Simulation and PLC-Based Control of a Weight-Based Conveyor Sorting System Using Factory I/O and CODESYS

PROGRAMMABLE INDUSTRIAL AUTOMATION SYSTEM

PROJECT REPORT

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ABSTRACT

Automated sorting based on weight is a critical requirement in manufacturing, packaging, and logistics systems where materials with similar dimensions must be classified according to mass. Designing and testing such systems using physical PLC hardware is often costly and time-consuming, especially in educational or early-stage development environments. This paper presents a fully virtualized weight-based sorting system developed using Factory I/O as a 3D industrial simulation platform and CODESYS as the IEC 61131-3 compliant PLC programming environment. Real-time synchronization between sensors, actuators, and control logic is achieved through the use of the OPC UA communication protocol. The system measures object weight using a simulated load cell, applies a controlled stabilisation delay, and classifies items into three categories using deterministic comparison logic. Objects are routed to the right, left, or forward conveyors based on predefined thresholds. The implementation demonstrates key aspects of Digital Twin methodology by mirroring real-world PLC behavior, sensor feedback, and actuator responses entirely within a virtual environment. Experimental results show accurate weight measure ment, stable sorting performance, reliable system response to Start/Stop/Emergency commands, and consistent communication without latency issues. The study validates virtual PLC-based training as an effective and scalable approach for industrial automation education and prototyping.

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CHAPTER 1

INTRODUCTION

Automation has become an essential component of modern industrial processes, enabling higher productivity, improved consistency, and reduced manual intervention in repetitive tasks. Sorting automation, in particular, plays a vital role in manufacturing, packaging, warehousing, and logistics, where products must be classified and routed based on specific physical properties such as weight, size, or shape. Weight based sorting is widely used when objects exhibit identical geometrical dimensions but differ in mass, making visual inspection or basic sensing insufficient for accurate classification. Programmable Logic Controllers (PLCs) are the standard control units used in industrial automation due to their robust This project implements a fully operational weight-based sorting system using Factory I/O for mechanical simulation and CODESYS for PLC programming. Objects are detected at various positions, weighed using a virtual load cell, assigned into weight categories through comparison logic, and sorted onto right, left, or forward conveyors. A two-second stabilization delay ensures accurate weight capture, while Start, Stop, and Emergency controls provide operator safety. The system demonstrates the core principles of industrial automation and exemplifies virtual commissioning, where control logic is validated in a digital environment before real-world deployment.

CHAPTER 2

PROBLEM STATEMENT

In many industrial and educational setups, implementing weight-based sorting systems using physical PLCs, conveyors, sensors, and load cells is expensive, time-consuming, and potentially unsafe for beginners. Additionally, traditional PLC training often lacks flexibility for rapid testing, debugging, and iterative improvements.

There is a need for a **cost-effective, safe, and scalable solution** that allows:

- Accurate weight-based classification
- Real-time PLC control
- Safe testing without physical hardware
- Practical exposure to Industry 4.0 concepts such as Digital Twins and OPC UA communication

This project addresses these challenges by developing a **fully virtual weight-based sorting system** using Factory I/O and CODESYS, integrated through OPC UA communication.

CHAPTER 3

LITERATURE SURVEY

Automated sorting systems have been widely studied in industrial automation, with early developments focused on PLC-based classification using height, size, or colour sens ing. Several works describe height-based sorting controlled by proximity or photoelectric sensors integrated with PLC logic [1], [2], [3]. These approaches are effective for basic material discrimination, but they are limited when objects possess identical geometry but differ in weight. Weight-based sorting implementations have also been reported, involving conveyor-mounted load cells connected to PLCs for threshold based routing [5], [6]. However, these systems rely heavily on physical hardware, making them costly, less flexible, and more difficult to reproduce in academic settings. Additionally, many of these works do not incorporate stabilisation delays or edge triggered detection, resulting in potential inaccuracies during dynamic weighing. PLCs remain essential in automation due to their deter ministic scan-cycle execution, real-time processing capability, and support for IEC-61131-3 languages [2], [3]. Despite their reliability, practical PLC training often requires expensive hardware and exposes students to mechanical risks. This has increased interest in virtual PLC simulation, where control logic can be developed and tested safely and efficiently. CODESYS provides a soft-PLC environment suitable for executing Structured Text and Ladder Logic on a standard PC, enabling virtual commissioning workflows and early detection of design errors [9], [14]. This approach significantly reduces development time and allows repeated experimentation with out hardware constraints. Factory I/O offers a realistic 3D industrial environment where conveyors, sensors, and actuators behave similarly to real-world equipment. Its tutorials demonstrate how simulated elements can be connected to PLC programs through OPC UA communication [7], [8]. While most examples focus on simple height-sorting or basic conveyor operations, the platform sup ports more advanced use cases. The system developed in this study extends beyond basic demonstrations by incorporating dynamic weighing, a two-second stabilisation delay, fully defined Start/Stop/Emergency logic, and multi-path routing behavior, which are not typically addressed in introductory simulation examples. OPC Unified Architecture (OPC UA) is a secure, platform independent communication protocol widely adopted in Industry 4.0 environments. It enables structured, encrypted, and real-time data exchange between controllers and simulated or physical devices [10]. OPC UA has been recognized as a key enabling technology for interoperable automation systems and Digital Twin integration [11], [12]. In this project, OPC UA establishes deterministic bidirectional communication between Factory I/O and CODESYS, ensuring continuous synchronization of sensor states, weight values, and actuator commands during operation. The concepts of Digital Twin aim to synchronise virtual models with real-time process data, enabling simulation, monitoring, and system optimization. Prior studies highlight the importance of Digital Twins in manufacturing for improving operational visibility and predictive capabilities [11]– [13]. Although many Digital Twin frameworks are complex and resource-intensive, the current system provides a simplified yet functional Digital Twin prototype suitable for educational use. Factory I/O represents the physical environment, CODESYS executes the PLC logic, and OPC UA handles real-time synchronization. This creates a closed-loop virtual system that accurately mirrors the behavior of a real sorting cell without requiring physical hardware. Compared to previous work, the developed system addresses several limitations by providing a fully virtualized weight-based sorting solution with accurate timing for weight stabilisation, event-driven control logic, and integrated safety functions. The result is a cost-effective, safe, and repeatable model appropriate for teaching PLC programming, testing automation logic, and exploring Digital Twin concepts.

