AYDIN ADNAN MENDERES UNIVERSITY
ENGINEERING FACULTY
ELECTRICAL AND ELECTRONICS ENGINEERING DEPARTMENT

DESIGN AND IMPLEMENTATION OF A PLC-CONTROLLED AUTOMATION SYSTEM (CONVEYING, SORTING, AND STORAGE)

Aleyna ARSLANOĞLU
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ACCEPTANCE AND APPROVAL SHEET

The thesis study entitled "**DESIGN AND IMPLEMENTATION OF A PLCCONTROLLED AUTOMATION SYSTEM (CONVEYING, SORTING, AND STORAGE)**" prepared by **Aleyna ARSLANOĞLU , Berna KILIÇ , Berkay KILAF** has been accepted by our jury as the Bachelor of Science Thesis in the Department of Electrical and Electronics Engineering on 18.05.2025

Jurors	Signatures
Supervisor **Prof. Dr. Yılmaz Kalkan**	....

....

Prof. Dr. Olcay ÜZENGİ AKTÜRK

Head of Electrical and Electronics Engineering Department

DECLARATION SHEET

I declare that scientific ethics and academic rules are meticulously complied with in the design, preparation, execution, research, and analysis of this thesis, and the findings, data, and materials that are not directly the primary product of this study are cited in accordance with scientific ethics.

Aleyna ARSLANOĞLU

Berna KILIÇ

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ABSTRACT

DESIGN AND IMPLEMENTATION OF A PLC-CONTROLLED AUTOMATION SYSTEM (CONVEYING, SORTING, AND STORAGE)

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This project aims to develop a PLC (Programmable Logic Controller)-based prototype system to automate production processes in factories. Autonomous systems offer significant advantages in terms of efficiency, speed, and flexibility. In this context, products are first transported on a conveyor, where color and size analysis is performed using a Raspberry Pi 4B-based image processing system. The information obtained from the image processing is then transmitted to the PLC via a relay.

Based on the information evaluated by the PLC, a second conveyor system is activated. In this system, a PLC-controlled elevator mechanism moves up and down, as well as left and right, automatically placing the products into the correct compartments of two separate four-level storage areas.

Image processing plays a critical role in accurately classifying and rapidly sorting objects. Using the Raspberry Pi-based image processing system, the color and size of the products are analyzed. The system can detect four different colors (yellow, red, blue, green) and three different sizes (4x4x4 cm, 7x7x7 cm, 10x10x10 cm).

Additionally, during the simulation and implementation phases, GXWorks3 and Factory I/O software were used to program and develop the PLC code, ensuring the system operates safely and efficiently.
The project aims not only to improve production efficiency but also to optimize the use of storage areas and enhance workplace safety. Through the integration of HMI (Human-Machine Interface) screens with the PLC unit, interaction with users was enabled, allowing operators to monitor and intervene in the system in case of any issues.
As part of this project, a prototype automation system with PLC control, equipped with an HMI unit and capable of image processing with a Raspberry Pi, was designed, developed, and presented as a graduation thesis at Adnan Menderes University.

Keywords: PLC, Factory Automation, Image Processing, HMI, Conveyor, Raspberry Pi

ÖZET

PLC KONTROLLÜ OTOMASYON SİSTEMİ (TAŞIMA, AYRIŞTIRMA VE DEPOLAMA) TASARIMI VE GERÇEKLEŞTİRİLMESİ

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Tez Danışmanı: Prof. Dr. Yılmaz KALKAN

{2025}, {19} sayfa

Bu proje, fabrikalardaki üretim süreçlerinin otomasyonunu sağlamak amacıyla PLC (Programlanabilir Mantık Denetleyici) tabanlı prototip bir sistem geliştirmeyi hedeflemektedir. Otonom sistemler; verimlilik, hız ve esneklik açısından önemli avantajlar sunmaktadır. Bu kapsamda, ürünler ilk olarak bir konveyör üzerinde taşınırken, Raspberry Pi 4B tabanlı bir görüntü işleme sistemi ile renk ve boyut analizi yapılmaktadır. Görüntü işleme sonucunda elde edilen bilgiler röle aracılığıyla PLC'ye aktarılmaktadır.
PLC tarafından değerlendirilen bu bilgiler doğrultusunda, ikinci bir konveyör sistemi devreye girmektedir. Bu sistemde, PLC kontrollü bir asansör mekanizması sayesinde yukarı-aşağı ve sağ-sol hareketleri gerçekleştirilerek ürünler, dört katlı iki ayrı depolama alanındaki doğru bölmelere otomatik olarak yerleştirilmektedir.
Görüntü işleme, nesnelerin doğru şekilde sınıflandırılması ve hızlı bir şekilde ayrıştırılması için kritik bir rol oynamaktadır. Raspberry Pi tabanlı görüntü işleme sistemi kullanılarak, ürünlerin renk ve boyut analizleri yapılmaktadır. Bu proje; sarı, kırmızı, mavi ve yeşil olmak

üzere dört farklı renkte ve 4×4×4 cm, 7×7×7 cm, 10×10×10 cm boyutlarındaki üç farklı ölçüdeki nesneleri algılayabilmektedir.
Ayrıca, projenin simülasyon ve uygulama aşamalarında, PLC'nin programlanması ve kod geliştirilmesi için GXWorks3 ve Factory I/O yazılımları kullanılmış, böylece sistemin güvenli ve verimli çalışması sağlanmıştır.
Proje yalnızca üretim verimliliğini artırmakla kalmayıp, aynı zamanda depolama alanlarının etkin kullanılmasını ve iş güvenliğinin artırılmasını da amaçlamaktadır. PLC birimi ile entegre edilen HMI (Human-Machine Interface) ekranları sayesinde kullanıcı ile sistem arasında etkileşim sağlanmış, operatörlerin sistem durumu üzerinde anlık kontrol ve müdahale imkanları oluşturulmuştur.
Bu çalışma kapsamında, PLC kontrollü ve HMI birimine sahip, Raspberry Pi ile görüntü işleme yapabilen bir otomasyon sistemi prototipi tasarlanmış, geliştirilmiş ve Adnan Menderes Üniversitesi'nde bitirme tezi olarak sergilenmiştir.

Anahtar Kelimeler: PLC, Fabrika Otomasyonu, Görüntü işleme, HMI, Konveyör, Raspberry Pi

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We would also like to acknowledge **AYDIN ADNAN MENDERES UNIVERSITY** for providing the resources and facilities necessary to conduct this research.
Finally, we extend our appreciation to all individuals and organizations who have directly or indirectly contributed to this project, supporting us in various aspects of our academic journey.

