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Development of a Product Pipeline System to Teach Industrial Manufacturing Automation

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Development of a Product Pipeline System to Teach Industrial Manufacturing Automation

Abstract

Our modern age is being forged by industrialization and automation. Processes that once required tedious handwork can now be completed with higher efficiency and consistent quality by machines and facilities that perform their operations automatically. Examples of automation technology in our daily lives are found in households where washing machines are used, on the streets where traffic lights regulate traffic, or even in buildings that use air-conditioning units and automatic lighting systems. Open-loop control systems or closed-loop control systems are used in all these systems to determine a predefined sequence of processing steps.

The Industrial Manufacturing System (IMS) developed at the college intends to address the need in education. This project introduces how the production assembly line develops. The system consists of Sorting, Assembly, Processing, Testing, Storage, and Buffering operations. The Siemens Simatic PLC (Programmable Logic Controller) S7-300 is used in the manufacturing system and TIA (Total Integrated Automation) Portal is used as the programming environment.

This project focuses on the automation of an industrial manufacturing system through several tools such as PLC, TIA PORTAL (V16), and PROFIBUS. The control of the whole system is implemented by using Siemens Sematic PLC. The main objective of this project is to create a fully automated production line for college education. The system consists of Buffering, Sorting, Assembly, Processing, Testing, Handling, and Storage to minimize the risk to workers' health [1] and the occurrence of accidents and increase production efficiency.

Introduction

Industrial automation plays a crucial role in enabling the manufacturing industry to compete globally in terms of productivity, cost, and demand-supply proportion [2]. The advent of Industry 4.0 has brought about a significant shift in the manufacturing landscape, with advanced technologies such as automation and AI being integrated into manufacturing processes to improve efficiency, lower costs, and enhance product quality. To keep up with these developments, education in automation processing is essential to develop the necessary skills and knowledge required to design, implement, and maintain automation systems, optimize production processes, and troubleshoot and integrate automation systems with other technologies.

The IMS project is aimed at providing education in automation technology for college students. Given the importance of automation in production and in industry, it is essential for students to have knowledge of PLC programming and communication. The purpose of this project is to enable students to comprehend the entire production pipeline process by understanding the PLC language required in the industry field, such as ladder diagrams, function blocks, sequence control, and structured text, and also to become familiar with TIA portal software, which is one of the most widely used software applications in the industry field.

The previous system had limitations. It does not have a power distribution calculation, insufficient testing/troubleshooting information, and slower productivity. In contrast, the current system addresses these limitations by providing power distribution calculation, a comprehensive manual with testing/troubleshooting information, and increased efficiency, enabling students to accomplish more work in less time. The use of TIA Portal software is an improvement over the previous Siemens S7 Simatic software version 5.1, providing better performance and advanced features that enable students to achieve better results.

To further elaborate on the improvements made in the IMS project, the 3D simulation demonstration has undergone significant enhancements. In contrast to the previous system that relied on IMS-Virtual simulation, the use of Factory IO for 3D demonstration represents a major upgrade, resulting in a more intuitive and effective system. The new and improved simulation is more realistic, providing students with a more engaging and authentic learning experience. This upgrade has also made the system more user-friendly and efficient, contributing to an overall enhanced user experience. As a result, students can now better visualize and understand the manufacturing process, making them more equipped to tackle industry-related problems.

The IMS project stands as a shining example of how technology and education can work together to create a brighter future for the manufacturing industry. By providing students with a comprehensive understanding of automation technology and addressing the shortcomings of the previous system, the IMS project is empowering the next generation of students with the skills and knowledge necessary to tackle the challenges of the modern world. With its emphasis on practical learning and cutting-edge technology, the IMS project is poised to revolutionize the way we approach automation education and training and to drive the industry forward into a new era of productivity, efficiency, and innovation.

Previous System vs Current System

Modes of The Automated Pipeline System

The current system has two modes. The first mode demonstrates only one product with one carrier in each round. This means that one carrier rotates four times to finish demonstrating four products from the start point to the end point. This process takes four minutes and thirty seconds.

The second mode demonstrates four products with four carriers concurrently. This means that the four carriers rotate only one round to finish demonstrating four products from the start point to the end point in a sequence. This process takes two minutes and thirty seconds with only one station distance difference.
However, the previous system its first mode process takes an estimated time of six minutes and thirty seconds, and the second mode process takes an estimated time of three minutes and thirty seconds to run two blocks concurrently in two rounds with three stations to be non-functional as a distance between carriers.

Table 2: Shows the 2nd mode movement for 4 products in 1 round

Positions	Buffering Down	Motor	Selecting	Assembly	Processing	Testing	Storage	Buffering Up
Scenario 1	1							
Scenario 2		1						
Scenario 3	2		1					
Scenario 4		2		1				
Scenario 5	3		2		1			
Scenario 6		3		2		1		
Scenario 7	4		3		2		1	
Scenario 8		4		3		2		1
Scenario 9			4		3		2	
Scenario 10				4		3		2
Scenario 11					4		3	
Scenario 12						4		3
Scenario 13							4	
Scenario 14								4

System Efficiency

Efficiency is a critical concept for engineering students to understand as it helps them design and develop systems and processes that make the best use of available resources, reduce costs, promote sustainability, and drive innovation [3]. By understanding efficiency, students have a better way of thinking about how to create products and processes that are better for the environment, the economy, and society.
With the implementation of a new and faster assembly line, the production process has become more efficient, leading to various benefits such as reduced production costs and quicker task completion. By decreasing the time duration for 4 carriers, power consumption has also been reduced, thus verifying the concept of efficient manufacturing.

