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Autonomous Theft Proof Robot for Item Delivery

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Abstract - **This paper presents the design and implementation of an Autonomous Theft-Proof Robot for Item Delivery. It aims to provide a secure and efficient solution for last-mile delivery in indoor and semi-structured environments. The proposed system combines autonomous navigation, obstacle detection, and a secure authentication method to prevent unauthorized access to delivered items. A Raspberry Pi-based controller manages sensor data collection, motor control, and security functions. Ultrasonic sensors allow for real-time obstacle detection, while the A* algorithm is used for autonomous path planning to ensure efficient navigation and dynamic rerouting. When the robot reaches its destination, access to the delivery compartment is limited by a password-based system that activates a servo-controlled locking mechanism only after successful verification. Experimental tests conducted in an indoor environment show reliable navigation, effective obstacle avoidance, and secure item delivery. This system provides a low-cost, scalable, and secure solution that is suitable for campuses, hospitals, offices, and institutional facilities.**

Keywords - Autonomous delivery robot, theft prevention, Raspberry Pi, A* path planning, obstacle detection, secure authentication, ultrasonic sensors.

I. INTRODUCTION

The rapid growth of e-commerce and on-demand delivery services has increased the need for secure, efficient, and self-sufficient last-mile delivery systems. Traditional delivery methods that rely on human assistance or courier services face challenges like higher labor costs, inefficient tracking, and more cases of package theft, also known as porch piracy [1], [2]. Surveys show that nearly one in three online shoppers has dealt with package theft, leading to major economic losses each year. The emergence of autonomous delivery robots provides a promising answer to these problems. They offer cost-effective, contactless, and theft-resistant delivery solutions for today's marketplace. Recent progress in embedded computing, machine learning, and IoT has made it possible to create small autonomous delivery systems at a reasonable cost. Single-board computers like the Raspberry Pi 4B help with real-time path planning, object detection, and network communication, allowing robots to make secure deliveries without needing human help [3]. The proposed system, called the Autonomous Theft-Proof Robot for Item Delivery, includes LiDAR, IR sensors, GPS, an IMU, and GSM communication. This setup ensures solid navigation, security checks, and theft prevention. The Raspberry Pi 4B serves as the main controller, managing data collection, path calculations, and user verification using Python-based software modules. The system is meant for short-range autonomous delivery in controlled areas like campuses, residential neighborhoods, and industrial parks. Its layered security model uses OTP-based verification, GSM alerts, and tamper detection to keep packages safe from unauthorized access. This creates an efficient and reliable delivery method.

A. Motivation: Concerns about package theft, especially during deliveries when no one is home, along with the need for automation and contactless logistics, drive this research. The COVID-19 pandemic increased interest in autonomous systems that can cut down on human contact while ensuring reliable deliveries. Although some existing solutions are innovative, they often lack multiple layers of security, are expensive to implement, or don't provide real-time theft prevention. This project aims to create a low-cost yet smart delivery robot that guarantees:

- Secure parcel delivery through OTP and GSM-based verification.
- Accurate navigation using a mix of sensors (IR, GPS).
- Immediate tamper alerts through IMU and GSM modules.
- Autonomous movement supported by real-time A* pathfinding algorithms.

By bringing together these technologies, this project hopes to connect affordable robotics with secure delivery systems, making a prototype that can be adapted for various uses in logistics, healthcare, and campus automation.

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II. LITERATURE REVIEW

This section reviews twenty relevant works on autonomous delivery robots and security/authentication techniques. Each entry follows the IEEE citation style, with a brief description and clear pros and cons. Citations appear in numeric IEEE format and match the References section at the end of the paper.

A. Survey of Key Works

IoT-Based Vehicle Safety and Security System Using Raspberry Pi, Patel and Khan [1]. Summary: This Raspberry Pi-based system combines facial recognition, ultrasonic sensing (HC-SR04), MQTT IoT integration, and SMS alerts (Twilio) for vehicle security. Pros: affordable hardware, real-time alerts, integration with mobile monitoring via MQTT. Cons: facial recognition is sensitive to lighting and pose, short obstacle detection range (≈30 cm), privacy concerns over stored images. [1]

Megatron: The Delivery Robot, Kumar et al. [2]. Summary: This Raspberry Pi 4B platform uses LiDAR, ultrasonic sensors, IMU, camera, and Bluetooth for navigation and monitoring. It reports high accuracy in obstacle detection and on-board streaming. Pros: robust multi-sensor collision avoidance, live video monitoring, precise distance sensing. Cons: increased cost due to LiDAR and vision stack, limited battery life, complex hardware/software integration. [2]