Aleyna ARSLANOĞLU

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LIST OF ABBREVIATIONS

PLC	Programmable Logic Controller
HMI	Human-Machine Interface
HSV	Hue, Saturation, and Value
IoT	Internet of Things

1.1 INTRODUCTION

In today's rapidly changing and evolving industrial world, technological advancements are reshaping production processes. Critical needs such as fast production, workplace safety, high product quality, and efficient time management have made the use of machinery indispensable. In this dynamic structure, achieving a successful and sustainable position requires the harmonious integration of factors such as efficiency, speed, flexibility, and innovation. For this reason, various solutions, including PLCs and autonomous systems capable of being operated without human intervention, are widely utilized. Autonomous systems enhance efficiency, reduce error rates, and ensure safety through their ability to perform tasks independently [1]. These systems carry out repetitive and challenging tasks more quickly and accurately, providing significant time and cost savings. Additionally, their capacity to operate in hazardous or hard-to-reach environments without risking human life offers revolutionary innovations in sectors such as industry, agriculture, logistics, and transportation [2].

Autonomous systems integrate with technologies such as image processing, machine learning, and the Internet of Things (IoT), creating a workforce model that adapts to environmental changes and continuously evolves, making them a critical element for the future of labor and production structures [3]. Automation, supported by the capabilities of Programmable Logic Controller (PLC) systems, has advanced significantly, enhancing the efficiency of industrial processes [4].

PLCs provide automatic control of machinery, devices, and processes in production lines, minimizing manual intervention and enabling error-free, uninterrupted production processes. Their programmable structure allows them to adapt quickly to different production requirements, offering flexibility and compatibility [5]. These advantages have not only increased production speed but also reduced costs, improved workforce efficiency, and enhanced safety levels [6].

The evolution of automation has optimized overall efficiency in industrial sectors by improving quality and minimizing human errors. In particular, the integration of image processing techniques into automation systems enables various controls and tasks based on product appearance to be performed automatically through embedded systems. This plays a critical role in meeting essential needs such as mass production, workplace safety, and product efficiency. Today, systems utilizing industrial cameras and image processing techniques are widely adopted as key components that enhance production performance and reduce costs.

For instance, in the automotive sector, applications such as rim detection, dimensional verification of crankshafts, wheel alignment angle measurements, and stereo visual odometry for mobile robotics are realized using cameras and microcontrollers [7]. Moreover, in various manufacturing sectors, tasks such as identifying production errors based on product appearance, managing quality control processes, and packaging products are automated through image processing techniques.

Image processing involves modifying the features and properties of real-world images after converting them into digital formats [8]. Throughout the production process, monitoring products is critical for ensuring quality assurance and high efficiency, and these goals are successfully achieved through image processing techniques [9]. Processes such as categorizing products quickly and accurately, detecting defective products, separating and packaging items with different characteristics, and removing substandard products from the production line are effectively carried out using cameras, robotic arms, and conveyor belt systems. As the cost of image processing systems with cameras decreases, their adoption has become widespread. Industrial cameras with broad spectrum capabilities efficiently perform tasks like color analysis and can handle any desired image processing task related to the product.

Studies combining image processing and automation have highlighted significant innovations in industrial processes. For example, Şenel and Çetişli [10] used a webcam and conveyor belt to detect defective products and employed a robotic arm to remove them from the production line. Using a Mini6410 development board, their study identified correctly manufactured products as red and cylindrical, while defective products had colors other than red and rectangular shapes. They achieved 100% accuracy in sorting 15 defective and 45 non-defective products.

In agriculture, Özdemir and Yılmaz [11] developed an autonomous machine to address issues faced during chickpea harvesting. The machine identified the location of cherries, determined their coordinates, and executed the initial stage of removing cherries. Using Raspberry Pi 3, C programming language, QT Creator compiler, and OpenCV library, the method achieved 100% success in detecting cherries on trees under non-high backlight conditions.

Çubukçu et al. [8] analyzed text entered via a camera, identified the positions of letters and numbers, and reassembled the word using a vacuum gripper and servo motors. The operations were performed using MATLAB image processing methods and an S7-1200 PLC control system.

Sorting and classification processes can also be carried out using various sensors.

For instance, Aydın and Yıldız [12] developed a robotic system for automatically classifying parts based on their colors. They used an Arduino Mega 2560 v3 microcontroller to control the system and a color sensor to detect part colors. Infrared sensors identified parts, and a robotic arm with six degrees of freedom managed their movement, transportation, and classification. Parts moved along a conveyor belt were placed in designated locations based on their colors.

However, systems using cameras and image processing software are faster than those using color sensors. Additionally, computer vision software is more versatile, allowing objects to be classified not only by color but also by features such as shape.

Yılmaz and Demir [13] demonstrated that a camera-based system worked approximately three times faster than a system using color sensors in their industrial object recognition study. They compared the two systems by replacing a color sensor with a camera and image processing software for sorting red, gray, and black cylindrical objects on a conveyor belt into designated sections. A Bayes classifier was used to detect the color of the objects, classifying a total of 45 items with 15 objects for each color.

This project features a system capable of performing sorting and storage operations commonly found in automation systems. Boxes of different colors and sizes are analyzed using image processing on the first conveyor system, with the information being transferred to the PLC. The second conveyor system then utilizes an elevator mechanism to move the boxes up and down, placing them into the correct sections of two separate storage areas. The system aims to optimize workforce efficiency, minimize human errors, and ensure the orderly stacking of packages after production. The main goal of the project is to develop a prototype of an unmanned automation system that ensures the quick and accurate transfer of products into the appropriate compartments.

In today's industry, accelerating production processes and increasing efficiency are essential for gaining a competitive edge [14]. This project seeks to enhance the effectiveness of automation in production lines, improve industry standards, and provide innovative solutions. By minimizing manual interventions, the system reduces error rates and ensures the accurate sorting and stacking of products. This, in turn, facilitates the efficient use of storage space and streamlines logistics processes [15].

Moreover, integrating this automation system into production lines will enable faster and more reliable production flows, reduce labor costs, and improve workplace safety. The project aims to contribute to the efficient, safe, and sustainable management of operational processes in modern factories, offering an innovative solution in the field of industrial automation.

1.2 MATERIALS AND METHODS

1.2.1 PLC-Based Factory Automation Systems and Applications

PLC (Programmable Logic Controller)-based factory automation systems play a significant role in industrial production processes. These systems enhance efficiency by offering advantages such as mass production, long-term cost savings, and real-time control. Their main objectives are to automate production processes, reduce the need for manual labor, and increase productivity.

