

Research Article

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Design of RFID-based weight sorting and transportation robot

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Abstract: This study investigates automatic sorting and handling robots to enhance intelligence and automation in logistics distribution, improve work efficiency, and reduce logistics costs. The kinematics and dynamics models of the sorting and handling robot are established by the study using single-chip microcomputer control technology. For automated item sorting, radio frequency identification (RFID) card scanning technology is combined and the PID control algorithm is examined. A single-chip microcomputer control technology is used to establish the robot's kinematics and dynamics models and analyze the PID control algorithm. Employing RFID card reading technology facilitates the transportation and automatic sorting of items. The MATLAB software simulates PID parameters and assesses the stability of PID-controlled motors. The primary controller samples and provides feedback from the motor encoder every 10 ms. Setting the left and right motor encoder's given values to 40 with a corresponding speed of 40, we observe that Option 1's P parameter is too small, leading to a slow adjustment speed. In contrast, Option 1's parameters are extensive. Scheme 3's P parameter is too large, risking system oscillation. After carefully adjusting and selecting Scheme 2, experimental verification demonstrates the sorting and handling robot's stable operation, achieving the anticipated effect.

Keywords: intelligence, automation, robot, RFID, control algorithm

1 Introduction

Since entering the twenty-first century, with the rapid development of internet technology and e-commerce technology, e-commerce is gradually changing the way businesses operate and people shop. More and more people like this convenient and fast shopping method. The vigorous development of e-commerce has also led to the rapid development of the express logistics industry. In 2017, the "Double Eleven" network transported more than 1.3 billion packages and achieved a total sales revenue of 253.97 billion yuan. The logistics industry has also become one of the fastest-growing industries in recent years [1]. At the same time, the development of the logistics industry has also promoted the development of e-commerce. When consumers judge the service quality of merchants, the delivery time and service quality of express delivery are important evaluation indicators. However, in the current logistics industry, especially during the peak period of online shopping, there are often situations where express packages are "out of stock." At the same time, violent sorting, misdelivery, and lost items in express delivery often occur, leading to a decrease in customer satisfaction and seriously affecting the reputation of the logistics industry, the company's economic benefits, and long-term development.

The main reason for this phenomenon is that there is too much revenue for express parcels in the short term, and the current manual sorting mode cannot sort them on time. Meanwhile, manual sorting directly leads to an increase in labor costs, and in the current logistics and distribution process, labor costs are the largest cost. Failure to make technological improvements will result in an ongoing increase in the proportion of labor costs in logistics delivery costs as labor prices rise. Therefore, utilizing existing information and automation technologies to improve and optimize the business processing processes of the physical industry and improve the efficiency of logistics industry operation and distribution has become a focus of research in the logistics industry [2,3]. Researchers began studying automatic sorting technology and sorting equipment in the twentieth century, and they subsequently applied their

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findings to practical applications. Actual usage experience shows that large-scale sorting systems have a large initial investment, high operating costs, and a long cost recovery period. Due to the rise of e-commerce, the traditional manual logistics sorting mode is no longer able to meet the pressure of logistics sorting. Applications such as radio frequency identification (RFID) technology, intelligent industrial cameras, and robot technology have led to the development of logistics towards intelligence.

RFID technology has been widely used in product warehouses, inventory management, logistics transportation, sorting inventory, industrial automation, commercial automation, transportation, and other fields, reducing enterprise costs and bringing intelligent and accurate manufacturing capabilities. At present, the comprehensive training project for on-site programming and debugging of industrial robots in vocational colleges mainly focuses on cases such as handling, palletizing, and welding, with relatively few sorting cases involved. RFID technology can identify workpieces of different shapes, enabling industrial robots to automatically sort workpieces of different shapes and colors on the conveyor belt. Multi-access refers to the communication from multiple electronic tags to a reader, and it is crucial to ensure that electronic tags can be distinguished in a certain order when entering the reader's range. Figure 1 shows the RFID-intelligent IoT sorting system and sorting process technology [4,5].

