

Simulation and Optimization of Material Handling Systems Using Factory I/O for Industrial Automation

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ABSTRACT

The advancement of automation technology has revolutionized manufacturing industries by enhancing productivity, accuracy, and efficiency. This study focuses on developing and simulating an intelligent material handling system using Factory I/O, aiming to replicate real world industrial automation scenarios. The objective of this project is to design a smart conveyor based system integrated with sensor technology and robotic manipulation to streamline the transfer and assembly processes. By employing precise object detection through diffusion sensors and timing control via encoders, the simulation ensures accurate handling and positioning of components. A manipulator equipped with a vacuum suction gripper automates the transfer of objects between conveyors, emulating real world assembly line operations. This simulation offers significant benefits, including reduced manual intervention, minimized errors, and optimized production flow, aligning with Industry 4.0 standards. The results demonstrate the effectiveness of integrating advanced sensors and automated handling systems in improving operational efficiency. Comparative analysis with existing studies validates the simulation's relevance and applicability to modern manufacturing environments. The project thus provides valuable insights into the potential of simulation based training and testing to drive future innovations in smart factories and industrial robotics.

Keywords: Material Handling Automation, Industrial Simulation, Smart Manufacturing, Factory I/O, Automated Conveyor System.

INTRODUCTION

In the rapidly evolving landscape of industrial manufacturing, automation has emerged as a pivotal force driving efficiency, precision, and productivity. The integration of advanced technologies such as robotics, artificial intelligence (AI), and sophisticated sensor systems has transformed traditional manufacturing processes, aligning with the principles of Industry 4.0, which emphasizes smart manufacturing and interconnected systems. A critical aspect of this transformation is material handling automation, encompassing the movement, protection, storage, and control of materials throughout manufacturing and distribution processes. Automated Material Handling Systems (AMHS) are designed to enhance operational efficiency, reduce human intervention, and improve safety standards within industrial environments. [1]

Material handling, traditionally reliant on manual labor, involves the movement, protection, storage, and control of materials and products throughout manufacturing, warehousing, distribution, consumption, and disposal. The efficiency of these processes is crucial, as they directly impact production timelines, labor costs, and overall operational efficiency. With the advent of automation technologies, material handling has undergone a significant transformation. Automated Material Handling Systems (AMHS) integrate robotics, conveyor systems, automated guided vehicles (AGVs), and advanced sensor technologies to streamline operations, reduce manual intervention, and enhance precision and safety. These systems are designed to handle repetitive tasks, heavy lifting, and precise movements, thereby minimizing human error and workplace injuries. The implementation of AMHS has been associated with increased throughput, optimized space utilization, and improved inventory management, making them integral to modern manufacturing and distribution centers. [2]



Figure 1: Represents Traditional pick and place operation in real world factory scenario

The evolution of material handling automation is closely linked to the broader context of Industry 4.0, characterized by the integration of cyber physical systems, the Internet of Things (IOT), and cloud computing in manufacturing. This paradigm shift towards smart factories enables real time data collection, analysis, and decision making, leading to more responsive and adaptive manufacturing processes. In this context, AMHS play a pivotal role by providing the necessary infrastructure for automated material flow, which is essential for synchronized production lines and just in time manufacturing.[3]The ability to monitor and control material movement in real time allows for greater flexibility and responsiveness to market demands, thereby enhancing competitiveness in the global market.

