Infact: Computer International Journal (ICIJ)
Vol.10, No.01, May 2026
p-ISSN : 2527-8363, e-ISSN: 2829-0259
DOI:

Prototype of an Automated Item Sorting System Using a Barcode Scanner and Servo-Based Directional Control with Microcontroller

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Submitted: 04/20/2026 , Revision: 05/01/2026, Accepted : 05/07/2026

Abstract

The increasing demand for efficiency in logistics and manufacturing highlights the limitations of manual sorting systems, which are prone to errors and inefficiency under high-volume conditions. Existing automated sorting systems often rely on multiple sensors or complex configurations, resulting in higher costs and system complexity. This study aims to develop a cost-effective and simplified automated sorting prototype using a single barcode scanner integrated with servo-based directional control. The system is designed using an Arduino Mega 2560 microcontroller, GM66 barcode scanner, infrared sensors, DC conveyor motors, and MG996R servo motors. The proposed method involves object detection, barcode identification, data processing, and directional sorting based on predefined servo angles. Experimental results show that the system successfully performs automated sorting with an overall success rate of 50%, demonstrating functional feasibility despite mechanical limitations. It can be concluded that the proposed system offers a practical and economical solution for prototype-scale automated sorting applications.

Keywords:
Automated Sorting System;
Barcode Scanner;
Servo Motor Control;
Arduino Mega 2560;
Conveyor System;

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1. Introduction

The rapid advancement of industrial technology has driven the logistics and manufacturing sectors to continuously enhance operational efficiency, particularly through the implementation of automated sorting systems. Manual sorting methods are no longer considered effective due to their slow processing speed, high susceptibility to human error, and inability to cope with the increasing volume of goods distribution. Consequently, many logistics companies have begun adopting automated conveyor systems integrated with electronic control to accelerate distribution processes. This trend highlights the urgent need for fast, accurate, and adaptive automated sorting systems in the digital era (Made et al., 2022).

Various sorting methods have been developed based on the characteristics of the items being processed. For instance, weight-based sorting systems utilizing load cell sensors are suitable for items with significant weight variation. In contrast, sorting methods based on color or shape are more appropriate for products such as fruits or electronic components; however, these approaches require expensive image sensors and complex configurations. As a more practical and cost-efficient alternative, barcode scanner technology has emerged as an effective solution for automated sorting processes, as it enables item identification through encoded data embedded in barcodes (Prameswari & Ilham, 2024).

The barcode scanner method is selected due to its capability to read product data accurately and rapidly, while also allowing direct integration with microcontroller-based systems. Essential information, such as item type and delivery destination, can be processed in real time. Previous studies have demonstrated that integrating barcode scanners with servo-based directional mechanisms in smart conveyor systems can significantly improve sorting efficiency and speed, while reducing reliance on manual labor (Putri et al., 2022).

Despite these advancements, several limitations remain in existing systems. Previous research implemented a single QR code scanner positioned above the conveyor, which limits scanning flexibility and lacks data integration capabilities. Other studies utilized multiple barcode scanners combined with IoT-based data processing, resulting in high accuracy but increased system complexity and cost. These limitations indicate a research gap in developing a more efficient, cost-effective, and simplified sorting system that can maintain high performance while minimizing hardware requirements.

This study addresses the identified gap by developing an automated sorting prototype designed for standard box-shaped objects with a maximum size of 10 × 10 cm, which are commonly found in small to medium-scale logistics and manufacturing applications. The proposed system is designed to meet user requirements, including automatic item identification using a barcode scanner, directional control using a servo motor, and autonomous operation with minimal human intervention. Various packages labeled with QR codes serve as sorting objects, allowing the system to classify and distribute them into three to five predefined output paths. The integration between the barcode scanner and servo angle control plays a crucial role in ensuring sorting accuracy.

