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Design and Development of Smart Warehouse Robot Prototype

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Abstract:*Efficient warehouse management depends heavily on accurate and reliable automation systems for inventory handling. This research paper presents a prototype of a smart warehouse robot designed to fulfil the objective of efficiently picking and placing boxes by utilising a colour-sensing system for identifying the correct placement in racks. The robot employs a lifting mechanism inspired by forklifts, consisting of a 12V DC motor, a rack and pinion, and a slider bar. The robot also features an obstacle avoidance system using an ultrasonic sensor and a buzzer, while navigation is done through two IR sensors. The colour-sensing system is done with the help of a TCS 3200 colour sensor and helps the robot to identify the colour codes on the boxes to determine their correct placement in the racks. The system is controlled by an Arduino Uno and uses five DC 12V motors, two L293D motor drivers, a TCS 3200 colour sensor, an ultrasonic sensor, a buzzer, and a rack and pinion with a slider bar for the lifting mechanism. The robot's performance was tested in a simulated warehouse environment, demonstrating accurate and efficient performance in picking and placing boxes. This research offers valuable insights into the development of smart warehouse robots, promoting sustainable warehouse management practices and enhancing overall efficiency.*

Keywords:TCS Color Sensor,IR Sensor, 12V DC Motors, Arduino UNO, L293D Motor Driver.

I. INTRODUCTION

In recent years, the use of robots in various industries, including warehousing, has seen a significant increase. Warehouse robots are designed to automate processes, improve efficiency, and reduce labor costs. However, current warehouse robots have limitations, particularly in tasks such as lifting and transporting heavy boxes while avoiding obstacles. To address this issue, the primary objective of this research project is to design and develop a prototype warehouse robot with advanced sensing and navigation capabilities. The need for greater efficiency and productivity in the modern warehousing industry has made the development of a warehouse robot with advanced capabilities more important than ever. The use of robots not only reduces labor costs but also enhances workplace safety by automating hazardous tasks.

The proposed warehouse robot aims to fill the gap by incorporating obstacle avoidance technology using sensors to detect obstacles in its path and navigate around them. Additionally, the robot will be equipped with a lifting mechanism capable of lifting boxes of varying weights and sizes, making it versatile for use in different warehouse settings. To achieve the objectives outlined in the previous sections, a robotic prototype was designed and built using a variety of components and technologies. The robot was designed to be capable of lifting and transporting boxes while avoiding obstacles in its path, and it was equipped with a range of sensors and intelligent features to achieve this goal. The robot was built on a frame made from wood as it is a prototype and mounted on four high-torque 12VDC motors, which provided the power and mobility required to transport boxes across the warehouse floor.

The lifting mechanism consisted of a linear actuator that was capable of lifting boxes, the lift system is inspired by forklift. To ensure the robot could navigate around obstacles in its path, several sensors were integrated into the design. The robot used ultrasonic sensors mounted on the front of the chassis to detect obstacles in its path, and TCS3200 color sensors were used to identify the colors of boxes and determine their destinations. In addition, a microcontroller based on the Arduino Uno platform was used to control the robot's movements and coordinate its various functions. The robot was programmed using C, with code developed to control the motors, lift mechanism, and sensor inputs. The code was designed to be modular and scalable, allowing for easy modification and expansion as required.

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II. COLOR SENSOR TCS3200

The TCS3200 color sensor can detect a wide variety of colors based on their wavelength. This sensor is especially useful for color recognition projects such as color matching, color sorting, test strip reading and much more. Here's the sensor specifications:

- Power: 2.7V to 5.5V
- Size: 28.4 x 28.4mm (1.12 x 1.12″)
- Interface: digital TTL.
- High-resolution conversion of light intensity to frequency
- Programmable color and full-scale output frequency
- Communicates directly to microcontroller

Construction:

The TCS3200 color sensor typically comes in a small rectangular package with four photodiodes arranged in a 2x2 matrix, along with color filters covering each photodiode. The color filters are designed to allow specific wavelengths of light to pass through, corresponding to red, green, blue, and clear (no filter) colors. The sensor package also includes pins for power supply, ground, and frequency output. The TCS3200 color sensor can be easily interfaced with microcontrollers or other electronic devices for color sensing applications. It requires an external light source, such as a white LED, to illuminate the object being sensed. The frequency output from the sensor can be connected to a microcontroller input pin, which can then be used to calculate the RGB components of the detected color based on the frequency of the output signal.