The integration of conveyor design with PLC-controlled systems offers an innovative approach to production processes and helps streamline these operations. In this project, objects will be detected using image processing techniques based on their color and shape. Then, these objects will be transported and placed into designated storage areas with the help of an elevator-integrated conveyor. The designed elevator conveyor system will enable materials to be moved into a total of eight different storage compartments, placed in pairs opposite each other.

Throughout the realization of this project, cost-effectiveness has been prioritized, and economically accessible materials have been selected. In line with sustainability principles, waste materials have been repurposed, adopting an environmentally friendly approach. This method has helped maintain the project within budget constraints while also contributing to the minimization of environmental impact.

The preliminary design of the project was prepared using **FLEXSIM** software and presented in Figure 1 with three different visuals. This design provides a detailed visual representation of the layout and functionality of the project.

In this section, the mechanical components of our project will be detailed, including the design process, materials used, and stages of construction.

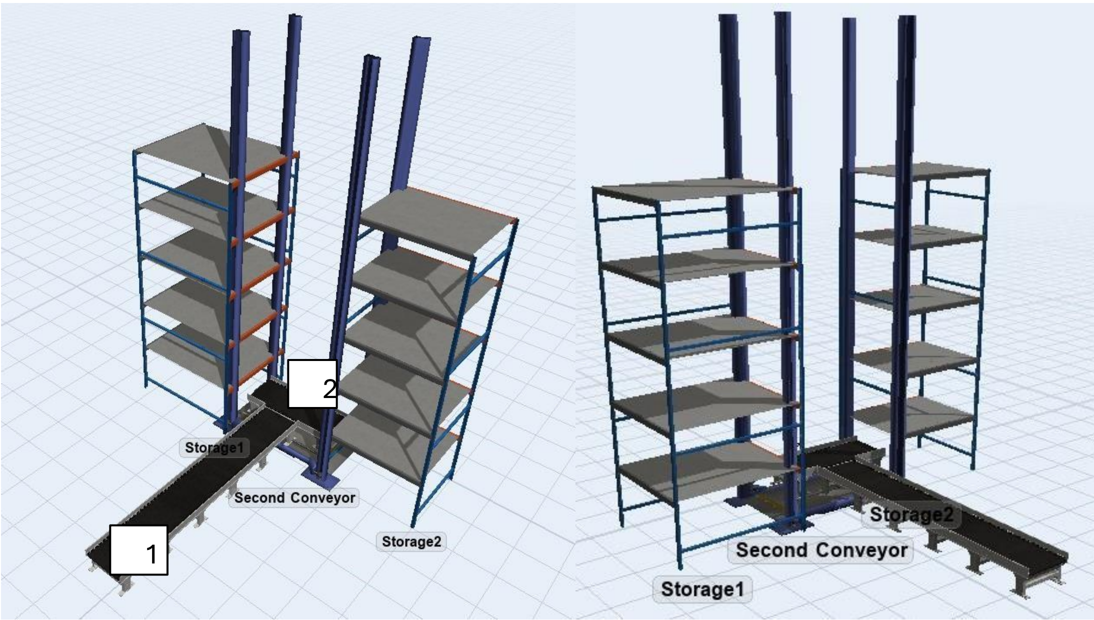

Figure 1: Project Design and Multi Angle Visualization

Project Design Process

First, a comprehensive system design was carried out using simulation software called FlexSim. FlexSim is a powerful platform that provides users with flexibility for modeling and simulating industrial processes. It was chosen due to its ability to offer real-time process analysis, allow testing of various scenarios, and provide visually supported simulations. This enabled a detailed analysis of the system's operation and facilitated the prediction of potential issues and optimization of the system.

One of the primary goals of the design process was to contribute a novel study to existing literature. Upon reviewing similar studies in the literature, it was observed that color separation is typically performed using robotic arms (ref). In another study (ref), this separation process was accomplished by moving the storage compartments themselves.

Inspired by these studies, we aimed to bring an innovative perspective to our system by opting for a movable conveyor design. This not only introduced a different method but also enhanced the system's dynamic structure, resulting in a more flexible and functional automation framework. This approach aims to offer more effective solutions in warehouse management and product sorting, standing as an alternative to current methods in the literature.

Diving into the details of our project, various software tools were used for different components of the system. The storage area was designed using **AutoCAD** to ensure precise technical specifications. This program was chosen for its accuracy in dimensional technical drawings.

The main conveyor, where image processing will take place, was built entirely using waste materials in accordance with our environmentally conscious approach. However, for the elevator mechanism—which enables the conveyor to move up and down—lightweight materials were deemed necessary to ensure efficient operation and reduce motor load.

Accordingly, relevant conveyor components were first designed in 3D using **SolidWorks** software, then 3D printed, and finally assembled by us. This method contributed to the lightweight structure of the moving parts and provided a cost- and labor-efficient solution during the production phase.

Below are the visuals of the drawings created with AutoCAD and SolidWorks.

MAIN CONVEYOR CONSTRUCTION

The core component of our project is the main conveyor system, which also hosts the image processing operations. This conveyor was entirely built using recycled materials, following a low-cost and eco-friendly approach.

For the frame of the conveyor, two wooden pieces—each 70 cm in length—were obtained from scrap MDF. These were joined with another wooden board with dimensions of XX cm (width) and YY cm (length) to form a sturdy structure. To enable the conveyor belt to rotate, cylindrical rotating parts located at both ends of the system were made from discarded water pipes. Two such pipes, each YY cm in length, were cut and mounted to the front and back ends of the conveyor.

The main element that enables the transportation of products is the conveyor belt. It was repurposed from an old tarpaulin material previously used for another purpose.

The conveyor's rotation is powered by a 5V DC motor salvaged from an old printer. This motor was mounted to the pipe in a way that allowed it to rotate the pipe, and in turn, move the conveyor belt. The required electrical power for the system was provided by an old charger, with its cables connected appropriately to the motor.

This production process was carried out entirely using repurposed materials, reflecting an environmentally responsible and sustainable approach at this stage of the project.