Despite the evident advantages, implementing AMHS presents several challenges that industries must address to fully harness their potential. One significant challenge is the high initial investment required for deploying advanced automation technologies. The costs associated with procuring and integrating robotics, conveyor systems, and control software can be substantial, posing financial constraints, especially for small and medium sized enterprises (SMEs). Additionally, integrating new automation systems into existing workflows can lead to operational disruptions if not managed meticulously. Another critical issue is the need for scalability and flexibility in automation solutions. Manufacturers often face fluctuations in demand and product variations, requiring systems that can adapt without extensive reconfiguration or downtime. Moreover, maintaining automated systems necessitates specialized skills and regular updates to ensure optimal performance, adding to operational costs and resource allocation. Addressing these challenges is essential for the successful adoption and sustainability of material handling automation in manufacturing environments.[4]

In response to these challenges, this study proposes the development and simulation of an intelligent material handling system using Factory I/O, a 3D industrial automation simulation platform. The objective is to design a conveyor based system integrated with sensor technology and robotic manipulation to streamline transfer and assembly processes. The simulation employs diffusion sensors for precise object detection and encoders for accurate timing control, ensuring the correct positioning and handling of materials.[5] A manipulator equipped with a vacuum suction gripper automates the transfer of objects between conveyors, emulating real world assembly line operations. By leveraging Factory I/O, the study aims to create a virtual environment that replicates industrial scenarios, allowing for the testing and optimization of automation strategies without disrupting actual production lines. This approach provides a cost effective and flexible solution for designing and refining material handling systems, addressing the challenges of high implementation costs and the need for adaptable automation solutions.

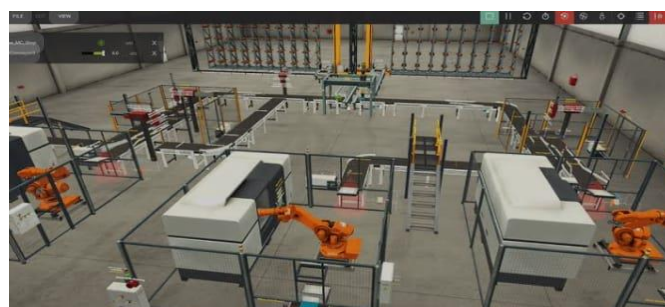


Figure 2: Simulation of Pick and place object detection in Factory IO

The novelty of this work lies in its comprehensive simulation of an automated material handling system that integrates advanced sensor technologies and robotic manipulators within a virtual environment. By utilizing Factory I/O, the study offers a platform for experimenting with various configurations and control strategies, facilitating the development of efficient and scalable automation solutions. This methodology not only mitigates the financial risks associated with implementing new technologies but also accelerates the innovation cycle by enabling rapid prototyping and testing.[6] Furthermore, the insights gained from the simulation can inform the design of real world systems, contributing to the advancement of smart manufacturing practices. The study also emphasizes the importance of upskilling the workforce to operate and maintain automated systems, aligning with the trend of integrating human workers with AI and automation in warehouse operations. This study addresses the pressing challenges in material handling automation by proposing a simulation based approach to design and optimize intelligent systems. The integration of advanced technologies within a virtual environment offers a practical pathway for industries to enhance efficiency, adaptability, and safety in their operations. By bridging the gap between theoretical research and practical application, this work contributes to the ongoing evolution of industrial automation and the realization of Industry 4.0 objectives. [7]

METHODOLOGY

System Design

The system design for the automated material handling simulation developed in Factory I/O is meticulously crafted to replicate an efficient and reliable industrial assembly line scenario. The primary objective of this system is to ensure seamless transfer and handling of objects between two conveyor systems, optimizing productivity while minimizing manual intervention. The design incorporates two distinct conveyor belts, one measuring 6 meters and the other 4 meters in length, positioned in sequence to facilitate the controlled movement of objects through various stages of the process. Both conveyors are fitted with rotary encoders to precisely monitor the motion and position of the objects. These encoders are calibrated to detect the movement intervals of the conveyor belts, ensuring that each item is positioned accurately for subsequent operations. In addition, diffusion sensors are strategically placed on both conveyors, enabling real time detection of incoming objects based on light reflection principles. When an object approaches, the sensor identifies its presence and signals the conveyor to halt momentarily, ensuring precise pick up and placement. To handle the objects efficiently, a manipulator arm integrated with a vacuum suction gripper is positioned between the conveyors.[8] This gripper utilizes negative pressure to securely lift and transfer the objects from Conveyor 1 to Conveyor 2 without causing any physical damage. The manipulator's movement is programmed to synchronize with the sensor inputs and conveyor operation, ensuring smooth coordination and eliminating the risk of collisions or misplacement. The entire process is controlled by a predefined logic sequence that governs the timing, sensor feedback, and actuator responses, maintaining consistency throughout the operation. This design not only emphasizes accuracy and efficiency but also allows scalability, making it adaptable to various industrial applications such as packaging, assembly, and automated sorting. Furthermore, integrating simulation tools like Factory I/O in the design process allows for thorough testing, modification, and optimization of the system without the need for physical prototypes, reducing development costs and time.