CHAPTER 4

METHODOLOGY

The methodology outlines the full development cycle of the weight sorting system in a virtual form using Factory I/O for the modeling of the hardware components, all the way to the real-time control using CODESYS based on the communication mechanism provided by the OPC UA. This involves a typical test-design-refine cycle that is common in the practice of automation engineering. Every step of the methodology entails that the whole system functions as expected. This is explained in detail in the following subsections.

4.1 System Architecture

The proposed system architecture combines Factory I/O as the virtual plant simulation platform, CODESYS as the PLC based control environment, and OPC UA as the standardized communication layer. The architecture adopts a modular design approach to ensure coordinated operation of sensing, control logic execution, actuation, and data transfer. It is structured to closely emulate a real-world industrial sorting cell comprising conveyor belts, sensors, diverter mechanisms, and a weight measurement unit. All field-level components exchange data with the PLC through OPC UA by means of mapped input and output variables, enabling reliable and real-time communication between the simulated plant and the control logic.

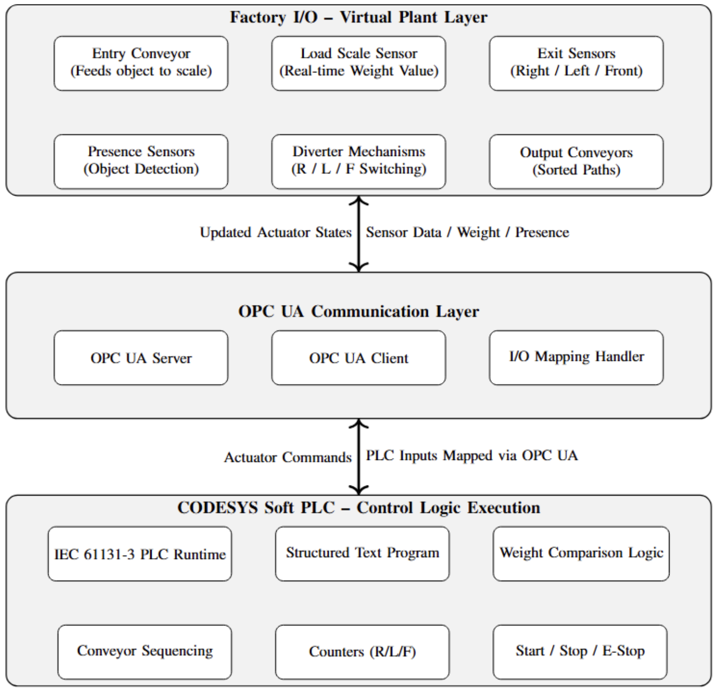

Fig 4.1 System architecture Block Diagram of weight sorting added Factory I/O, OPC UA, and CODESYS PLC layers

Block Diagram Overview: As shown in Fig. 1, sensor data generated within the Factory I/O virtual plant is transmitted to the CODESYS PLC environment through the OPC UA communication interface. The PLC processes this realtime input data using programmed control logic and subsequently issues corresponding actuator control commands back to Factory I/O. This continuous bidirectional data exchange establishes a closed-loop control system, effectively forming a fully functional Digital Twin of the industrial weight-based sorting process.

System Components: 1) Sensors: The system uses multiple virtual sensors, including:

• At Scale Entry – Detects object presence before weighing.

• Load-Scale Sensor – Outputs real-time weight value.

• Exit Sensors (Right, Left, Front) – Confirm object arrival at respective output conveyors.

• Path Entry Sensors – Trigger counter increments.

2) Conveyors: Four conveyor systems are implemented:

• Emergency Button – Emergency is safety to the hole system with emergency alarms and indications.

• Timers – Timers are help to measure the fraction of weights during passing through a weight scaler(load cell).

• Counters – counts each conveyor carried the box or weighted objects.

• Entry Conveyor – Feeds objects to the scale.

• Right Conveyor – For objects under 3 kg.

• Left Conveyor – For objects between 3–6 kg.

• Front Conveyor – For objects between 6–10 kg or higher.

Diverters: Three diverter mechanisms (Send Right, Send Left, Send Forward) are controlled by the PLC to route objects based on weight classification.

