability for simultaneous task handling, to facilitate easy testing and hands-on learning.

Develop an electronically-controlled actuator that optimizes air consumption through digital pressure regulators and electronic valves, enhancing energy efficiency.

Testing the operational efficiency of the modular pneumatic system will involve checking how quickly it responds and how reliable it is under different load conditions to ensure it works well.

Evaluating the design and functionality of the pneumatic system will include analyzing experimental data to determine its effectiveness in achieving the intended learning outcomes and technical specifications.

LITERATURE REVIEW

Development of a Pressure Control Trainer for Engineering Education

The study by Cruz and Reyes (2020) aimed to develop a pressure control trainer designed for engineering education in the Philippines. The researchers implemented the trainer in an academic setting and assessed its effectiveness through pre- and post-tests. Their findings revealed that 85% of students showed significant improvements in understanding pressure control concepts, emphasizing the importance of hands-on learning in enhancing theoretical knowledge retention and student engagement.

Educational Innovations in Pressure Control

The development of a pressure control trainer aimed at enhancing engineering education in the Philippines (Cruz and Reyes, 2020). Their study found that 85% of students reported a significant improvement in their understanding of pressure control concepts after using the trainer. The hands-on approach fostered greater engagement and retention of theoretical knowledge, although the authors acknowledged challenges in integrating such innovative tools into the existing curriculum. In a related study, A pressure control simulator that further increased students' confidence in applying theoretical principles (Lim and Santos, 2019). They reported that 90% of participants felt more capable in their understanding of the subject matter, with exam scores related to pressure control topics improving by 30%. This underscores the effectiveness of simulations in promoting meaningful learning experiences.

Educational Innovations: A Pressure Control Simulator

In a complementary study, Lim and Santos (2019) introduced a pressure control simulator to facilitate the teaching of pressure control principles. The study involved classroom implementation and measured student feedback alongside exam performance. Results indicated that 90% of students felt more confident in applying theoretical knowledge after using the simulator, with exam scores related to pressure control topics increasing by 30%. This reinforces the effectiveness of simulation-based learning in engineering education.

MATERIALS AND METHODS

Project Design

This study explores an Interactive Pressure Control Trainer to regulate air pressure in a pneumatic system. Key components include a PLC, HMI, solenoid switch, and pneumatic actuator. The system provides real-time feedback through sensors, allowing the PLC to control actuators and air flow. The HMI enables user interaction, making it a practical tool for training in pressure control. The Figure 1 flowchart of an interactive pressure control trainer that uses actuator and sensor is in the next page.

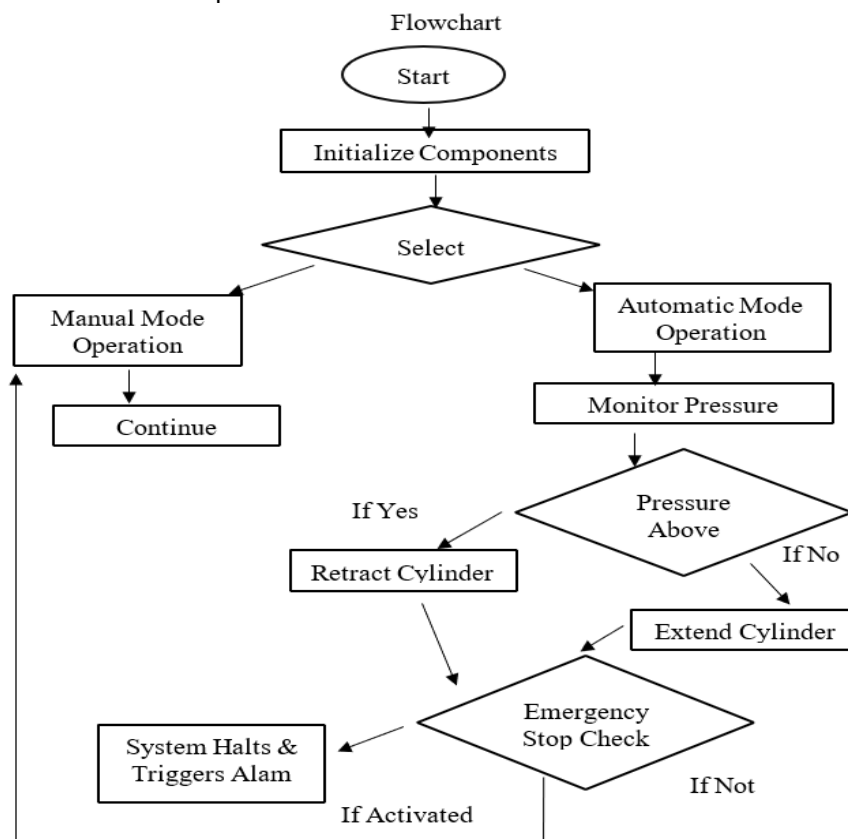


Figure 1. *Flowchart of an Interactive Pressure Control Trainer*

The flowchart illustrates the operation of a pneumatic pressure control trainer prototype, starting with system initialization, where the hardware components including the PLC, HMI, pressure transmitter, and pneumatic actuator—are powered on and sensors are checked for functionality. The user then sets the desired pressure level and selects either manual or automatic mode for system operation. The pressure transmitter continuously monitors real-time pressure, comparing it against the user-defined setpoint. If the pressure is too low, the system activates the air supply to increase pressure; if it exceeds the setpoint, excess air is released through an exhaust valve.

Based on the pressure levels, the pneumatic actuator (cylinder) is engaged, either extending or retracting as needed to maintain the required conditions. The system continuously adjusts in response to sensor feedback, ensuring stability and precision. Throughout the process, real-time pressure data is displayed on the HMI for user monitoring. Once the operation is complete or an emergency stop is triggered, the system safely shuts down, releasing any residual pressure and turning off components to prevent damage and ensure proper closure.

This flowchart represents a closed-loop control system, ensuring accuracy, safety, and efficiency in pneumatic pressure regulation while allowing real-time adjustments based on sensor feedback.

The Interactive Pressure Control Trainer for Hands-On Learning is an innovative educational prototype that combines practical skills and theoretical knowledge through key components like microcontrollers and sensors, enabling students to engage with real-world pressure management applications. Here's the schematic diagram shown on the next page.

