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Design and Implementation of a PLC-Based Two-Axis Pick and Place System Using Factory I/O

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ABSTRACT

This paper presents the design and virtual implementation of a PLC-based pick-and-place automation system using Factory I/O and Siemens TIA Portal within a virtual commissioning environment. The system consists of a two-axis pick-and-place mechanism, a virtual PLC, and a conveyor-based material handling system.

Digital and analog I/O mapping is used to control the movement of the X and Z axes and gripper operations. The implemented control logic includes object detection, sequential pick-and-place operations, emergency handling, and cycle repetition.

Simulation results demonstrate that the proposed system achieves reliable automation, effective safety response, and accurate placement of metal product lids into stackable boxes. The study highlights the effectiveness of virtual commissioning as a cost-effective approach for the development, testing, and validation of industrial automation systems.

KEYWORDS: PLC, Factory I/O, Virtual Commissioning, Pick and Place System, Industrial Automation, Siemens TIA Portal, Ladder Logic.

1. INTRODUCTION

In modern industrial environments, automation plays a significant role in improving productivity, accuracy, and safety. Automation systems are widely used to reduce manual effort, minimize human errors, and maintain consistent product quality during material handling and packaging processes. Pick-and-place operations are essential in manufacturing industries for tasks such as sorting, assembly, and packaging.

Programmable Logic Controllers (PLCs) are extensively used in automation due to their precision, repeatability, real-time operation, and ability to control sequential processes. PLC-based pick-and-place systems provide reliable and repeatable control and can be easily integrated with sensors and actuators. However, developing and testing such systems on physical hardware can be time-consuming, costly, and potentially unsafe.

To address these challenges, virtual commissioning is used to design and validate automation systems before real-world deployment. Factory I/O provides a 3D industrial simulation environment where PLC control logic can be tested and validated. By integrating PLC programs with Factory I/O, system behavior, task sequencing, and safety responses can be evaluated without physical equipment, thereby reducing development time and risk.

However, many existing systems lack structured control strategies for robotic pick-and-place operations and do not provide comprehensive analysis of sequencing logic, safety handling, and performance evaluation. This creates a need for a structured and validated approach for developing pick-and-place automation systems using virtual commissioning.

- **Problem statement**

Although PLC-based automation and Factory I/O simulation are widely used, many existing studies focus mainly on conveyor sorting or simple simulation exercises. They do not clearly show a structured step-based control method for a two-axis pick and place system with proper safety handling and box-filling logic. Because of this, there is a need for a low-cost virtual commissioning setup that can be used to design, test, and validate the complete automation sequence before physical deployment.

- **Research gap**

The main gap in the existing work is the lack of a complete pick and place automation model that combines conveyor control, step-based motion sequencing, emergency handling, and timing analysis in one virtual environment.

2. LITERATURE REVIEW

Virtual commissioning is a method used to develop and test automation systems before their actual deployment. It helps in identifying issues that may arise during system implementation. With Factory I/O, engineers can visualize, test, and validate PLC control logic in a realistic 3D industrial environment. This allows evaluation of system behavior, task sequencing, and safety response without requiring physical hardware. By integrating PLC programs with Factory I/O, development time and associated risks can be reduced.

Many automation systems based on PLCs have been developed; however, several existing approaches lack structured control strategies for robotic pick-and-place operations. Some systems still rely on conventional conveyor-based sorting methods without advanced motion control techniques. Factory I/O helps improve these limitations by enabling efficient and safer system design and testing. It also allows engineers to verify system performance before implementation, thereby saving time and reducing risk.

Previous studies have focused on material classification using sensors such as optocouplers and inductive sensors. The performance of such systems was evaluated based on the time required for sorting cycles. The results showed that Factory I/O is effective for testing PLC logic and evaluating automation system performance in a virtual environment. However, these systems were mainly limited to conveyor-based sorting and did not include robotic pick-and-place operations or step-based control strategies [1][6].