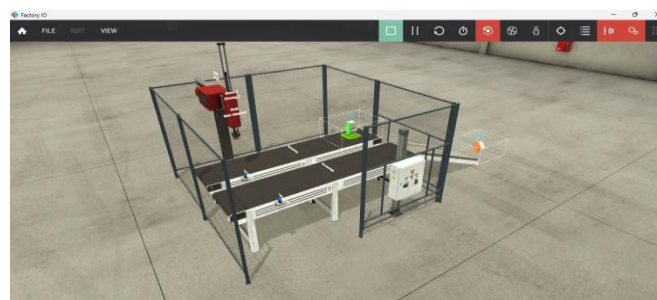


Figure 3: Work environment of Object pick and placing in factory IO simulation software

The simulation mimics real world industrial conditions, providing valuable insights into system behavior, potential bottlenecks, and areas for improvement. Overall, the system design demonstrates a balanced

combination of mechanical components, sensors, and control logic, creating a robust and flexible automated handling solution suitable for modern smart manufacturing environments.[9]

Component Selection

The success of any automated industrial simulation or real time system heavily depends on the careful and strategic selection of its components. In this project, the selection of components is carried out based on key criteria such as accuracy, efficiency, responsiveness, and compatibility with automated control systems. Each component is chosen to ensure smooth synchronization between object detection, handling, and transfer processes within the simulated production environment. Emphasis is placed on selecting components that not only provide reliable performance but also reflect real world industrial applicability, allowing the simulation to serve as a practical prototype for actual implementation.[10] Factors such as sensor sensitivity, actuator precision, control system flexibility, and scalability are carefully considered to ensure the system meets the demands of modern manufacturing processes. The integration of these selected components contributes to the overall robustness, safety, and efficiency of the automated workflow, setting a strong foundation for the system's design and operation.

Conveyor system

In the simulation project, the conveyor system plays a pivotal role in ensuring the smooth and continuous flow of materials throughout the automated process. Two conveyor belts of differing lengths one measuring 6 meters and the other 4 meters are strategically incorporated to facilitate the staged transfer of objects between various workstations. The conveyors are selected for their durability, consistent speed regulation, and adaptability to integration with control systems. Their primary function is to transport the objects or components from the initial pick up zone to the designated drop off or assembly zone with minimal human intervention. Powered by high efficiency electric motors, these conveyors maintain a steady, controlled motion that is critical for the accuracy of subsequent operations such as object detection, gripping, and placement. [11] An essential feature of the conveyor system is its ability to work in coordination with sensors and manipulators, ensuring precise timing for halting and resuming motion when objects are detected or handled. The belts are made of robust, anti slip material to securely carry components of various shapes and weights without the risk of slippage or misalignment. The inclusion of rotary encoders on both conveyors enhances their functionality by providing real time feedback on belt movement and speed, allowing the control system to monitor and adjust conveyor dynamics accurately. This integration is particularly valuable when synchronizing with external components like diffusion sensors and manipulators, as it ensures that the conveyors stop precisely at the required positions, minimizing errors during pick up and placement activities. Furthermore, the conveyor system is designed for scalability and flexibility, making it adaptable for different production requirements, whether it's adjusting belt speed, length, or load capacity. Another critical consideration in selecting the conveyor is its compatibility with the PLC and Factory I/O simulation environment, which enables seamless virtual testing and fine tuning of conveyor operations before real world implementation.[12] The conveyors are programmed to operate based on sensor feedback and encoder signals, allowing automated control over start, stop, and speed variation commands without manual intervention. In real world applications, such conveyor systems are vital components of industries such as automotive assembly, packaging, and electronics manufacturing, where they significantly enhance productivity by automating material handling tasks. They reduce the dependency on manual labor, minimize the risk of accidents, and improve the overall efficiency of production lines. Additionally, the conveyor design in this simulation emphasizes low maintenance, energy efficiency, and long operational life, which are key attributes sought after in industrial environments. In summary, the conveyor component in this project is meticulously selected and integrated to provide a reliable, precise, and efficient means of transporting materials, serving as the backbone of the automated workflow and ensuring the smooth execution of all subsequent operations.[13]