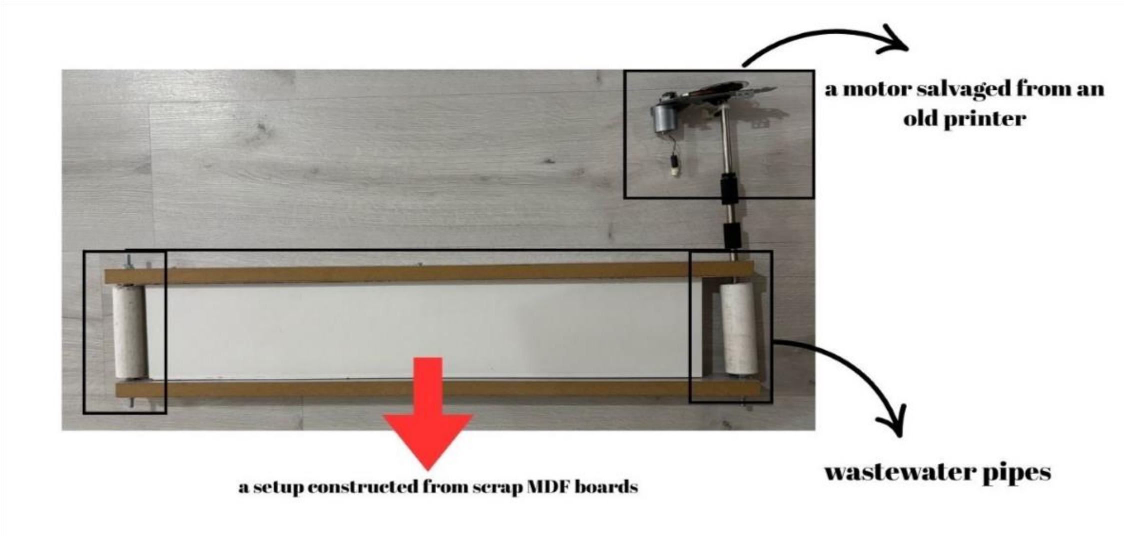

Figure 2: Components of Conveyor No. 1

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Figure 3: Components of Conveyor No. 1

CONVEYOR DESING FOR ELEVATOR MECHANISM

The conveyor to be used as the elevator mechanism in our project is shown as number 2 in the design visual. The main purpose of this conveyor is to move products up and down, as well as left and right, with the elevator system, placing them in the correct location. During the design of the conveyor, weight was a key consideration, as it must be lightweight due to its movement with the elevator mechanism. Therefore, it was decided that the conveyor should be made of a light material.
To achieve this, the most practical solution was to 3D print our own parts and assemble them. The parts were designed using SolidWorks and printed out, then assembled by the project team. This approach reduced production costs and provided flexibility during the design process.

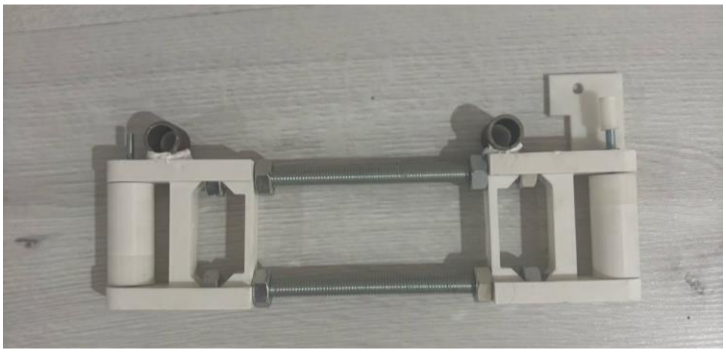

Figure 4: Conveyor No. 2

The small cylindrical metal parts located on the sides of this conveyor were repurposed from industrial waste. These components were used to ensure the conveyor's secure and stable integration into the elevator mechanism.

Figure 5: Metal Parts

The foundation of the elevator system and the metal rods that enable the suspended movement of the conveyor were constructed by repurposing waste iron bars. These iron bars were cut to precise measurements and welded together to form a robust support structure. This cost-effective and sustainable approach not only contributed to waste reduction but also ensured the mechanical stability required for the vertical and horizontal movements of the elevator mechanism. A visual representation of the elevator base is provided below.


Figure 6: Elevator Base

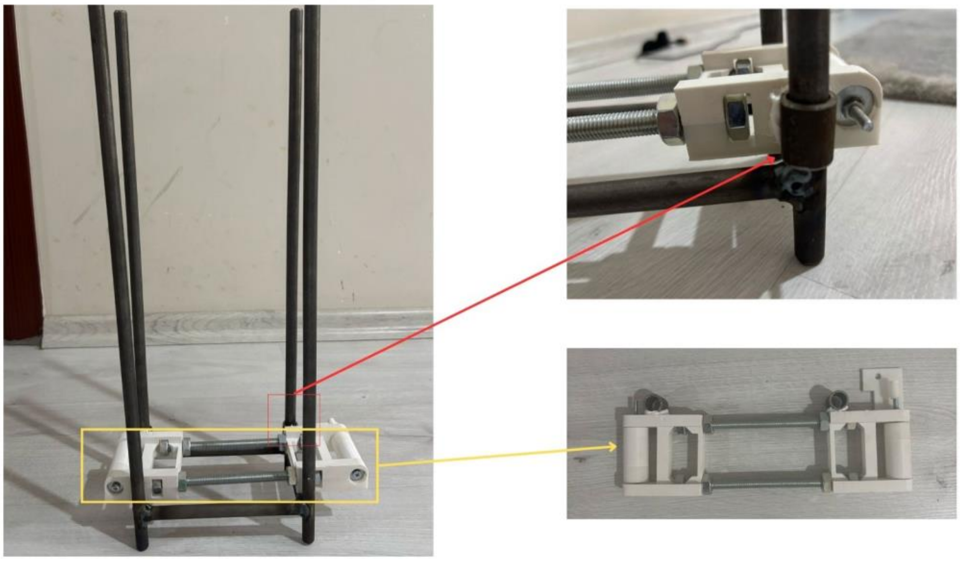

Figure 7: Components of Conveyor No. 2

STORAGE AREA

During the development of the storage area, it was determined that eight compartments were needed to categorize products based on their colors, sizes, and to separate those not meeting quality standards. To enable the elevator conveyor to not only move vertically but also rotate the belt to the left and right, two separate storage units—each containing four compartments—were positioned at the beginning and end of the elevator conveyor. This configuration contributes to a more dynamic and continuous system flow.

To support sustainability and reduce project costs, the storage compartments were constructed using scrap MDF boards obtained from local carpenters. This approach not only ensured budget efficiency but also demonstrated an environmentally conscious production strategy.

Visual representations of the completed storage area are presented below.