Therefore, this research proposes a microcontroller-based prototype system that utilizes a GM66 barcode scanner and an MG996R servo motor to achieve multi-directional sorting with a single scanner. The system is expected to provide an efficient, cost-effective, and practical solution for modern industrial sorting applications. The objectives of this study are to design and develop an automated barcode-based sorting prototype capable of performing multi-lane sorting using a single scanner autonomously, as well as to implement and evaluate a servo motor angle-based sorting mechanism for directing items into five different output paths.

2. Methods

This study adopts an experimental and prototype-based methodology to design, develop, and evaluate an automated item sorting system utilizing a barcode scanner and servo motor control. The methodology is structured into several stages, including system design, hardware implementation, software development, system integration, and performance evaluation. To facilitate understanding of the proposed system, the methodology is represented through a block diagram and a system flowchart.

The system design begins with the identification of the main components and their functional relationships. The system is designed to integrate multiple input devices, a central processing unit, and several output actuators into a unified control mechanism. The Arduino Mega 2560 functions as the main controller, responsible for processing data received from all input components and generating appropriate control signals for the output devices. Input components include infrared sensors, an ON/OFF switch, and a GM66 barcode scanner, while output components consist of DC motors for conveyor movement, servo motors for sorting direction, relay modules, LED indicators, and an LCD with I2C interface. This configuration enables a continuous data flow from input detection to processing and final actuation.

The overall architecture of the system is illustrated in the block diagram, which provides a visual representation of the interaction between system components and the data flow mechanism.

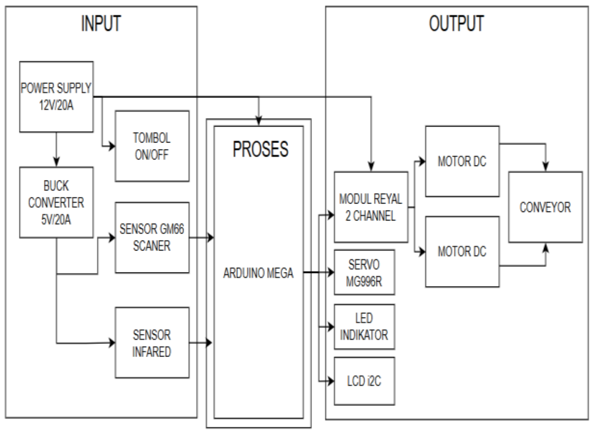

Figure 1. System Block Diagram

The system operates by receiving signals from sensors and barcode data, which are then processed by the microcontroller to determine the appropriate sorting action. The integration between hardware and software ensures that items are automatically directed to predefined output paths based on barcode identification. This mechanism enables the system to operate autonomously with minimal human intervention, thereby improving efficiency and reducing manual labor.

The power supply requirement of the system is fulfilled using a Switching Mode Power Supply (SMPS), selected due to its higher efficiency compared to linear voltage regulators. The total power consumption of the system is calculated using the electrical power equation based on the principle of energy conservation:

$$.... P = V \times I \quad (1)$$

where P represents electrical power (Watt), V is voltage (Volt), and I is current (Ampere). Based on the calculation of all components, the total power requirement of the system is approximately 97.522 W. The detailed power requirements for each component used in the system based on equation 1 are presented in table 1.

Table 1. Power Supply Requirements

Component	Qty	V	I	P
Arduino Mega 2560	1 Buah	12V	0,75A	9W
Motor DC	2 Buah	12V	2A	24W
Modul Relay	1 Buah	12V	0,06A	0,072W
GM66 Barcode	1 Buah	5V	0,16A	0,8W
Servo MG996R	5 Buah	5V	12,5A	62,5W
LCD i2C	1 Buah	5V	0,05A	0,25W
Sensor Infared	8 Buah	5V	0,14A	0,7 W
LED	5 Buah	5V	0,04A	0,2W
Total Power Requirement				97,522 W

The prototype is engineered to accommodate small to medium-sized objects with a maximum volume of 10 X 10 cm. The physical assembly comprises several essential structural modules, including a storage box frame, a dual-conveyor system, a sorting frame, a barcode scanner mount, and a dedicated wiring enclosure. The dual-conveyor system is strategically divided into two stages: the first conveyor, measuring 38 cm in length and 15 cm in width, functions to transport items toward the scanning zone. In this zone, a dedicated scanner holder with dimensions of 17 cm in height and 23 cm in width is positioned to ensure optimal scanning alignment.