Sensor selection

In this simulation project, the primary sensor component utilized is the diffuse proximity sensor, which plays a crucial role in the precise detection and monitoring of objects moving along the conveyor system. The diffuse sensor operates based on the principle of light reflection; it emits a beam of light and detects the reflected light

when an object interrupts the beam, allowing for reliable identification of an object's presence without requiring physical contact. This non contact detection method is especially advantageous in automated manufacturing setups where high speed and non intrusive object detection is critical. The sensor is strategically placed at key points along the conveyor, ensuring timely detection of incoming objects to trigger corresponding control actions, such as activating the manipulator arm or halting the conveyor. [14] The sensor's sensitivity and response time are calibrated precisely to match the conveyor speed and the size of the objects, ensuring accurate detection even in continuous operation. One of the primary reasons for selecting the diffuse sensor in this simulation is its adaptability to various object surfaces, shapes, and colors, making it highly versatile and effective in dynamic environments. Additionally, it provides consistent performance regardless of the material properties of the objects, which is essential in mixed product assembly lines. The sensor's compact design allows easy integration into the system without consuming excessive space or requiring complex installation procedures. Furthermore, the sensor interfaces seamlessly with the programmable logic controller (PLC) and the Factory IO simulation software, ensuring real time data transmission and coordination between the sensor inputs and actuator responses. The robustness and reliability of the diffuse sensor contribute significantly to minimizing errors in object detection, thereby enhancing the overall efficiency of the automated process. To complement its performance, the encoder is used alongside the sensor to provide continuous feedback about the conveyor's motion, helping to synchronize object positioning with the sensor's detection range. [15] Together, these sensing components form the backbone of the automation logic, ensuring that every object is accurately identified, picked, and placed without manual intervention. The diffuse sensor's role extends beyond simple detection; it also contributes to system safety by halting conveyor operations in case of unplanned obstructions or misplaced objects, thereby preventing potential system faults. Moreover, the sensor's long operational life and minimal maintenance requirements align with the industrial need for sustainable and cost effective solutions. Through the use of simulation, the sensor's behavior is tested under varying operational conditions, fine tuning its detection range, angle, and delay settings to replicate realistic factory environments. In conclusion, the selection and integration of the diffuse proximity sensor in this project underscore its vital role in ensuring precise, reliable, and efficient object handling, reinforcing the system's capability to meet the demands of modern automated production lines. [16]