Figure 8: Storage Area

Figure 9: Overall View of the System

1.2.2 Simulation Process and Software to Be Used

In the proposed project, the automation system was controlled by a PLC (Programmable Logic Controller) unit. The code intended to run on the PLC was first developed and tested in a simulation environment before being uploaded to the actual PLC in real-time. This ensured that the code functioned correctly, and it was then transferred to the PLC for testing on real devices and project equipment. Since experimenting on real systems can be costly and risky, the simulation environment provided a safe platform to test various scenarios (Banks, Carson, and Nelson, 2005). Simulation not only validated the system's functionality but also provided the project team with insights into optimizing different scenarios and resolving potential errors.

In this project, Mitsubishi FX5U PLCs located in the Department of Electrical and Electronics Engineering at Aydın Adnan Menderes University were used. Programming of the Mitsubishi PLCs was carried out using GXWorks3 software, a powerful platform developed for industrial automation systems. GXWorks3 facilitates the development and simulation of PLC programs, making the programming and debugging process faster and more reliable. Additionally, GTWorks3 software was used to program Mitsubishi HMI (Human-Machine Interface) units, helping to design visual interfaces.

Another key tool in this project was Factory I/O. This platform is a powerful simulation software that allows for the visual and interactive modeling of industrial automation scenarios. By creating virtual factory environments, it enables the visualization of various PLC control scenarios. Thus, the system's operational behavior could be observed in advance, and potential problems could be identified. Factory I/O serves as a critical tool for engineers to detect design errors early in the process and minimize potential challenges in the field.

Thanks to the simulation environment, potential errors were identified before the system was applied in the real world, and the code's expected behavior was verified. Moreover, factors such as conveyor speeds, belt placement, and overall system efficiency were tested during the simulation process, ensuring more accurate and effective system performance. This approach also contributed to time and cost savings related to the project.

Simulations are valuable not only for software development but also for the training and education of industrial automation systems. Mistakes made on real systems can be costly even for experienced operators or engineers. Therefore, simulation environments offer project teams an important opportunity to understand system operations and correct errors before they occur. Figure 2 presents a draft project visual created by the project team using the Factory I/O simulation software.

In conclusion, the use of simulation played a critical role not only as a tool for software testing but also in increasing the reliability of the project and foreseeing potential problems that could occur in the field. The advantages provided by simulation in terms of real-time control, optimization, and error detection enabled the project to be implemented more efficiently and safely.

Additionally, a Raspberry Pi 4B board was used in the project for image processing purposes. This board is often preferred in industrial applications due to its low cost and high performance. Image processing tasks are of critical importance for the system to correctly perform functions such as box sorting and color recognition. In this context, coding was carried out on the Raspberry Pi using commonly used Python libraries such as OpenCV and NumPy. OpenCV provides real-time image processing functions, while the NumPy library was used for numerical computations and matrix operations. With the help of these software tools, camera data was processed and the obtained information was synchronized with the PLC system to ensure automatic system control. The flexible structure and open-source software support of Raspberry Pi increased the system's modularity.

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Figure 4: Simulation Work Performed Using Factory I/O

1.2.3 Image Processing

Image processing involves converting images captured by a camera from analog to digital format and then applying specific techniques to the digital image to create a new image that meets the desired purpose [16]. This process is essential for detecting and sorting objects of different sizes and colors on a conveyor according to their desired characteristics. Color and size analysis enables the rapid and accurate identification and classification of objects, significantly enhancing the efficiency of automated systems and optimizing production processes [17].

In this project, image processing methods will be utilized to sort objects based on their color and size. The image processing phase plays a crucial role in ensuring accuracy in color and size differentiation. By ensuring precise classification of objects, it enhances the efficiency of the automated system while minimizing the risk of errors. Additionally, the quick identification and classification of objects save time on the production line, resulting in a faster and more efficient manufacturing process.

As part of the project, the Raspberry Pi platform was selected as the suitable hardware for performing image processing tasks. Raspberry Pi is a highly suitable platform for embedded systems and image processing applications due to its low cost, large user community, open-source software support, and compact design. In line with these advantages, the Raspberry Pi 4 Model B was chosen for its ability to meet the project requirements. This model was preferred over its predecessors due to its higher processing power, increased RAM capacity, and enhanced connectivity options.

Figure 5: Raspberry Pi 4 Model B+

In the image processing workflow, a microcontroller is needed to establish a connection between the camera and the PLC. This microcontroller plays a critical role in rapidly processing and transmitting data. Raspberry Pi is highly suitable for this purpose, as it provides time efficiency, low cost, flexibility, and educational benefits, making it a valuable tool in engineering and technology development [18]. As a result, the Raspberry Pi 4 Model B+ has been selected for image processing in this project. This device offers the processing power required to handle images captured by the camera and transmit them to the PLC. Its flexibility and speed during the software development phase enable engineers to quickly test different scenarios during the prototyping stage.

Figure 4 shows the Raspberry Pi 4 Model B+ board that will be used in the project. This model is particularly suited to meet the processing demands of video and image processing tasks, ensuring that the project requirements are successfully fulfilled.

In the early stages of the project, a problem occurred where the display from the Raspberry Pi could not be seen on the monitor. In such cases, the blinking pattern of the green and red LED lights on the board provides important clues for identifying whether the issue is hardware or software-related. Explanations of what these LED patterns mean can be found on the official Raspberry Pi website. In the case of the Raspberry Pi 4B model used in our project, no abnormalities were observed in the blinking pattern of these LEDs. Therefore, it was concluded that the issue of not getting a display on the monitor could be related to the cable or display output settings.

To diagnose the cause of the black screen problem, an attempt was made to establish a remote connection to the Raspberry Pi. The Raspberry Pi requires an SD card to host the operating system and project files. The recommended minimum SD card capacity for the 4B model is 8 GB, but a 16 GB SD card was used in this project.

After writing the appropriate operating system (Raspberry Pi OS) to the SD card using the Raspberry Pi Imager software, the card was inserted into the Raspberry Pi and powered with a suitable power adapter. One of the most important points to consider at this stage is that the SD card must be formatted (reset) before the operating system is written, and SSH access should be enabled from the "Advanced Settings" menu during the writing process. Additionally, the username, password, and the name (SSID) and password of the wireless network to which the device will connect must be correctly defined.

After the necessary configurations, a mobile hotspot was created using a Samsung modem from a smartphone. Since the IP addresses of devices connected to the internet can be easily viewed on this device, access to the Raspberry Pi's IP address was established. Then, using the "PuTTY" remote connection software, a connection was made to the Raspberry Pi via SSH with the specified IP address and password.

After a successful connection, the user accessed the Raspberry Pi system via the command line (terminal), and the desktop interface of the device was remotely controlled. This revealed that the black screen issue was not related to hardware or the operating system but was likely caused by an issue with the display transmission cable or the display hardware.

