Design and Implementation of a PLC-Driven IoT-Connected Color Sorting System for Inventory Management

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Abstract

With the advancement of Industry 4.0, the integration of automation systems and the Internet of Things (IoT) into industrial processes has seen significant progress. This paper presents the technical design and implementation of a color-based object sorting system using a Siemens Programmable Logic Controller (PLC) integrated into an IoT-enabled inventory management platform. The system utilizes photoelectric sensors for color detection, with control logic executed by the Siemens PLC. Key system components include power supplies, actuators, Ethernet switches, connectors, and an LCD display for real-time user interaction and system monitoring. By integrating these elements, this research demonstrates a novel methodology for automating color-based sorting while enabling real-time data acquisition for inventory management. The architecture is optimized for industrial applications, contributing to enhanced automation efficiency and operational agility.

Keywords: Color-based sorting, Internet of Things (IoT), Siemens PLC, Photoelectric sensors, Industrial automation, Smart inventory management.

Introduction

The fourth industrial revolution, commonly referred to as Industry 4.0, marks a transformative era in manufacturing and industrial processes (1). Characterized by the convergence of digital technologies, advanced automation, and the Internet of Things (IoT), Industry 4.0 (2) seeks to create smart factories and intelligent manufacturing systems. This paradigm shift is driven by the need for increased efficiency, flexibility, and responsiveness in production environments. As a result, the integration of IoT and automation technologies has become paramount in achieving these objectives (3).
One of the critical components of Industry 4.0 is the ability to manage and sort materials efficiently within a manufacturing or warehousing setting. Traditional sorting methods often rely on manual labor (4) or rudimentary automation systems, which can be inefficient, error-prone, and unable to meet the demands of modern production lines. In contrast, advanced sorting systems that leverage IoT and automation can significantly enhance the accuracy and speed of material handlingprocesses.

Despite the advancements in automation, there remains a substantial gap in the implementation of sophisticated sorting systems that can seamlessly integrate with IoT infrastructure for real-time inventory management. Most existing systems are designed for specific applications and lack the flexibility to adapt to diverse industrial requirements (5). Additionally, many current solutions focus on sorting materials based on their physical properties, such as weight or size, rather than more complex attributes like color.

Color-based sorting is particularly valuable in various industries, including manufacturing, packaging, recycling, and food processing, where the differentiation of products by color is crucial. However, implementing a reliable and efficient color- based sorting system requires advanced sensing technologies (6) and robust integration with processing and communication platforms.

This research paper aims to address the aforementioned challenges by designing and implementing an IoT-integrated color-based sorting system using a Siemens Programmable Logic Controller (PLC). The primary objectives of this study are to design and implement a sorting system capable of categorizing objects based on their color using photoelectric sensors (7). The integration of this sorting system with an IoT infrastructure is crucial to enable real-time monitoring and inventory management. A key aspect of the project involves the seamless integration of essential components such as color sensor TCS3200, the Waveshare Industrial IoT Wireless Expansion Module, power supplies, actuators, Ethernet switches, cables, connectors, and an LCD display. Finally, the system's performance (8) will be evaluated in terms of sorting accuracy, speed, and reliability to ensure its effectiveness and efficiency.

The significance of this study lies in its potential to revolutionize material sortingprocesses within the framework of Industry 4.0.By leveraging IoT (9) and advanced automation technologies, the proposed system offers several key benefits. The automated sorting process enhances efficiency by reducing the need for manual labor, thereby increasing operational efficiency and minimizing human error. The integration with IoT enables real-time monitoring (10), allowing for the tracking of sorted materials and providing valuable data for inventory management and decision-making. Additionally, the system's modular design ensures flexibility and scalability, making it easily adaptable to various industrial applications and capable of accommodating different production volumes. Finally, the reduction in manual labor and the optimization of sorting processes contribute to overall cost savings for manufacturers and warehouses, highlighting the system's cost-effectiveness.

The existing body of literature on material sorting and inventory management highlights several approaches and technologies. Traditional sorting systems often rely on mechanical methods or basic sensors to differentiate materials based on simple attributes like size or weight (11). While effective in certain applications, these systems lack the sophistication required for more complex sorting tasks, such as color differentiation.
Recent advancements in sensor technology have introduced photoelectric sensors capable of detecting a wide range of colors with high precision. These sensors, when integrated with advanced processing units and IoT platforms, can significantly enhance the capabilities of sorting systems. Previous studies have demonstrated the feasibility of using photoelectric sensors for color-based sorting in specific contexts, but comprehensive solutions that integrate these sensors with IoT for real-time inventory management remain limited.