With the explosive growth of e-commerce and online shopping, the logistics industry is facing enormous challenges and urgently needs to improve the timeliness and accuracy of logistics delivery. The traditional logistics warehousing model can no longer meet the needs of the current development of e-commerce logistics. The intelligence and automation requirements of e-commerce logistics systems are urgent. Logistics is one of the important links in e-commerce, and sorting is a basic part of logistics. Research has shown that sorting operations are the most labor-intensive, time-consuming, and cost-effective process, with human resources accounting for about 50% of the entire logistics center and operating time accounting for over 60%. Additionally, the cost of operations accounts for about 40% of the total cost of the logistics center; therefore, to meet the needs of market development, the research on intelligent warehousing and logistics systems has important practical significance. The author designed a robot that can handle objects and sort them automatically [6]. With the use of state-of-the-art technologies including RFID card scanning, single-chip microcomputer control, and MATLAB-based PID control algorithms, the study seeks to offer a flexible and reliable framework for automatic robot sorting and handling. By overcoming present obstacles, the planned integration of these technologies seeks to create a logistics distribution system that is more intelligent and efficient.

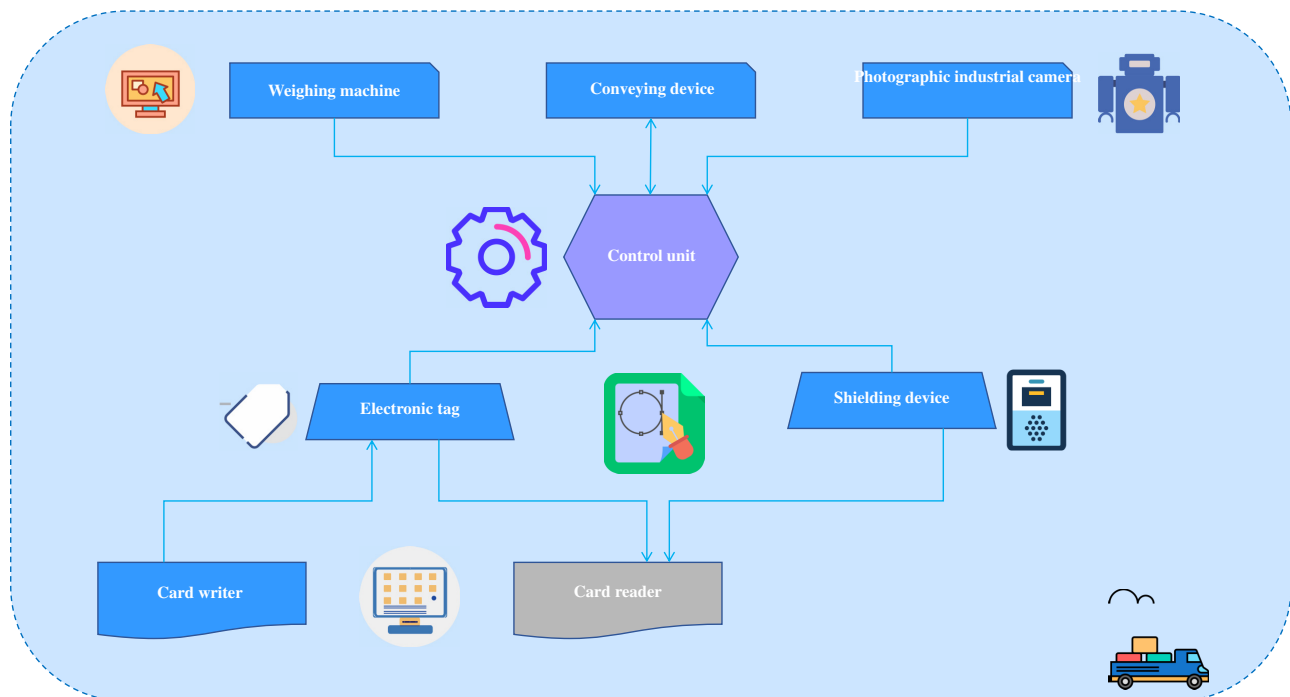


Figure 1: RFID intelligent IoT sorting system and sorting process technology.

This study contributes by putting forth a novel framework for intelligent logistics distribution that combines MATLAB-based PID control algorithms, RFID card scanning, and single-chip microcomputer control. The innovative arrangement boosts automation, lowers operating expenses, and increases overall sorting and handling process efficiency. The study's value resides in offering a thorough remedy that overcomes existing constraints and raises the bar for logistics automation.