In addition, several researchers have explored PLC and Factory I/O applications in automated warehousing systems. For example, Vijaya Chitra et al. developed a PLC-based warehouse automation system using simulation techniques. Their work mainly focused on system integration and improving efficiency. However, the proposed system is more suitable for large-scale applications and does not provide a clear step-by-step control approach for pick-and-place operations [2].

Other studies have used Factory I/O mainly for educational purposes, PLC training, and basic automation visualization. These works highlight advantages such as reduced commissioning time, lower hardware dependency, and improved testing capability. However, most of these approaches lack detailed analysis of sequencing logic, safety mechanisms, and cycle-time evaluation for pick-and-place systems [3].

From the existing literature, it is observed that although PLC-based automation and Factory I/O simulation are widely used, there is limited work on implementing structured state-machine-based control for two-axis pick-and-place systems along with integrated safety handling and timing analysis [4][5].Therefore, there is a need for a system that combines conveyor operation, step-based control, safety mechanisms, and performance evaluation within a virtual commissioning environment.

To address this gap, this paper presents a PLC-based two-axis pick-and-place system developed using Factory I/O. The system integrates conveyor-based material handling with state-machine control, safety features, and performance analysis, providing a scalable solution for industrial automation testing before real-world implementation.

3. SYSTEM ARCHITECTURE

The proposed system is a PLC-based pick-and-place automation system with a two-axis mechanism. The system is developed using a virtual commissioning approach. A Siemens PLC is simulated, and an industrial setup is created using Factory I/O. The simulated environment represents a 3D industrial setup. This environment allows complete testing of the pick-and-place system. It enables verification of control logic, interaction between sensors and actuators, and system safety operations. The major advantage of this approach is that system validation can be performed without using physical hardware. All testing is carried out in a virtual environment. We can do everything on the computer with the pick-and-place automation system.

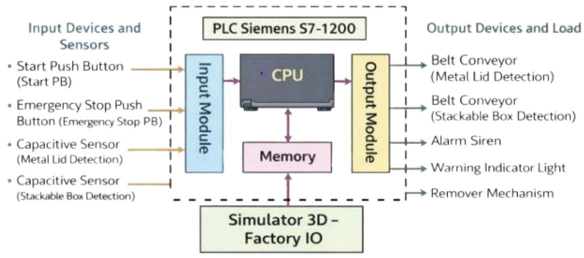

Fig. 1. Block diagram of the PLC-based two-axis pick and place system

3.1. Overall System Block Diagram

The block diagram illustrates the interaction between input devices, the PLC controller, output devices, and the Factory I/O simulation environment. The central control unit is implemented using Siemens S7-PLCSIM, which executes the PLC program developed in TIA Portal**.** The PLC receives input signals from sensors and push buttons, processes them using control logic and internal memory, and generates output signals to control actuators in the simulated system**.** The PLC consists of the following main functional units:

- CPU: Executes ladder logic, state-machine control, timers, and counters
- Memory: Stores control variables, step values, and intermediate process data.
- Input Module: Receives digital signals from sensors and operator controls.
- Output Module: Sends digital and analog control signals to actuators.

3.2. Input Devices and Sensors

The system includes an input section consisting of operator controls and object detection sensors. This section includes push buttons and sensors used for detecting objects. A start push button is used to initiate system operation, and an emergency stop button is provided to stop the system in case of unsafe conditions. Capacitive sensors are used to detect the presence of metal lids and stackable boxes at specific positions on the conveyor.

All input signals are sent to the Siemens S7-PLCSIM controller and are continuously monitored by the PLC program. The controller is like a brain that watches all these things all the time with a program.

3.3. Output Devices and Actuators

The output section of the system includes two conveyors, a two-axis pick-and-place mechanism, alarm indicators, and a removal unit. The PLC is responsible for controlling a 4-meter conveyor used for transporting metal lids and a 6-meter conveyor for moving stackable boxes. The pick-and-place system is operated through PLC outputs that control the X-axis movement, Z-axis movement, and gripper action. In addition, the PLC activates the alarm siren, warning light, and the remover mechanism when a box becomes full. To achieve proper sequencing and smooth operation, the PLC generates digital output signals along with required control setpoints.