The Importance of Power Distribution for System Operation

The previous system did not have power distribution calculations, making it difficult for students to manage and troubleshoot power-related issues. However, the power distribution calculations is calculated for current system to identify the allowed maximum load of the system. This calculation helps students understand the importance of power distribution when working in the industry.
Understanding power distribution is crucial for students to fully comprehend how a system operates with and without loads. Efficient and effective operation depends on the proper

calculation of power distribution in the system. Normally, power distribution is balanced, resulting in optimal system function.
However, when the system is under maximum load stress, the distribution may become uneven, which can lead to potential issues such as overheating, equipment failure, and shutdowns. This process considers several factors, including the type of energy source, power transmission and distribution infrastructure, and system load demands. The process covers load balancing, safety, capacity planning, energy efficiency, backup power, and maintenance.

IMS System Manual

The previous system manual does not provide comprehensive testing and troubleshooting information. This made it more challenging for students to diagnose and fix problems that might arise while working with the system. Without clear guidance on how to conduct proper testing, students have not been able to identify the root cause of the issue or take the necessary steps to address it. A lack of troubleshooting information could have left students feeling uncertain about how to approach fixing the problem once it was identified.

The current system manual is designed to assist students in testing and troubleshooting with simplicity while gaining a comprehensive understanding of the testing process. The manual is structured into three sections for each test - Successful Tests, Failed Tests, and Safety Tests [4].

In the Successful Tests section, students can gain a clear understanding of the successful test conduct, enabling them to confidently replicate the process. The Failed Tests section informs students of any potential issues that may prevent a particular test from working, providing valuable troubleshooting guidance.

Additionally, The Safety Tests section highlights crucial safety precautions and guidelines that students follow to maintain a secure testing environment for everyone. Students can use this comprehensive guide to conduct tests safely and confidently, while also being able to troubleshoot any potential issues that may arise.

These tables show an example of the tests for Hardware System Assembling and Wiring work.

PLC and Computer Connection	Test 1
Successful Test	
• Connect the main Computer with the PLC by using the MPI Cable	
Failed Test	
• Uploading to the SD card directly failed due to insufficient memory storage.	
Safety Test	
• Make sure the power is off: Ensure that the power to the PLC is turned off before connecting or disconnecting the MPI connection. This prevents electrical shock or damage to the equipment.	

• Verify correct cable: Verify that the cable you are using is the correct one for the MPI connection. Using the wrong cable may cause communication errors or damage to the PLC. • Check for damaged connectors: Check the connectors on the cable for any damage, such as bent pins or cracked plastic. Using a damaged cable may cause the connection to fail or damage the PLC.

Stations Safety Measurement Cables	Test 2
Successful Test	
• Set your DMM to measure DC voltage. • Connect the red probe to the positive (+) terminal of the cable connector and the blue probe to the negative (-) terminal. • Turn on the PLC that is supplying the voltage to the cable. • Check the DMM reading to see if it displays the expected voltage. • The voltage level should be within the range of the cable's specifications.	
Failed Test	
• The DMM reading does not show any voltage, and then there may be a problem with the cable or the PLC. In this case, you may need to check the cable for damage or check the PLC to make sure it is providing the correct voltage.	
Safety Test	
• Wear appropriate personal protective equipment (PPE) such as rubber gloves, insulated boots, and goggles. • Ensure that the equipment is properly grounded and that there is no chance of an electrical shock. • Make sure that the test area is clear of any debris or objects that could interfere with the test. • Identify the correct circuit and ensure that it has been properly de-energized. • Always handle the probes by their insulated handles and avoid touching any bare metal parts.	

Hardware System Sequence	Test 3
Successful Test	
• Buffering Station • Extension double conveyor belt segment • Double conveyor belt segment with motor • Extension double conveyor belt segment • IMS 180° curve conveyor belt segment • Selecting Station • Assembly Station • Processing Station • Testing Station	

• Storage Station • IMS 180° curve conveyor belt segment • Extension double conveyor belt segment
Failed Test
• Using any other hardware system sequence does not improve the efficiency of the current mode at the specified time mentioned
Safety Test
• Review the test plan: Before starting the test, review the test plan to ensure that the sequence of operations is understood and any safety precautions that need to be taken. • Ensure personnel safety: Ensure that all personnel involved in the test are trained on the equipment and safety procedures and that students are wearing appropriately. for example, long hair should be tied up into ponytails and maxi skirts may not be proper for experiments. • Check the equipment: Check all equipment involved in the test to ensure that it is in good working condition and that there are no damaged or worn-out parts that could cause safety hazards or affect the test results.