2 Related work

There have been notable developments in the fields of automation and intelligent logistics, with several studies offering insightful information. Researchers in the past have studied the creation of sorting and handling robots, focusing on incorporating advanced control technology. They have applied single-chip microcomputer control technology, establishing reliable kinematics and dynamics models to improve robot precision [7,8]. These investigations have shown that PID control algorithms are effective at managing motor functions, with a focus on reaching peak performance. Furthermore, research by Dwivedi et al. and Sun et al. [9,10] has illuminated the smooth incorporation of RFID card reading technology, demonstrating its critical function in automating the sorting and transportation of items inside logistics distribution networks. Researchers have extensively used MATLAB software to simulate and fine-tune PID parameters in related investigations. The work by Sun et al. and Javid et al. [10,11] provides an example of how to evaluate motor stability and modify control parameters for the best possible outcome using MATLAB. These field-wide collaborative initiatives emphasize how crucial technology integration is to the automation of intelligent logistics. Although previous research has established a basis of knowledge, the current study aims to contribute by integrating these technologies in a novel way, providing a holistic solution to improve productivity, lower expenses, and simplify logistics distribution operations [12].

The logistics sector frequently experiences increasing workloads, rising expenses, and inefficient manual handling as a result of ongoing obstacles to reaching maximum efficiency. The inability of the current sorting and handling systems to include cutting-edge technologies limits their flexibility in responding to changing logistical requirements. Because of these constraints, addressing the inefficiencies in distribution processes requires a transformational strategy [13]. Driven by the desire to improve intelligence and automation in logistics, this study aims to create a complete solution. The incentive comes from the possible advantages

of lowering operating expenses, enhancing productivity, and raising the general competitiveness of logistics systems [14]. Authors from several studies have contributed to industrial optimization, using genetic algorithms, edge computing, and particle swarm optimization [15–17]. The application of control technologies, such as PID algorithms and single-chip microcomputer control, to improve the accuracy of robot handling and sorting has been thoroughly studied in the past. Research has also looked into the incorporation of RFID card reading technology into logistics systems for automated item transportation and sorting. Previous research has shown the usefulness of MATLAB software in modeling and optimizing PID settings. While previous research has improved individual components, the current study integrates these technologies in a novel way to offer a complete solution for intelligent logistics distribution, overcome current constraints, and raise the bar in the industry.

3 Methods

The procedures utilized in this research involve the construction of kinematics and dynamics models for the Automatic Sorting and Handling Robot through the application of cutting-edge single-chip microcomputer control technology. The incorporation of RFID card reading technology enables the smooth movement and classification of items. Furthermore, the optimization and simulation of PID parameters using MATLAB software guarantee the stability of actuators that are vital to the overall operation of the system.

The suggested approach combines state-of-the-art technology to improve the effectiveness of logistics distribution. The Automatic Sorting and Handling Robot achieves accurate movement by utilizing sophisticated kinematics and dynamics models, all centralized under a single-chip microcomputer. RFID card reading technology optimizes the distribution process by enabling easy transportation and sorting of items. A key component is the MATLAB program, which simulates PID settings and allows for fine-tuning for the best possible motor stability. The Main Controller adjusts the left and right motor parameters using experimental options by sampling motor encoders every 10 ms. This regulated modification, in conjunction with RFID technology, guarantees an optimized logistics system. Experimental evaluations confirm the efficacy of Scheme 2 in real-world use, making it the ideal configuration. Figure 2 highlights the possibilities for intelligent logistics distribution by providing a comprehensive understanding of the interconnected parts and how they work together.