3.4 Factory I/O Simulation and PLC Communication

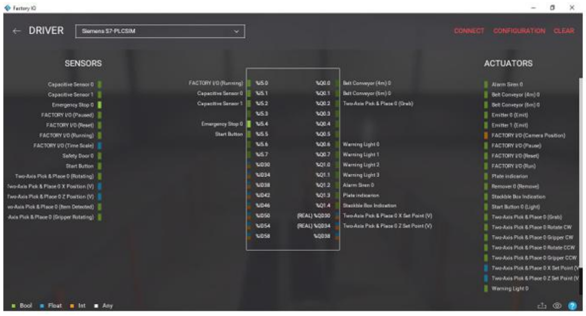

Fig. 2. Sensor and actuator mapping using Siemens S7-PLCSIM in Factory I/O.

Factory I/O is used as the 3D industrial simulation environment to represent the virtual warehouse and pick and place cell. The Siemens S7-PLCSIM driver is used to establish communication between the PLC and Factory I/O, enabling real-time input and output data exchange. The input addresses in the PLC are mapped to the sensor states in Factory I/O, and the output channels in Factory I/O are mapped to the actuator commands created by the PLC. This two-way communication allows real-time monitoring and validation of the control logic, supporting effective virtual commissioning of the system.

4. CONTROL METHODOLOGY

4.1 Step-Based Control Algorithm

The pick-and-place system uses a step-based control strategy to ensure predictable, safe, and reliable operation of the two-axis mechanism. Instead of executing all control actions at the same time, the controller performs tasks in a sequence of well-defined steps. Each step represents a specific action in the operation, such as axis movement, gripping an object, transferring it, or placing it in position. This approach improves clarity of control logic, reduces the possibility of overlapping operations, and enhances system safety. A memory word in the PLC is used as a state variable to represent the current step of operation. Each value of the state variable corresponds to a specific stage in the pick-and-place sequence. Each value of the state variable means the system is at a stage of operation. The system will only move to the stage when it is done with what it is doing now and The system transitions to the next step only after completion of the current action and after the required time delay has elapsed. PLC timers are used to control these delays and ensure proper synchronization of operations. These timers help prevent collisions and ensure smooth and safe system operation. The step-based approach also improves system monitoring and simplifies troubleshooting in case of faults. In addition, modifications such as adding new steps or changing the sequence can be implemented without major changes to the control program.

This approach is well suited for pick-and-place applications involving repetitive operations. Each step is executed sequentially, and the system transitions to the next step only when all required conditions and timing constraints are satisfied. After completing all steps, the PLC checks the object count to determine whether the box is filled. If the required number of objects is reached, the filled box is moved forward and replaced with a new box; otherwise, the cycle continues. The state variable is continuously updated to track the current stage of operation, providing a structured and reliable control mechanism.

Step (State Variable	Operation Description
0	System idle and waiting for start command
1	Z-axis moves downward to reach the pick position
2	Gripper is activated to pick the metal

	product lid
3	Z-axis moves upward after successful gripping
4	X-axis moves forward towards the stackable box
5	Z-axis moves downward to the placement position
6	Gripper is deactivated to release the object into the box
7	Z-axis moves upward after placement
8	X-axis returns to the home position
9	State check for object count and cycle repetition

TABLE : 1 Step Based Control Algorithm for Pick and Place Operation.

4.2 Flowchart of System Operation

The flowchart shown in Fig. 3 represents the overall operation of the PLC-based pick-and-place automation system. The system begins with initialization, where the PLC is set to an idle state. At this stage, all outputs are turned OFF, the object counter is reset to zero, and the pick-and-place mechanism is moved to its home position. This ensures that the system starts from a safe and defined condition.

