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Unmanned Supermarket System Design Based on Internet of Things

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Abstract: Traditional supermarkets face several challenges, such as restricted shopping hours and long checkout queues, which negatively impact the consumer experience. To address these issues, this paper proposes an intelligent unmanned supermarket system based on the Internet of Things (IoT) and human hand bionics. The system consists of merchandise shelves, handling trolleys, storage cabinets, and servers, interconnected via a local area network (LAN). Each product is tagged with a barcode, stored in a database, and serves as the smallest IoT node, enabling seamless product identification and tracking.The system integrates multiple technologies, including image recognition, location navigation, Wi-Fi communication, and barcode scanning, with a Raspberry PI 3B and a 32-bit microcontroller serving as the core control units. This architecture resolves key challenges in automation, communication, and inventory management, ultimately enabling autonomous product retrieval, transportation, and real-time stock monitoring.

Keywords: Raspberry Pi; 32-bit microcontroller; Unmanned supermarket; Local Area Network (LAN); Embedded system

1. Introduction

In recent years, consumer shopping behaviors have diversified significantly as people pursue enhanced shopping experiences. Within the new economic landscape, retail innovation has become a crucial driver of industrial advancement. The application of IoT and big data technologies has laid a solid foundation for novel sales models, while developments in AI algorithms have provided technical support for offline unmanned retail. With technological progress and evolving consumer demands, AI applications have expanded across various sectors. As a key component of "smart retail," unmanned supermarkets have emerged as a focal area of development. Although China's research in this field started relatively late, and pilot unmanned supermarkets have been deployed in some cities, their intelligent capabilities still require improvement. Given the rapid advancement of IoT technology, the proposed "IoT-based Intelligent Unmanned Supermarket System" presents an optimal solution to address these challenges.

2. System Architecture Design

The integrated system architecture encompasses two core components: the autonomous handling trolley and the intelligent shelf structure. The trolley's comprehensive design incorporates three interdependent subsystems - mechanical configuration, electronic circuitry, and control programming. The mechanical system integrates optimized wheel assemblies, a modular chassis design, and a multi-degree-of-freedom robotic arm. The electronic system features a central control unit coupled with dual-channel motor drive circuitry. The programming framework implements SLAM-based mapping with real-time localization, computer vision for obstacle detection and avoidance, automated object retrieval control, and multi-sensor data fusion processing.

3. Equipment Scheme Design

3.1 Body and Chassis Design

The chassis serves as the fundamental structural platform for the autonomous handling trolley, requiring precise arrangement of electronic components to ensure optimal functionality. This design employs a four-wheeled configuration utilizing independently controlled brushless motors with Mecanum wheel technology, selected for its superior efficiency, minimal maintenance requirements, and exceptional maneuverability. The lower chassis integrates Mecanum wheels with their corresponding motor drives, LiDAR sensors, the central Raspberry Pi controller, and power systems, while the upper platform accommodates the robotic manipulator, storage compartments, and vision systems. This innovative arrangement enables omnidirectional movement - including lateral, longitudinal, and rotational motions - through coordinated wheel speed and orientation control.[1]

The chassis system integrates these key components: an Arduino Teensy 3.1 microcontroller for motion control, a GY-85 IMU (Inertial Measurement Unit) for orientation tracking, four L298N motor drivers with optical encoder feedback, and four Mecanum wheels for omnidirectional mobility.

3.2 Robotic Arm Design

Robotic arms are electromechanical devices that employ articulated mechanical structures and advanced control systems to perform automated operations. These systems typically emulate the kinematic functionality of the human arm to execute diverse tasks across industrial, medical, service, and agricultural applications. The operational flexibility of a robotic arm is fundamentally determined by its degrees of freedom (DOF), making DOF classification crucial for understanding robotic arm capabilities. Robotic arms can be categorized based on degrees of freedom as follows[2].

(1) Underactuated Robotic Arm: Characterized by having more degrees of freedom than actuated joints. The limited number of actuators necessitates sophisticated control algorithms to compensate for unactuated directions and achieve desired task performance.