PLC Logic: CODESYS executes:

• Weight stabilization timer (0.1 seconds)

• Classification logic using nested IF–ELSIF conditions

• Conveyor and diverter sequencing

• Safety logic for Start/Stop/E-Stop

• Counter updates for each output path

Communication Layer (OPC UA): OPC UA provides:

• Deterministic bidirectional I/O mapping

• Real-time value updates

• Secure and reliable communication

• Support for Digital Twin synchronization

Input/Output Mapping Table: As illustrated in Fig. 2, the interaction between the Factory I/O virtual plant and the CODESYS PLC is achieved through mapped global input and output variables using the OPC UA protocol. Table I presents a detailed list of the primary sensor inputs and actuator outputs exchanged between Factory I/O and CODESYS. These mapped variables enable reliable real-time data transfer, allowing the PLC control logic to monitor plant conditions and issue appropriate control commands within the virtual simulation environment.

Fig 4.2 Input/Output mapping of the Global Variables in Both Factory IO and CODESYS.

4.2 System Modelling and Sensor Placement in Factory I/O

The system development process starts with the design of the sorting layout in Factory I/O software, as depicted in Fig.3. The sorting layout has an Entry Conveyor for the transfer of material from the Load Scale to the sorting lines consisting of three output conveyor belts placed in the Right, Left, and Forward positions. The sorting layout allows for the segregation of the material as it leaves the Load Scale into the three sorting lines. The Load Scale in this design acts as the sensing element that provides the weight value of the material as it stays put on its platform. Accurate placement of the sensors is required for proper functionality of the system. In this project, there is the placement of one At-Scale Entry sensor at the entrance of the weighing station to indicate the entry of a product into the station. On activation of the entry sensor, it sends a signal to stop the entry conveyor and initiates the weight stabilization delay time programmable. The exit sensors are placed at the end of the Right, Left, and Forward conveyors of the product diversion path for the indication of product entry into the diversion path for proper functionality of the product diversion path.

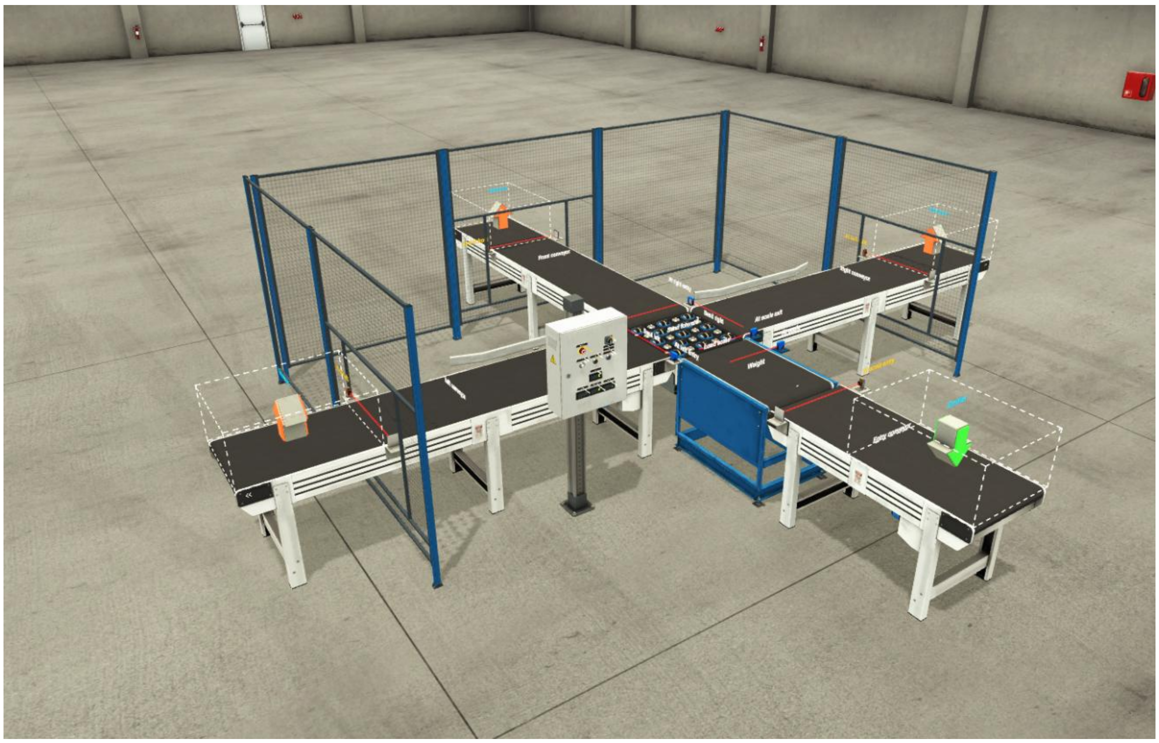

Fig 4.3: Factory IO Sensors and Acuators virtual assembly in Factory IO.

For better reliability, the detection ranges, sensitivities, and filter values of the sensors have to be set in such a way that no incorrect activation triggered by the oscillation of the object or the partial area detection of the sensors is possible. However, before the PLC logic is used to incorporate the system, the sensors have to be checked individually in the FactoryIO setup to ensure the proper signal operation

4.3 Weight Measurement and Stabilization Logic

Fig. 4.4 Weight measuring sensor (load cell) configuration in Factory IO.