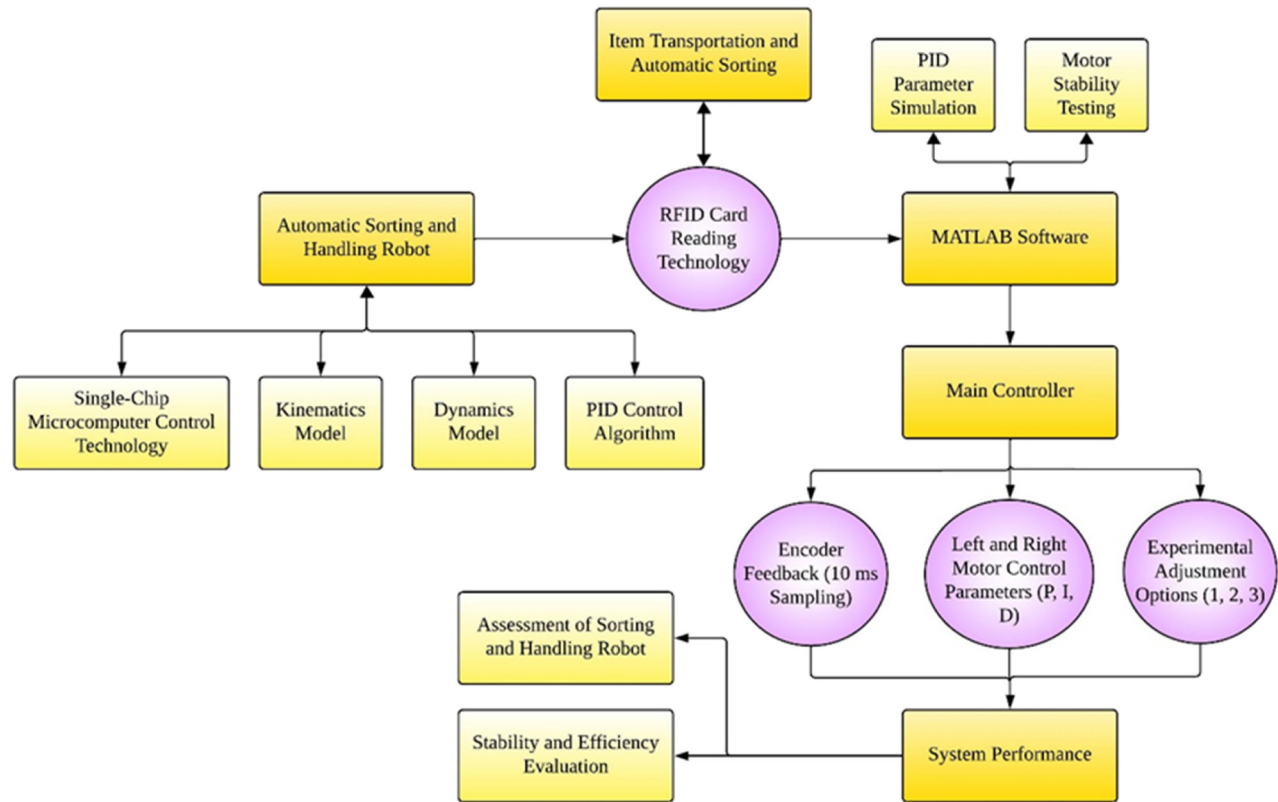


Figure 2: Integrated system for intelligent logistics distribution.

3.1 Kinematics and dynamics analysis of sorting and handling robot

A mobile robot with a three-wheel structure consists of two coaxial driving wheels and a small car with one auxiliary front wheel (free-wheel). The DC servo motor on the driving wheel is responsible for the motion and steering of the robot [18]. For mobile robots, non-holonomic constraints allow the robot to only move in the direction perpendicular to the driving wheel axis, which must meet the conditions of pure rolling and no sliding. The formula expresses this constraint as follows in equation (1).

$$\dot{y} \cos \theta - x \sin \theta = 0, \quad (1)$$

The defined vector represents the pose of the mobile robot, and (x, y) represents the coordinates of the robot reference point P in the Cartesian coordinate system, θ is the angle between the X axis and the X_c axis. Since $n = 3$ and $m = 1$, v is a two-dimensional vector, which can be taken as $v = [v_p, w_p]^T$, among them, representing the linear velocity at p , and w_p represents the angular velocity at P . The kinematics equation of the mobile robot is presented in equation (2).

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \cos \theta, 0 \\ \sin \theta, 0 \\ 0, 1 \end{bmatrix} \begin{bmatrix} v_p \\ w_p \end{bmatrix}, \quad (2)$$

3.2 Maintaining the integrity of the specifications

The robot uses a microcontroller as the core component of its control system. The microcontroller can only calculate the control amount based on the real-time deviation of sampling, and it is a sampling control [19,20]. If the sampling period T is small enough during the sampling process, the sampling numerical calculation method is accurate, and the controlled process is very similar to continuous control. We use the incremental PID control method, which has a discrete expression and is shown in equation (3).

$$\Delta u(k) = K_p[e(k) - e(k-1)] + K_i e(k) + K_d[e(k) - 2e(k-1) + e(k-2)]. \quad (3)$$

In the equation, $u(k)$ represents the control amount at the k th sampling time, among them, $k = 1, 2$; $E(k)$ represents