Autonomous Theft-Proof Delivery Robot for Food & E-commerce, Sharma et al. [3]. Summary: This Arduino Mega-based theft-proof delivery design features GPS, RF modules, a password-protected container, and an anti-theft siren for food and e-commerce delivery. Pros: straightforward anti-theft features (password + siren), relatively high payload capacity. Cons: lacks advanced navigation and networked authentication, less suitable for dynamic obstacle environments. [3]

Automated Guided Food Delivery Robot (line-follower design) [4]. Summary: This Raspberry Pi setup uses line sensors, a Pi Camera, L298N drivers, and PID control for indoor food delivery and tray handling. Pros: efficient for structured indoor routes, fast charging, and durable chassis. Cons: restricted to pre-defined paths, limited payload, reduced flexibility in unstructured environments. [4]

Privacy-Preserving Robotic Multi-factor Authentication, Mehrab et al. [5]. Summary: This approach uses a transformer-based audio-visual fusion (ResNet + ECAPA-TDNN) combined with ECC cryptography for robust face and voice verification and privacy preservation (tested on TurtleBot3). Pros: high resilience to adversarial attacks, strong cryptographic protection, multi-modal biometric security. Cons: computation and power hungry, relies on accurate biometrics under varied conditions, higher implementation complexity. [5]

Sidewalk Autonomous Delivery Robot (SADR), Singh et al. [6]. Summary: This level-4 sidewalk robot uses GPS, LiDAR, and multiple cameras for urban navigation and route optimization. Pros: capable of long operating hours and varied urban tasks, optimized routing for efficiency. Cons: regulatory constraints for sidewalk deployment, vulnerability to vandalism and theft, limited ability on stairs and complex terrain. [6]

Design and Implementation of Autonomous Car using Raspberry Pi, Pannu et al. [7]. Summary: This Raspberry Pi system uses OpenCV for lane tracking, ultrasonic sensors for collision avoidance, and basic Wi-Fi remote control. Pros: low cost, good educational platform, integrates vision for lane guidance. Cons: limited processing and memory for heavy vision workloads, ultrasonic sensor range limitations. [7]

Autonomous Ground Vehicles (AGVs) for Urban Last-Mile Delivery, a survey/work on AGVs [8]. Summary: This overview covers AGV architectures, sensors (radar, LiDAR, cameras), energy systems, and cost per mile analyses for last-mile logistics. Pros: demonstrates cost efficiency and environmental benefits, flexible delivery models. Cons: high sensor costs for full autonomy, barriers in infrastructure and regulation. [8]

Smart Secure Shipping Infrastructure using Autonomous Robots (Siamese + QR), Kumar & Patel [9]. Summary: This hybrid authentication combines cooperative QR codes and non-cooperative Siamese network person re-identification, along with formal security analysis (ProVerif). Pros: combined cryptographic and visual methods increase resilience to replay and forgery, formal verification of protocols. Cons: complexity in deployment, privacy concerns from person re-identification, higher computing needs. [9]

Contactless Delivery Robot for Medical Applications, Sinha & Reddy [10]. Summary: This Arduino Uno-based robot is designed for hospital logistics and features Bluetooth, RFID, password-protected compartments, and line/IR navigation. Pros: reduces infection risk, well-suited to structured hospital corridors, simple and reliable. Cons: limited payload, Bluetooth/RF range issues in large facilities, less autonomy in open or unstructured spaces. [10]

Autonomous Delivery Robot (DonkeyCar based), an open-source ML approach [11]. Summary: This Raspberry Pi 3b+ uses the DonkeyCar stack, camera input for ML navigation, and Arduino for peripheral control, with training based on joystick data. Pros: leverages machine learning to improve with data, modular and open for experimentation. Cons: substantial data and training needed, security mechanisms for parcel protection are not addressed. [11]

Autonomous Delivery Robots (ADRs), taxonomy and architectures [12]. Summary: This comparative study covers ADR types (sidewalk, road, mothership) and common tech stacks (GPS, LiDAR, blockchain proposals). Pros: highlights scalability and integration potential, shows energy and routing benefits. Cons: practical deployment hampered by regulations and limited payload capacities. [12]

OTP-Based Authentication Model for Autonomous Delivery Systems Using Raspberry Pi, an OTP model study

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[13]. Summary: This study analyzes the implementation of GSM/SMS OTP verification for delivery events to securely unlock compartments. Pros: simple, low-cost authentication, widely compatible with basic GSM networks. Cons: depends on cellular network availability, potential latency in OTP delivery. [13]