After the cable issues were resolved, the camera setup was carried out. However, in this attempt, the camera did not work properly. The functionality of the camera can be tested as follows: Camera problems and connections may vary depending on the version of Raspberry Pi that is running. In this project, the Bullseye version was chosen because it is newer and provides more up-to-date software support. Additionally, since it is the latest version of Raspberry Pi, the Bullseye version offers more security updates and better compatibility with software.

Initially, the Bullseye version was used, and the installation was done with this version. In this version, older commands commonly used in the literature (such as raspistill and raspivid) have been moved to the libcamera library. This change provides users with a more modern and powerful camera control interface. A simple command, libcamera-hello, is used to test if everything is working correctly. This command should display a 5-second camera preview on the connected monitor. However, when this command was executed, the camera still did not work, and the following steps were attempted to resolve the issue.

1. **Camera Cable Connection and Cable Orientation:** It was checked whether the camera cable was connected correctly. Specifically, the blue part of the cable must be oriented toward the USB ports of the Raspberry Pi. The correct connection is shown in the image below.

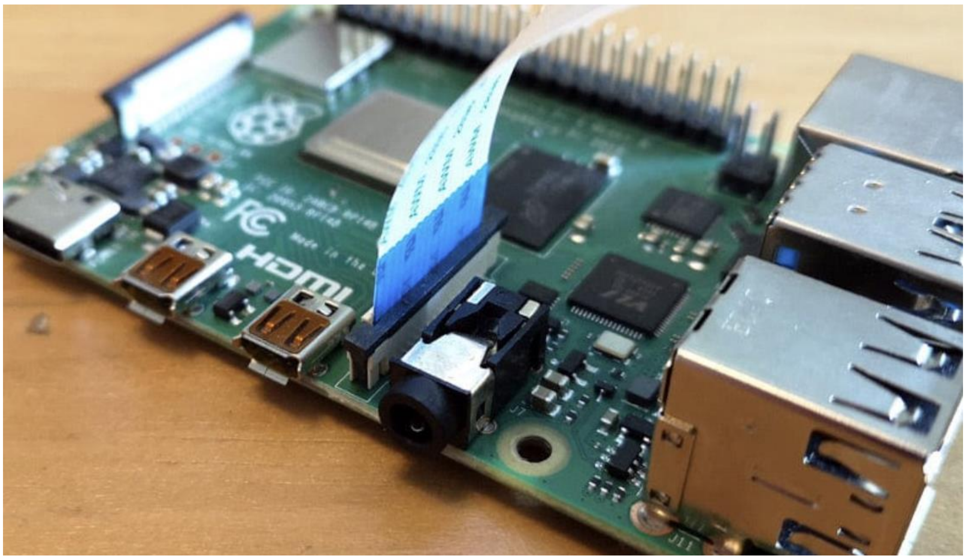


Figure 6: Correct cable connection

2. Updates: When using Raspberry Pi, especially for image processing tasks, it is essential to keep the system up to date. To ensure the most recent version of the software is being used, the commands sudo apt-get update and sudo apt full-upgrade were employed. These commands are crucial for ensuring that all software packages are up to date and any security patches or bug fixes are applied. By regularly updating the system, the latest features and improvements are incorporated, and compatibility issues with new libraries or software tools are minimized. Keeping the Raspberry Pi updated is particularly important in ensuring the stability and efficiency of the system during the execution of image processing algorithms.

Based on the steps followed, it was determined that there is a hardware issue with the camera. The board and commands functioned correctly, yet the image capturing function could not be performed. Given this, it was concluded that the issue lay with the camera itself. As a result, a new camera was procured to resolve the problem and ensure the proper functioning of the image processing system.

1.2.4 Conveyor Belt System Installation

Conveyor belts are mechanical systems widely used in industrial automation for material handling and processing tasks. These systems automate the material transport processes, reducing labor requirements and increasing production speed. Conveyor systems are generally classified into two main categories: fixed and movable. In this project, a movable conveyor has been chosen to enhance the dynamic nature and flexibility of the system, and its production has been carried out by the project team.

One of the key components of the conveyor system is the conveyor belt. In this project, the conveyor belt used has been sourced from an old tarp that was previously used for a different purpose. Electrical tape was initially tested, but its slippery surface proved to be unsafe for transporting products in the experiments. The tarp, on the other hand, does not have a slippery surface and provides adequate friction, ensuring stable product transport. Moreover, as this material has been sourced from waste, it contributes to environmental sustainability.

Such material selection and reuse strategies not only help in reducing production costs but also allow the project to be completed on a more affordable budget. This approach also serves as an important example of efficient resource utilization.

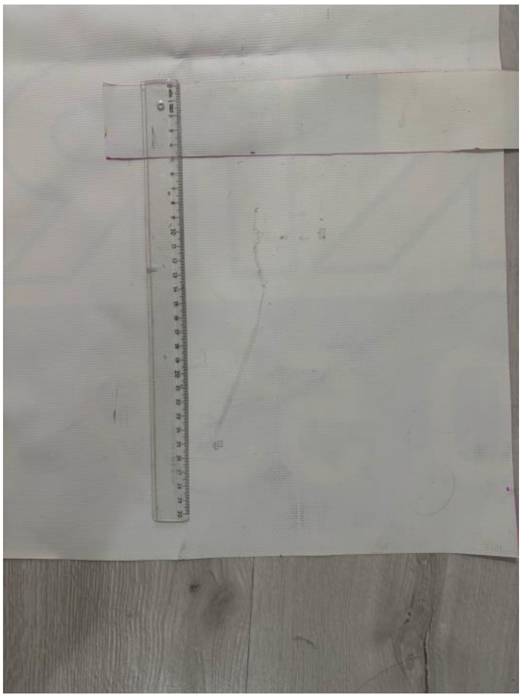


Figure 6: Production of the Conveyor Belt from Tarp

1.2.5 Objects to Be Sorted

In the scope of this project, products are classified based on both their color and physical dimensions. The classification process is initiated through user-defined commands entered via a Human Machine Interface (HMI) screen, allowing for real-time control and configurability of the sorting criteria.

Size-based discrimination is performed using infrared (IR) proximity sensors strategically positioned along the conveyor line. These sensors detect the presence and dimensions of objects by measuring the interruption or reflection of infrared light beams, thereby enabling accurate classification according to predefined size thresholds.

Color-based classification is implemented using a camera module connected to a Raspberry Pi, which executes a computer vision algorithm developed in Python using the OpenCV library. The algorithm processes the captured images in real-time to detect and classify the product's color by converting the RGB image into the HSV color space and applying thresholding techniques for robust segmentation.