The need for accurate weight retrieval, as depicted in Fig. 4.4 below, plays a crucial role in the sorting process as the entire routing logic depends solely on the stability of the load scale output. The moment the item is placed upon the weight platform, it may experience oscillations from the conveyor system, causing the weight to fluctuate. The strategy employed to eliminate this problem involves using a timer in the PLC logic. The entry of the object onto the scale is completed when the At-Scale Entry sensor generates a rising edge, indicating the start of a TON (On-Delay) timer set up for a time period of two seconds. During this period, the Entry Conveyor stops, and the actual weight readings obtained from the load scale are ignored. The floating-point weight obtained from the load scale is then read, and its value is stored in a separate variable named Stable weight. This data is unaltered for the entire sorting process to avoid assigning wrong categories to an object based on sensor readings or minute movements. The weighed object will then be compared to the set limit thresholds to decide the corresponding path to take for the object to move towards the Right, Left, or Front conveyor. This stabilization method provides a stable decision on the classification of the object based on reliable data only. The strategy works in the same manner as the industrial object weighing procedures that use sampling methods over time to obtain a stable automated sorting decision.

4.3 OPC UA Configuration and Bidirectional I/O Mapping

The communication layer in OPC UA is the main interaction interface of the Factory I/O virtual plant and the CODESYS soft PLC. This enables it to communicate in real time in order to control the system. The configuration begins with enabling the OPC UA server in the CODESYS environment. This enables it to have access to its namespace containing all relevant PLC variables. These are Boolean sensor inputs, actuator outputs, along with the floating-point weight measurement signal.

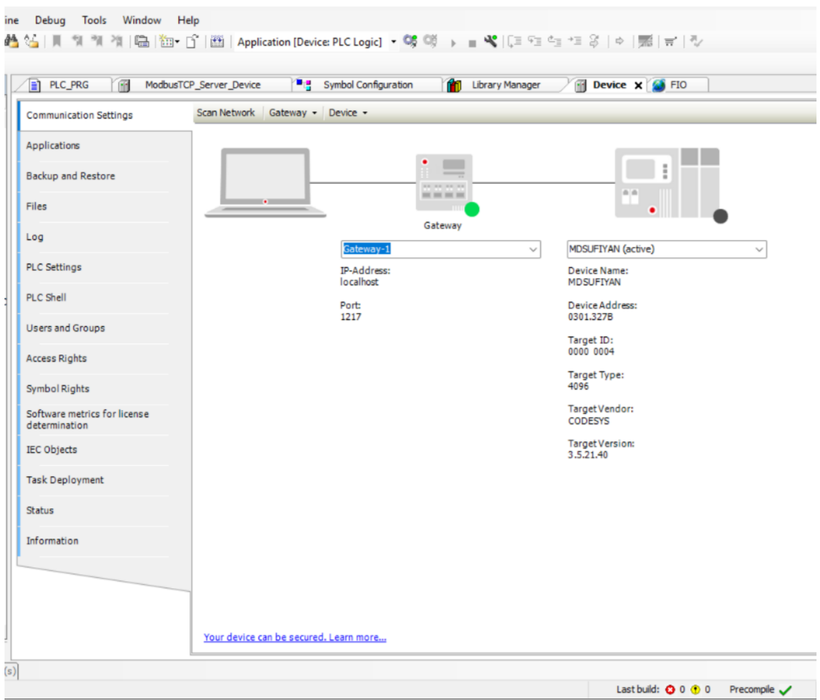

Fig.4.5 OPC UA protocol communication initialization in CODESYS.

The server is appropriately configured with relevant communications settings such as endpoint selection, binding to a network interface, security configuration, and update cycle timing, as illustrated in Fig. 5, to facilitate reliable and secure real-time data transfer between the control system and virtual environment properly. Once the OPC UA server is active, Factory I/O establishes a persistent client connection using the specified IP address and port. Within Factory I/O, the OPC UA I/O driver is configured by browsing the CODESYS namespace and binding selected variables to the corresponding simulated devices. Sensor signals, including At Scale Entry, At Right Exit, At Left Exit, and At Front

Exit, are mapped to Boolean input variables in CODESYS. Likewise, actuator components such as conveyors and diverter mechanisms are linked to PLC output variables, allowing direct command execution from the control logic. The Load Scale output is connected to a floating-point variable, enabling continuous monitoring of real-time weight data by the PLC.

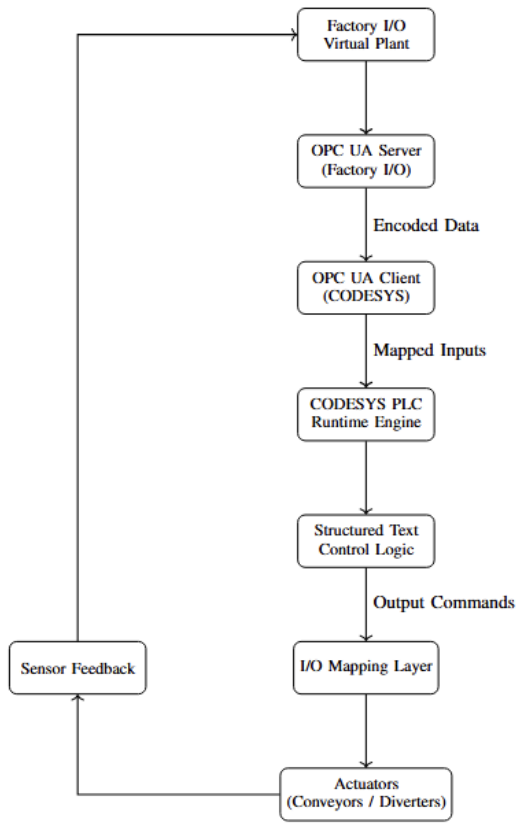

Fig. 6. Communication protocol diagram showing the complete OPC UA data flow between Factory I/O, OPC UA server/client layers, and CODESYS PLC control logic.