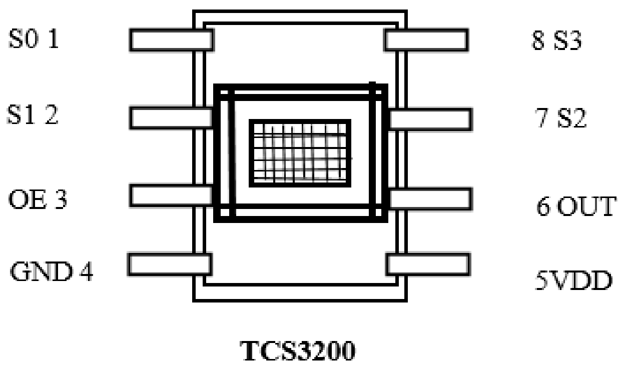

Figure 1: Circuit Diagram of TCS3200 Color Sensor

Pin Name	I/O	Description
GND (4)		Power supply ground
OE (3)	I	Enable for o/p frequency
OUT (6)	O	Output frequency
S0, S1 (1,2)	I	O/P frequency scaling selection inputs
S2,S3 (7,8)	I	Photodiode type selection inputs
VDD (5)	Voltage Supply	VDD (5)

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Filter selection: The photodiodes are connected in parallel and can be selected by setting the control pins S2 and S3 to different combinations of LOW and HIGH states. Refer to the table below for the different color selections available.

Photodiode Type	S2	S3
RED	LOW	LOW
BLUE	LOW	HIGH
GREEN	HIGH	HIGH
No Filter (Clear)	HIGH	LOW

The Working Principle of TCS3200 Color Sensor: The TCS3200 color sensor is based on the principle of color filtering and photodiode array. It consists of a grid of color-sensitive filters, also known as the Bayer filter, and an array of photodiodes underneath. The color sensor module typically includes a high-intensity white LED that projects modulated light onto the object being sensed. The light reflected from the object passes through the Bayer filter, which consists of four filters - red, blue, green, and clear (no filter) - arranged in a pattern known as the Bayer pattern. The TCS3200 color sensor operates by detecting the intensity of light at different wavelengths. The photodiodes in the array are designed to detect specific colors of light depending on the filter they are placed under. When light passes through the filters, it is absorbed by the photodiodes, generating an electrical current proportional to the intensity of the light. The intensity of light is measured by the frequency of the square wave output generated by the sensor. Frequency Measurement

The TCS3200 color sensor has an internal current-to-frequency converter that converts the output from the photodiodes into a square wave whose frequency is proportional to the intensity of the chosen color. The output frequency of the sensor typically ranges from 2 Hz to 500 kHz, depending on the intensity of the detected color. The frequency of the square wave output is determined by the intensity of light falling on the photodiodes. Higher intensity of light results in a higher frequency output, while lower intensity of light results in a lower frequency output. This frequency measurement allows the sensor to quantify the intensity of each color component (red, green, and blue) in the reflected light from the object being sensed. Color Recognition: The color of the object being sensed is determined by measuring the relative level of red, green, and blue light using the frequency output of the TCS3200 color sensor.