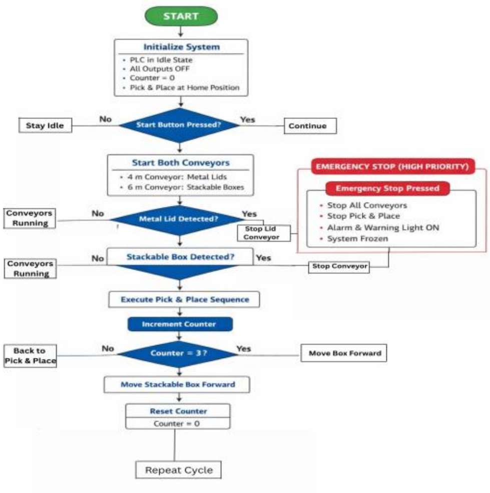

Fig. 3. Flowchart of PLC-based two-axis pick and place system operation

When the start button is pressed, the system transitions from idle to active mode. Both conveyors, one for metal lids and the other for stackable boxes, begin to operate simultaneously, allowing objects to move along the conveyor belts. The PLC continuously monitors the sensor inputs to detect the presence of metal lids and boxes. When a metal lid is detected, the corresponding conveyor is stopped. Similarly, when a box reaches the required position, its conveyor is also stopped. Once both objects are in position, the pick-and-place sequence is initiated.

The pick-and-place operation is executed step by step. First, the Z-axis moves downward to pick the metal lid, and the gripper is activated. Then, the Z-axis moves upward, and the X-axis transfers the object towards the box. After that, the Z-axis moves downward again to place the object inside the box, and the gripper releases it. Finally, the Z-axis moves upward, and the X-axis returns to its home position.

After each successful placement, the object counter is incremented. The PLC checks whether three metal lids have been placed in the box. If the required count is not reached, the process repeats for the next object. Once three lids are placed, the filled box is moved forward using the conveyor and remover mechanism, and the counter is reset. The system then continues the cycle for the next box.

During operation, the emergency stop condition is continuously monitored. If the emergency stop button is pressed, all conveyors and pick-and-place movements stop immediately, and the alarm and warning indicators are activated. The system remains in this state until the issue is resolved, and the system is restarted.

4.3. Ladder Programming Strategy

The control logic of the proposed pick-and-place system is developed using ladder programming in Siemens. TIA Portal Ladder logic is used due to its wide acceptance in industrial automation, ease of understanding, and suitability for sequential control tasks. Only selected ladder logic networks are presented to explain the control methodology clearly. The focus is on ladder logic networks representing the key functional parts of the pick-and-place system.

In the following sections, major revisions have been carried out to improve clarity, technical quality, and writing style. Due to the extent of these changes, highlighting each modification has not been feasible.

1) Start–Stop and Emergency Stop Logic

The overall operation of the system is controlled using start–stop logic. A latch mechanism is used so that once the start button is pressed, the system continues to operate without requiring continuous input.

The emergency stop is treated as a high-priority input and can stop the system immediately. It overrides all ongoing operations in case of unsafe conditions. When activated, it halts all moving components, including conveyors and pick-and-

place mechanisms, and activates alarm and warning indicators.
This ensures safe operation and protects both the system and the operator. The safety mechanism improves system reliability under abnormal operating conditions.

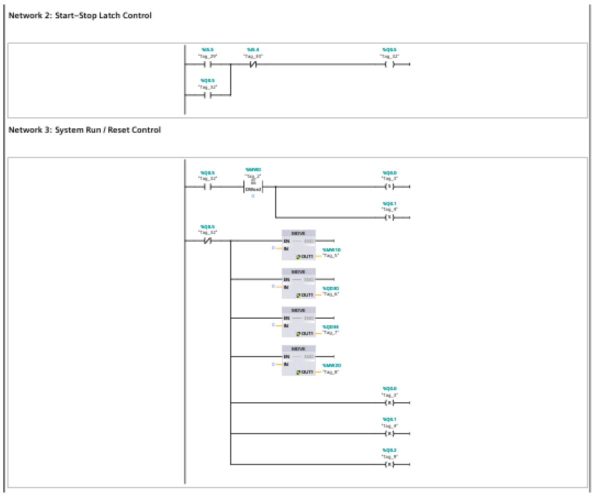

Fig. 4. Start–Stop and Emergency Stop Logic

2) State- Machine Based Pick and Place Control:
The system is controlled using a state-machine-based approach implemented in ladder logic. An internal PLC memory location is used as a state variable to represent the current step of the pick-and-place process.
Each state corresponds to a specific action such as axis movement, object gripping, or object placement. The system transitions to the next state only when the required conditions are satisfied, and the associated timer has completed.
This approach ensures structured operation and improves clarity of control logic. It also simplifies troubleshooting and allows easy modification of the control sequence when required.