Furthermore, the role of PLCs in industrial automation (12) is well-documented, with numerous studies highlighting their reliability, flexibility, and ease of integration with various sensors and actuators. However, the integration of PLCs with IoT platforms, particularly for complex sorting tasks, is an area that requires further exploration and development.
This research paper contributes to the field by presenting a novel approach to material sorting that combines the strengths of photoelectric sensors, PLCs, and IoT technologies. The key contributions of this study include a detailed design and implementation of a color-based sorting system that leverages advanced sensing and IoT technologies. Additionally, it provides a comprehensive integration framework that outlines the seamless incorporation of various components to achieve efficient and reliable sorting and inventory management. Furthermore, the study offers an in-depth evaluation of the system's performance, providing valuable insights into thepractical applications and limitations of the proposed approach.

This introduction provides a comprehensive overview of the research paper, setting the stage for a detailed exploration of the design and implementation of the IoT-integrated color-based sorting system using PLCs.

Materials and Methods

System Components

The color-based sorting system integrates key industrial components optimized for real-time sorting and data acquisition. The central processing unit of the system is the Siemens PLC (CPU ST30DC/DC/DC), which processes input signals from the photoelectric sensors used to detect object colors. The TCS3200 color sensor significantly enhances the system by enabling precise color detection, which serves as a critical input for sorting operations. It integrates seamlessly with the system's computational framework, ensuring accurate data processing and classification. Additionally, it supports real-time communication with the IoT cloud platform, allowing for efficient data exchange and remote monitoring of sorting processes. This integration ensures a robust and reliable solution for automated inventory management in industrial applications.Wireless data transfer is facilitated by the Waveshare Industrial IoT Wireless Expansion Module, enabling the system to interact with the cloud infrastructure for real-time inventory updates.

Other critical components include a robust power supply unit, Ethernet switches for networking, high-quality connectors, and cabling to ensure stable communication between devices. An industrial-grade Wintake 7-inch LCD display provides a user interface for monitoring and controlling the system locally

Methodology

Component Integration

- **Sensor-PLC Integration**: Photoelectric sensors calibrated for color detection are connected to the input terminals of the Siemens PLC. These sensors detect the object's color and relay this data to the PLC for processing.
- **PLC-Actuator Integration**: The PLC processes the color data and activates corresponding actuators to sort objects into predefined categories based on color.
- **PLC-Color Sensor Communication**: The PLC interfaces with the TCS3200 color sensor, receiving data from the

sensor for further processing and analysis. This communication facilitates accurate object classification and sorting, ensuring efficient and real-time data exchange with minimal latency.

- **IoT Cloud Connectivity**: The Waveshare Industrial IoT Wireless Expansion Module enables wireless data transmission to the cloud for real-time monitoring and inventory management. Data integrity is ensured through error-checking mechanisms during transmission.

User Interface

The Wintake 7-inch LCD display provides a graphical interface for system operators, displaying operational status, sorting counts, and real-time inventory updates. The interface also supports basic user interaction for system calibration and manual overrides if necessary.

Software Configuration

The Siemens PLC is programmed using ladder logic, enabling real-time sorting based on input data from the photoelectric sensors. The IoT platform is set up to visualize real-time data and generate reports for inventory management purposes.