This integrated system architecture ensures a fully automated and adaptive sorting process, where both hardware-based sensing and software-driven image analysis operate synchronously to enhance the precision and flexibility of the production line.

1.2.6 PLC Programming

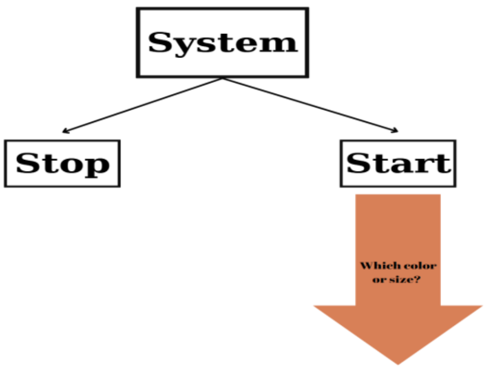
PLC (Programmable Logic Controller) is a device that plays a critical role in industrial automation systems, controlling production processes. It is widely used, particularly in manufacturing and assembly lines, to provide flexibility and control. Due to their programmable structure, PLCs can be adapted to a variety of production processes and customized for different industrial needs. In our project, Mitsubishi PLCs will be used. Mitsubishi PLCs are known for their high performance and reliability, and they are commonly preferred in industrial automation projects.

For the programming and simulation of Mitsubishi PLCs, the GX Works3 and GT Works3 software will be used. These software tools offer powerful capabilities for PLC programming and visualization.

- **GX Works3**: This software allows for the programming of Mitsubishi PLCs and the creation of ladder diagrams. It is widely used in the industry due to its ease of use and broad resource access. With this software, programs will be written quickly and simulations will be conducted, saving time during the project development process.

- **GT Works3**: GT Works3 is used to visually represent projects. This software helps users better understand the project and explore the interactive aspects of the application. As a result, the visualization and management processes in the project will be enhanced.

In this section, the flowchart representing the general operation of the PLC program developed for the automation system is presented. The flowchart visually illustrates the logical steps and control process of the system, making the program's working principle more understandable. It demonstrates, step by step, how input signals are evaluated, control decisions are made, and commands are executed on the outputs. This structure enables a clear analysis of how the PLC program functions within the system and serves as a fundamental reference for potential improvements.



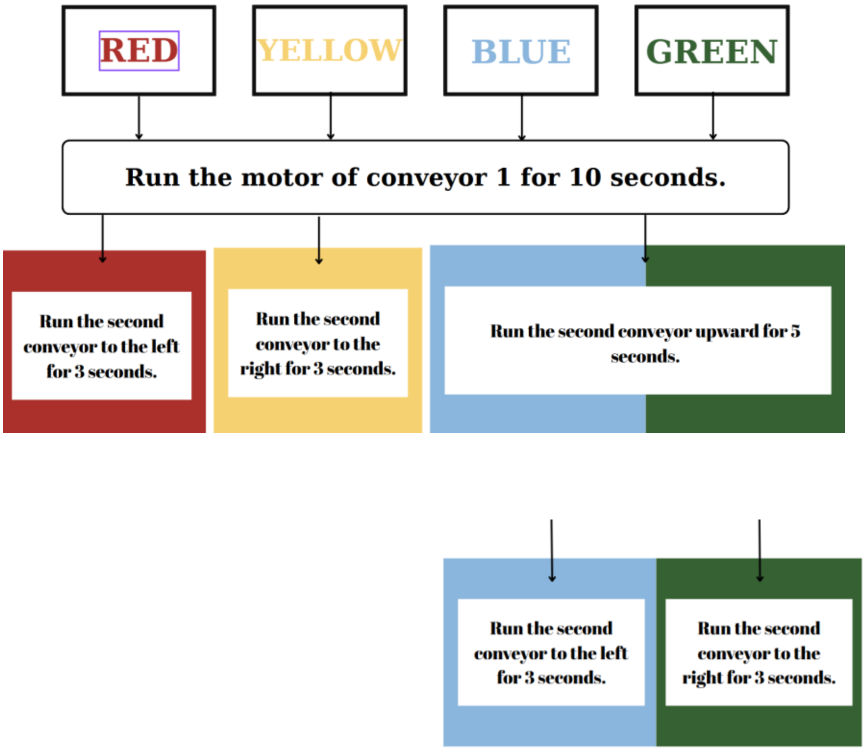


Figure 7: Logic Diagram of Separating Color

The developed PLC program was created using Mitsubishi Electric's GX Works3 software and was uploaded to an FX5U-32MT-DSS model PLC CPU via an Ethernet cable. During the transfer of the program to the relevant hardware, proper communication within the system and uninterrupted execution of control processes were ensured. This connection method provided high data transmission speed and reliability during the programming process, contributing to the stable operation of the system.

1.2.7 HMI (Human-Machine Interface) Design

HMI is an interface that allows users to interact with automation systems. Typically running on a computer or industrial screen, HMI panels enable users to monitor and control the operational status of machines. The primary tasks of an HMI are to transmit commands from the user to the control panel and to present data received from the control panel to the user in a visual format.

In this project, the interaction between the automation system and the user will be managed through the HMI screen. A custom interface design will be created to allow users to easily intervene with the system and monitor its status. The HMI design will be carefully planned to ensure the project functions smoothly and is user-friendly.

Through the HMI screen, operators will be able to easily monitor and intervene with the conveyor's speed, position, and other parameters as needed.

Table 1: Work Package

No	The Name and Objectives of the Working Packages	Timeline	The Criterion of Success
1	Modeling and Testing of Conveyor Belts and Two-Level Storage System in a Simulation Environment with GXWorks3 and Factory I/O Software.	0-2 month	The control of output units will be ensured based on input parameters through the simulation program. Input data will be simulated using switches, and output data will be simulated using lamps to ensure optimal performance of the PLC and HMI code. The success criterion is the correct functioning of the PLC and HMI code. Contribution to Project Success (%): 20
2	Adjustable Conveyor Belt Design and Production	1-4 Month	The conveyor system will be designed and manufactured to the desired dimensions, and a four-level storage area will be created to accommodate the boxes according to their sizes. Contribution to the project's success (%): 10
3	Object detection and sorting through image processing.	3-6 month	The colors and sizes of the objects will be determined. It is essential that the objects can be detected according to the desired properties. Contribution to the project's success (%): 30
4	Integration of the entire system with Mitsubishi PLC.	5-8 month	The developed software should control the movement of the conveyor belt, the separation of objects, their direction to the storage area, and monitor the occupancy status. With the integration of Mitsubishi PLC and HMI, the system status should be visualized on the HMI screen, allowing operators to intervene. The fault detection system will automatically detect any errors and provide alerts, ensuring quick intervention by operators. The software should undergo performance and speed tests, ensuring it operates in accordance with conveyor speed and storage capacity. Contribution to the project's success (%): 40
5	Testing Process	8-9 month	The software's full functionality should be tested with different scenarios. The functions of transportation, separation, storage, image processing integration, and fault detection should be validated through comprehensive testing to ensure they work correctly. Contribution to the project's success (%): 10