Once identified, items proceed to the second conveyor, which has a length of 63 cm and a width of 15 cm, serving as the main sorting path. The entire sorting frame is designed with a total length of 140 cm and a width of 22 cm to provide an adequate travel distance for precise diversion. Vertically, the sorting frame stands at 35 cm; however, the total system elevation reaches 95 cm upon integration with the storage box. This additional 60 cm height provides a storage capacity for up to five units, acting as a gravity-fed buffer for continuous material supply while maintaining an ergonomic loading position and structural stability.

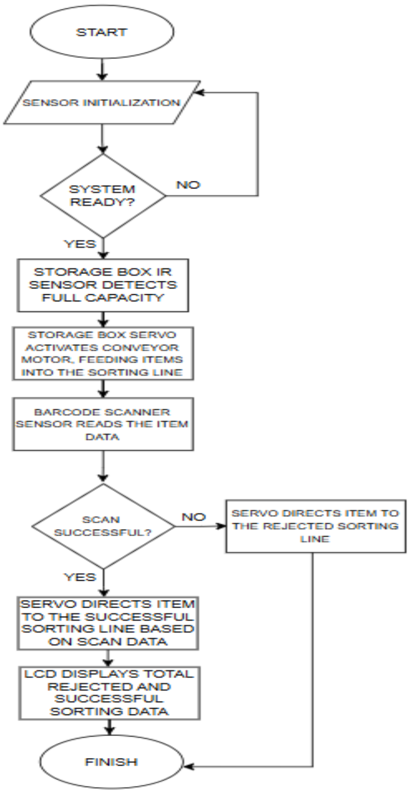

Figure 2. Overall System Flowchart

To evaluate system performance, several parameters are considered, including barcode reading accuracy, sorting accuracy, and system response time. These parameters are used to assess the effectiveness and reliability of the proposed system in performing automated sorting tasks. The evaluation process involves multiple testing scenarios using different barcode data to ensure consistent system performance under varying conditions.

3. Results and Discussion

This section presents and discusses the performance of the proposed automated sorting prototype in relation to the research objectives, including barcode reading capability, servo motor accuracy, infrared sensor reliability, and overall system sorting performance. The overall prototype of the system is shown in Figure 2, which illustrates the integration of hardware components, including the conveyor system, barcode scanner, sensors, and sorting mechanisms.

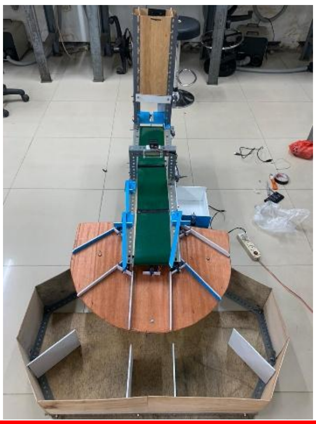

Figure 3. Overall Prototype System

Table 2 presents the operational voltage levels of the eight infrared (IR) sensors used in the prototype. The empirical data confirms that the sensors function based on an Active Low logic configuration. When an object is detected within the predefined range, the output voltage drops to a 'Low' state, yielding an average value of 0.222 V. In contrast, the 'Undetected' state produces a 'High' voltage signal with an average of 4.53 V. This substantial voltage gap (approximately 4.3 V) provides a robust signal-to-noise ratio, allowing the microcontroller to execute interrupt-driven sorting commands with high precision. The consistency of these measurements across all sorting stations, from the initial storage box (IR 1-2) to the final failed sorting station (IR 8), demonstrates the reliability of the sensing module in maintaining system synchronization.