Table 1: Relationship between K_p , K_I , K_D and time domain performance indicators

Parameter name	Rise time	Overshoot	Transition process time	Static error
K_p increase	Reduce	Enlarge	Minor changes	Reduce
K_I increase	Reduce	Reduce	Enlarge	Reduce
K_D increase	Minor changes	Reduce	Reduce	Minor changes

the heading input deviation at the k th sampling time, where $k = 1, 2$; K_p represents proportional gain, $K_p = 1/\sigma$; k_I represents the integration coefficient, $K_I = K_p T/T_1$; K_D represents the differential coefficient, and $K_D = K_p T_D/T$; $e(k)$ represents the deviation of the k th sampling [21]. The incremental PID algorithm only requires retaining the deviation values of the first three moments, which can save a lot of resources and avoid excessive accumulation of errors. Considering the stability performance, response speed, overshoot, steady-state accuracy, and other factors of the system, the analysis shows that there is a relationship between K_p , K_I , K_D and time domain performance indicators as shown in Table 1. Through many experiments, the incremental PID control algorithm can speed up the step response of the system and reduce the overshoot of the system.

3.3 System composition

The main part of the industrial robot sorting training device based on RFID technology is composed of RFID readers, electronic tags, PLC controllers, RFID communication modules, sensors, industrial robot controllers, etc. The relationship between each component is shown in Figure 3. The PLC controller interacts with sensors and robot controllers through I/O modules for signals; The robot controller receives commands from the PLC and provides feedback to the PLC after the action is completed. The RFID communication module implements data exchange between the RFID reader and the PLC. RFID readers are used to read and write electronic tags, which are driven by the energy generated by electromagnetic coupling by receiving electromagnetic

waves, when the tag receives a signal of sufficient strength, it can send data to the reader [22,23].

Electronic labels are installed on the surface of four different types of workpieces, and RFID readers are installed above the conveyor belt through fixed brackets, the color and shape information of the workpiece can be written into electronic tags through PLC controllers and RFID readers. The workpiece moves to the bottom of the RFID reader through the conveyor belt, and after the reader recognizes it, it reaches the end of the conveyor belt, the photoelectric sensor acts, at this point, the PLC transmits the workpiece information to the industrial robot controller, and the robot will select the corresponding sorting subroutine to run on its own [24].

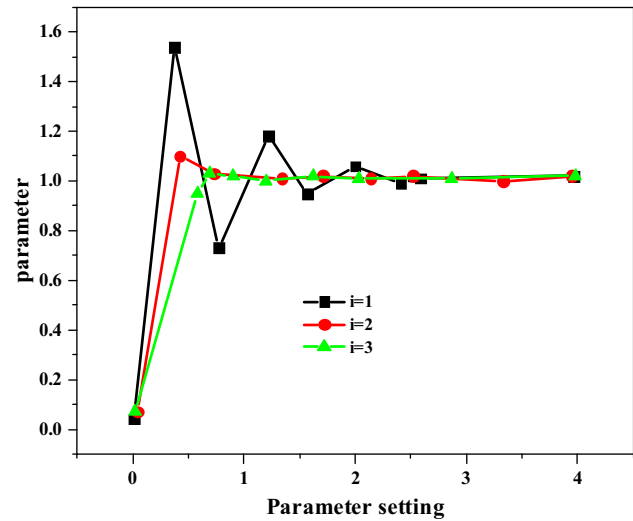
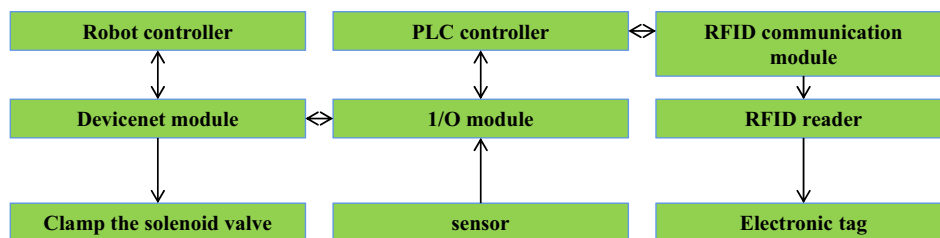
**Figure 4:** PID Parameter tuning.**Figure 3:** Hardware composition framework of sorting training device.