Development of Educational Process for Industrial Automation

The objective of this project is to effectively introduce students to the necessary knowledge and skills to successfully understand industrial automation. The process sequence aims to provide students with a solid foundation in automation and control systems, as well as hands-on experience with the specific tools and technologies used in the IMS project, such as the Siemens Simatic PLC S7-300 and TIA Portal. The following are the steps for the effective course sequence:

- Introduction to Automation and Industrialization: This module provides an overview of the impact of automation and industrialization on modern society and a brief history of the development of automation technology.
- Assembly Line Operations: This module examines the various operations involved in the production assembly line, including Sorting, Assembly, Processing, Testing, Storage, and Buffering.
- Programmable Logic Controllers: This module provides a comprehensive introduction to PLCs, including programming and operations. It also covers the Siemens Simatic PLC (Programmable Logic Controller) S7-300 and its use in the IMS.
- TIA (Totally Integrated Automation): This module covers the use of the TIA Portal in the IMS, including its functions, implementation, and advantages.
- PLC Programming and Debugging: This module focuses on programming the Siemens PLC using TIA Portal and debugging techniques to ensure proper operation of the PLC control method.

• Automating the Production Line: This module discusses the implementation of the fully automated production line, including the integration of various operations such as Buffering, Sorting, Assembly, Processing, Testing, Handling, and Storage [5].
• PROFIBUS and MPI Communication Protocols: This course provides students with a comprehensive understanding of the PROFIBUS and MPI communication protocols, including their structure, components, and applications in industrial automation systems.
• IMS Project Implementation: This course is the culminating project for the students, through the course, they can apply the knowledge and skills they have learned in previous courses to design and implement the IMS. The course provides students with hands-on experience in programming the Siemens Simatic PLC S7-300 and integrating the IMS into a complete, automated production line.
• Project Conclusion: This module provides a comprehensive overview of the project and its objectives, including a review of the results achieved and recommendations for future work.

By following this project sequence, students have the necessary knowledge and skills to successfully complete the IMS project and have a solid foundation in industrial automation and control systems that they can build upon in their future careers.

Previous Course

The current course focuses on teaching programmable logic controllers (PLCs) and how they work as an individual station to complete manufacturing task, such as Sorting, Testing, Storage, and so on, using a Siemens PLC S7-1200 PLC for control. In general, the course provides detailed information on manufacturing a single station, how to build a product at a step, and overviews of how a PLC is configured and used to control a station. The knowledge and skills gained from the course are valuable for professionals in the field of industrial automation and control engineering [6], who need to understand the basics of PLC networking and data exchange. However, this class teaching in this way allows students to learn how individual manufacturing station works but students still cannot envision how the sequence of products is developed in an assembly line in a highly efficient way.

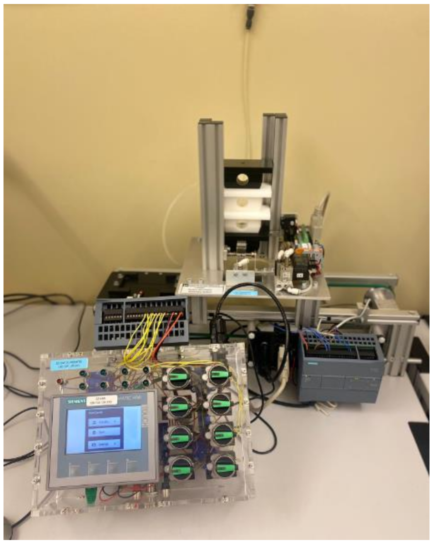


Figure 1: Single Station Connection

Furthermore, this approach lacks the opportunity for students to experience the actual production process in a real-world setting. This type of hands-on learning is crucial for students to understand the complexity of manufacturing systems, including the synchronization of different workstations and the optimization of the entire production process

Developed Course Content for Multiple Stations in An Assembly Line

To enhance the previous course, we can add a new type of connection. This connection is a widely used industrial communication protocol and provides a cost-effective solution for connecting PLCs and other automation devices.

Introducing the use of a Siemens PLC S7-300 in the course would be a significant improvement as it not only enhances participants' knowledge on different types of Programmable Logic Controllers (PLCs) but also offers them the opportunity to learn about its various communication capabilities.

The Siemens PLC S7-300 has a reputation for being a highly functional, dependable, and user-friendly device, which makes it the perfect choice for integrating into the course's curriculum. By incorporating this technology, participants gain a deeper understanding of how PLCs operate, how to troubleshoot problems, and how to develop efficient solutions to real-world challenges. Ultimately, the addition of the Siemens PLC S7-300 helps participants build practical skills and improve their overall performance in the course.