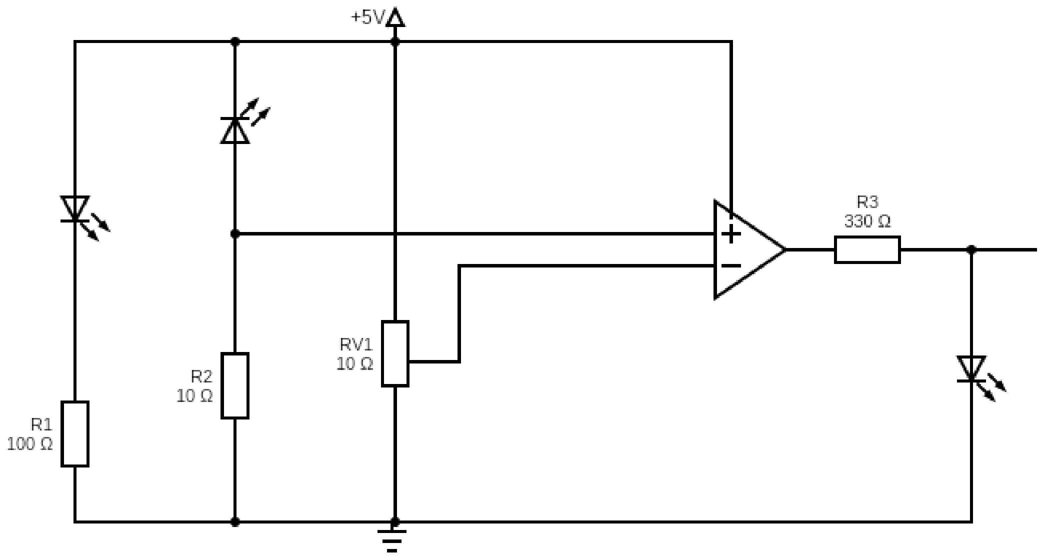
The frequency of each color component is compared to a reference value or a pre-defined threshold to determine the color of the object. The TCS3200 color sensor module provides control pins (S2 and S3) that allow selection of the color array to be read by enabling specific photodiodes. By selectively enabling the photodiodes under the red, blue, and green filters, the sensor can measure the intensity of each color component separately. The intensity of each color component is then converted into a frequency by the internal current-to-frequency converter, and the frequency output is used to determine the color of the object based on the pre-defined thresholds or reference values.

Conclusion: In conclusion, the TCS3200 color sensor works based on the principle of color filtering and photodiode array. It uses a grid of color-sensitive filters and an array of photodiodes to detect the intensity of light at different wavelengths. The internal current-to-frequency converter converts the output from the photodiodes into a square wave whose frequency is proportional to the intensity of the detected color. The frequency output is used to determine the color of the object being sensed based on pre-defined thresholds or reference values. The TCS3200 color sensor is widely used in various applications, such as color detection, color sorting, and color-based automation systems. Further research and development of the TCS3200 color sensor can lead to improved color sensing technologies and applications in fields such as robotics, industrial automation, and smart devices.

II. IR SENSOR

These sensors consist of a matched pair of an IR transmitter and an IR receiver. When the IR transmitter emits infrared rays onto the surface, the receiver measures the amount of light that is reflected back. White surfaces generally reflect a significant amount of light, while black surfaces reflect very little. By analyzing the reflected IR rays, the robot can determine whether it is on a white or black surface. To ensure accurate detection, the IR reflectance sensors need to be shielded from ambient light, and the distance between the sensors and the reflective surface should be small, ideally between 2 to 10 mm. In the robot design, eight sensors are used, and their positioning in relation to each other is critical. The distance between sensors needs to be adjusted depending on the line width of the path being followed. If the line width is thin, the distance between sensors must be reduced to ensure timely detection of curves in the line path. The analog signals from the IR sensors need to be converted to digital form for processing by the robot's microprocessor.

This can be achieved by using an external Analog-to-Digital Converter (ADC). In the design, the LM324 ADC is used, with two LM324 chips supporting eight sensors. The resistance of the receiver sensor decreases when exposed to IR radiation, and a good sensor will have near-zero resistance in the presence of the rays, and a high resistance in their absence. This property can be utilized to create a potential divider circuit, which allows for the conversion of the analog signals from the sensors to digital form for further processing by the robot's processor. In summary, the robot design incorporates IR reflectance sensors that emit and detect IR rays to follow a line path. The sensors are positioned close to the reflective surface and shielded from ambient light. The analog signals from the sensors are converted to digital form using an external ADC, and the resistance change of the sensors due to IR radiation is utilized in a potential divider circuit. This allows the robot to accurately detect the line path and navigate along it.



The IR sensor used in the line following robot consists of a matched pair of an IR transmitter and an IR receiver. These components are typically housed in a compact module. The IR transmitter emits infrared rays onto the surface, while the IR receiver measures the amount of light that is reflected. The module is designed to have a small distance between the transmitter and receiver, typically around 2 to 10 mm, to ensure accurate detection of the reflected rays.