Table 2. Infrared Sensor Testing Results

ID Sensor	Infrared Sensor Function	Detected Voltage (V)	Undetected Voltage (V)
IR 1	Goods Storage	0,223	4,58
IR 2	Goods Storage	0,221	4,5
IR 3	Sorting Station 1	0,224	4,51
IR 4	Sorting Station 2	0,223	4,5
IR 5	Sorting Station 3	0,225	4,58
IR 6	Sorting Station 4	0,22	4,52
IR 7	Sorting Station 5	0,221	4,5
IR 8	Sorting Station 6 (Failed)	0,224	4,51

The performance of the MG996R servo motors (Servo 3, 4, and 5) in executing sorting directions is detailed in Table 3. The evaluation was based on the precision of the achieved angle compared to the target angle and the pulse width modulation (PWM) signals. The results demonstrate that the motors can achieve the target angles with high accuracy, particularly in the lower to mid-range positions. Although minor deviations were observed specifically in the measured PWM values at higher angles (e.g., at 150° and 160°) the average deviation remains within a manageable range of 0 to 0.31 ms. These results confirm that the PWM signals generated by the Arduino Mega are sufficient to drive the mechanical sorting gates reliably, ensuring that items are correctly directed to their respective sorting lanes.

Table 3. PWM Measurement Results for Servo Movement

Servo ID	Function	Angle (°)	Target Angle (°)	Calculated PWM (ms)	Measured PWM (ms)
Servo 3	Sort Direction 1 (Left)	40	40	1.20	1.00
Servo 4	Sort Direction 2 (Right)	30	30	1.10	0.90
Servo 3	Sort Direction 1 (Left)	60	60	1.30	1.20
Servo 4	Sort Direction 2 (Right)	65	60	1.38	1.30
Servo 3	Sort Direction 1 (Left)	80	80	1.40	1.40
Servo 4	Sort Direction 2 (Right)	100	90	1.55	1.60
Servo 3	Sort Direction 1 (Left)	110	110	1.60	1.70
Servo 4	Sort Direction 2 (Right)	130	120	1.70	1.90
Servo 3	Sort Direction 1 (Left)	150	150	1.80	2.10
Servo 4	Sort Direction 2 (Right)	140	150	1.70	2.00
Servo 5	Failed Sort Direction	90	90	1.50	1.50
Servo 5	Failed Sort Direction	160	160	1.89	2.20

The percentage error is calculated using the following equation:

$$\cdots\cdots\cdots\; Erorr\ (\%) = \frac{PWM_{measured} - PWM_{calculated}}{PWM_{calculated}} \times 100 \quad (2)$$

The comparative analysis between the calculated and measured PWM signals, along with the corresponding percentage errors, is summarized in Table 4 The data reveals that the system achieves high precision at specific operational points, notably at a 0% error rate for Servo 3 (1.40 ms) and Servo 5 (1.50 ms). The percentage error across all test points ranges from 0% to 18.18%, with the highest deviations occurring at the extreme ends of the pulse width spectrum. The total accumulated error for all recorded data is 120.30%, resulting in an average error per measurement of approximately 10.02%. This average error value indicates that the PWM signals generated by the Arduino Mega remain functionally reliable for driving the MG996R servo motors in real-time sorting tasks, as the mechanical gates effectively reached their intended positions despite the minor electrical deviations.