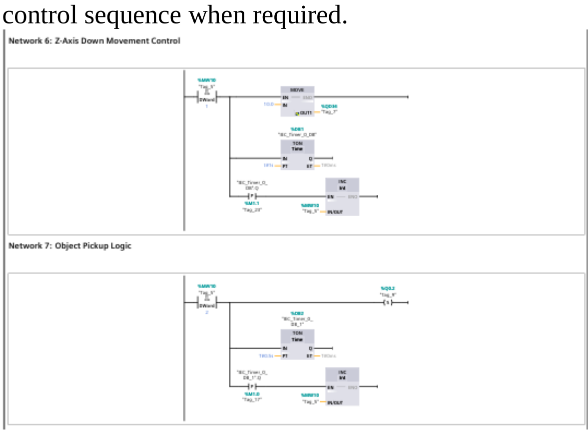

Fig. 5. State- Machine Based Pick Control

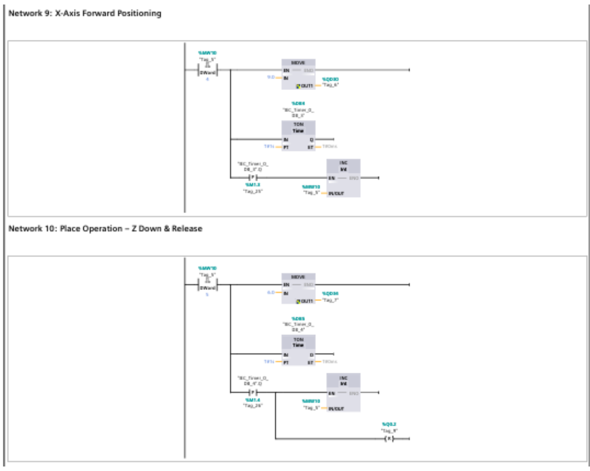

Fig. 6. State- Machine Based Place Control

3) Counter Logic for Box Filling Control:
To ensure consistent packaging, a counter-based control method is used to regulate the number of metal lids placed in each box. The counter is incremented after each successful placement of a lid.
When the counter reaches the preset value, the system initiates the box transfer sequence, and the counter is reset for the next cycle. This enables continuous and automatic operation without manual intervention.
The overall control program also includes logic for motion timing, conveyor coordination, sensor monitoring, and alarm handling. Although the complete ladder program is not included due to space limitations, it has been implemented and verified in the Factory I/O virtual environment.

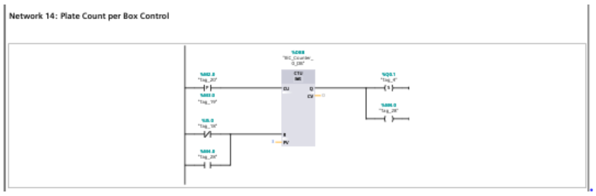

Fig. 7. Counter Logic for Box Filling Control

5. EXPERIMENTAL SETUP AND IMPLEMENTATION

The system is implemented in a virtual environment using Factory I/O. A virtual industrial warehouse is used to test the PLC control logic, interaction between sensors and actuators, and system safety features. This approach eliminates the need for physical hardware during testing. The entire pick-and-place automation system is validated through virtual commissioning.

A. Virtual Warehouse Setup

The virtual warehouse layout is implemented in Factory I/O and is designed to resemble a real industrial material handling system.

Fig. 8. Warehouse Top View & Side view

The virtual warehouse includes conveyor systems, a two-axis pick-and-place mechanism, safety fencing, sensors, and indicator lights. All components are arranged to ensure proper object flow, accurate sensing, and safe operation.