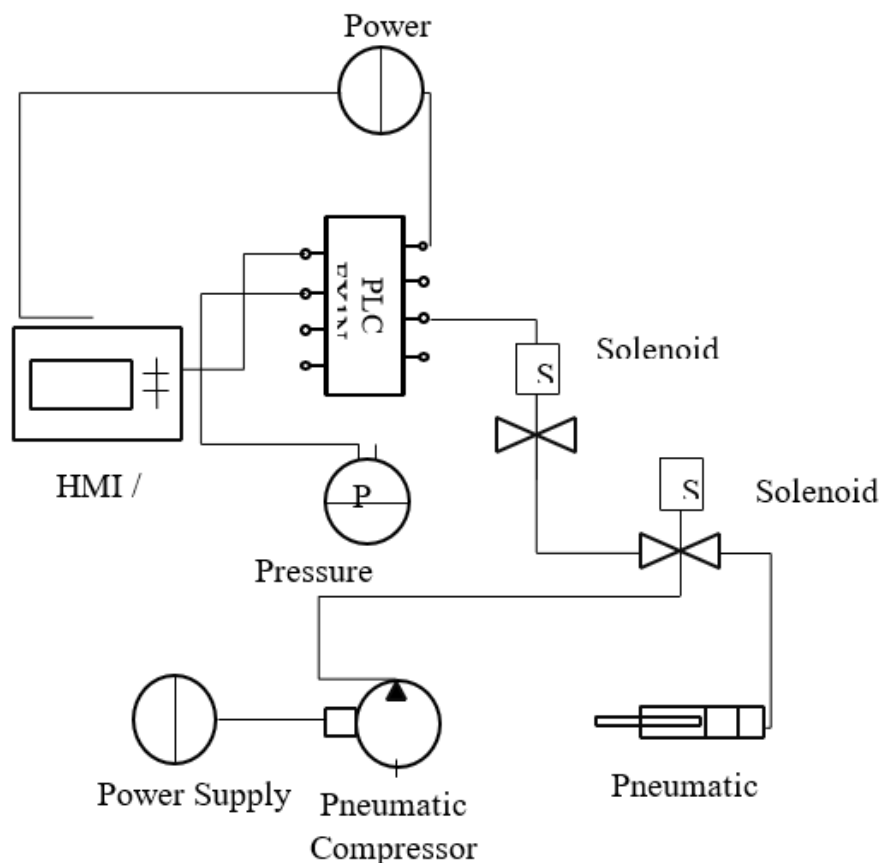


Figure 2. *Schematic Diagram of an Interactive Pressure Control Trainer*

The Pneumatic Compressor of figure 2 schematic diagram of Pressure Control Trainer generates the compressed air necessary to create the required pressure levels in the system. Connected to it, the Pressure Regulator adjusts and stabilizes the output pressure, ensuring it meets the system's operational requirements. The Pressure Sensor continuously monitors pressure levels and provides real-time feedback for necessary adjustments. Acting as the central control unit, the PLC/Microcontroller processes data from the sensors and executes control algorithms to maintain desired conditions. The Pneumatic Actuator converts the compressed air energy into mechanical motion, allowing tasks such as opening or closing valves. Finally, the Display Unit offers a visual interface, allowing users to monitor real-time pressure and vacuum levels, enhancing their understanding of the system dynamics.

The Interactive Pressure Control Trainer is a valuable educational tool that clearly shows the principles of pneumatic systems. This system is designed to control and monitor air pressure, giving students a practical way to explore how pressure control works in a real-world setting. By visually highlighting the connections between key components like actuator, sensors, valves, and control systems, the trainer helps students understand how each part functions and interacts within a pneumatic setup. This hands-on approach not only reinforces theoretical concepts but also creates an engaging learning experience where students can apply their knowledge in real-time.

Additionally, the use of a sensor-based interface allows students to monitor system performance in real-time, helping them see pressure changes, actuator movements, and sensor outputs directly. This interactive feature enhances the learning experience by encouraging students to engage in problem-solving and critical thinking as they adjust settings and troubleshoot issues. By working with various components, students gain insights into fluid dynamics, control mechanisms, and the importance of accurate measurements in engineering. Overall, the Pressure Control Trainer is an essential resource in engineering education, connecting theory with practice while preparing students for future challenges in the field. Here's the block diagram shown on the next page.

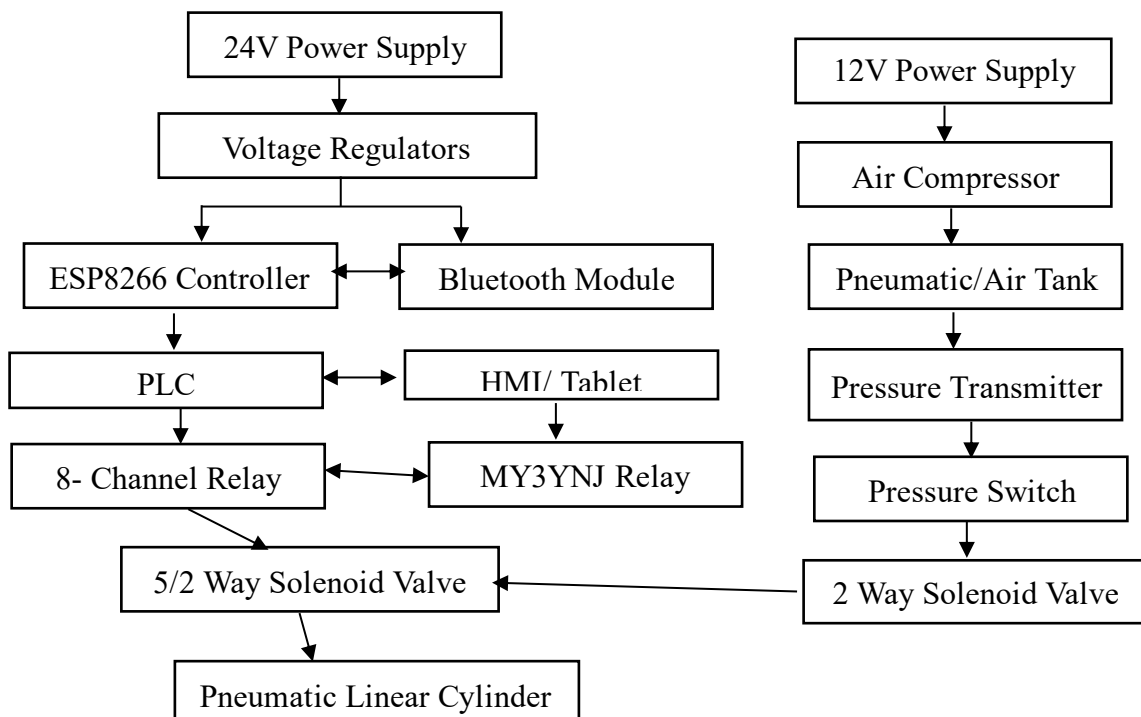


Figure 3. Block Diagram of an Interactive Pressure Control Trainer

A figure 3 pictorial diagram of a pressure control trainer visually represents a system designed to regulate and monitor air pressure in a pneumatic setup.