Pick and place manipulator

In the context of this simulation project, the manipulator plays a crucial role in facilitating the automated handling and transfer of objects between different stages of the assembly process. Specifically, the manipulator is designed to perform precise object positioning tasks, ensuring seamless movement of items from one conveyor belt to another without human intervention. The selection of the manipulator is based on its ability to offer flexibility, repeatability, and accuracy within an industrial environment. This manipulator is configured as a multi axis robotic arm capable of executing a wide range of motions, including linear and rotational movements, to align with the orientation and position of incoming objects. One of the key features of this manipulator is its integration with a vacuum suction gripper, which enhances its gripping capabilities by allowing it to handle objects of various shapes, sizes, and weights without causing mechanical damage. The vacuum suction mechanism operates using negative pressure, providing a secure hold on the object during transfer and ensuring reliable placement onto the target conveyor. The manipulator's movements are precisely coordinated using programmable logic controllers (PLCs) and simulation software, which dictate the timing, speed, and trajectory of the arm based on real time feedback from sensors installed along the conveyor belts. [17] Additionally, encoders are used to monitor the manipulator's joint positions and ensure that its operations are synchronized with conveyor speed and object detection. The manipulator is designed with a lightweight yet sturdy frame, allowing for fast actuation without compromising structural stability. Its modular construction allows for easy customization and scalability, making it adaptable to different production line requirements. The end effector, in this case, the vacuum suction gripper, is selected for its simplicity and efficiency, particularly in applications involving delicate or irregular shaped items that might be unsuitable for mechanical grippers. Moreover, the manipulator's control system incorporates safety protocols such as collision detection and emergency stops to prevent operational hazards during automated cycles. The ability of the manipulator to repeat the same sequence of movements with high precision reduces the risk of assembly errors, increases productivity, and lowers dependency on manual labor. In the simulation environment, virtual testing of the manipulator's performance is carried out to fine tune its motion parameters and ensure optimal coordination

with other system components. This helps in identifying potential bottlenecks and ensures smooth operation before any real world implementation. Overall, the manipulator in this project serves as a vital component, bridging the gap between automated detection and delivery stages, while ensuring consistent and efficient material handling in a controlled and reliable manner. Its inclusion not only demonstrates the practical application of robotic arms in modern manufacturing systems but also showcases how such technology can enhance operational efficiency, product quality, and workplace safety. [18-20]

IMPLEMENTATION

Integration with PLC

The integration of the Programmable Logic Controller (PLC) plays a pivotal role in orchestrating the seamless operation of the entire automated system presented in this simulation project. PLC act as the central processing unit, connecting all sensors, actuators, conveyors, encoders, and the manipulator arm to a unified control framework. The key reason behind incorporating PLCs lies in their flexibility, reliability, and real time control capabilities, which are essential for industrial automation tasks. In this setup, the PLC is programmed to receive continuous feedback from the diffusion sensors and encoders placed along both conveyor belts. The diffusion sensors detect the presence of objects on Conveyor 1, while the encoders provide precise positional data, enabling the PLC to accurately time the manipulator arm's actions. Upon receiving input signals from these sensors, the PLC processes the logic to control the conveyor motors start stop operations and synchronize the vacuum suction gripper's pick and place motion.[21] Ladder logic programming is utilized to design a sequence of operations where conditions are clearly defined to ensure smooth object transfer from Conveyor 1 to Conveyor 2 without collision or delay.



Figure 4: Integration of PLC with the aid of Siemens TIA Portal

The real time adaptability of the PLC ensures that any variation in the object flow or unexpected obstruction is handled promptly through preset fault handling routines, minimizing downtime and improving operational safety. Moreover, the PLC interfaces with the Factory I/O simulation platform, providing a virtual yet highly realistic visualization of the entire process, allowing for easy troubleshooting, monitoring, and optimization of control logic. Communication protocols such as Modbus or Ethernet are implemented to enable efficient data exchange between the PLC and other hardware modules. This integration facilitates scalability, meaning the system can be modified to accommodate additional sensors, actuators, or even AI driven decision making systems in future expansions. [22] One of the major advantages of integrating a PLC in this project is its ability to provide deterministic control, ensuring that every input triggers a precise and timely output, which is crucial for high speed production lines. Additionally, the PLC setup includes safety interlocks and emergency stop features that safeguard the system and operators in the event of unexpected anomalies. Maintenance and troubleshooting are simplified due to the modularity of the PLC, allowing individual components to be isolated and tested without disrupting the entire process. The human machine interface (HMI) can also be integrated with the PLC, giving operators real time access to system status, error logs, and manual override options. This comprehensive control integration not only mirrors the requirements of real world industrial environments but also offers a hands on learning experience in understanding how PLCs govern the coordination and efficiency of automated systems. In conclusion, the integration of the PLC in this simulation ensures precise control, operational reliability, and scalability, ultimately contributing to the system's effectiveness and practical relevance to modern manufacturing automation. [23]