(2) Redundant Robotic Arm: Features a greater number of degrees of freedom than minimally required for end-effector positioning. While this configuration enhances dexterity and manipulability, it introduces significant control complexity in coordinating multiple joints to achieve target configurations.

(3) Six-Degree-of-Freedom Robotic Arm: A fully articulated manipulator with six independent motion degrees of freedom, comprising three translational (x, y, z axes) and three

rotational (roll, pitch, yaw) degrees. This configuration enables comprehensive spatial manipulation and precise orientation control for complex operational requirements.

For this design, a six-degree-of-freedom robotic arm architecture has been selected to ensure the robotic vehicle can rapidly and accurately execute goods-handling operations. The complete mechanical configuration is illustrated in Figure 1.

Figure. 1 Robotic arm

4. Hard Ware Design

4.1 Main Controller Module Design

This system is an autonomous navigation system based on ROS, with Raspberry Pi 3B as the core, which is the host computer of the whole system. The main function is to collect the environmental information obtained by LiDAR and the wheel speed data obtained by photoelectric encoder, and upload the collected data to the ROS system, through the processing of the uploaded data, it is able to calculate the current position information and acceleration information of the handling trolley, and then send the new command to the lower computer control layer, and at the same time equipped with IMU sensors to calibrate the various parameters, to achieve the control of the trolley, construction of maps and navigation[3].

The lower computer is the motion control layer, which receives the signals transmitted from the Raspberry Pi, converts the speed signal into a digital-analog signal and sends it to the motor drive module to control the movement of the robot cart, and transmits the speed of the motors back to the drive board to realize closed-loop control[4]. The control system connection diagram is shown in Figure 2.

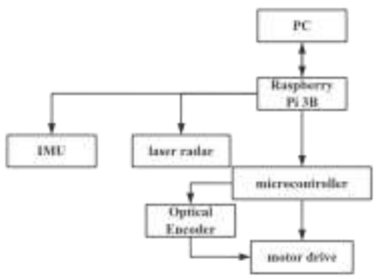

Figure. 2 Main controller connection diagram

4.2 Motor Drive Module

The truck achieves comprehensive motion control through independent operation of four 57-series stepper motors, enabling forward/backward movement, diagonal travel, and rotation. This functionality is implemented using L298N motor driver modules, which receive direct pulse signals from the controller to independently regulate each motor. The L298N modules represent high-efficiency dual H-bridge motor controllers capable of bidirectional speed control for both DC and stepper motors, featuring a 25W power rating and 46V maximum operating voltage. Designed for robotics and automation applications, these drivers incorporate standard logic-level signal compatibility while maintaining independent enable/disable functionality regardless of input signals.

The L298N module features a dedicated 5V logic power input for its internal circuitry along with two enable controls (ENA and ENB). The front motor's bidirectional speed control is achieved by activating ENA and using IN1/IN2 inputs to drive OUT1/OUT2 outputs, while the rear motor is similarly controlled through ENB activation with IN3/IN4 inputs driving OUT3/OUT4 outputs. This dual-channel architecture enables independent yet synchronized control of both drive motors.

4.3 Radar Navigation Module

The system employs the Silan Rpliar Al Lidar for environmental perception, which provides millimeter-level distance measurement accuracy with high-frequency laser scanning capabilities. This 360-degree rotating lidar rapidly captures dynamic environmental data and generates comprehensive point clouds for enhanced spatial awareness. For SLAM implementation, the system utilizes the Gmapping algorithm from the ROS open-source ecosystem - currently the most mature and widely-used filtered SLAM solution[5]. The ROS host processes raw lidar data through the RPLIDAR SDK, converting it into standardized LaserScan messages. These sensor_msgs/LaserScan messages, combined with odometry data, feed into the Gmapping node to construct real-time 2D occupancy grid maps. Figure 3 illustrates the complete workflow of this Gmapping implementation.