Table 4. PWM Error Analysis Results

Servo ID	Calc. PWM (ms)	Meas. PWM (ms)	PWM (ms)	Error (%)
Servo 3	1.20	1.00	0.20	16.67
Servo 4	1.10	0.90	0.20	18.18
Servo 3	1.30	1.20	0.10	7.69
Servo 4	1.38	1.30	0.08	5.80
Servo 3	1.40	1.40	0.00	0.00
Servo 4	1.55	1.60	0.05	3.23
Servo 3	1.60	1.70	0.10	6.25
Servo 4	1.70	1.90	0.20	11.76
Servo 3	1.80	2.10	0.30	16.67
Servo 4	1.70	2.00	0.30	17.65
Servo 5	1.50	1.50	0.00	0.00
Servo 5	1.89	2.20	0.31	16.40

The evaluation of the MG996R servo motor response time is summarized in Table 5 The data reveals a significant discrepancy between the calculated (theoretical) response time and the measured performance. While theoretical calculations—based on the manufacturer's no-load specification—predict a rapid movement ranging from 0.028 to 0.198 seconds, the actual measured response time ranges from 0.57 to 1.54 seconds. This difference is primarily attributed to the mechanical torque required to move the sorting gate assembly and the implementation of software-based delays in the Arduino IDE to prevent jitter and ensure smooth mechanical operation. Despite these deviations, the maximum response time of 1.54 seconds remains well within the operational threshold, allowing the system to successfully redirect items before the next object arrives at the sorting junction

Table 5. Servo Response Time Measurement Results

Servo ID	Function	Initial Angle (°)	Target Angle (°)	Calc. Time (s)	Meas. Time (s)
Servo 3	Sort Direction 1 (Left)	90	40	0.142	1.12
Servo 4	Sort Direction 2 (Right)	90	30	0.170	
Servo 3	Sort Direction 1 (Left)	90	60	0.085	0.76
Servo 4	Sort Direction 2 (Right)	90	65	0.085	
Servo 3	Sort Direction 1 (Left)	90	80	0.028	0.57
Servo 4	Sort Direction 2 (Right)	90	100	0.028	
Servo 3	Sort Direction 1 (Left)	90	110	0.057	0.98
Servo 4	Sort Direction 2 (Right)	90	130	0.113	
Servo 3	Sort Direction 1 (Left)	90	150	0.170	1.54
Servo 4	Sort Direction 2 (Right)	90	140	0.142	
Servo 5	Failed Sort Direction	90	160	0,198	1,28

The barcode scanning performance at various distances is documented in Table 6. Interestingly, the results indicate a 'dead zone' for detection within the 1 cm to 30 cm range when the GM66 scanner is positioned at a 20 degree inclination. This phenomenon is primarily attributed to the focal point limitations and the angle of incidence. At close proximity with a 20 degree tilt, the optical sensor suffers from perspective distortion and specular reflection, preventing the scanner from correctly resolving the QR code's modules. However, as the distance increases beyond 30 cm, the angular offset becomes less significant relative to the field of view, allowing the lens to achieve a proper focus and successfully decode the data up to a range of 50 cm..

Table 6. Barcode Reading Distance Test Results

No.	Distance Limit (cm)	Detected Range (cm)	Not Detected Range (cm)
1	1–50	1–40	1-20
2		1–45	1-25
3		1–50	1-30

The results of the overall system integration tests are detailed in Table 7 The system's performance fluctuated across the five experimental trials, with success rates recorded at 33% for Trial 1, 50% for Trial 2, 67% for Trial 3, and consistently remaining at 50% for both Trials 4 and 5. The peak performance in Trial 3 (67%) indicates the system's potential for higher reliability under optimal conditions. However, the lower success rates in other trials highlight persistent technical challenges. The dominant causes of failure were identified as barcode detection errors (Trial 1), mechanical jamming of servo motors (Trials 2, 3, and 5), and infrared sensor misses (Trials 4 and 5). These results suggest that while the automation logic is sound, mechanical synchronization and sensor alignment remain the primary bottlenecks for achieving consistent 100% accuracy5.