Testing and debugging

Testing and debugging are critical phases in the development of any automated simulation system, ensuring the overall reliability, accuracy, and functionality of the designed model before real world implementation. In this project, after assembling the simulation layout within the Factory I/O environment, extensive testing procedures were carried out to verify each component's individual operation and their interaction with one another. The process began with verifying the functionality of the conveyor systems, ensuring that both the 6 meter and 4 meter conveyors operated smoothly without any jerks or delays. The encoder integration was specifically tested to confirm that the timing feedback was accurate, particularly with the 1 second object detection timing configured for the simulation.



Figure 5: Testing and Debugging of the simulation

The next step involved testing the diffusion sensors, focusing on their ability to correctly detect the presence of an object regardless of shape or size, and triggering the appropriate stop command in synchronization with the conveyor's operation.[24] Multiple objects were virtually introduced on the conveyor to test the sensor's consistency and its response under varying conditions. Following this, attention shifted to testing the manipulator arm's movement path and verifying the precision of the vacuum suction gripper during pick and place actions. Several test cases were simulated to examine the arm's ability to accurately pick objects from Conveyor 1 and place them on Conveyor 2 without collision or misalignment. Debugging during this stage involved checking the arm's kinematic configuration, fine tuning joint angles, and adjusting suction timings to eliminate any inconsistencies. The PLC programming logic controlling the entire operation was subjected to rigorous debugging, analyzing the ladder logic for logical errors, incorrect signal routing, or unexpected behavior. Step by step simulation runs were conducted to trace the control flow and ensure that every sensor input resulted in the expected actuator output. Breakpoints and monitoring tools available within the simulation software were used to closely observe signal transitions, conveyor status, and manipulator actions. Specific focus was given to handling edge cases, such as scenarios where no object was present, or when multiple objects were introduced simultaneously, to validate the robustness of the control logic.[25] Furthermore, stress testing was performed by increasing conveyor speeds and object flow rates to check how the system behaved under higher loads, ensuring the simulation remained stable and error free. Throughout the debugging phase, logs and simulation reports were reviewed meticulously to identify and correct timing mismatches, missed detections, or synchronization delays. Once all individual components functioned seamlessly, integrated system testing was conducted to confirm the smooth coordination of conveyors, sensors, encoders, manipulator, and gripper, simulating an uninterrupted workflow from start to finish. The end result of this thorough testing and debugging process was a fully functional, reliable simulation model capable of replicating real world automated assembly operations with high accuracy. This approach not only enhanced the efficiency of the simulated system but also provided confidence in the scalability and adaptability of the model for future real time industrial applications.[26]

RESULTS AND DISCUSSION

Performance Evaluation

The performance evaluation of the developed simulation focuses on key metrics such as accuracy, efficiency, reliability, and synchronization. The system was tested under various conditions, including continuous

operation, increased object flow, and deliberate introduction of errors, to assess its stability and responsiveness. The diffusion sensors demonstrated high detection accuracy, ensuring precise identification of objects on the conveyor without false triggers. The encoders effectively maintained the timing sequence, allowing smooth coordination between the conveyors and the manipulator.