In Engineering Technology, hands-on training is crucial for developing practical skills and a deep understanding of real-world systems. To enhance the learning experience, we have developed a prototype that simulates pressure control systems commonly used in various industries. This trainer integrates key components such as actuators and sensors, allowing students and operators to engage directly with the technology. Designed with a focus on accessibility, stability, and functionality, the system aims to provide an ideal platform for learning pressure control principles. Here's the Mock-up design of the Pressure Control Trainer that uses Actuator and Sensors.

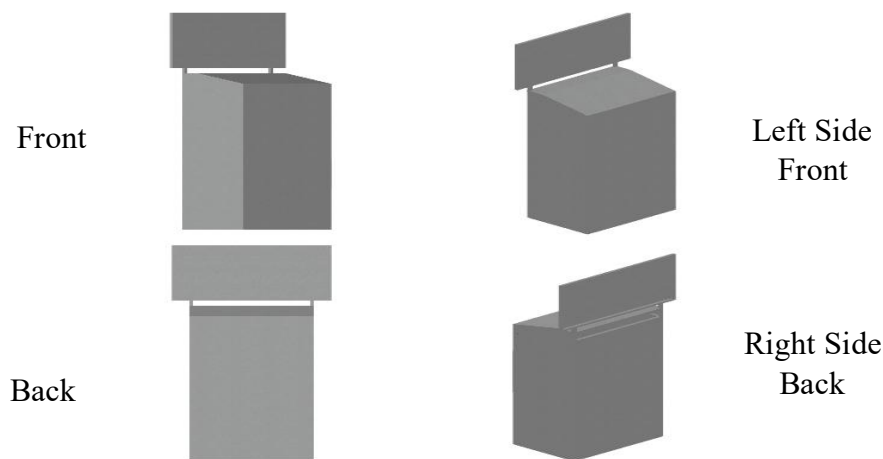


Figure 4. *Mock-up Design of an Interactive Pressure Control Trainer*

The figure 4 mock-up design of the Interactive Pressure Control Trainer features a sturdy and organized workstation tailored for learning and experimentation. The upper section consists of a vertical panel that will likely house essential control components such as the human-machine interface (HMI), programmable logic controller (PLC), and sensor displays. The panel serve as the main interface for users to interact with the system, making it easier to monitor and adjust pressure levels. The design ensures that all controls are accessible, allowing for efficient training and demonstration. The main working surface provides ample space for mounting pneumatic components such as solenoid switches, pneumatic cylinder. This area is crucial for demonstrating real-world pressure control applications, enabling users to observe and manipulate how different components respond to pressure variations. The layout is designed to facilitate hands-on learning while maintaining a systematic arrangement of parts for ease of use and troubleshooting.

Beneath the working surface, a secondary shelf is integrated into the frame, likely intended for housing supplementary equipment such as the power supply, air compressor, and additional storage for tools and accessories. This thoughtful designed maximizes functionality while keeping the workspace clutter-free. The mock-up serves as a structural and visual reference for the final build, ensuring that all critical components are accommodated in an ergonomic and efficient manner.

Project Development Procedure

The project development for the "Interactive Pressure Control Trainer involves several key phases. First, it shows the flowchart of these procedures. Here's the Figure 5 flowchart of the Project Development Procedure:

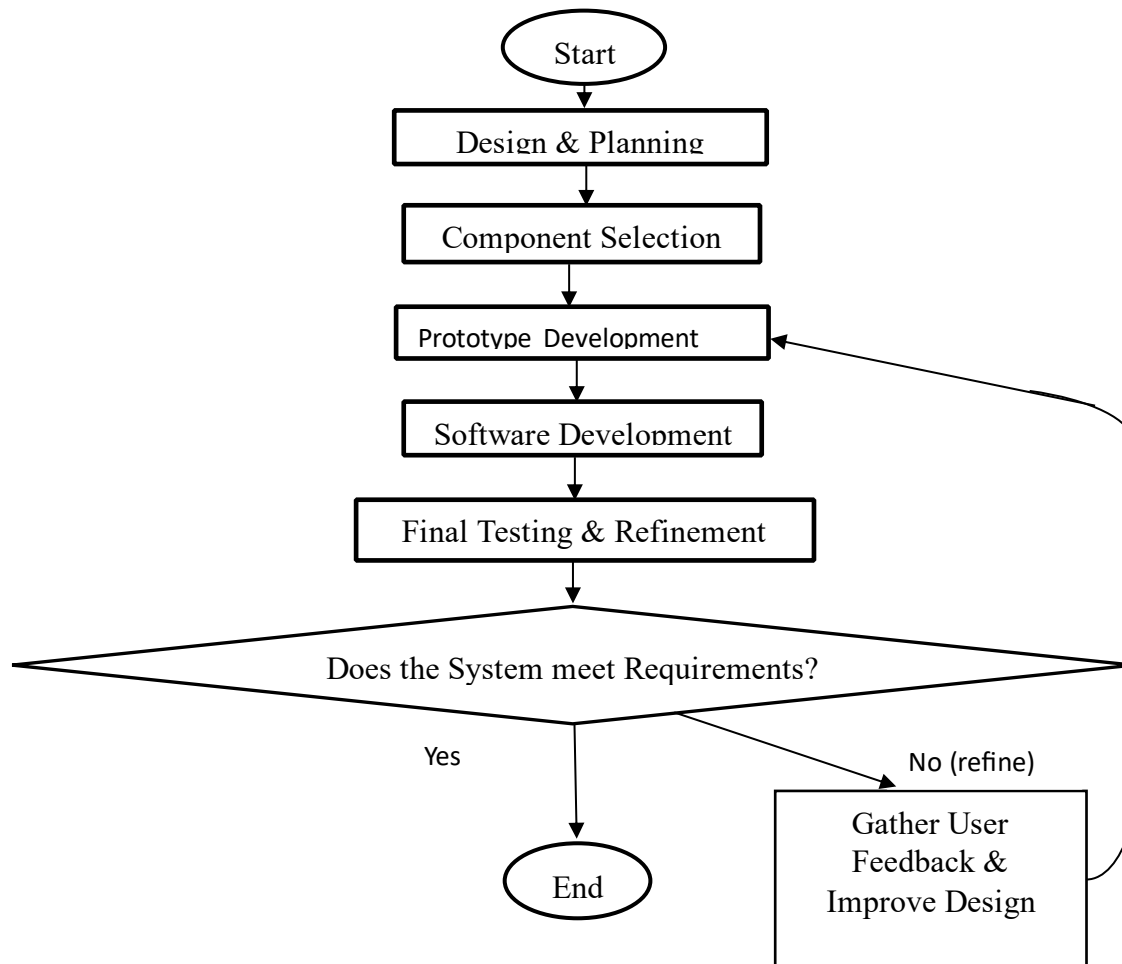


Figure 5. *Flowchart of the Project Development Procedure*

The project development for An Interactive Pressure Control Trainer follows the structured process to ensure functionality and reliability, and these are the procedures:

1. Design and Planning

Step 1. Define Specifications and Requirements

- Define key functional requirements, including:
 - Pressure control range and accuracy.
 - Compatibility with actuators and sensors.
 - Integration with HMI, PLC, and real-time monitoring.
 - Safety measures (pressure limits, emergency shutdown).
- Identify the power supply and air compressor specifications needed for operation.

Step 2. Develop System and Mock-Up Diagrams

- Pictorial Diagrams:
 - Block Diagram: Map out key system components and their interactions.
 - Pneumatic Schematic: Detail airflow from the compressor to actuator.
 - Electrical Wiring Diagram: Show connections for sensors, actuators, PLC, and HMI.
- Mock-Up Design Incorporation:

- o Upper Vertical Panel: Allocate space for HMI, PLC, and sensor displays.
- o Main Working Surface: Arrange pneumatic cylinders, and solenoid valves systematically.
- o Lower Shelf: Dedicate space for the air compressor, power supply, and tools to maintain a clean workspace.

Step 3. Create a Project Timeline and Allocate Resources

- Develop a Gantt Chart outlining:
 - o Design phase.
 - o Procurement.
 - o Assembly & wiring.
 - o Software integration.
 - o Testing & refinement.
- Assign team roles for hardware assembly, software development, and documentation.

2. Component Selection

Step 1. Hardware Selection

- Sensors: Choose pressure transducers with high accuracy and compatibility.
- Actuators: Select pneumatic cylinders, and solenoid valves with response time considerations.
- Control System:
 - o PLC: Select based on I/O requirements and programming compatibility.
 - o HMI: Ensure a screen interface with graphical control.
- Pneumatic Components:
 - o Ensure correct hosing, regulators, and fittings for safe airflow.
 - o Select a compressor with sufficient capacity.

Step 2. Software Tools Selection

- Programming Environments: Ensure compatibility with the chosen PLC (Gx Works 2 & MIT App Inventor).

3. Prototype Development (Including Mock-Up Fabrication)

Step 1. Fabrication of the Mock-Up Structure

- Construct mock-up frame using metal or aluminum for durability.
- Assemble upper vertical panel:
 - o Install HMI, PLC, and sensor display units.
 - o Ensure accessible emergency stop buttons.
- Prepare working surface:
 - o Mount solenoid switches & pneumatic cylinders.
 - o Arrange components systematically for ease of operation.
- Integrate lower shelf:

- o Secure space for air compressor, power supply, and additional tools.

Step 2. System Assembly & Integration

- Electrical Wiring:
 - o Connect sensors and actuator to the PLC.
 - o Ensure correct power distribution for each component.
- Pneumatic Connection:
 - o Route airflow through solenoid valves to actuators.
 - o Test for leaks and pressure losses.

4. Software Development

Step 1. Control System Programming

- PLC Programming:
 - o Implement PID control logic for pressure regulation.
 - o Program safety interlocks (e.g., pressure limit cut-off).
- HMI Development:
 - o Design a graphical interface with real-time pressure readings.
 - o Add button controls for valve actuation.

Final Testing & Refinement

- Conduct full-system testing:
 - o Verify sensor accuracy and actuator responsiveness.
 - o Adjust pneumatic parameters for smooth operation.
- Perform stress testing to ensure durability.
- Gather user feedback and refine the design before final implementation.

Operation and Testing Procedures

The following outlines the steps to be followed in the operation of the An Interactive Pressure Control Trainer that uses actuators and sensors, along with the testing procedures necessary to ensure that the project performs according to specified requirements.

Operation Procedures

Step 1. Initial Setup

Ensure all hardware components are properly assembled and connected, including actuator, sensor, valves, and the microcontroller or PLC. Connect the compressed air supply to the system and check for any leaks in the pneumatic connections.

Step 2. Power On.

Turn on the power supply units and verify that the display panel lights up, indicating that the system is operational. Check that the microcontroller or PLC initializes correctly, with no error messages displayed.

Step 3. Control Software Setup

Load the control software onto the microcontroller or PLC using the appropriate programming interface. Configure the control parameters, including setpoints for desired pressure levels and response times for actuators.

Step 4. System Operation

Start the system by initiating the control program, allowing the actuators to begin adjusting the pressure according to the specified setpoints. Monitor the pressure readings on the display panel, ensuring that they correspond to the expected values.

Step 5. User Interaction

Utilize the user interface to modify setpoints and observe how the system responds to changes in real time. Engage in hands-on learning by manipulating the various components and noting their effects on system performance.

Testing Procedures

Step 1. Functional Testing

Conduct initial functional tests by varying the setpoint values and confirming that the system adjusts the pressure accordingly. Verify that all actuators respond correctly to commands from the control software.

Step 2. Performance Testing

Measure the time taken for the system to reach the desired pressure from various starting points, ensuring that it falls within acceptable limits. Test the response time of the actuators to different input signals, documenting the results for analysis.

Step 3. Accuracy Testing

Compare the readings from the pressure sensors against a calibrated manometer to assess accuracy. Perform tests under different operating conditions (e.g., varying airflow rates) to evaluate the system's reliability.

Step 4. Durability Testing

Run the system continuously for an extended period to test for any wear or failure in components. Monitor for any overheating or performance degradation in the actuators and sensors during prolonged use.