The overall bidirectional data flow between Factory I/O, the OPC UA communication layer, and the CODESYS PLC logic is illustrated in Fig. 6. The states of the sensor are communicated from Factory I/O to the OPC UA server in each scan cycle in the PLC. The CODESYS acts upon these inputs according to the implemented control algorithm and returns the commands of the actuators to Factory I/O. This type of communication architecture is intended for describing synchronous motion control in the simulated sorting environment of the virtual environment. For the sake of communication integrity, the transition times for signals can be evaluated by direct interaction simulation and monitoring via the Factory I/O simulation and monitoring the status through the watch window in CODESYS. The purpose of this is to guarantee proper assignment, delay times, and flawless data transfer. Based on precise assignment for variables, a seamless OPC UA interface, and correct assignment, the entire system is therefore one digital twin.

4.4 PLC Logic Development Using Structured Text

Codes for the Weights and Sorting control logic programming are developed in CODESYS programming language using Structured Text programming, which has applications in arithmetic calculations, decisions, and time-controlled logic. The processes for input in the structuring of the programming include start processes, stop processes, and emergency stop processes implemented by logic interlocking for proper system function. Other processes meet all the system requirements for proper system function.

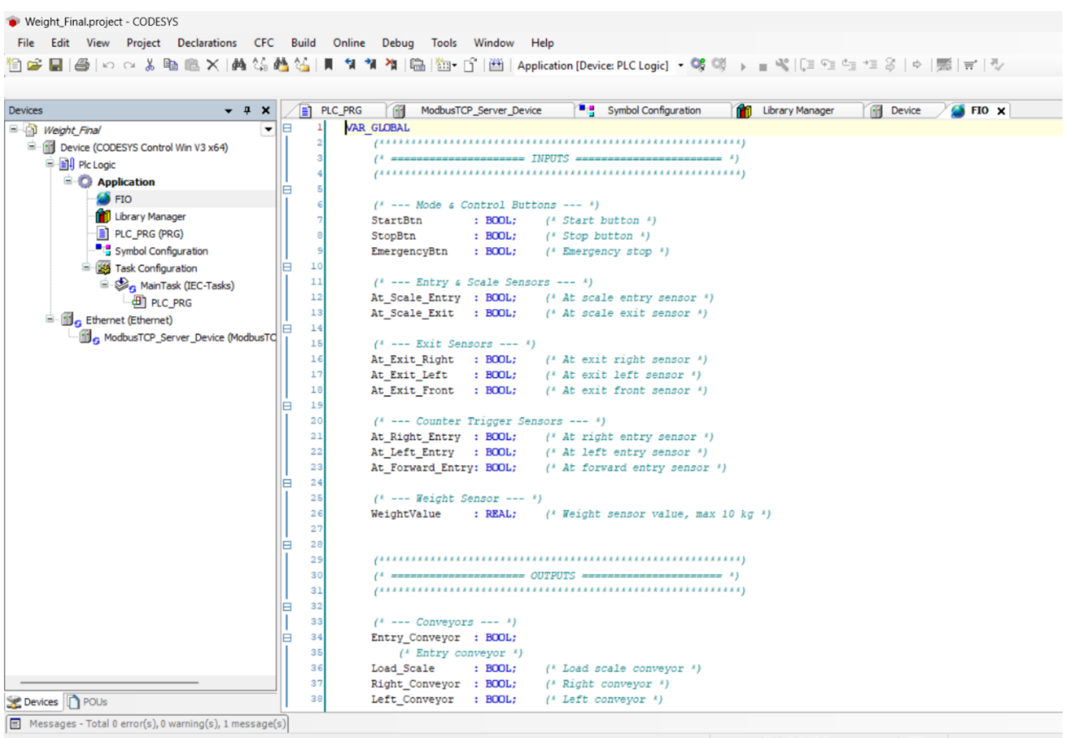

Fig 4.7 PLC Structured Text intilations of Local variables and Logic Controlling unit building in CODESYS. building in CODESYS.

The Mapped Sensor Inputs are processed when the system is enabled, meaning that the PLC runs all of the Mapped Sensor Inputs in every scan cycle when the system is enabled. This ensures that discrete events are processed in the program by using F-TRIG rising-edge trigger functions for events such as the reception of a product at the load scale, the end of the two second stability time, and the activation of the exit sensors. The following is a code snippet in Figure 4.7 that illustrates the initialization of the Local variables and the implementation of the main control structure in Structured Text. After the timer expires for stabilization, the data for weighing will be recorded and stored in the variable Stable Weight. Subsequently, the decisions for routes using nested IF-Elseif statements will be made within the PLC according to the following rules for classification based on pre-defined thresholds for weight:

- If Weight < 3 kg: activate Right route
- If 3 ≤ Weight < 6 kg: activate Left route
- If 6 ≤ Weight ≤ 10 kg: activate Front route

This structure of the decision ensures that for every object, only one routing path will be selected. Once a route has been assigned, the assigned conveyor and diverter outputs are turned on along with the route-specific status flag. This flag remains on until an exit sensor associated with it confirms that the object has reached its assigned output conveyor. Upon detecting, the PLC turns off all actuators and resets internal variables, ready to go for the next sortation cycle.