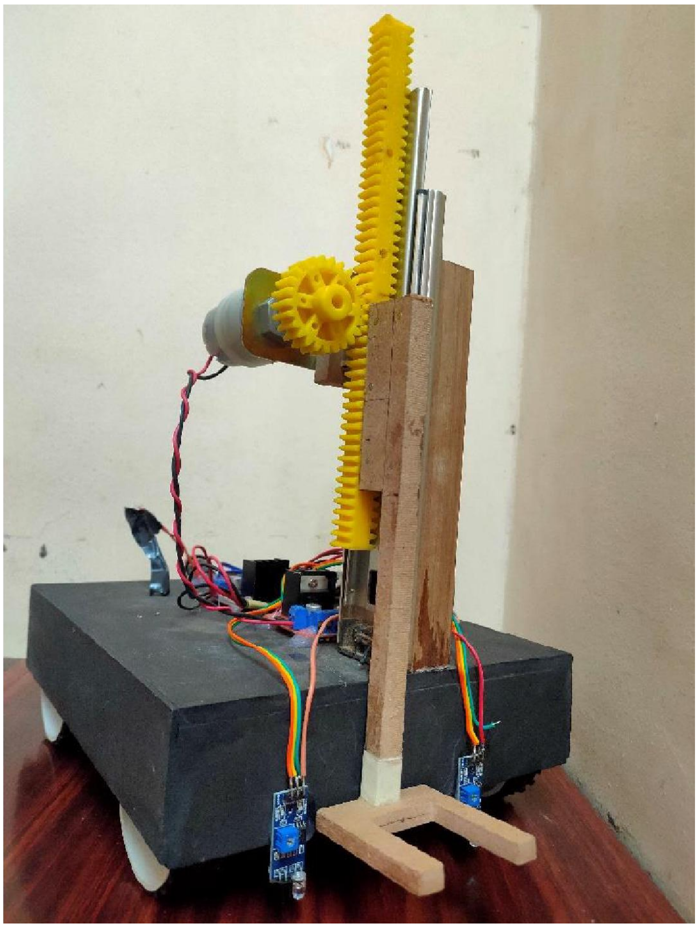
The IR sensor operates based on the principle of reflectance. When the IR transmitter emits infrared rays onto a surface, the number of reflected rays depends on the color and reflectivity of the surface. White surfaces generally reflect a significant amount of light, while black surfaces reflect very little. The IR receiver measures the intensity of the reflected rays and generates an analog signal that represents the detected light intensity. To convert the analog signals from the IR receiver to digital form for processing by the robot's microprocessor, an external ADC is used. In the design, the LM324 ADC is utilized, with two LM324 chips supporting eight sensors. The resistance of the IR receiver sensor changes with the intensity of the IR radiation it receives. A good sensor will have near-zero resistance in the presence of the rays, and a high resistance in their absence.

This property of the IR receiver can be utilized in a potential divider circuit. The analog signal from the IR receiver is connected to the input of the LM324 ADC, and the sensor's resistance is connected in series with a fixed resistor to create a voltage divider. The voltage across the IR receiver sensor is measured at the junction of the two resistors and is converted to a digital value by the ADC. This digital value represents the detected light intensity and can be processed by the robot's microprocessor to determine the position of the line path. The positioning of the IR sensors on the robot is critical for accurate line following. The sensors need to be positioned close to the reflective surface and shielded from ambient light to minimize interference. The distance between sensors may need to be adjusted depending on the line width of the path being followed. If the line width is thin, the distance between sensors needs to be reduced to ensure timely detection of curves in the line path. In summary, the IR sensor in the line following robot uses an IR transmitter and an IR receiver to emit and detect infrared rays for line detection. The analog signals from the IR receiver are converted to digital form using an external ADC, and the resistance change of the IR receiver due to IR radiation is utilized in a potential divider circuit. This allows the robot to accurately detect the line path and navigate along it. Proper positioning and shielding of the sensors are crucial for reliable operation.

III. EXPLANATION OF THE DESIGN AND IMPLEMENTATION PROCESS OF THE SMART WARE HOUSE ROBOT

Body Construction:

The body of the robot is meticulously constructed using high-quality wood, selected for its durability, strength, and ability to withstand the demands of the robot's operation. The wood is carefully cut and shaped to form a robust base and frame, providing ample space for accommodating the electronic components, as well as ensuring stability and reliability during the robot's operation.