Autonomous Delivery Robot to Prevent Coronavirus Spread, pandemic-response designs [14]. Summary: This design features autonomous robots with contactless handover and optional disinfection modules for safe deliveries. Pros: reduces human contact, adds sanitization benefits for critical supplies. Cons: added mechanical and chemical systems increase complexity and cost, navigation challenges in varied environments. [14]

Campus Courier: Autonomous Delivery Robot On-Campus, campus-scale deployment [15]. Summary: This campus robot uses LiDAR and GPS, focusing on user experience, path optimization, and secure locker access. Pros: well-suited for controlled campus areas, good user experience and route efficiency. Cons: performance drops in bad weather, high maintenance demands for multi-robot deployments. [15]

Intelligent Drug Delivery Robot Based on ROS, ROS and STM32 architecture [16]. Summary: This system combines STM32 low-level control with a Raspberry Pi running ROS for hospital logistics and scheduling. Pros: ROS offers modularity and community tools, scalable for complex tasks. Cons: heavy computational and integration demands, ROS may be excessive for very low-cost platforms. [16]

Meal Delivery Robot: Fusion of LiDAR and Machine Vision, Zhang et al. [17]. Summary: This design uses sensor fusion techniques that combine LiDAR mapping with machine vision to enhance obstacle classification and path planning. Pros: richer environmental awareness, leading to better avoidance and fewer false positives. Cons: higher costs for sensors and computation, fusion algorithms require calibration and tuning. [17]

E-Commerce Door Delivery Robot, multi-terrain and stair-capable concepts [18]. Summary: This design includes stair-climbing mechanisms, Wi-Fi and Bluetooth connectivity, and improved user interfaces for building deliveries. Pros: can reach multi-story customers, better accessibility for door-to-door delivery. Cons: mechanical complexity raises safety concerns, performance relies heavily on building infrastructure. [18]

Autonomous Theft-Proof Robot for Food and E-commerce (Improved Design), integrated anti-theft design [19]. Summary: This design combines GPS, camera surveillance, electronic locks, and alarms with multi-sensor navigation to prevent theft during last-mile delivery. Pros: comprehensive approach to theft prevention, multiple redundant alerts and locks. Cons: relatively high bill of materials cost, limited operational time without enhanced power solutions. [19]

Ditto: The Delivery Robot, depth-camera and QR localization [20]. Summary: This Raspberry Pi 4B+ platform utilizes a depth camera for segmentation, QR code localization, and a rack and pinion locking mechanism. Pros: accurate short-range localization, reliable locking through mechanical actuation. Cons: relies on QR infrastructure, depth cameras struggle in harsh lighting and reflective conditions. [20]

B. Cross-paper Observations and Identified Gaps The reviewed literature emphasizes common themes:

(i) sensor fusion (LiDAR + vision) improves obstacle detection and route reliability [2], [17];
(ii) multi-factor authentication (OTP, biometrics, QR) boosts delivery security but often increases computational or infrastructure demands [5], [9], [13];
(iii) power/runtime and cost trade-offs are crucial, as high-performance sensors drive up costs and energy use, limiting practical runtime [2], [17], [19]; and
(iv) regulatory and environmental constraints (sidewalk rules, weather, building interiors) heavily influence deployability [6], [18].

Based on these insights, this work aims to develop a low-cost Raspberry Pi 4B platform that integrates OTP/GSM authentication, Ultrasonic and IR sensor fusion for effective navigation, and IMU-based tamper detection. This approach addresses the gap between affordability and theft resistance highlighted in the literature.

III.SYSTEM DESIGN

The Autonomous Theft-Proof Robot for Item Delivery is a compact, modular, and cost-effective robotic system. It combines sensing, navigation, communication, and security features within one control framework. The system uses a Raspberry Pi 4B as the main processing unit. This unit connects with different hardware and software subsystems for autonomous operation, pathfinding, and theft prevention.

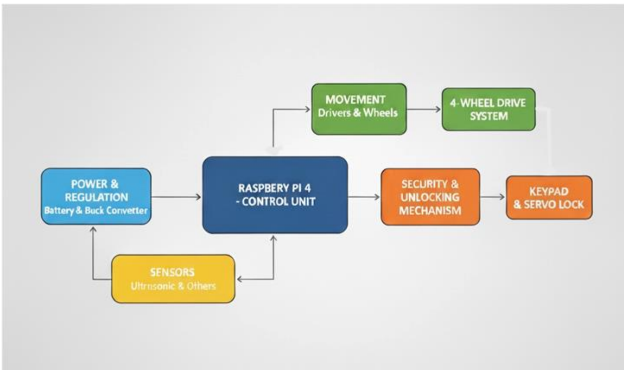

Fig. 3.1: Block Diagram

A. Overall Architecture:

The overall layout of the proposed system is shown in Fig. 3.1. The system is centered around a Raspberry Pi 4 control unit, which manages sensing, motion control, power regulation, and security tasks. The design is divided into four main functional units to ensure reliable movement and safe parcel handling.