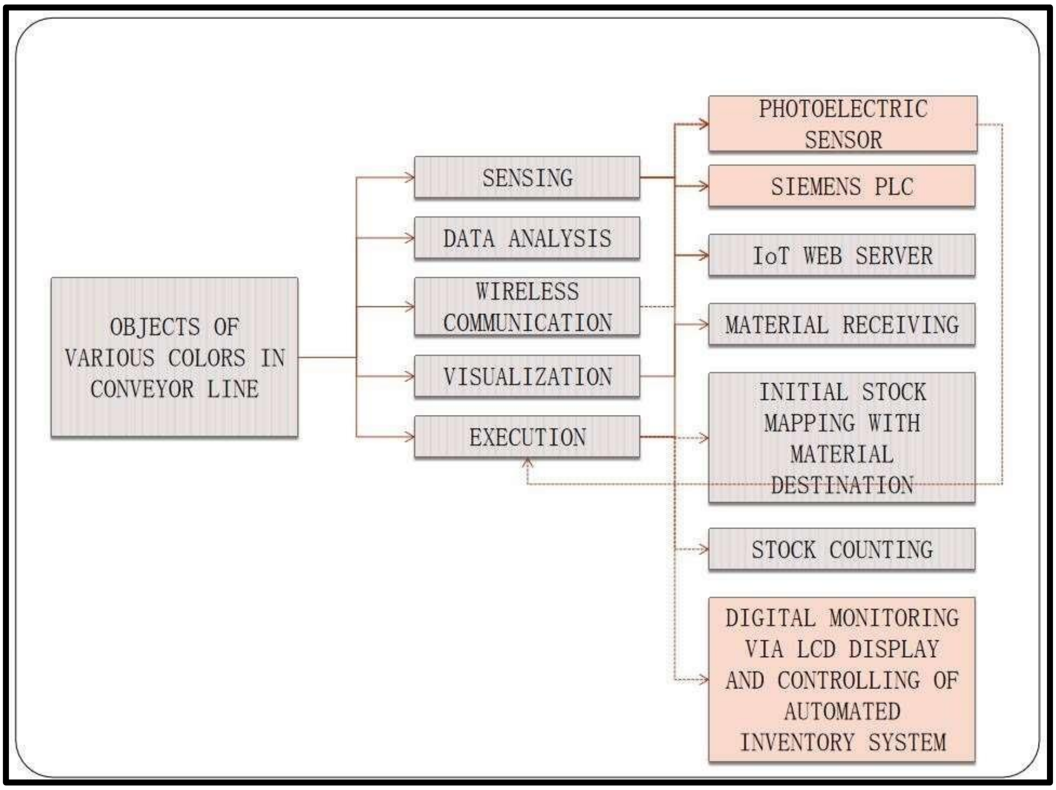


Figure 1. System architecture of the proposed IMSResults and Discussion

Hardware Setup

The hardware configuration begins with the connection of photoelectric sensors to the Siemens PLC, which is programmed to sort objects based on detected color. Theactuators are wired to the PLC’s output terminals to facilitate mechanical sorting. A communication link between the PLC and the sensor was established via a predefined protocol, ensuring data flow for subsequent transmission to the IoT cloud via theWaveshare Industrial IoT Wireless Expansion Module.