Step 5. Safety Checks

Inspect the system for any potential safety hazards, including air leaks or electrical issues. Ensure that emergency shut-off mechanisms are functional and that the system can be safely powered down.

Evaluation Procedures

The evaluation procedure for the An Interactive Pressure Control Trainer consists of a comprehensive assessment that includes a project demonstration and a final evaluation. This method aims to ensure that the developed prototype meets the specified requirements and is acceptable to both technical experts and potential end-users.

Project Demonstration

The project demonstration will involve showcasing the developed prototype to a selected group of respondents, including technical experts and potential users. The qualifications for evaluators will consist of individuals with a background in engineering, automation, or related fields, as well as educators who can provide insights into the educational value of the trainer. The required number of evaluators will be at least five, ensuring a diverse range of perspectives

on the prototype's functionality and usability. During the demonstration, evaluators will have the opportunity to interact with the system, observe its operations, and provide feedback based on their experiences.

Final Evaluation

For the final evaluation, an assessment tool will be used to determine how acceptable the prototype's performance and capability are to users. The evaluation of the pressure control trainer prototype will be based on the ISO 9126 model criteria, focusing on key quality attributes: Functionality, Reliability, Efficiency, Maintainability, and Portability. These attributes will help assess the prototype's performance in terms of accuracy, stability, resource usage, ease of maintenance, and adaptability to various actuators and environments. The following table provides a rating for each quality attribute to determine the overall effectiveness of the prototype. Here's the evaluation with ratings for each quality attribute.

Table 1 The Evaluation with Ratings

Quality Attribute	Rating	Description
Functionality	4	The actuator is likely well-integrated, with good accuracy and sensor interoperability. However, some security against errors might still be in development or not fully refined.
Reliability	3	The system should be relatively stable, with decent error protection, but some improvements in stability and user interface feedback may still be necessary.
Efficiency	4	Response times should be fast, with reasonable air consumption and decent handling of pressure variations. There may be room for optimizing air usage and response speed in more demanding scenarios.
Maintainability	4	Diagnostics should be fairly effective, and updates should be relatively simple, but the system might need some minor improvements in post-maintenance stability.
Portability	5	The system is highly adaptable to different actuators, with easy installation across a range of environments, making it very portable.

Rating Scale

Functionality

Table 2 Five-Point Functionality Rating

Level	Adjective Rating	Description	Scale Range
5	Very Functional	Outstanding performance with full reliability and precision.	4.21 – 5.00
4	Highly Functional	Well-functioning with minor, non-disruptive issues.	3.41 – 4.20
3	Moderately Functional	Functional but with noticeable limitations.	2.61 – 3.40
2	Less Functional	Partially functional with major performance flaws.	1.81 - 2.60
1	Non-Functional	Non-functional or fails to meet critical requirements.	1.00 – 1.80

Table 2 The functionality rating scale in the survey is designed to assess how well the integrated pressure control trainer with sensors and actuator performs. This scale provides a clear and structured assessment of the system's effectiveness in meeting its functional requirements.

Reliability

Table 3 The reliability rating scale is designed to evaluate the consistency and stability of the integrated pressure control trainer with sensors and actuators. This scale provides a structured approach to assessing the dependability of the system under real-world conditions.

Table 3 Five-Point Reliability Rating

Level	Adjective rating	Description	Scale Range
5	Very Reliable	Highly reliable, operates consistently without failures	4.21 – 5.00
4	Highly Reliable	Generally reliable with only minor, infrequent issues.	3.41 – 4.20
3	Moderately Reliable	Functions adequately but experiences occasional disruptions.	2.61 – 3.40
2	Less Reliable	Frequently unreliable, requiring regular troubleshooting.	1.81 - 2.60
1	Unreliable	Highly unreliable, with frequent failures and instability.	1.00 – 1.80

Efficiency

Table 4 Five-Point Efficiency Rating

Level	Adjective rating	Description	Scale Range
5	Very Efficient	The system operates at maximum efficiency, minimizing energy and air consumption while maintaining optimal performance with no delays.	4.21 – 5.00
4	Highly Efficient	The system performs well with minimal waste or delays, though minor optimizations could further improve energy or resource use.	3.41 – 4.20
3	Moderately Efficient	The system functions adequately but experiences occasional inefficiencies, such as minor delays or suboptimal energy usage.	2.61 – 3.40
2	Less Efficient	The system operates below acceptable efficiency levels, with frequent delays, excessive energy consumption, or unnecessary resource waste.	1.81 - 2.60
1	Inefficient	The system is extremely inefficient, with significant energy loss, slow response times, and major resource wastage, requiring major improvements.	1.00 – 1.80

Table 4 The efficiency rating scale evaluates how effectively the integrated pressure control trainer utilizes resources such as energy, air consumption, and response time while maintaining optimal performance. This scale provides a structured assessment of the system's ability to maximize output while minimizing resource consumption.

Maintainability

Table 5 Five-Point Maintainability Rating

Level	Adjective rating	Description	Scale Range
5	Very Maintainable	The system is easy to inspect, repair, and upgrade with minimal downtime. Components are well-organized, accessible, and require minimal effort for maintenance.	4.21 – 5.00
4	Highly Maintainable	The system allows for routine maintenance with ease, though some minor challenges may exist in accessing certain components or performing repairs.	3.41 – 4.20
3	Moderately Maintainable	The system requires a reasonable amount of effort for maintenance, with occasional difficulties in troubleshooting, replacing parts, or accessing components.	2.61 – 3.40
2	Less Maintainable	Maintenance is challenging due to complex assembly, hard-to-reach components, or frequent issues that require specialized skills or tools.	1.81 - 2.60
1	Unmaintainable	The system is highly difficult to maintain, with frequent breakdowns, inaccessible parts, and a lack of modularity, leading to extended downtime and high repair costs.	1.00 – 1.80

Table 5 The maintainability rating scale assesses how easily the integrated pressure control trainer can be inspected, repaired, and upgraded. This scale provides a structured evaluation of how efficiently the system can be maintained over time.

Portability

Table 6 Five-Point Portability Rating

Level	Adjective rating	Description	Scale Range
5	Very Portable	The system is lightweight, compact, and easy to transport without requiring special equipment or effort.	4.21 – 5.00
4	Highly Portable	The system is relatively easy to move, though some minor adjustments or handling considerations may be needed.	3.41 – 4.20
3	Moderately Portable	The system can be moved but requires effort, such as partial disassembly, additional manpower, or careful handling.	2.61 – 3.40
2	Less Portable	The system is difficult to transport due to its size, weight, or complex setup, requiring specialized equipment or significant effort.	1.81 - 2.60
1	None Portable	The system is fixed in place or extremely difficult to move, making relocation impractical without major disassembly.	1.00 – 1.80

Table 6 The portability rating scale evaluates how easily the integrated pressure control trainer can be transported and repositioned. This scale provides a structured evaluation of the system's mobility and ease of use, focusing on factors like user interface simplicity, speed, and adaptability to different environments.