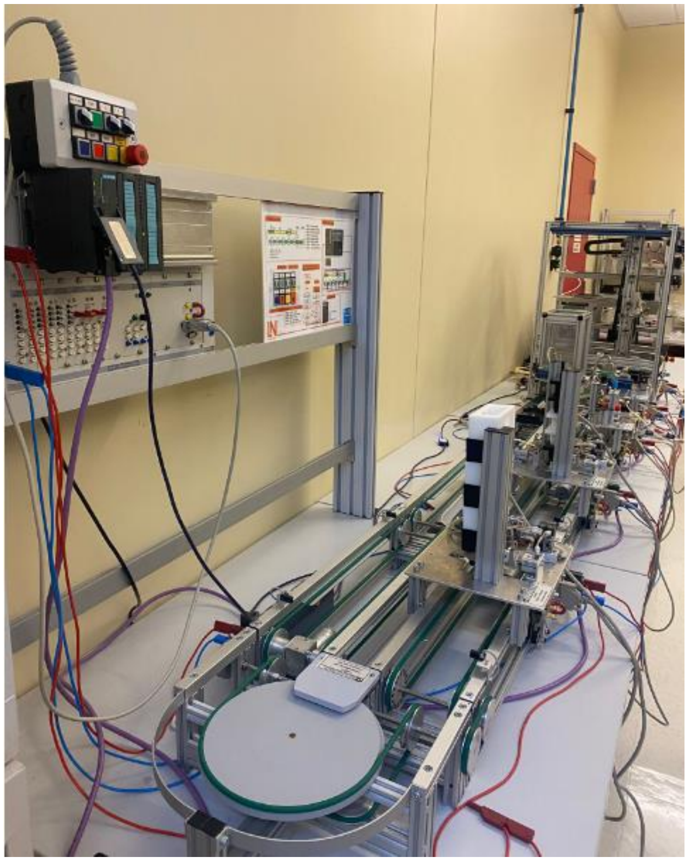


Figure 2: The Integrated Manufacturing System

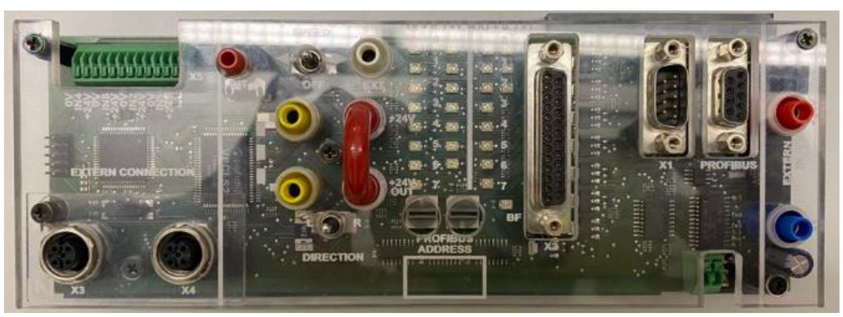


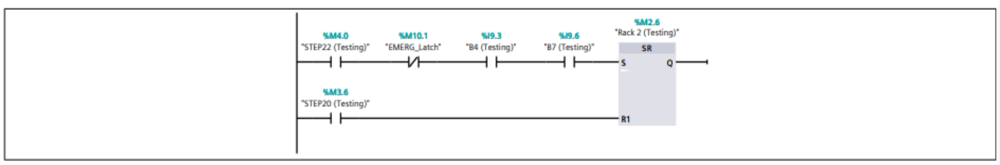
Figure 3: Profibus Connection Board

By adding the Profibus connection and connecting the Siemens S7-300 PLC and the multiple stations, we integrate manufacturing assembly line configurations into the course. This means that participants learn how multiple stations work concurrently with the Profibus [7] connection of each station. This provides a more comprehensive understanding of industrial automation and control and enables participants to apply the knowledge and skills learned from classes to a wider range of applications.

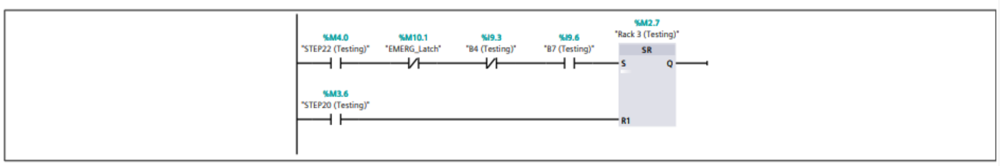
The simulation of this system is a useful tool for students as they can see how the system works and become more familiar with it [8]. This is done through a software simulation program that mimics the behavior of the PLCs and the communication between them. By observing the simulation, students understand the work of the system, including the flow of data and the communication protocols used.

In addition to the simulation, we provide a student manual that describes and simplifies everything in detail. The manual covers the theory behind the Profibus connection, the Siemens S7-300 PLC, as well as the step-by-step instructions for setting up and configuring the system. The manual is written in a clear and concise manner, making it easy for students to understand and follow.

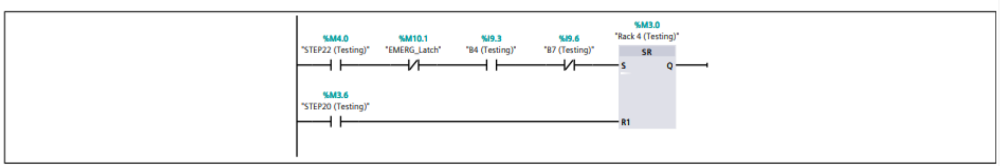
In summary, by adding the Profibus connection and the Siemens S7-300 PLC, we make the previous course more comprehensive and closer to industrial manufacturing applications. The simulation and student manual provide students with an effective and interactive way to learn about industrial automation and control, giving them the knowledge and skills, they need to succeed in their careers.