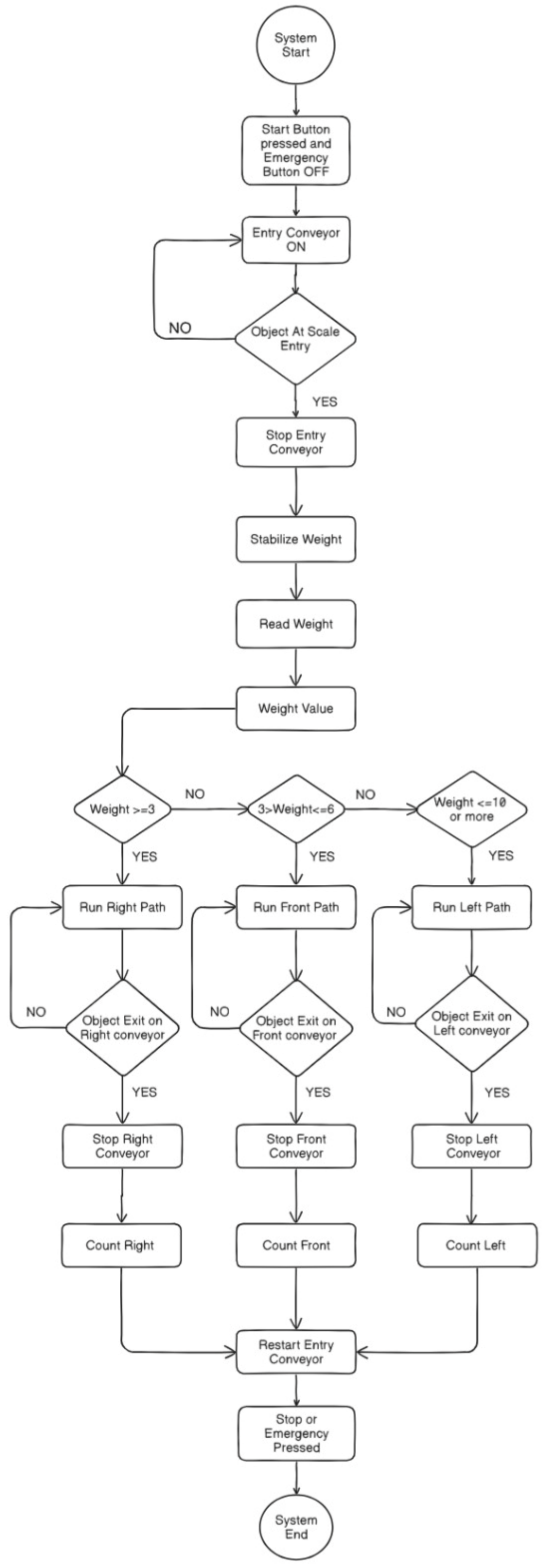

Fig 4.8 Flowchart of the Factory I/O weight-based sorting system.

Alongside the regular process, error-handling logic is also implemented to cope with unusual sensor status and emergencies. Unexpected sensor combination or activation of the emergency stop button will result in an immediate disablement of all outputs for system safety. The whole process and decision path flow of the sorting procedure is shown in Fig. 4.8.

4.5 Conveyor Control and Sequencing

The strategy for controlling the conveyor is designed to facilitate collision-free and sequential movement, as depicted in Fig. 9. The main transport unit is the Entry Conveyor, which runs continuously until the activation of the At-Scale Entry sensor, when an object is detected. The PLC stops this conveyor the moment an object is detected to prevent more than one object from entering the weighing station at the same time. This sequenced entry system prevents traffic jams and ensures that one item is being processed per cycle of the sorting process. The Load Scale conveyor is constantly working as far as positioning objects for stable weighing is concerned.

Once the weight of the item is approximated and grouped, based on weight, the PLC will activate the diverter, whose output will move to activate the required conveyor based on the programmed routes. The available routes are set to three: Right Conveyor for items under 3 kg, Left Conveyor for items between 3 kg and 6kg, and Front Conveyor for items between 6kg and 10kg. Every route available will have a route flag activated once in each sortation process, promoting exclusive use to respective available conveyors to avoid simultaneous actuation. Exit sensors are employed to halt the motion of the conveyor. As soon as any object enters its defined exit sensors, for instance, Right, Left, and Front, the PLC will automatically halt the respective conveyor and reset the route selection flags. There is power efficiency since the motors are not powered unnecessarily. Additionally, there is a logic incorporated in the control system that does not allow the actuation of the Entry Conveyor until the object placed inside is out of the sorting area. The integrated conveyor control system ensures that there is a smooth flow of material, reduces the chances of machinery collisions, and achieves a uniform rate of flow through the entire weight sortation system.

4.6 Counter Implementation and Event Logging

The system has a counting function that is intrinsic to the system, which helps monitor the number of objects that pass through each of the output paths. The system has three independent counters, namely the Right Counter, the Left Counter, and the Front Counter, all of which have been designed using CODESYS. The system ensures that each counter only increases by one each time an object passes into the respective output channel, so that there is no repetition or duplication of counting. The system uses FTRIG for rising-edge detection for the sensors that detect entry into each output conveyor, thereby ensuring that only one count is done for each object, irrespective of the time for which the sensor is activated. The system uses INTEGER variables, which are then displayed on the CODESYS watch window for monitoring. The system can initialize the counting process so that repeated experiments can be performed without any lingering effects.