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-The Power and Regulation Unit includes a battery supply and a buck converter. This unit provides the regulated voltage needed for the Raspberry Pi, sensors, motor driver, and locking mechanism. It ensures stable operation for both the logic and drive components.
-The Sensing Unit features ultrasonic sensors and other supporting sensors that help with obstacle detection and awareness of the environment. These sensors continuously send distance information to the Raspberry Pi, allowing the robot to identify obstacles and make movement decisions based on that data.
-The Movement and Drive Unit contains motor drivers linked to a four-wheel drive system. Using control signals from the Raspberry Pi, the motor driver controls the direction and speed of the motors with PWM signals, enabling the robot to move forward, turn, or stop.
-The Security and Unlocking Mechanism provides controlled access to the parcel compartment. It includes a keypad for user input and a locking mechanism based on a servo motor. Authentication occurs locally with a predefined password or OTP logic. If verification is successful, the servo motor unlocks the compartment; if not, access is denied.

This modular design makes system integration easier and allows the Raspberry Pi to make real-time decisions through continuous communication with sensors, actuators, and security components.

B. Hardware Implementation

The hardware design forms the physical basis for sensing, actuation, and communication tasks as shown in Fig 3.2. Each component was chosen for efficiency, cost, and compatibility with the Raspberry Pi 4B.

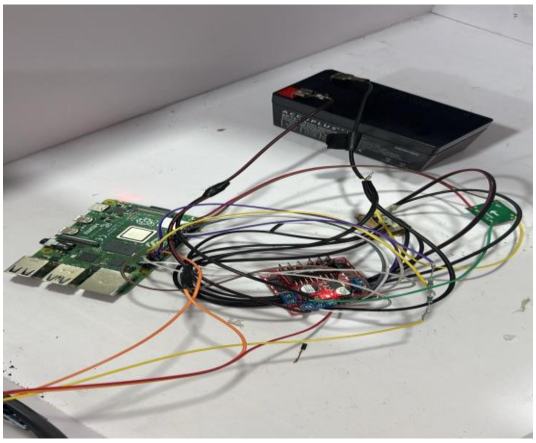

Fig 3.2: Hardware Connections

The Raspberry Pi 4 is the main control unit of the system. It processes sensor inputs, runs navigation logic, manages motor control, and handles the security and unlocking mechanism. The Raspberry Pi uses Raspberry Pi OS and supports Python-based control programs.

The sensing subsystem mainly includes ultrasonic sensors that measure the distance between the robot and nearby obstacles. These sensors give real-time feedback to the controller, enabling obstacle detection and collision avoidance.

The motion control subsystem has a motor driver connected to a four-wheel drive system. The motor driver gets control signals from the Raspberry Pi and drives the DC motors accordingly. PWM-based control allows precise adjustments of motor speed and direction.

The security subsystem includes a keypad and a servo motor lock. The keypad lets the user enter the authentication code, while the servo motor locks or unlocks the parcel compartment based on the verification results.

The power supply subsystem consists of a rechargeable battery and a buck converter, which lowers the battery voltage to suitable levels for the Raspberry Pi and other components. This provides consistent and safe power delivery during system operation.