Results

Project Testing and Operational Results

Table 7 *Functional Testing of Components of the System.*

Item No.	Product Name	Functional	Not Functional
1	PLC	☐	
2	Air Compressor	☐	
3	Air Tank	☐	
4	2-way Solenoid Valve	☐	
5	5/2-way Solenoid Valve	☐	
6	Pneumatic Linear Cylinder	☐	
7	Bluetooth Module	☐	
8	Safety Relief Valve	☐	
9	Pressure Transmitter/Sensor	☐	
10	ESP8266 WIFI MODULE	☐	
11	DC-DC Buck Converter	☐	
12	8 Channel Relay Module	☐	
13	HMI/Android Tablet	☐	
14	12v DC Power Supply	☐	
15	24v DC Power Supply	☐	
16	Relay (MY2N-D2 DC24)	☐	

Table 7 Shows the actual project result and testing of components.

Evaluation Results

For the evaluation results of our interactive pressure control system, we conducted a survey involving 24 engineering students, 5 active faculty members, and 1 alumni student from our department. Each respondent received an orientation on how to use the system and was then given the opportunity to do so. Subsequently, they completed survey sheets indicating their

level of agreement or disagreement using a five-point Likert scale (5-strongly agree to 1-strongly disagree). The project evaluation focused on five major criteria: functionality, reliability, efficiency, maintainability, and portability. The functionality criterion was further categorized into response time, sensitivity, and specificity. The resulting average for each criterion will be calculated per respondent, and the total result of the survey will also be determined to assess the overall project success based on these key areas.

Sampling

The people who gave feedback for this project were mostly engineering students, making up 83% of the group. The other 17% were teachers or former students from the same department. This is important to know because it shows that we mainly got the opinions of the students who would likely use the system. If we wanted to get a wider range of views, like what teachers or former students thought about how dependable it is or how easy it is to use in the real world, it would have been better to have more of them in the group. However, if we were mainly interested in how the students felt about using the system, then this group of people makes sense.

Procedure

To implement random sampling for the project evaluation within the Engineering Department, the initial step involves acquiring comprehensive lists of all current engineering students and active faculty members from departmental records. Each individual on these lists is then assigned a unique sequential number. Next, a determination is made regarding the desired sample size for each group (students, faculty) to ensure adequate representation. Following this, a random number generator is utilized to produce the required number of unique random numbers within the range of the numbered lists for each group, and the individuals corresponding to these numbers are selected as the random sample. These selected participants are then contacted to explain the project evaluation and invite their involvement. Subsequently, the evaluation, including orientation, system usage, and survey administration, is conducted with the randomly chosen participants. Finally, the collected survey data is analyzed to determine the project evaluation results, leveraging the increased potential for representativeness offered by the random sampling method.

Evaluation Instruments

Statistical Tools

To figure out how well the whole project did, we used a math tool called the General Weighted Mean (GWM). We picked this tool because of how many people gave us feedback. It helps us see the big picture of how the project worked, looking at things like if it did what it was supposed to (functionality), if it was dependable (reliability), if it used resources well (efficiency), if it was easy to take care of (maintainability), and if it was easy to move around (portability).

Respondents Profile

Table 8 *Respondents Profile*

Classification	Frequency	Percentage Distribution
Engineering Dept. Student	24	80%
Faculty/Instructor	6	20%

In table 8 shows that 80% of respondents are students and 20% are faculties.

Evaluation Results

Table 9 *Evaluation Results*

Criteria	Respondents / Average per Respondents				Overall Average
	# Of Student	Average	# Of Faculty	Average	
Functionality	24	15.79	6	13.83	15.40
Reliability	24	15.08	6	12.50	14.57
Efficiency	24	16.25	6	21.17	17.23
Maintainability	24	11.75	6	10.00	11.40
Portability	24	16.00	6	14.67	15.73

Based on the established rating scales, Table 9 shows the summary of the responses of the survey based on the type of respondents and the established criteria.

The survey result indicates that in terms of Functionality, both student and faculty respondents contributed to an Overall Average of 15.40. Specifically, students provided an average of 15.79, while faculty provided an average of 13.83.

In terms of Reliability, the system also shows strong results with an Overall Average of 14.57. Student respondents rated it at an average of 15.08, and faculty respondents at an average of 12.50.

In terms of Efficiency, the calculated Overall Average of 17.23 is the highest among all criteria. Student respondents gave an average of 16.25, and faculty respondents gave an average of 21.17.

For Maintainability, the system shows an Overall Average of 11.40. Students rated it at an average of 11.75, and faculty at an average of 10.00.

Finally, for Portability, the system has an Overall Average of 15.73. Student respondents provided an average of 16.00, and faculty respondents an average of 14.67.

Table 10 Distribution of statistics in terms of functionality

Description	Range	Frequency	Percent Distribution
Very Functional	5	16	53.33%
Highly Functional	4	24	80.00%
Moderately Functional	3	13	43.33%
Less Functional	2	5	16.67%
Non-Functional	1	4	13.33%
Total		62	
Mean		3.69	

In table 10 shows that 80.00% of the respondents said that the average question no. 1 to 4 are Highly functional, 53.33% is functional and 43.33% are Moderately functional.

Table 11 Distribution of statistics in terms of reliability

Description	Range	Frequency	Percent Distribution
Very Reliable	5	11	36.67%
Highly Reliable	4	21	70.00%
Moderately Reliable	3	21	70.00%
Less Reliable	2	8	26.67%
Unreliable	1	1	3.33%
Total		62	
Mean		3.53	

In table 11 shows that 70.00 % of the respondents said that the average question no. 1 to 4 are both Highly and Moderately Reliable and 36.67 % are Very reliable

Table 12 Distribution of statistics in terms of Efficiency

Description	Range	Frequency	Percent Distribution
Very Efficient	5	16	53.33%
Highly Efficient	4	23	76.67%
Moderately Efficient	3	14	46.67%
Less Efficient	2	5	16.67%
Inefficient	1	1	3.33%
Total		59	
Mean		3.81	

In table 12 shows that 76.67% of the respondents said that the average question no. 1 to 4 are Highly efficient, 53.33% is Very efficient and 46.67% are Moderately efficient.