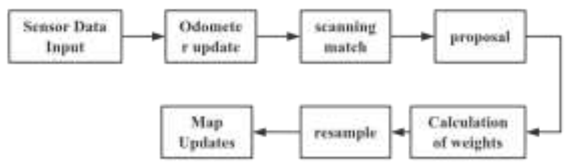

Figure. 3 Flowchart of Gmapping algorithm

5. Software Design

5.1 Path Planning

The path planning module consists of two parts: the LiDAR and odometer information connected to the Raspberry Pi, and the program that publishes the coordinates of the navigation points, which is mainly used to obtain the map information to the Raspberry Pi 3B, and then the Raspberry Pi processor analyzes and processes the information[3]. The navigation function requires a map to be constructed in advance in order to navigate, and the program processes the map into two costal maps to preserve real-world obstacle information[6].

5.2 Vision-based Obstacle Detection

In this system, visual recognition complements LiDAR for enhanced obstacle avoidance in supermarket environments. The implementation utilizes Python's OpenCV library with Haar feature-based cascade classifiers, specifically employing the detectMultiScale function for robust pedestrian detection through face and leg recognition.

Use python code to load the opencv module, import the training data, use the function related to recognizing the face and legs of a person to detect each frame of the image, and after recognizing the legs of a person with the LIDAR to measure the distance from the customer to achieve the effect of obstacle avoidance.

5.3 Object Grasping Control

The system utilizes QR-code labeled products arranged in predefined order. Upon order reception, the robotic trolley autonomously navigates to the target zone. The control system then initiates a precision positioning routine: (1) lateral micro-adjustments via chassis control while continuously scanning QR codes, (2) image-based spatial calculation to determine product relative position, and (3) longitudinal fine-tuning until reaching optimal operational range. Finally, the main controller triggers the robotic arm's pickup sequence to complete the retrieval task. The fetch flowchart is shown in Figure 4.

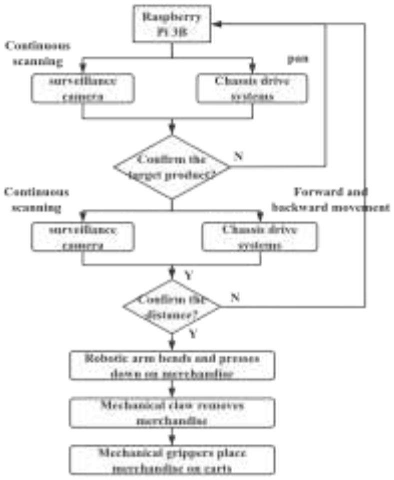

Figure. 4 Retrieval Flowchart

6. System Testing

Consumers can choose the goods they need in the WeChat small program and then place an order, after the order is completed WeChat public number will return to the customer a QR code, which is used to pick up the goods offline. The cart receives the commodity information and starts to build a radar map and search for traces autonomously. During the tracing process, the trolley uses the camera to read the QR code information on the shelves in order to calibrate the navigation route in real time.

During the autonomous positioning, the trolley realizes double calibration through the radar map and the face detection of the camera, effectively avoiding dynamic and static objects to ensure driving safety. When the trolley arrives at the merchandise location, the camera reads the QR code on the merchandise to further calibrate the trolley's position. Then the robotic arm on the smart shelf will automatically grab the commodity and put it into the storage box inside the cart.

After completing the grabbing of commodities, the handling cart will return to the storage cabinet position at the front counter according to the established route, and finally put the commodities into the designated storage cabinet. Through this intelligent process, the whole shopping process becomes more time-saving and convenient, providing customers with a better shopping experience.

7. Conclusion

Traditional supermarkets often require significant time for both product selection and checkout, particularly during peak hours. This paper presents an IoT-based unmanned supermarket system that integrates intelligent robotics to revolutionize the shopping experience. The proposed solution enables online ordering, where automated robots retrieve pre-selected items and store them in front-end cabinets for QR code-based collection. Compared to conventional models, this design offers three key advantages: (1) significant reduction in labor costs, (2) elimination of in-store shopping time, and (3) complete avoidance of checkout queues. With continuous technological improvements, this automated control system demonstrates substantial potential for transforming retail operations and has promising development prospects in smart commerce applications[7].

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