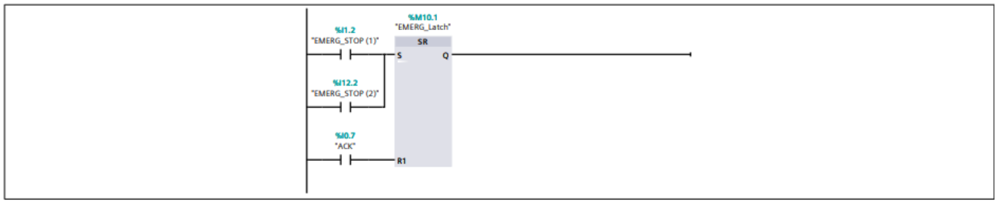
Network 10:



Network 11:



Network 12:



Network 13:

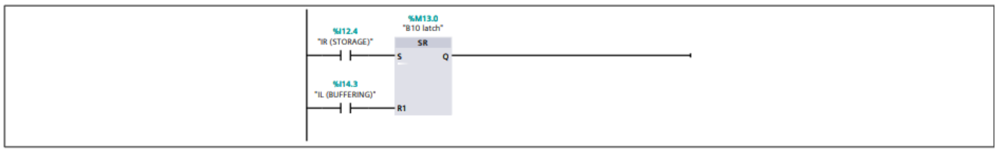


Figure 4: Networks 9 to 13 In the Testing Station Program

Figure 4 represents steps 9 to 13 of the testing station code. The testing station program detects the colors of the top and bottom pieces of a product. Based on the colors of the two pieces, the testing station provides information about the colors to the storage station, which then places the product on the appropriate storage rack.