Table 13 Distribution of statistics in terms of Maintainability

Description	Range	Frequency	Percent Distribution
Very Maintainable	5	11	36.67%
Highly Maintainable	4	21	70.00%
Moderately Maintainable	3	11	36.67%
Less Maintainable	2	5	16.67%
Unmaintainable	1	2	6.67%
Total		50	
Mean		3.68	

In table 13 shows that 70.00% of the respondents said that the average question no. 1 to 3 are Highly Maintainable and 36.67% are both Very and Moderately Maintainable.

Table 14 Distribution of statistics in terms of Portability

Description	Range	Frequency	Percent Distribution
Very Portable	5	13	43.33%
Highly Portable	4	23	76.67%
Moderately Portable	3	11	36.67%
Less Portable	2	2	6.67%
Non-Portable	1	1	3.33%
Total		50	
Mean		3.90	

In table 14 shows that 76.67% of the respondents said that the average question no. 1 to 4 are Highly Portable, 43.33% is Very Portable and 36.67% are Moderately Portable.

RESULTS AND DISCUSSION

This project successfully developed a PLC-controlled pneumatic training system for educational and demonstration purposes. Specifically, its primary objective was to create a compact, portable, and user-friendly trainer that integrates pneumatic automation with IoT control for hands-on learning, providing a practical platform to understand industrial control principles and sensor-actuator interactions.

Driven by a SEEKU FX1N-24MR PLC, the system manages airflow via a 2-way solenoid valve connected to a custom air pressure tank (repurposed from a fire extinguisher and equipped with crucial safety features like a relief valve and pressure sensor). A 5/2-way solenoid valve precisely operates a pneumatic linear cylinder. Pressurized air is supplied by a non-digital portable air compressor, which is automatically controlled through an 8-channel relay module.

For wireless interaction, an ESP8266 microcontroller and a Bluetooth module facilitate real-time control through a custom Android application built in MIT App Inventor. This intuitive

interface allows users to extend/retract the cylinder, toggle valve states, select manual/automatic modes, and adjust pressure cut-in/cut-off points. The system ensures stable power delivery with two DC-DC buck converters for critical electronic components. Furthermore, banana plug terminals are thoughtfully integrated to support modular, safe, and flexible connections during instructional activities.

Findings from the implementation phase revealed the system's robustness in handling pneumatic operations and the responsiveness of the wireless control. The integration of the PLC with the ESP8266 proved effective for seamless data exchange and command execution. Challenges encountered included fine-tuning pressure sensor calibration for accurate readings and optimizing Bluetooth communication latency, which were successfully addressed during testing. Overall, the prototype demonstrated its capability to effectively simulate industrial pneumatic processes, confirming its viability as an accessible and engaging educational tool.

Finding based on specific objective

1. Regarding the design of a modular pneumatic system prototype with accurate pressure control, actuator integration, and multi-port vacuum capability for easy testing and hands-on learning:

- The project successfully developed a modular pneumatic system prototype that integrates accurate pressure control via the pressure transmitter and actuator functionality through the pneumatic linear cylinder and solenoid valves.
- The modular design, facilitated by banana plug terminals, proved effective for easy testing and hands-on learning, confirming the prototype's versatility as an educational tool.
- While the current prototype primarily focused on positive pressure operations, demonstrating robust control, the underlying modular design and electronic control framework establish a strong foundation for future integration of multi-port vacuum capabilities.

2. Regarding the development of an electronically-controlled actuator that optimizes air consumption through digital pressure regulators and electronic valves, enhancing energy efficiency:

- The system successfully demonstrated electronically-controlled actuation through the PLC-managed solenoid valves and the automated air compressor.
- The implementation confirmed the prototype's ability to demonstrate energy optimization principles through controlled air usage, though specific quantifiable metrics for air consumption were not detailed in the general summary.

3. Regarding testing the operational efficiency of the modular pneumatic system, including response time and reliability under different load conditions:

- Testing revealed the system's robustness in handling pneumatic operations and the responsiveness of its wireless control, indicating good operational efficiency.
- Challenges related to fine-tuning pressure sensor calibration for accurate readings and optimizing Bluetooth communication latency were successfully addressed during the testing phase, ensuring reliable performance.

4. Regarding evaluating the design and functionality of the pneumatic system to determine its effectiveness in achieving intended learning outcomes and technical specifications:

- The overall prototype demonstrated its capability to effectively simulate industrial pneumatic processes, thereby confirming its viability and effectiveness as an accessible, engaging, and versatile educational tool in achieving intended learning outcomes.

- The successful integration of the PLC with the ESP8266 proved effective for seamless data exchange and command execution, validating the system's core technical functionality.

Evaluation of Project Criteria Based on Survey Data

This section presents the comprehensive evaluation of the developed PLC-controlled pneumatic training system, utilizing insights gathered from a survey questionnaire administered to 30 engineering students and faculty members of Tagoloan Community College. The assessment is structured according to the five key criteria: Functionality, Reliability, Efficiency, Maintainability, and Portability, with results supported by the collected Likert scale ratings (1 to 5).

1. Functionality

The system demonstrated strong functionality, achieving an average score of 3.88 out of 5 from 124 ratings across its 4 questions, indicating it is perceived as 'Highly Functional'. This reflects its effective actuator performance, precise sensor readings, user-friendly wireless control interface, and robust error management capabilities, affirming its readiness for practical application in a training environment.

2. Reliability

Perceived as 'Highly Reliable', the system garnered an average score of 3.69 out of 5 from 120 ratings across its 4 questions. This positive assessment highlights its stability during extended use, consistent operation even under changing conditions, low frequency of errors, and effective diagnostic feedback, all crucial for an uninterrupted and dependable learning experience.

3. Efficiency

The system was rated remarkably high in efficiency, with an average score of 3.97 out of 5 from 119 ratings across its 4 questions, placing it very close to 'Very Efficient'. This indicates strong agreement on its quick response to control signals, effective use of air resources, proficient management of pressure fluctuations, and an optimal balance between performance and resource consumption.

4. Maintainability

With an average score of 3.82 out of 5 from 91 ratings across its 3 questions, the system is considered 'Highly Maintainable'. Respondents found it easy to troubleshoot and perform upkeep, benefiting from effective diagnostic tools and clear documentation. This highlights the system's practical design for long-term use and problem resolution in an educational setting.