4.7 Digital Twin Integration and Real-Time Synchronization

The integration of Factory I/O, CODESYS, and OPC UA creates a holistic digital twin that perfectly mimics the operation of a weighted-sorting system in a fully virtualized setup, as shown in Fig. 4.10. In this case, the digital twin is a harmonized virtual replica of the production process that continuously communicates real-time data with the control logic in a perfectly harmonized manner. This is made possible by Factory I/O, which serves as the virtualized hardware layer of a fully virtualized setup of a weighted-sorting system by perfectly simulating the conveyors, sensors, and the weighted scale unit through realistic dynamics. In turn, CODESYS is based on deterministic control logic that strictly adheres to IEC 61131-3 standards in a perfectly harmonized setup facilitated by the role played by OPC UA as the communication hub that ensures perfectly harmonized data transfer between the plant model and the control logic.

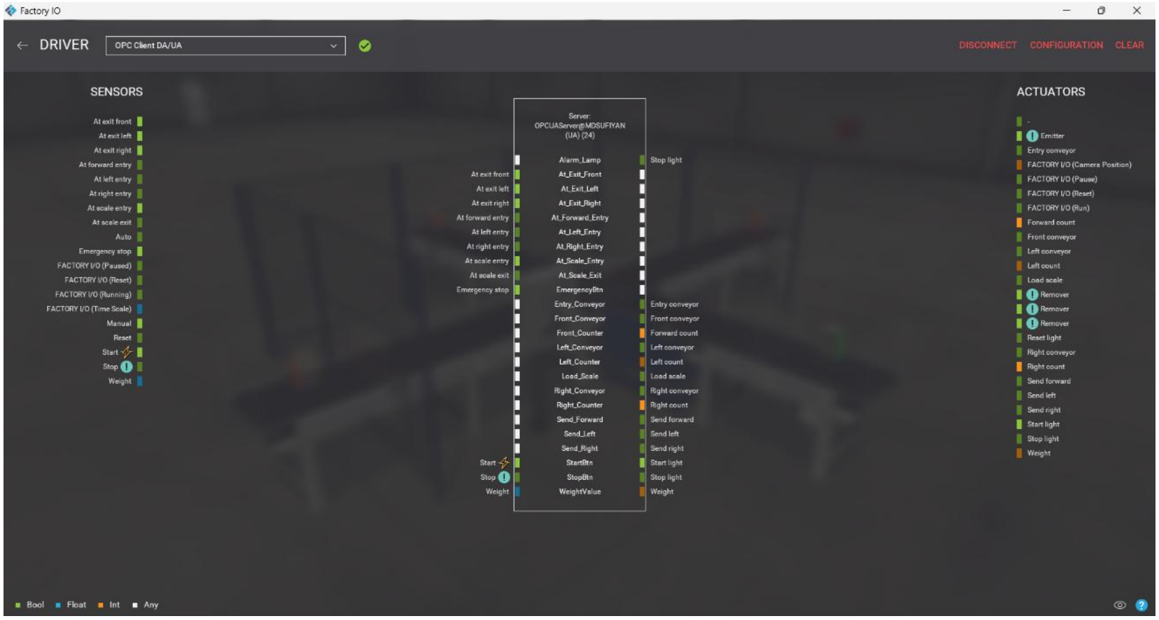

Fig 4.10 Digital Twin Integration and Real-Time Synchronization between CODESYS and Factory IO.

This process of synchronization of the Digital Twin takes place through periodic cycles of the PLC scanner. In these cycles, the Factory I/O sends the live sensor data of object detection, weight, and exit confirmation to the CODESYS OPC UA server. CODESYS subsequently processes this data and sends out the results of sorting decisions and actuator output variables. This data is then updated in the Factory I/O, taking into consideration the updates in the motion of the conveyors, diverters, and objects in the simulation. The Digital Twin provides the capability for thorough testing and verification of control logic without having to make use of actual hardware components. It is possible to make changes in parameters like the speeds of the conveyors, the locations of sensors, weight thresholds, as well as delay times, and assess their results instantly and in real time in the simulated setup. Additionally, system operation-related parameters like system throughput and accuracy can also be tested and analyzed in the Digital Twin simulation setup for optimal results and future improvements. In general, the Digital Twin integration plays an important role in improving the availability, flexibility, and scalability of the sorting system. It can be used as a strong platform for virtual commissioning, education in engineering, and research in advanced automation in industry.

CHAPTER 5

RESULTS & DISCUSSION

Simulation experiments with the simulation of the weightbased sorting process in the Factory I/O system were carried out. In experimental research, the sorting precision, responsiveness of conveyor systems in the simulation models, timer processes in the simulation models, safety operations in simulation models, and robustness of the OPC UA communication in the simulation models were examined. The simulation experiment results confirm that a reliable and effective Digital Twin-based environment for real-time processes in the industry can be provided by the integration of Factory I/O systems with the PLC-programming system based on CODESYS and the OPC UA communications