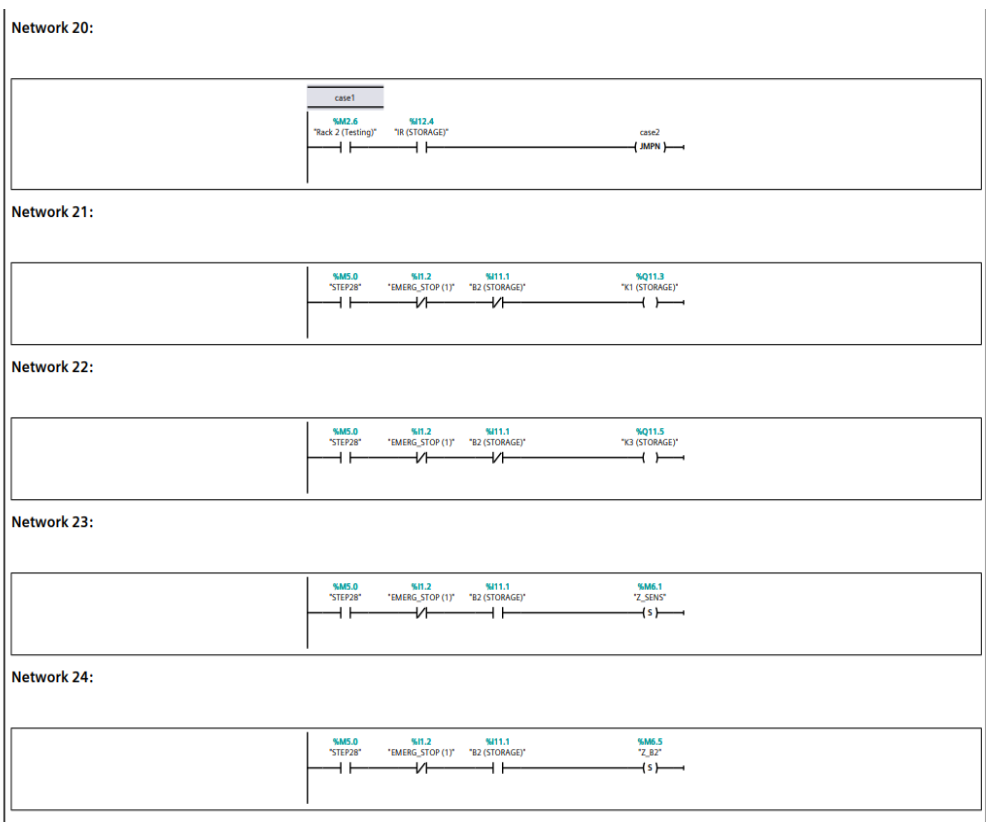


Figure 5: Networks 20 to 24 In the Storage Station Program

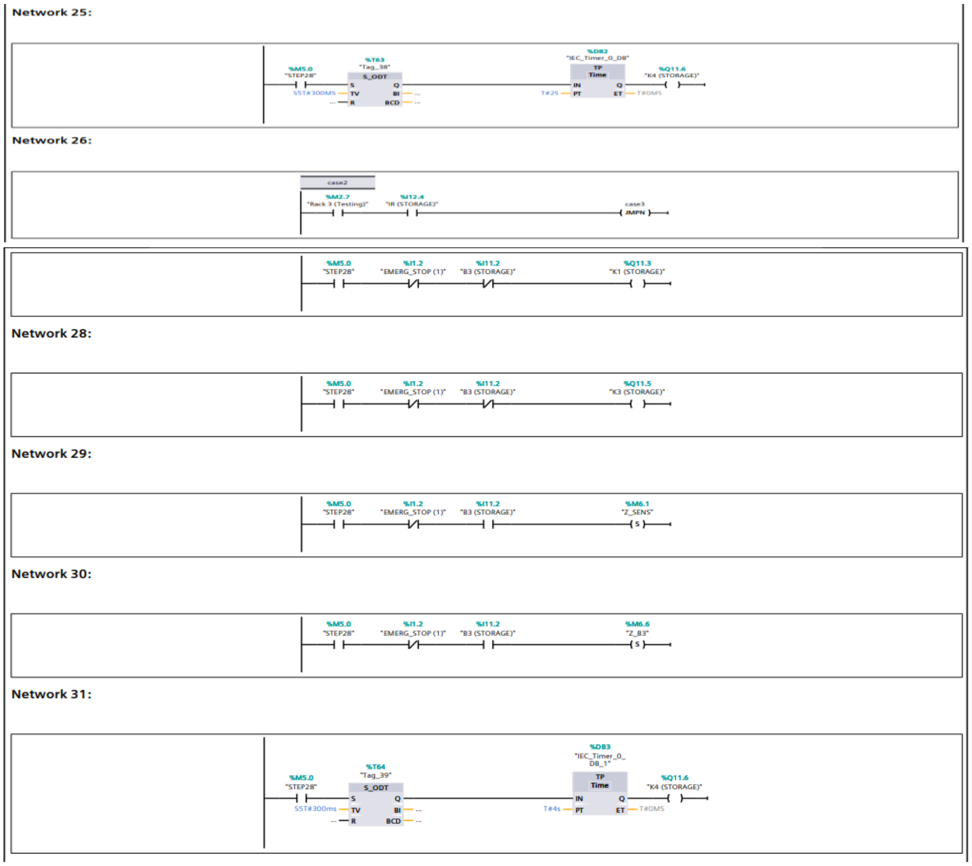


Figure 6: Networks 25 to 31 In the Storage Station Program

Figures 5 and 6 represent steps 20 to 31 in the storage station code. The storage station program includes several cases that determine the positions of products on the racks. For instance, Case 1 is used for the first position of the rack, Case 2 is used for the second of the rack, and so on.

3D Simulation

The simulation part of the developed course is done using the Factory I/O software, which is a real-time simulation tool for industrial automation and control. By creating an environment in Factory I/O, students can see how a manufacturing system operates, including the interactions between the PLCs and other automation devices.

In the Factory I/O simulation environment, students can set up and configure a virtual manufacturing system that includes real Siemens PLCs or other PLCs in the loop. Students can then observe the flow of data between the PLCs and the controlled devices and see how the system operates in real time. The simulation environment provides an interactive way to engage students in learning about industrial automation and control, allowing them to apply the concepts they have learned in action.

Figure 7: Factory I/O Progress

Pick and Place handling machines

Practical skills that are highly sought after in the modern manufacturing industry can be acquired by students through learning how to design and program Factory I/O Pick and Place Handling machines, which are commonly used in manufacturing plants to automate assembly lines and improve productivity. The ability to perform a wide range of tasks, such as assembly, packaging, and palletizing, can be included in these skills. Furthermore, a safe and controlled environment for students to test and refine their skills is provided using Factory I/O software, allowing them to learn at their own pace without risking damage to expensive machinery.

Figure 8: Assembly parts by using the pick and place handling machine

As a result, their problem-solving and critical thinking abilities can be improved, and their technical expertise can be developed, making them well-suited for future careers in the field of manufacturing.

The Factory I/O simulation is also useful for demonstrating various control scenarios, such as how different PLCs communicate with each other and coordinates control processes [9]. This gives students a deeper understanding of the technical aspects and helps them to see how these technologies are used in real-world applications.

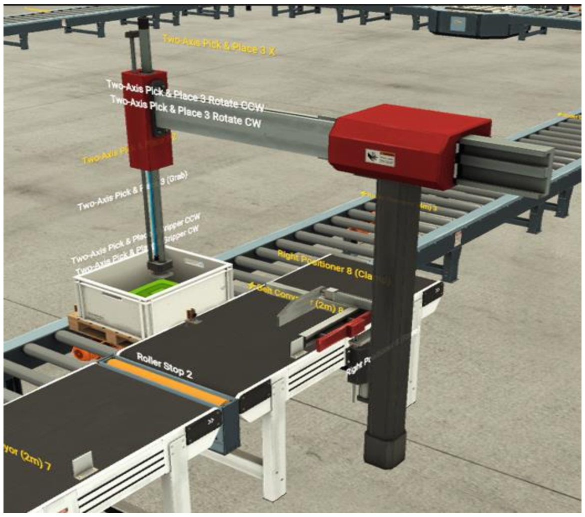


Figure 9: pick and place the product in the box by using the handling machine

The importance of accurate and efficient packaging in the manufacturing process can be learned by students through the Pick and Place handling machine on Factory I/O. The machine can be programmed to pick up products and place them into boxes, providing valuable experience to the students.

Color Sensor Gate

The color sensor gate on Factory I/O can also be used to differentiate between different products based on their color. This can be particularly useful in manufacturing and packaging industries, where different products may have similar shapes and sizes but different colors. By programming the color sensor gate to detect and sort products based on their color, students can learn how to improve efficiency and accuracy in production processes. For example, students can simulate a production line where different colored products are identified by their different colors and use the color sensor gate to sort and direct each product to its corresponding station. This can help students understand the practical applications of color sensors in industrial automation and develop the necessary skills to succeed in the modern manufacturing industry.

Figure 10: Color sensor gate

Routing Station

The Routing Station on Factory I/O can be an efficient tool for students to learn about industry components and their practical applications in manufacturing. The Routing Station simulates a common component in industrial automation that is used to direct the flow of products on a production line. Students can learn how to program and control the Routing Station, enabling them to gain practical skills that are highly sought after in the modern manufacturing industry.