Lift System:
The lift system of the robot is designed with precision, incorporating a slider bar and gear and pinion mechanism. A 12V DC motor is utilized to power the lifting mechanism, which is connected to a gear system for efficient and reliable lifting capability. The slider bar enables smooth vertical movement of the lifting mechanism, allowing the robot to pick and drop objects with precision and accuracy.

Mobility:
The robot is equipped with four 12V DC motors, each with a speed of 30 RPM, for mobility. These motors are connected to a motor driver L293D, which is controlled by an Arduino Uno. The motor driver provides precise control over motor speed and direction, enabling the robot to move in various directions and navigate through obstacles with ease.

Color Recognition:
The robot is equipped with a TCS3200 color sensor for accurate color recognition. The color sensor is capable of detecting RGB colors and provides analog output signals. The Arduino Uno processes these signals to determine the color of the object placed in front of the sensor.

Path Following System:
The robot utilizes two infrared (IR) sensors positioned at the front of the bot for efficient path following. These IR sensors use infrared rays to detect the color of the surface and determine the path to follow. The IR sensors consist of a matched pair of infrared transmitter and receiver. The receiver measures the amount of reflected light and sends analog signals to the Arduino Uno for processing. The robot is programmed to follow a specific path based on the color detected by the color sensor.

Working:
Color Recognition:
The robot initiates the color recognition process by using the TCS3200 color sensor to detect the color of the object in front of it. The sensor emits light on the object, and the reflected light is captured by the sensor. The sensor converts the RGB color information into analog signals, which are then processed by the Arduino Uno.

Object Lifting:
Once the color is recognized, the robot utilizes the lifting mechanism to pick up the object. The DC motor attached to the gear system drives the lifting mechanism, allowing it to slide up and securely grip the object. The robot can then move to the desired destination while safely holding the object with the lifting mechanism.

Path Following:
The robot employs the two IR sensors at the front to accurately follow the path. The IR sensors emit infrared rays on the surface, and the reflected rays are received by the sensors. The Arduino Uno processes the analog signals from the sensors and determines the color of the surface (white or black). Based on the color detected, the robot adjusts its motor speed and direction to correctly follow the designated path.

Object Dropping:
Once the robot reaches the designated destination based on the color, it uses the lifting mechanism to lower and drop the object. The lifting mechanism smoothly slides down, releasing the object at the intended location.

Conclusion:
The wood-based robot with color recognition and path following system is designed and implemented using Arduino Uno, DC motors, motor driver L293D, TCS3200 color sensor, and IR sensors. The robot showcases efficient color recognition and path following capabilities, making it suitable for various applications such as automation, logistics,

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and transportation. The meticulous construction of the wooden body, precise lift system, and reliable mobility mechanism allow the robot to accurately detect colors, pick and drop objects, and follow designated paths, making it a promising solution for diverse practical applications.

IV. OVERVIEW OF IOT AND MECHANICAL SYSTEMS

The Internet of Things (IoT) is a system of physical devices, vehicles, buildings, and other objects that are equipped with sensors, software, and network connectivity, allowing them to gather and exchange data. This technology is built upon the idea of linking ordinary objects to the internet, allowing them to communicate and exchange information with each other and with humans with proper interface.

When combined, IoT and mechanical systems can create powerful and intelligent systems that can automate processes, optimize operations, and improve efficiency in various domains. For example, IoT sensors can collect data on environmental conditions, machine performance, or product quality, which can then be processed and analyzed by the mechanical system to make informed decisions and take appropriate actions. The integration of IoT and mechanical systems can bring numerous benefits. Real-time data collection from IoT sensors allows for better monitoring, control, and optimization of mechanical systems, leading to increased efficiency, reduced downtime, and improved safety. Additionally, the ability of IoT devices to communicate with each other and with humans enables remote control, monitoring, and management of mechanical systems, allowing for more flexible and convenient operations. In various industries, the combination of IoT and mechanical systems has the potential to revolutionize processes and operations. For example, in manufacturing, IoT sensors can collect data on machine performance, predictive maintenance needs, and supply chain optimization, which can then be used by the mechanical system to optimize production processes and reduce downtime. In smart cities, IoT sensors can collect data on traffic patterns, environmental conditions, and energy usage, which can be used by the mechanical system to optimize transportation systems, manage resources, and improve sustainability.