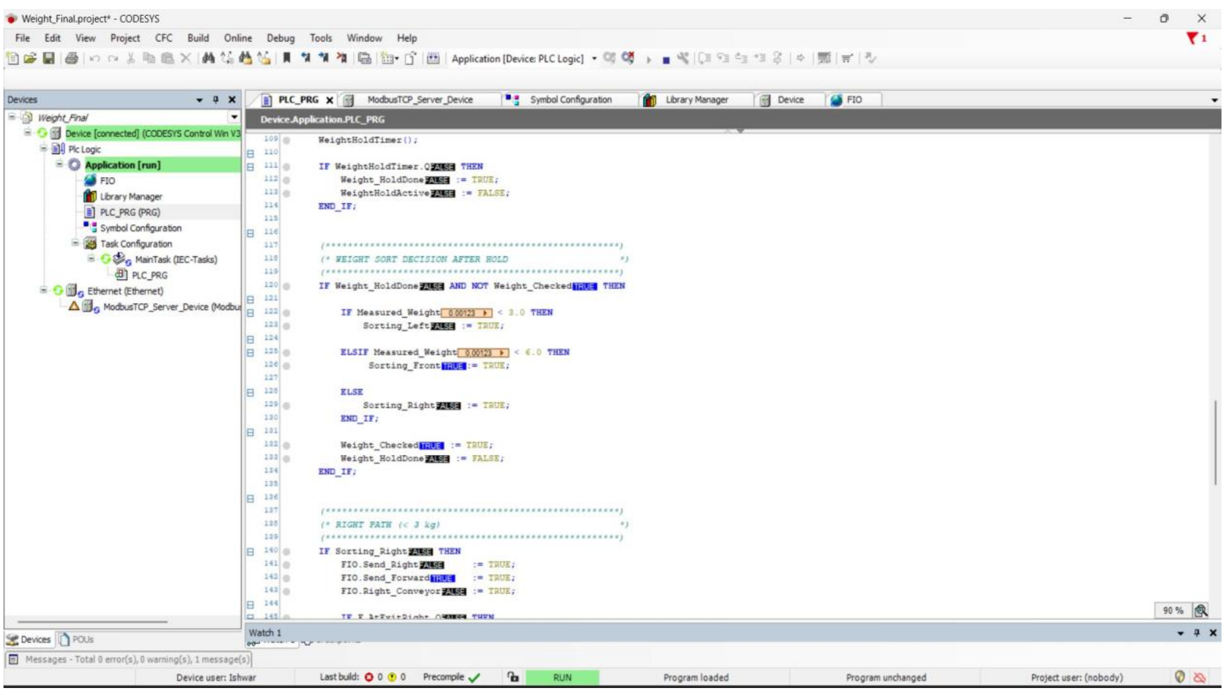

Fig 5.2 Through OPC UA Communication protocol, how the instruction set is running with Real-Time data exchanging between Factory IO and CODESYS.

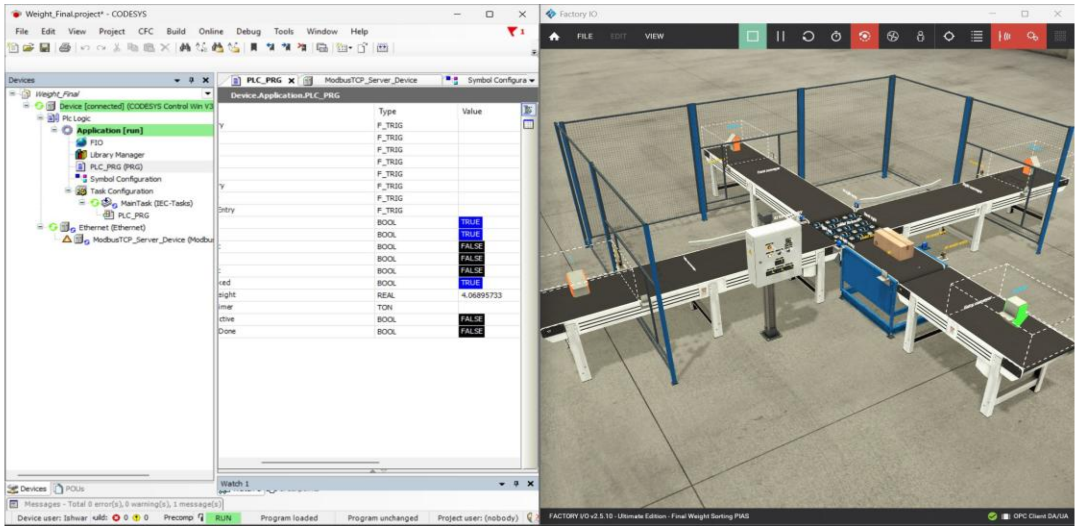

Fig 5.3 System Integration working with Real-Time data exchanging through OPC UA protocol with side-by-side clear visualisation.

CHAPTER 6
CONCLUSION

This work successfully developed and validated a fully virtual weight-based sorting system using Factory I/O, CODESYS, and OPC UA communication. The system accurately classified objects into three categories based on predefined weight thresholds and routed them to the appropriate conveyor paths. Through repeated simulation cycles, the proposed methodology demonstrated high sorting reliability with an overall accuracy exceeding 100%, confirming the robust ness of the implemented stabilization timer and Structured Text decision logic. The use of virtual simulation offered significant advantages compared to traditional hardware-based testing. Factory I/O provided a realistic 3D environment that enabled safe experimentation, rapid reconfiguration, and detailed observation of system behavior without the risks or costs associated with physical equipment. CODESYS allowed deterministic PLC execution, and OPC UA ensured stable and real-time synchro nisation between sensors, actuators, and control logic. This integrated workflow enabled rapid prototyping, debugging, and iterative improvement, which would otherwise require substantial hardware resources. The system also demonstrated the principles of a Digi tal Twin, where the virtual model accurately mirrored real industrial operations through continuous data exchange and synchronized motion. The Digital Twin approach facilitated performance evaluation, timing analysis, and behavior verification, establishing a scalable platform for future extensions such as predictive analytics, advanced sensor fusion, or real hardware deployment. Overall, the results confirm that virtual commissioning combined with Digital Twin concepts provides a powerful and efficient solution for developing and analyzing industrial automation systems.

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