Figure 11: Routing Station

By using the Routing Station, students can learn how to automate and optimize the movement of products on a production line, improving efficiency and productivity. In this case, students can simulate a production line where different products are assembled, and then use the Routing Station to direct each product to a storage station for further processing. This can help students understand the importance of routing stations in industrial automation and how they are used to improve the overall flow of a production line.

Storage Station

The Storage Station in Factory I/O is a useful tool for students to learn about industrial automation and develop practical skills in handling and managing materials. By simulating a storage area in a manufacturing facility, students can learn how to design The Storage Station in Factory I/O is used in combination with other components such as the Routing Station to simulate a complete production line, allowing students to obtain a comprehensive understanding of how different components work together to achieve a common goal, as well as an appreciation for the complexity of industrial automation systems. By gaining experience with these components and developing their technical skills, students can prepare themselves for future careers in the field of manufacturing.

age and retrieval systems.

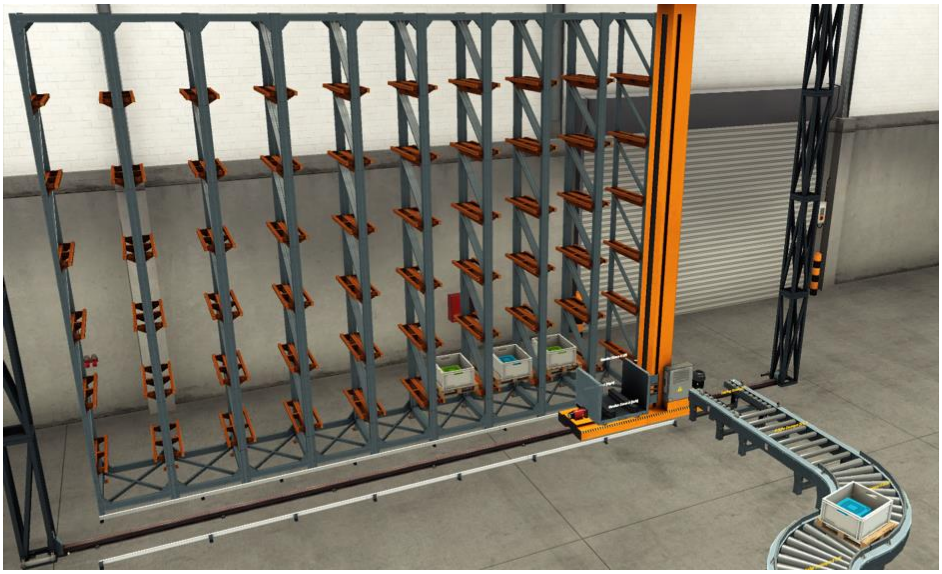


Figure 12: Storge Station

The Storage Station in Factory I/O is used in combination with other components such as the Routing Station to simulate a complete production line, allowing students to obtain a comprehensive understanding of how different components work together to achieve a common goal, as well as an appreciation for the complexity of industrial automation systems. By gaining experience with these components and developing their technical skills, students can prepare themselves for future careers in the field of manufacturing.