The project revolves around the development of a warehouse robot that incorporates IoT sensors and a mechanical system. The IoT sensors are advanced sensors that are capable of collecting various types of data, such as motion, temperature, humidity, and pressure, and transmitting this data to other devices or the cloud for processing and analysis. These sensors are integrated into the robot to enable it to gather real-time data on the environment and its surroundings. The mechanical system of the warehouse robot includes mechanisms, actuators, and components that allow it to navigate, move, and perform tasks within the warehouse. The mechanical system is designed to work in tandem with the IoT sensors, allowing the robot to interpret the data collected by the sensors and make informed decisions based on the environment it operates in. The IoT sensors and mechanical system work collaboratively to optimize the warehouse robot's operations. For example, the sensors can provide real-time data on the location and status of inventory, environmental conditions, and obstacles in the robot's path.

The mechanical system can then use this data to adjust the robot's movements, optimize its path, and perform tasks efficiently. The warehouse robot project aims to demonstrate the potential of IoT and smart sensor technologies in combination with a mechanical system for warehouse automation. The use of these technologies can enable more efficient and streamlined warehouse operations, such as inventory management, order picking, and item tracking. The project also seeks to showcase the benefits of using IoT and smart sensors for real-time data collection, analysis, and decision-making in a warehouse setting. Overall, the warehouse robot project aims to leverage the power of IoT sensors and a mechanical system to improve the efficiency, accuracy, and sustainability of warehouse operations. By integrating cutting-edge technologies, the project seeks to provide a practical solution for optimizing warehouse management and automation in the modern era.

V. FUTURE SCOPE

1. Full Automation with AI: The warehouse robot can be made fully autonomous by incorporating advanced AI algorithms. The robot can use computer vision and image recognition technologies to identify and locate the boxes in the warehouse, and autonomously pick and transport them to their destinations. The robot can also learn from its interactions and experiences, continuously improving its efficiency and accuracy in box recognition, path planning, and navigation.

2. Real-time Order Management: The warehouse robot can directly receive order information from a centralized database or an e-commerce platform. The robot can dynamically prioritize and optimize its tasks based on the order requirements, warehouse inventory, and delivery deadlines. This can enable real-time order management, reducing delays and improving customer satisfaction.
3. Path Planning and Navigation: With the help of AI, the warehouse robot can intelligently plan and optimize its path within the warehouse without the need for external sensors like infrared (IR) sensors. The robot can analyze the layout of the warehouse, identify the shortest and safest routes, and navigate through the aisles, avoiding obstacles in real-time. This can result in improved efficiency, reduced collision risks, and optimized space utilization.
4. Advanced Sensing and Perception: IoT sensors can be integrated into the robot to provide real-time data on the warehouse environment. This may include sensors for temperature, humidity, lighting, and even RFID sensors for tracking inventory. The robot can use this data to make informed decisions on box handling, storage, and retrieval, ensuring optimal conditions for the stored items.
5. Scalability and Flexibility: The warehouse robot can be designed to be scalable and adaptable to changing warehouse layouts, inventory types, and order volumes. The robot can be easily reconfigured or expanded to accommodate new requirements or business growth. This can provide long-term sustainability and flexibility in meeting evolving warehousing needs.
6. Integration with Warehouse Management Systems: The warehouse robot can be integrated with existing warehouse management systems (WMS) or enterprise resource planning (ERP) systems, creating a seamless flow of data and information. This can enable better coordination and synchronization of tasks, leading to improved overall warehouse operations and productivity.

In conclusion, the future scope of your warehouse robot project integrating IoT and mechanical systems is promising, with potential advancements in AI, automation, and sensing technologies. This can result in a fully autonomous, intelligent, and efficient warehouse robot that can recognize boxes, receive orders, plan paths, and navigate the warehouse, ultimately optimizing warehouse operations and enhancing customer satisfaction.

VI. CONCLUSION

In conclusion, our warehouse robot project, leveraging IoT and mechanical systems, presents a practical and efficient solution for optimizing warehouse operations. With the integration of IoT sensors and a user-friendly interface, the robot can effectively handle box recognition, order management, and path planning, leading to improved efficiency and reduced manual labor in the warehouse. And cut down the time it takes to manage the warehouse and reduce the error that occurs while processing the orders from warehouse.

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