Factory I/O provides real-time visualization of system behavior, allowing observation of conveyor movement, pick-and-place operations, and system alerts during operation. This integrated setup ensures smooth and safe functioning of the virtual warehouse.

B. Conveyor System Configuration

Fig. 9. Conveyor system for metal lid and stackable box transport Two belt conveyors are used in the system to transport different objects.

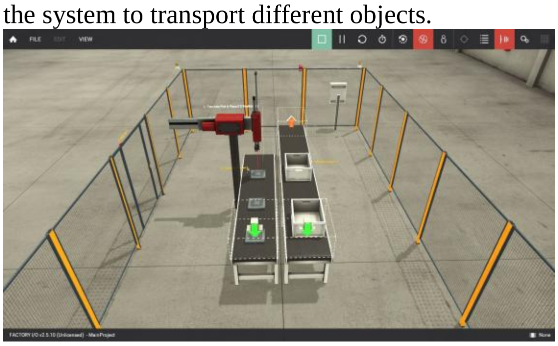

Fig. 9. Conveyor System Configuration

Two conveyors are used in the system to transport different objects. A 4-meter conveyor is used for carrying metal product lids, while a 6-meter conveyor is used for moving stackable boxes. Both conveyors operate continuously to ensure a steady supply of objects.

Capacitive sensors are installed at specific positions on the conveyors to detect the presence of metal lids and stackable boxes. When an object is detected, the PLC stops the corresponding conveyor to ensure proper positioning for the pick-and-place operation. The system ensures that metal product lids and stackable boxes are accurately positioned for handling and placement.

C. Two-Axis Pick and Place Mechanism

Fig.10. Two-axis pick and place mechanism in Factory I/O The pick and place unit consists of two linear axes and a gripper mechanism.

Fig. 10. Axis view Pick and Place Mechanism

The X-axis is used for horizontal movement between pickup and placement positions, while the Z-axis controls vertical motion for picking and placing operations. A gripper is mounted at the end of the Z-axis to securely pick and release metal product lids.

The PLC controls the positioning of both axes by generating appropriate control signals and predefined setpoints. This ensures smooth and coordinated operation of the system. The combined operation of the X-axis, Z-axis, and PLC enables accurate handling and placement of metal product lids.

D. Electric Switchboard and Operator Interface

The electrical switchboard serves as the operator interface for the pick-and-place automation system. It allows the operator to control the system manually and monitor its operational status. The switchboard is designed to resemble a standard industrial control panel. It includes a start push button to initiate the automation process and an emergency stop button to shut down the system in case of unsafe conditions. The emergency stop is treated as a high-priority input in the PLC program, ensuring that all operations are stopped immediately when it is activated.

Fig. 11. Electric Switchboard

The indicator lights display the detection status of metal product lids and stackable boxes, allowing the operator to easily monitor system conditions.

All control buttons and indicator lights are connected to the Siemens S7-PLCSIM controller through digital inputs and outputs in Factory I/O. This setup enables testing of operator control functions, safety response, and system status indication within the virtual environment.

6. RESULTS AND DISCUSSION

This section presents the results obtained from testing the PLC-based two-axis pick-and-place system in a virtual environment. The system performance is evaluated based on object handling time and response under emergency conditions. All tests were conducted using the Factory I/O simulation platform. The measurements were recorded by observing the simulation and using a mobile stopwatch to determine the time required for object handling and emergency response.