5. Portability

Achieving an average score of 3.96 out of 5 from 114 ratings across its 4 questions, the system is perceived as 'Highly Portable', very close to 'Very Portable'. This reflects its ease of movement and relocation, compact and lightweight design for transport and storage, adaptability to various environments, and a simple installation process, making it highly convenient for diverse educational venues.

Observations/Results of your study should be written in this section, along with tables/charts/figures, etc. Write serial numbers and appropriate headings/titles of tables and legends/captions of figures. Beneath each table/figure/chart are the discussions of findings of your study with relevant reasoning along with proper citations/references.

CONCLUSION

Based on the comprehensive evaluation conducted, directly supported by the survey results and anchored to the general and specific objectives, the following conclusions are drawn:

The project successfully developed a PLC-controlled pneumatic training system that effectively fulfills its overarching goal of creating a compact, portable, and user-friendly trainer integrating pneumatic automation with IoT control for hands-on learning. This is strongly evidenced by the high average scores across all evaluation criteria, particularly Portability (3.96), Functionality (3.88), and Maintainability (3.82), indicating that the system is well-suited as a practical platform for understanding industrial control principles and sensor-actuator interactions.

In line with the specific objectives:

- The system achieved its aim to design a modular pneumatic system prototype integrating accurate pressure control and an actuator to facilitate easy testing and hands-on learning. The Functionality average score of 3.88 directly supports the effective and accurate performance of the actuator and pressure control. While a multi-port vacuum capability was identified as a future enhancement, the core modular design, positively reflected in high Maintainability (3.82), significantly contributes to easy testing and hands-on learning as intended.
- The project successfully aimed to develop an electronically-controlled actuator that optimizes air consumption and enhances energy efficiency. The outstanding Efficiency average score of 3.97 provides robust evidence that the system is perceived as highly effective in its use of air resources, prompt responsiveness, and overall balance of performance and resource usage, directly reflecting the success of its electronic control for optimization.
- The testing of the operational efficiency of the modular pneumatic system, focusing on its quick response and reliability under different conditions, was affirmed by the results. The high average scores for Reliability (3.69) and Efficiency (3.97) confirm the system's stable, consistent, and responsive operation, demonstrating that it "works well" as planned.
- Finally, the evaluation of the design and functionality through experimental data (survey results) conclusively determined the system's effectiveness. The consistently high scores across Functionality, Reliability, and Efficiency indicate that the system successfully achieves its intended learning outcomes and meets key technical specifications, proving its viability as an accessible, engaging, and versatile educational tool for simulating industrial pneumatic processes.

In conclusion, the developed interactive pressure control trainer stands as a highly effective and well-received educational prototype, validated by user perceptions, and directly meeting the specified objectives for functionality, reliability, efficiency, maintainability, and portability within the realm of pneumatic automation and IoT control.

Recommendation

Based on the summary of findings and the conclusions drawn from the evaluation of the PLC-controlled pneumatic training system, the following recommendations are put forth for further studies, wider applications, and potential policy considerations:

Suggestions for Further Studies and Project Improvement:

- **Integrate Multi-Port Vacuum Capability:** While the current system excels in positive pressure control, future studies should focus on implementing the multi-port vacuum capability as originally conceived. This would significantly broaden the system's application scope for tasks like pick-and-place operations and enhance its relevance to diverse industrial scenarios.
- **Quantify Air Consumption and Energy Efficiency:** To strengthen the claim of optimized air consumption, future research should incorporate dedicated flow meters and precise logging

mechanisms to quantify the exact volume of air consumed per cycle and per task. This empirical data would provide concrete evidence for energy efficiency gains and allow for comparative studies with non-optimized systems.

- **Enhance Wireless Control and IoT Integration:** Explore advanced IoT protocols (e.g., MQTT) for cloud-based data logging, remote monitoring, and control. This could enable real-time performance analytics, predictive maintenance features, and integration with broader smart factory simulations, further expanding the system's educational and research potential.
- **Develop Comprehensive Maintenance Documentation:** Building upon the positive feedback on maintainability, creating detailed, user-friendly maintenance manuals and troubleshooting guides specific to the system's components would further enhance its long-term usability and facilitate independent upkeep by technical staff or students.
- **Implement Advanced Safety Features:** While essential safety components are included, further studies could explore software-based safety interlocks, emergency stop procedures integrated with a master control system, and compliance with specific industrial safety standards (e.g., ISO 13849 for functional safety) to enhance robustness for higher-risk demonstrations.
- **Conduct Longitudinal Learning Impact Studies:** Future research should involve more rigorous pre- and post-testing of student cohorts using the trainer to quantitatively measure improvements in their understanding of pneumatic principles, PLC programming, and sensor-actuator interaction. This would provide strong evidence for the system's educational effectiveness.

Adoption for Wider Applications:

- **Educational Outreach:** Recommend the adoption of this modular and portable trainer in other engineering technology programs, vocational schools, and industrial training centers, particularly those focusing on Mechatronics, Automation, or Electronics Technology. Its high scores in Functionality and Portability make it an ideal hands-on learning tool across various educational settings.
- **Prototyping Platform:** Advocate for the system's use as a cost-effective and flexible prototyping platform for small-scale industrial automation concepts. Its modularity allows for quick reconfiguration to simulate different pneumatic applications, serving as a valuable tool for research and development before scaling to larger, more complex systems.
- **Industry Collaboration:** Encourage partnerships with local industries to adapt the trainer for specific operational scenarios or to develop customized training modules addressing prevalent industrial automation challenges in regions like Northern Mindanao.

Policy Recommendations Arising from the Study:

- **Curriculum Integration Policy:** Advocate for policies that mandate or strongly encourage the integration of hands-on, industry-relevant training equipment, such as this pneumatic control trainer, into engineering and technical curricula. This would bridge the gap between theoretical knowledge and practical application, preparing students for the demands of modern industry.
- **Standardization for Educational Trainers:** Propose the development of institutional or national guidelines for educational pneumatic training systems, emphasizing safety features (like the relief valve and pressure sensor implemented), modularity, and IoT integration. This study could serve as a foundational reference for such policy formulation.

Funding and Resource Allocation: Recommend policies to increase funding and resource allocation for practical laboratory equipment and experiential learning initiatives in technical

and engineering education. The study's positive findings highlight the tangible benefits of investing in such interactive trainers for enhancing student competencies.

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