Table 7. Prototype Testing Results (Trial 1-5)

Trial	Distance (cm)	Avg. Barcode Time (min)	Avg. Total Time (min)	Success Rate (%)	Dominant Failure Cause
1	100	5.03	24.97	33	Barcode not detected
2	100	4.27	24.60	50	Servo jam / barcode
3	100	4.00	22.70	67	Servo jam
4	100	5.00	22.70	50	IR sensor miss / jam
5	100	7.40	26.27	50	IR miss / servo jam

The average conveyor travel performance indicates that the time required per centimeter ranges between 0.10–0.19 min/cm during barcode reading and 0.22–0.26 min/cm for the total sorting process. Based on 30 total trials, 15 were successful, and 15 failed, resulting in an overall system success rate of 50%.

The primary issues affecting system performance are related to hardware limitations, particularly the barcode scanner and mechanical design. The barcode scanner performance is influenced by lighting conditions, scanner angle (approximately 20°), and reading distance (±50 cm), which reduces reading consistency. In addition, the vertical storage box design causes uncontrolled object movement, leading to misalignment during scanning. Mechanical issues were also observed in the sorting mechanism, where items occasionally became stuck, disrupting the sorting sequence.

Furthermore, the conveyor system experienced performance limitations due to excessive load on the belt, causing DC motor instability and increased temperature during operation. These mechanical constraints prevented the system from consistently executing the programmed control logic, despite the software functioning correctly.

To address these limitations, several improvements are proposed, including optimizing the barcode scanner position, adding light shielding, redesigning the storage box with an inclined surface, refining the sorting mechanism, and reducing conveyor load or adjusting motor specifications. These improvements are expected to enhance system stability and overall performance.

Despite the current success rate of 50%, the results demonstrate that the proposed system is capable of implementing a multi-directional sorting mechanism using a single barcode scanner integrated with servo-based control. The novelty of this study lies in the simplified and cost-effective design, which utilizes a single scanner to control multiple sorting paths through servo angle adjustment. The limitations identified in this study primarily relate to mechanical aspects, providing opportunities for further development to improve system performance.

4. Conclusions

This study successfully developed and implemented a prototype of an automated item sorting system utilizing a barcode scanner and servo-based directional control integrated with an Arduino Mega 2560 microcontroller. The system is capable of performing sequential operations, including object detection using infrared sensors, item transportation via a conveyor mechanism, barcode identification through a GM66 scanner, and automatic sorting into predefined paths using MG996R servo motors. The results demonstrate that the system can effectively process barcode data without data loss and utilize this information to control servo movement accurately based on predefined angles. The infrared sensors reliably distinguish object presence through clear voltage differences, while the conveyor system, supported by a relay module, operates consistently as the main transport mechanism. Overall, the prototype fulfills the research objectives by demonstrating a functional, low-cost, and integrated solution for automated multi-path item sorting at a prototype scale.

However, the system performance is influenced by several practical limitations, particularly in mechanical design and barcode scanning conditions. Factors such as scanner positioning, lighting conditions, and object stability affect the consistency of barcode reading, while mechanical constraints in the conveyor and sorting mechanisms impact overall system reliability. Despite these limitations, the study confirms that the proposed approach utilizing a single barcode scanner combined with servo angle control offers a simplified and economical alternative compared to more complex multi-scanner systems.

For future development, improvements are recommended in both hardware and system integration aspects. Enhancing the flexibility and positioning of the barcode scanner, strengthening the mechanical structure of the conveyor and sorting components, and optimizing the load capacity are essential to improve system stability. Additionally, incorporating data logging or monitoring features would enable better tracking and analysis of sorting performance. Expanding the number and variation of sorting paths is also suggested to increase system scalability and adaptability for more complex industrial applications. With these improvements, the proposed system has strong potential for further development into a more robust and efficient automated sorting solution.

Acknowledgments

The author would like to express sincere gratitude to Mr. Mohd. Ilyas Hadikusuma and Mr. Hasan for their invaluable assistance throughout the research process. Despite the various challenges and obstacles encountered during this five-month study, their consistent guidance and support ensured that this research was successfully completed properly and on schedule.

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