A.Time Analysis

The time required for the pick-and-place operation was determined by measuring the duration needed to place multiple metal lids into stackable boxes. Figure 13 shows the recorded timing during continuous system operation. During testing, the system placed five metal lids sequentially, and the time for each placement was recorded. Based on these observations, the average time required to place a single metal lid was approximately 9.0 seconds. Since each stackable box contains three metal lids, the total time required to fill one box is calculated as:

$$\text{Time per box} \approx 3 \times 9.0 = 27 \text{ seconds}$$

Fig. 12. Formulae of Time required to fill one stackable box

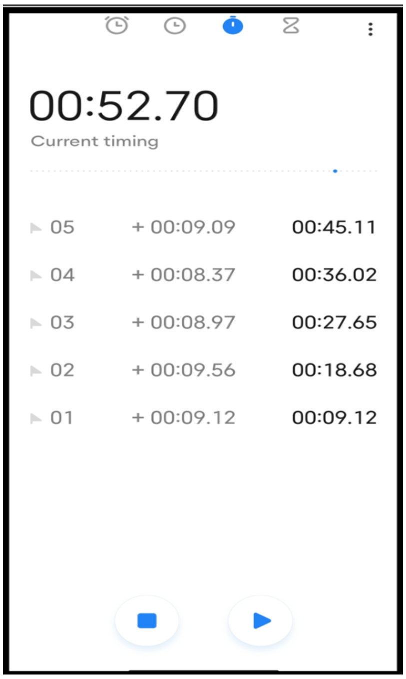

Fig. 13. Real Time Analysis

These results show that the step-based PLC control logic results in repeatable operation. Small variations in the placement time of individual items are due to the timing of axis motion and the delay of the gripper actuation. The system is stable and reproducible for an automated packaging application. Fig. 13. Pick and place time measurements for multiple metal product lids.

B. Comparison with Existing Methods

To further evaluate the effectiveness of the proposed system, a comparison with conventional automation approaches is presented in Table 2.

Parameter	Conventional System	Proposed System
Control Type	Basic sequential logic	Step-based state machine
Flexibility	Limited	High
Safety Handling	Basic	Emergency stop + alarm + indicators
Development Cost	High (hardware required)	Low (virtual commissioning)
Testing Time	Long	Reduced
Error Detection	Difficult	Easy (visual simulation)
Scalability	Limited	Easy to modify
Validation	Physical only	Virtual + future physical

Table 2: Performance Comparison between conventional and proposed system .

From the comparison, it can be observed that the proposed system provides improved flexibility, safety handling, and reduced development time due to the use of virtual commissioning.

C. Safety Response Analysis

To evaluate system safety performance, the emergency stop push button is activated at different stages of system operation. The emergency stop is treated as a high-priority input in the PLC logic and is continuously monitored throughout the automation cycle.

When the emergency stop is pressed, all conveyors and pick-and-place operations are halted immediately, and the alarm siren along with the warning indicator light is activated to alert the operator. The system remains in this halted state until the emergency condition is cleared and the system is restarted.

The safety response analysis indicates that the system responds quickly and reliably during emergency conditions. Immediate stoppage of motion along with clear visual and audible indications enhances both operator and system safety, demonstrating the effectiveness of the proposed control strategy for industrial automation applications.

Event	System Response
Emergency stop activated	Immediate halt of conveyors and pick and place motion
Alarm Siren	Activated instantly
Warning	Turned ON

Indicator	
System State	Frozen until manual reset

Table 3: Safety response of the proposed system under emergency conditions.

7. CONCLUSION AND FUTURE SCOPE

This paper presents the design and virtual implementation of a PLC-based two-axis pick-and-place automation system using Factory I/O. The system was developed using Siemens S7-PLCSIM and validated through a virtual commissioning approach.

The proposed system successfully performs conveyor operation, object pickup, placement, and box handling using step-based control logic. The experimental results demonstrate consistent pick-and-place performance, reliable safety response, and stable cycle operation in a simulated industrial environment.

The key outcomes include effective integration of conveyor-based material handling with a two-axis pick-and-place mechanism, implementation of a state-machine-based control strategy, and validation of system performance using timing analysis. The inclusion of emergency stop handling, alarm indication, and operator control through an electrical switchboard enhances the practical relevance of the system.

For future work, the system can be extended by integrating SCADA or HMI for real-time monitoring and data logging. Implementation using real PLC hardware with actual sensors and actuators can further validate system performance under practical conditions. In addition, the pick-and-place mechanism can be expanded to multi-axis or robotic configurations to support more complex industrial applications and improve system throughout.

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