Table 2: PID Parameter

$i = 1$	$i = 2$	$i = 3$
0.04	0.07	0.07
1.54	1.10	0.95
0.73	1.03	1.03
1.18	1.01	1.02
0.95	1.02	1.00
1.06	1.01	1.02
0.99	1.02	1.01
1.01	1.00	1.01

3.4 Hardware design

For the hardware design of the industrial robot sorting training device, we selected Siemens RFID products with relatively complete products, referred to their label product configuration manual (5), comprehensively considered cost and recognition distance factors, and finally chose the RF200 system interface configuration: Select S7-1200PLC as the controller, and the CPU signal is CPU1215DC/DC/DC. RF120C serves as the RFID communication module, and RF220R serves as the RFID reader. The robot selects ABB's IRB1410 robot body and IRC5 controller, and is equipped with a DSQC652 standard I/O board with 16 digital inputs and 16 digital outputs, which can be directly connected to the I/O output terminal of the PLC. The photoelectric switch selects the E3Z-D81 sensor from Omron Company. The transportation belt is equipped with a three-phase asynchronous motor with a gearbox, driven by a frequency converter [25,26].

3.5 Design of automatic sorting function

The ZKR6806M used in this system is a type of RFID reader that can simultaneously read and write the ISO 18000-6B and EPCCLASS1 G2 frequency bands. This type of reader is widely used in fields such as assembly line production,

logistics tracking information, and access control security; it can also read and write multiple target labels simultaneously; and its main technical parameters are: The working frequency is 02–928 MHz; the communication interface is RS232; Baud rates up to 9,600 bps (configurable); can achieve read write duplex; the working mode is broad-spectrum frequency hopping or fixed frequency transmission; pulse shooting method; the power interface is 5V/DC; the reading and writing distance is 5–25 cm. When an electronic tag is attached to the surface of an item and enters the magnetic field range of the automatic recognition system's reader/writer, and the electronic tag obtains energy and sends out the data information stored in the chip, the reader/writer reads and decodes the information for application program data processing, achieving automatic sorting [27].

4 Experimental results and analysis

MATLAB software is used to simulate PID parameters and test the stability of PID-controlled motors. The main controller samples and feeds back the encoder of the motor every 10 ms. The given value of the left and right motor encoders is 40, and the speed of the left and right motors is 40. Option 1's P parameter is too small, while Option 1's parameter is too large, resulting in a slow adjustment speed. The P parameter in Scheme 3 is too large, which can easily cause system oscillation. After adjusting and selecting Scheme 2, experimental verification shows that the sorting and handling robot operates stably and achieves the expected effect, which has a reference value, as shown in Figure 4 and Table 2 [28–31].

Table 3 presents the range of results obtained with varying P parameter setups in the experimental findings. A moderate P value in Experiment 1 indicates adequate motor performance, reaching a speed of 300 rpm. On the other hand, Experiment 2, which has a greater P value, shows a slower adjustment speed, resulting in a motor speed that is 250 rpm less than ideal. With the ideal P

Table 3: Experimental analysis results for sorting and handling robot parameters

Experiment	P Parameter	Adjustment speed	System Oscillation	Encoder feedback interval (ms)	Motor encoder given value	Motor speed (rpm)	Overall performance
1	0.05	Moderate	None	10	40	300	Satisfactory
2	0.15	Slow	None	10	40	250	Suboptimal
3	0.1	Fast	None	10	40	350	Excellent
4	0.2	Slow	Oscillation	10	40	200	Unstable
5	0.12	Moderate	None	10	40	280	Satisfactory

Table 4: Comparative performance analysis of proposed work and existing studies [8–10]