1.3 RESULTS AND DISCUSSION

Autonomous systems play a key role in industrial transformation due to their ability to perform tasks independently without human intervention. These systems increase efficiency, reduce error rates, and ensure the safety of workers [1]. For example, by performing repetitive and physically demanding tasks more quickly and precisely, they offer time and cost savings. Additionally, their ability to operate in dangerous or hard-to-reach areas without risking human lives makes them indispensable in fields such as industry, agriculture, logistics, and transportation [2].

Programmable Logic Controllers (PLCs) have become an indispensable component of automation processes. PLCs, which provide automatic control of machines, devices, and processes on production lines, minimize manual intervention, creating a flawless and uninterrupted work environment. Thanks to their programmable nature, PLCs offer flexibility and versatility, quickly adapting to different production requirements, thus reducing costs, increasing production speed, and optimizing overall efficiency [5], [6].

In this project, an automation system has been designed to meet the needs of the current era. The system features an integrated structure capable of detecting and classifying objects based on their size and color. The design consists of two conveyor belts, a camera, motors, and a PLC control unit. The first, longer conveyor belt moves along the X-axis, ensuring the primary transport of objects, while the second, shorter conveyor belt moves along the Y-axis to transport classified objects to appropriate storage areas.

There are four levels of storage areas, located on the right and left sides of the second conveyor. The first level is positioned below the first conveyor, the second level is at the same level as the first conveyor, and the third and fourth levels are positioned higher.

Recent studies related to this topic show that in a study by Çelik, M. [19], objects were classified in real-time based on their color using image processing in a PLCcontrolled conveyor system. The classified objects were then directed to different bins in real-time. In a project by Shah et al. [20], the advantages of PLC-based automatic object sorting systems were emphasized. Actuators were used to direct objects to the correct compartments, while sensors detected the objects' colors and sizes. Image processing was not used to differentiate the objects in this study.
Another study by Yılmaz, H. [21] proposed an approach to detect and count moving objects. Morphological operations were applied to images to detect object details, the background was removed using a Gaussian mixture model, and objects were identified and counted. The separation of overlapping or adjacent objects was performed using convex hulls. In a study where red and green

balls moving on a conveyor belt were transported by a stepper motor-controlled endless shaft and classified into separate boxes based on their color, the color of the ball was detected using color sensors.

Şenel and Çetişli [10] used a web camera and a conveyor belt to detect faulty products passing on the belt, using a robotic arm to remove the faulty product from the production line. In the study, the correctly produced product was red and cylindrical in shape, while the faulty product had a color other than red and was rectangular in shape. The color detection was based on whether the object's color was within a specific range in the HSV color space, and the shape detection was based on pixel values, where objects occupying more space were determined to be rectangular. A total of 15 faulty products and 45 correct products were successfully separated with 100% accuracy.

Aydın and Yıldız [12] developed a robotic system to automatically classify parts based on their color. The system used an Arduino Mega 2560 v3 microcontroller for control and a color sensor to detect the parts' color. Infrared sensors were used to detect parts, and a robotic arm with six degrees of freedom was used to manipulate, transport, and classify the parts.

In agriculture, for example, Özdemir and Yılmaz [11] proposed a solution to the problems faced by producers during chickpea harvesting. The study involved an autonomous machine designed to detect the location of cherries, determine their coordinates, and harvest the cherries from the identified locations. The detection was performed using image processing methods, and the system successfully detected cherries with 100% accuracy under normal lighting conditions.

Systems that use cameras and image processing software are faster than systems using color sensors. Furthermore, computer vision software is more versatile. Objects can be classified based on not only color but also shape and other characteristics using camera and image processing methods. In an industrial object recognition application, Yılmaz and Demir [13] demonstrated that a camera-based system was approximately three times faster than a system using a color sensor. In their study, they compared a PLC system using an electro-pneumatic arm and color sensors with a system using a camera and image processing software for sorting red, gray, and black cylindrical objects on a conveyor belt. A Bayes classifier was used to detect the color of the objects, and 45 objects in total were classified.

In the proposed project, image processing methods will be used instead of color sensors due to the advantages mentioned above. Unlike the study by Yılmaz and Demir [13], in the proposed project, objects will be detected and classified based on both color (yellow, red, blue, green) and size (three different sizes). The system will be controlled autonomously by a PLC, and the operations performed will be visually displayed on an HMI screen, allowing for remote monitoring and intervention if needed. Based on our research, no similar comprehensive

automation project is found in the literature. The studies mentioned above highlight the unique value of this project.

1.4 CONCLUSIONS

This study presented the design and implementation of an advanced automation system capable of detecting and classifying objects based on their color and size, using a PLC-controlled system with image processing methods. The system integrates two conveyor belts, a camera, motors, and a PLC unit, ensuring efficient sorting and storage of objects in designated compartments.

The results demonstrate the superiority of image processing over traditional sensorbased methods in terms of speed, accuracy, and versatility. The proposed system advances the state-of-the-art in industrial automation by enabling simultaneous classification based on multiple object characteristics (color and size). The findings confirm that computer vision technologies significantly enhance the performance of automated systems, making them more adaptable to complex industrial requirements.

This study's contributions to the fields of automation and industrial transformation are multifaceted. It highlights the potential of integrating PLCs with advanced image processing techniques to create more efficient, reliable, and flexible systems. From an economic perspective, such systems can reduce labor costs, minimize human errors, and increase production throughput, offering substantial cost savings for industries. Additionally, the project provides a scalable framework that can be adapted for other applications such as quality control, waste management, and agricultural automation.

Suggestions for future research:

1. Integration of artificial intelligence and deep learning algorithms to enhance system performance.
2. Utilization of spectral imaging techniques to detect different types of materials in the production line.
3. Investigation of the potential use of such systems in complex processes integrated with robotic automation.
4. Integration of the system into Industrial IoT (IIoT) platforms to enable capabilities such as big data analytics and remote monitoring.

This project establishes a foundation for further innovations in industrial automation and showcases the transformative potential of combining traditional PLC-based systems with modern image processing technologies.

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