Figure 6: Simulation of final inspection in Factory IO

The vacuum suction gripper exhibited reliable gripping strength and positional accuracy during object transfer, minimizing errors in placement. The overall system achieved consistent cycle times without unnecessary delays, indicating efficient material handling.[27] Additionally, the ladder logic implemented in the control system maintained logical integrity, responding correctly to all sensor inputs and process variations. Stress testing confirmed that the simulation could handle higher loads while maintaining consistent performance, which highlights its scalability for real world applications. By evaluating these performance parameters, the simulation demonstrates its capability to replicate industrial automation scenarios effectively, providing a strong foundation for future enhancements and practical deployment.

Comparison with real world systems

The simulation model developed in this project closely mirrors real world industrial automation systems commonly utilized in manufacturing and assembly lines. In actual factory settings, conveyor systems integrated with object detection sensors and robotic manipulators are widely used to streamline material handling and assembly tasks. The use of diffusion sensors and encoders in the simulation reflects the standard practices employed in industries for precise object detection and position tracking. Similarly, the manipulator equipped with a vacuum suction gripper replicates robotic arms used in sectors such as automotive, electronics, and packaging, where delicate and accurate handling is essential. However, while the simulation provides a controlled, error free environment, real world systems face additional challenges such as hardware wear and tear, environmental factors, and maintenance constraints. Moreover, real time systems require strict adherence to safety protocols and real time adjustments, which may not be fully represented in a virtual simulation. Despite these differences, the simulation serves as an effective prototype for understanding system behavior, debugging control logic, and testing process optimization strategies before physical deployment. This alignment between the simulated and real world systems highlights the practical relevance and applicability of the project, making it a valuable tool for training, design validation, and performance evaluation.[28]

Challenges and limitations

Despite the successful implementation of the automated simulation, several challenges and limitations were encountered throughout the project. One of the primary challenges was ensuring precise synchronization between the conveyor system, sensors, and the manipulator arm within the simulation environment. Minor delays or timing mismatches often led to inaccuracies in object detection or misalignment during the transfer process, requiring continuous fine tuning. Another challenge was optimizing the control logic to handle multiple operational scenarios, such as varying object sizes, conveyor speeds, and unexpected stoppages, without compromising system stability. [29] Additionally, configuring the vacuum suction gripper's strength and timing to reliably pick and place objects without slippage posed technical difficulties. A key limitation of the simulation lies in its virtual nature, where environmental factors such as material inconsistencies,

mechanical wear, or real world latency are not fully replicated. This restricts the simulation's ability to account for unforeseen mechanical failures or sensor inaccuracies that might occur in a real factory setting. Furthermore, while the simulation provides valuable insights, scalability and adaptability to complex, multi line industrial environments require additional validation. These challenges highlight areas for future improvements and emphasize the need for careful transition when applying simulation models to physical production systems.[30]

CONCLUSION

In conclusion, the successful development and simulation of the automated object transfer system in the Factory I/O environment demonstrate the potential of integrating modern automation technologies to streamline manufacturing processes. This project effectively showcased how precise coordination between conveyors, sensors, encoders, manipulators, and grippers can be achieved through meticulous system design and rigorous testing. The use of diffusion sensors and encoders ensured accurate object detection and position feedback, while the vacuum suction gripper provided a reliable mechanism for smooth object handling without human intervention. By focusing on efficiency, accuracy, and synchronization, the simulation model not only reflects the capabilities of contemporary industrial automation but also offers a scalable solution adaptable to various production lines. Through extensive debugging and validation, all logical and operational challenges were resolved, ensuring seamless operation throughout the system. This project highlights the importance of simulation tools like Factory I/O in offering a safe, flexible, and cost effective platform to prototype and refine automated systems before actual implementation. Furthermore, the outcomes emphasize the real world relevance of such automation techniques, particularly in sectors requiring high speed assembly, material handling, and quality consistency. The insights gained from this simulation serve as a foundation for further advancements in smart manufacturing and Industry 4.0 initiatives, encouraging the adoption of intelligent automation solutions to meet growing industrial demands. Ultimately, this work contributes to fostering innovation, improving productivity, and reducing manual effort in modern manufacturing environments.

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