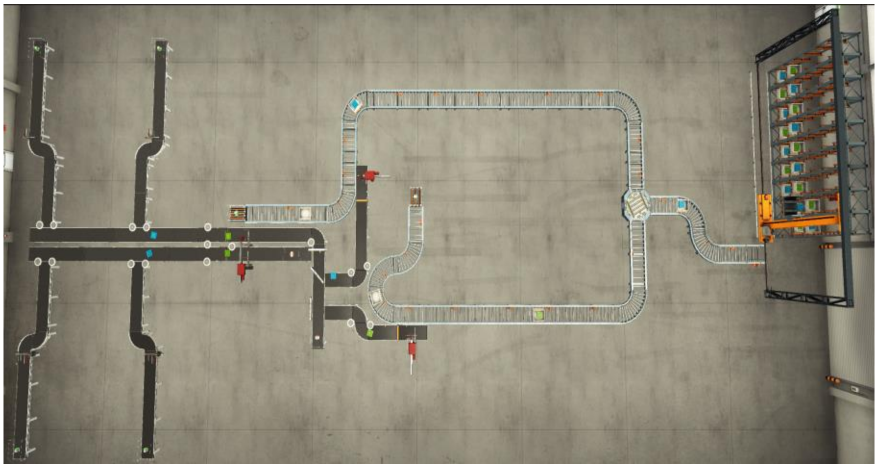


Figure 13: Top view for Factory I/O Progress

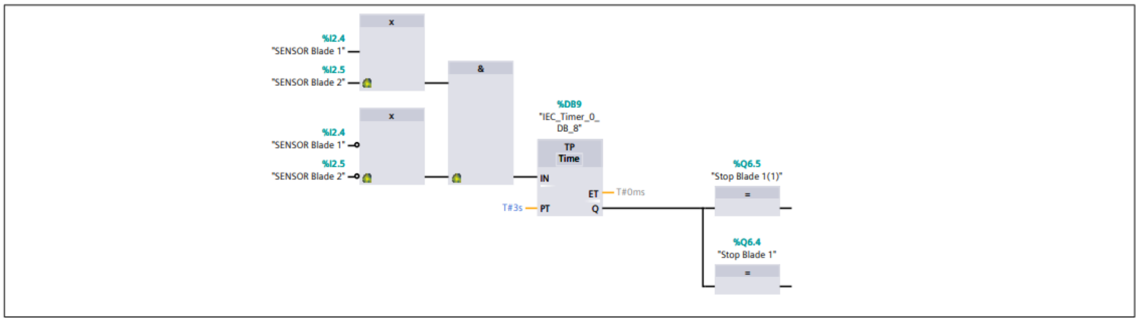
In summary, the Factory I/O simulation is an excellent tool for teaching industrial automation and control. It provides students with hands-on experience to reinforce the concepts they learn. Students can see how these technologies are used in real world manufacturing systems and gain a deeper understanding of industrial automation and control.

```

#Value:=PEEK(area := 16#82,
   dbNumber := 0,
   byteOffset := 511);
#Value := #Value + 1;

POKE(area := 16#82,
   dbNumber := 0,
   byteOffset := 511,
   value := #Value);

POKE(area:=16#81,
   dbNumber:=0,
   byteOffset:=1016,
   value:=#Value_01_DW);
POKE(area := 16#81,
   dbNumber := 0,
   byteOffset := 1020,
   value := #Value_02_DW);

POKE(area := 16#81,
   dbNumber := 0,
   byteOffset := 511,
   value := B#16#00);

FOR #forVal := 0 TO 120 DO
  FOR #forVal_2:=0 TO 10 DO
    #rdTimeReturn:=RD_SYS_T(#outputTime);
    #rdTimeReturn := WR_SYS_T(#outputTime);
    #rdTimeReturn := RD_SYS_T(#outputTime);
    #rdTimeReturn := WR_SYS_T(#outputTime);
  END_FOR;
  #SyncVal:= PEEK(area := 16#81,
          dbNumber := 0,
          byteOffset := 511);
  IF #SyncVal = #CompVal THEN
     GOTO M_1;
  END_IF;
END_FOR;
RETURN;

M_1:
```

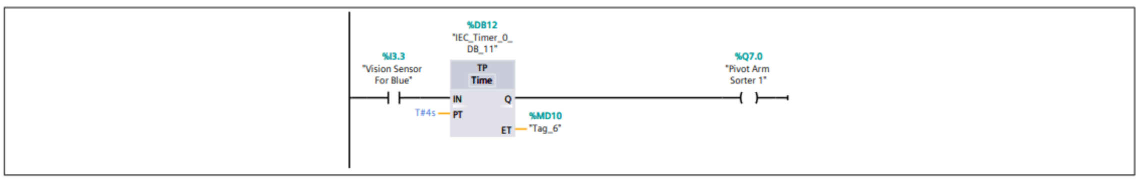
Figure 14: Structured Text

This code displayed in Figure 14 provides an example of how TIA Portal V16 software can be used to interface with Factory I/O, displaying the communication capabilities between the two software applications. The code's purpose is to read and write data to specific memory locations, demonstrating the versatility of the TIA Portal in handling data transfers. The code's ability to increment and update variables in specific memory locations highlights the importance of data management in the context of industrial automation. The nested loops and system function calls demonstrate the potential complexity of data processing and the importance of efficient code execution.

The functionality of the code in Figure 15 serves as an example of how software applications can work together to achieve specific goals. This code's underlying principles could be leveraged to develop more complex software systems in the future. Overall, this code is a valuable resource for researchers studying the integration of different software applications in industrial automation, providing insight into how TIA Portal and Factory I/O can be used in conjunction to exchange data and execute complex tasks.



Network 15:



Network 16:

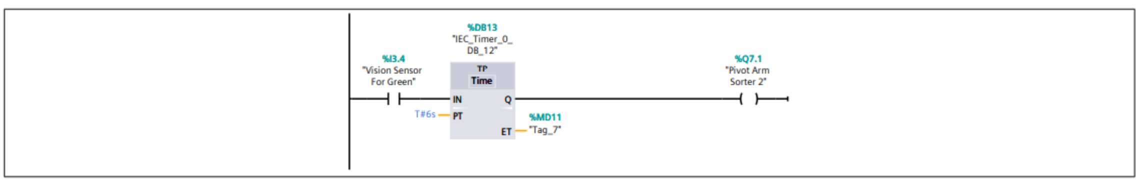


Figure 15: Networks 14 to 16 (Factory IO)

The pick and place station is a critical component of any manufacturing or production process. To ensure the safety and efficiency of the system, it is equipped with stop blades that play a vital role in the station's operation. After the station's process has been completed, the stop blades are required to be in an open position, allowing the object to move safely to the next stage.

The next step in the process involves the color sensor gate. This gate accurately detects the current color of the product being processed, providing crucial information for the system. This information is then used to control the movement of the pivot arms, which determine the object's path for the next process. By using this data, the pivot arms can quickly and accurately move the object to its correct destination.

Conclusion

In conclusion, the previous system had significant limitations that hindered its efficiency and ease of use. The current system has addressed these limitations by providing power distribution calculations, and a more comprehensive manual with testing and troubleshooting information, and increased efficiency. The use of advanced TIA Portal software and Factory IO for 3D simulation can further improve the user experience, resulting in a more intuitive and effective system [10]. Overall, the enhancements made to the current system have significantly increased its performance, efficiency, and usability, ultimately contributing to a better learning experience for students.

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