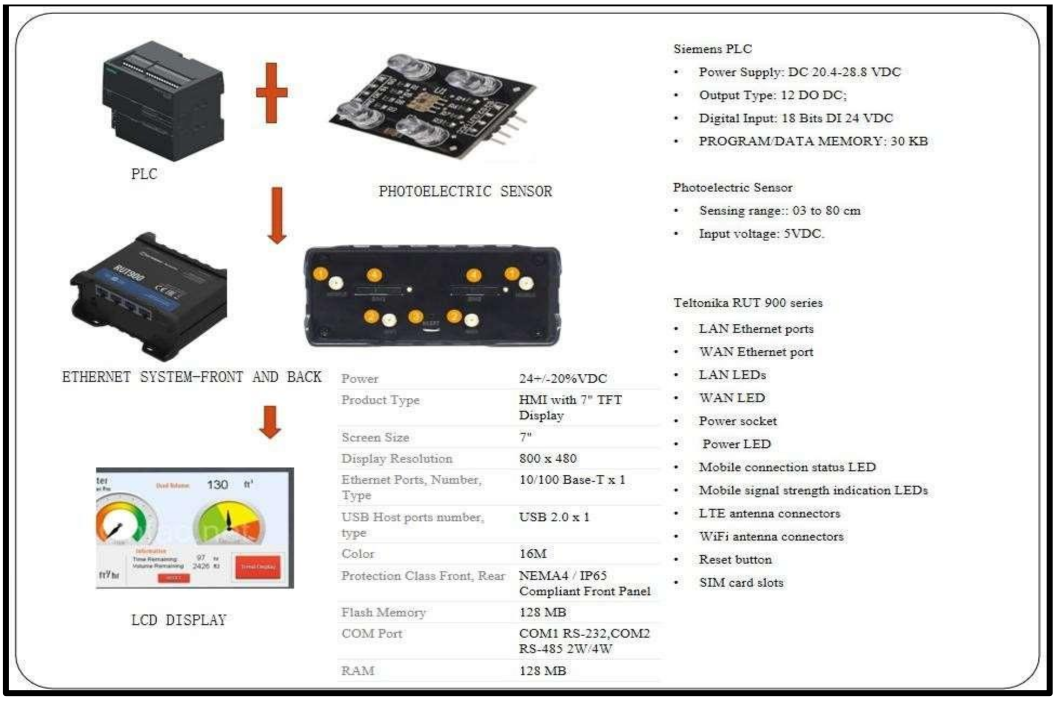


Figure 2. The hardware assembly of the developed system

Testing and Calibration

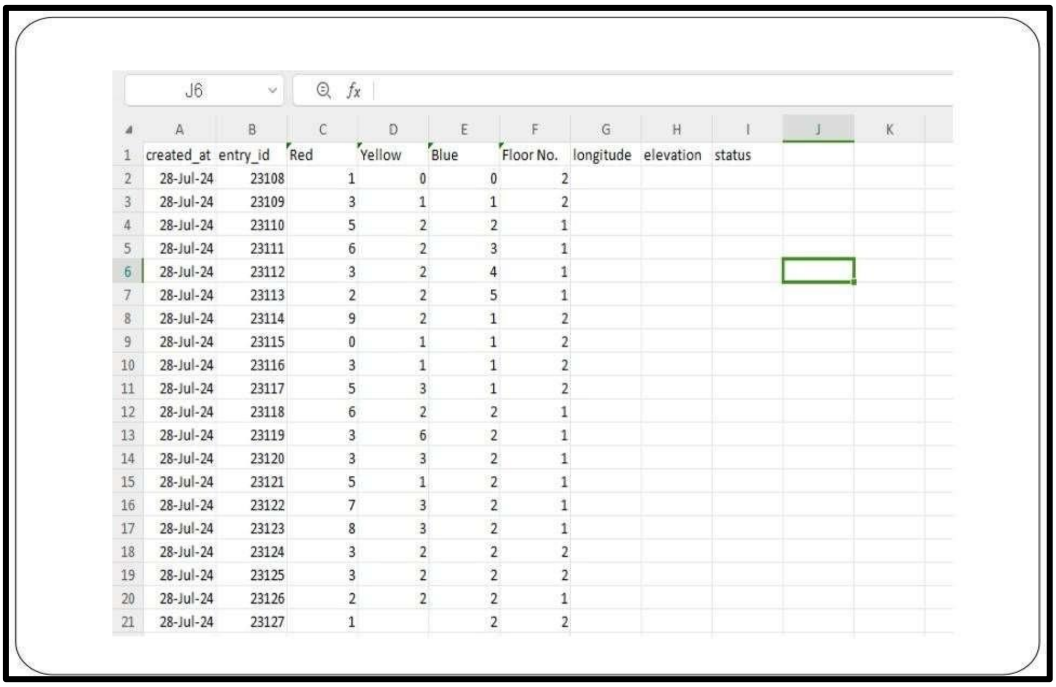
The system underwent rigorous testing using objects of various colors. Calibration of the photoelectric sensors ensured precise color recognition across different object materials. The actuators demonstrated reliable performance in sorting objects at the required throughput. Wireless communication between the color sensor and the cloud was validated to ensure real-time data transfer without significant delays.

Data Visualization and Analysis

Real-time data visualization was implemented on the Wintake LCD display, showing the color-sorting process and the number of objects sorted per category. Data storedon the IoT platform could be exported for further analysis, such as generating Excel sheets detailing the count of objects by color. This feature improves decision-making by providing operators with detailed insights into the sorting process and inventory status.

Figure 3. The developed prototype for color based sorting of objects

Figure 3 describes the prototype model with photoelectric sensor for color based sorting of goods in a smart inventory management.



created_at	entry_id	Red	Yellow	Blue	Floor No.	longitude	elevation	status
28-Jul-24	23108	1	0	0	2			
28-Jul-24	23109	3	1	1	2			
28-Jul-24	23110	5	2	2	1			
28-Jul-24	23111	6	2	3	1			
28-Jul-24	23112	3	2	4	1			
28-Jul-24	23113	2	2	5	1			
28-Jul-24	23114	9	2	1	2			
28-Jul-24	23115	0	1	1	2			
28-Jul-24	23116	3	1	1	2			
28-Jul-24	23117	5	3	1	2			
28-Jul-24	23118	6	2	2	1			
28-Jul-24	23119	3	6	2	1			
28-Jul-24	23120	3	3	2	1			
28-Jul-24	23121	5	1	2	1			
28-Jul-24	23122	7	3	2	1			
28-Jul-24	23123	8	3	2	1			
28-Jul-24	23124	3	2	2	2			
28-Jul-24	23125	3	2	2	2			
28-Jul-24	23126	2	2	2	1			
28-Jul-24	23127	1		2	2			

Figure 4. Spreadsheet downloaded to store real time data on cloud

Figure 4 describes the spreadsheet downloaded as a real time data visualization while showing no. of items with specific colors. The real time photos have been shared inFig 5. Fig 5(a) shows the real time work screenshots while color based sorting is in progress.

Figure 5. Real time work pictures for color based sorting of goods and display on screen

Conclusion

This research successfully demonstrates the development of an IoT-integrated color- based sorting system using Siemens PLCs and advanced photoelectric sensors. The system offers a high degree of accuracy in color recognition and sorting, real-timedata transfer via IoT infrastructure, and a user-friendly interface for local monitoring. Rigorous testing confirmed the reliability and efficiency of the system in an industrial environment, showcasing its potential for scalability and broader application in smart factories. Future research can expand on this framework by exploring additional sensor technologies or incorporating machine learning algorithms to further enhance sorting accuracy and adaptability.

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