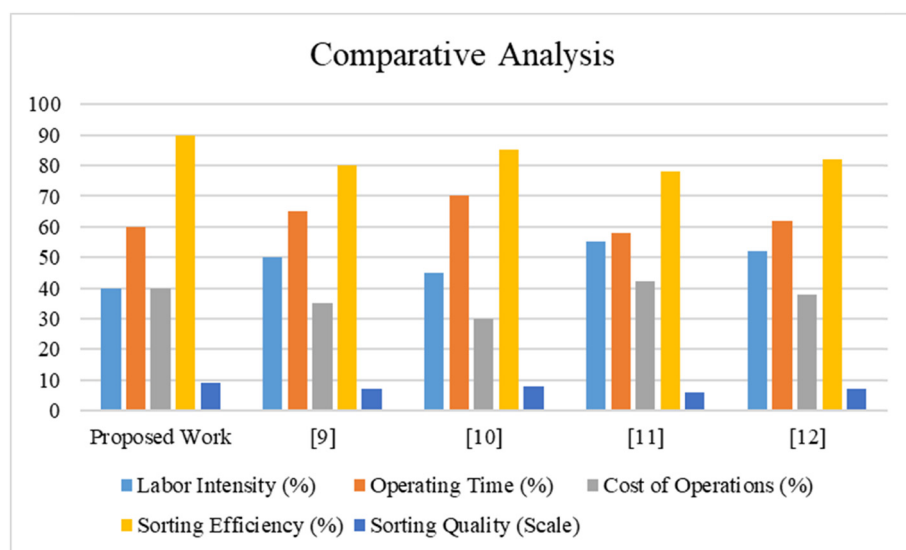
Study	Control technologies	RFID Integration	Simulation tool	P Parameter (optimal)	Adjustment speed	System oscillation	Overall performance
Proposed Work	Single-Chip Microcomputer, PID, MATLAB	Yes	MATLAB	0.12	Moderate	None	Satisfactory
[8]	PID	No	Not specified	0.08	Slow	None	Suboptimal
[9]	PID	No	Not specified	0.18	Fast	Oscillation	Unstable
[10]	Proportional-Integral	Yes	Not specified	0.15	Moderate	None	Satisfactory
[10]	Not specified	Yes	Not specified	0.1	Slow	None	Moderate

parameter, Experiment 3 achieves a fast motor speed of 350 rpm with good performance. Experiment 4's overly high P value causes system oscillation, leading to motor instability at 200 rpm. In Experiment 5, we achieve a good motor speed of 280 rpm by using a well-balanced P parameter, which ensures steady and anticipated overall performance. A comparison between the suggested study and four previous studies on logistics distribution automation is shown in Table 4. It includes important variables, including control technologies, RFID integration, modeling tools, ideal P parameter values observed, adjustment speeds, oscillation events in the system, and overall performance results. The suggested work exhibits satisfactory performance with a moderate P parameter and little system oscillation by utilizing PID algorithms, single-chip microcomputer control, and MATLAB simulations. On the other hand, the methodologies and results of previous research differ, emphasizing the distinctiveness of every methodology. By showing a good example, sample values show how the suggested integrated approach might be better than traditional PID-focused and RFID-integrated systems.

The important logistics metrics – labor intensity, operating time, cost of operations, sorting efficiency, and sorting quality – between the planned study and four previous studies are presented in Figure 5. It gives a summary of the key areas in which the proposed work varies from previous research in the field of logistics performance. In summary, the suggested approach shows advantages over the researched logistics methodologies, including lower labor intensity, shorter operating times, and better sorting efficiency.

5 Conclusion

In the world of e-commerce, logistics is crucial, and sorting is a basic function in this industry. According to research, sorting activities are the most labor-intensive and time-consuming, and they also contribute significantly to costs, with operational time and human resources accounting for a large amount of logistics center costs. Of the entire costs of a logistics center, operating time exceeds 60% and accounts for around 40%. Human resources alone account

**Figure 5:** Comparative analysis of the proposed study with existing models for Labor Intensity, Operating Time, Cost of Operations, Sorting Efficiency, and Sorting Quality.

for nearly 50% of these costs. In light of this, effective logistics and warehousing solutions are essential for market expansion. This study's concept and design of the sorting and handling robot offer a workable remedy for the inefficiencies found in conventional sorting procedures. By using a PID algorithm to manage the robot's motor drive and leveraging microcontroller control technology, the system makes item handling easy and effective. The integration of RFID scanners for automatic sorting greatly improves the efficiency and quality of the sorting process. Through its practical value in maximizing resource usage and cutting operational expenses, this research advances intelligent logistics systems. Subsequent investigations may concentrate on augmenting the flexibility and expandability of the suggested sorting and handling robot. Investigating sophisticated control algorithms, machine learning strategies, and sensor technologies can further optimize the robot's performance, enabling it to handle a wider variety of objects and dynamic logistical settings. Furthermore, looking into data analytics and real-time networking can help to continuously improve the system's responsiveness and efficiency, bringing it closer to the changing needs of contemporary logistics practices.

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