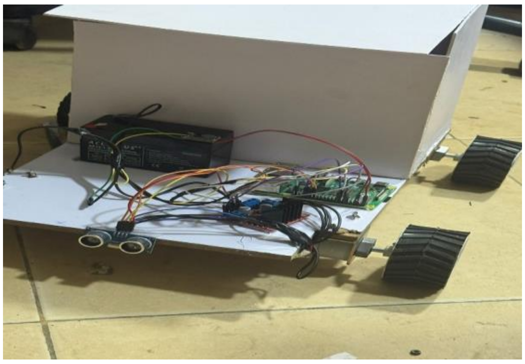

Fig 3.3: Chassis Design

C. Software Implementation

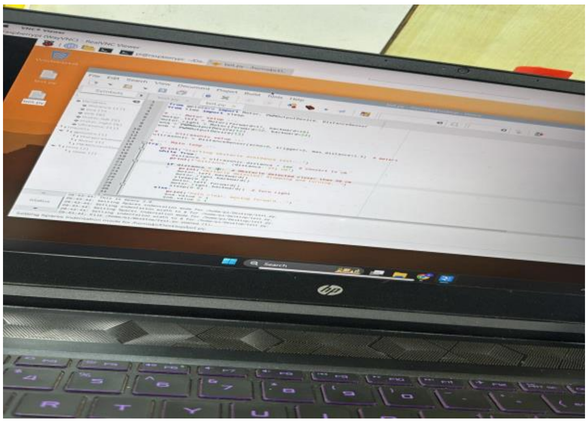

Fig 3.4: Software Implementation

The software implementation controls how the robot behaves and combines sensing, motion control, and security functions. It is developed using Python and runs on Raspberry Pi OS (Linux).

The system software is organized into modular routines. A sensor monitoring routine continuously reads data from the ultrasonic sensors to check for obstacles. A motion control routine processes the sensor data and creates the right control

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signals for the motor driver to avoid collisions and direct movement.

The authentication routine handles keypad input and checks the entered code. If the code is correct, it sends a control signal to the servo motor to unlock the parcel compartment. An incorrect code means access is denied, and the system stays locked.

GPIO-based libraries like RPi.GPIO are used to connect with motors, sensors, and the servo lock. The system follows a step-by-step process that includes initialization, obstacle detection, motion control, authentication, unlocking, and system shutdown.

D. Integration and System Performance Considerations

The combination of hardware and software components ensures smooth and reliable system operation. The Raspberry Pi manages sensor data acquisition, motor control, and security verification in real time. The system design focuses on simplicity, low cost, and reliability. This makes it suitable for controlled environments like campuses and indoor delivery applications. The modular approach allows for easy modification or expansion of system functionality in future implementations.

IV.RESULTS AND DISCUSSIONS

The proposed autonomous secure delivery robot was designed, built, and tested successfully in a controlled indoor environment. The system showed reliable performance in navigation, obstacle detection, secure access control, and motion execution. The results confirmed that a Raspberry Pi-based embedded platform can work for low-cost autonomous delivery applications.

-Navigation and Obstacle Detection Performance

The navigation system, powered by ultrasonic sensors connected to the Raspberry Pi 4, was tested in various obstacle scenarios. The sensors detected obstacles within a range of about 2 to 300 cm with acceptable accuracy. When an obstacle was found, the control algorithm initiated corrective motor actions, allowing the robot to stop or change direction effectively.

By combining sensor feedback and PWM-based motor control, the system ensured smooth maneuvering and reduced collisions. Although ultrasonic sensors have limitations, such as sensitivity to surface angles and soft materials, the system maintained consistent obstacle avoidance in structured indoor settings like corridors and laboratories.

-Motion Control and Drive System Analysis

The four-wheel drive system, managed with motor drivers, provided stable movement and enough torque to carry the payload. Differential steering allowed the robot to turn left, right, and rotate with reasonable precision. Using PWM signals enabled the robot to vary its speed, which helped control acceleration and deceleration.

Minor misalignments in straight-line motion were noted because of mechanical alignment and differences in wheel friction. However, these factors did not majorly affect overall navigation. The results show that the chosen drive mechanism works well for short-distance delivery tasks.

-Security and Access Control Evaluation

The security system, which includes a keypad-based authentication mechanism and a servo motor lock, performed reliably during tests. Authorized users could unlock the delivery compartment only after entering the correct password. Incorrect attempts kept the lock engaged, ensuring protection against unauthorized access.

The servo motor consistently moved at the correct angles, providing smooth locking and unlocking. This approach offers a simple and effective way to secure delivered items without needing complex communication systems.

-System Reliability and Power Performance

The power and regulation unit supplied stable voltage levels to both the Raspberry Pi and other components. The system operated continuously without unexpected resets or voltage drops during tests. Battery performance allowed sustained operation for the planned demonstration duration, proving the effectiveness of the power management design.

-Discussion

The experimental results confirm that the proposed system meets its design goals of autonomous navigation, obstacle avoidance, and secure delivery. Compared to traditional delivery methods, the robot reduces manual effort and improves security through controlled access. While the system performs well indoors, expanding to outdoor or unstructured areas will need more sensing and localization techniques.

Overall, the project shows a practical and cost-effective approach to autonomous secure delivery systems, making it suitable for applications like campus deliveries, offices, and controlled institutional environments.

V. CONCLUSION AND FUTURE SCOPE

This paper describes the design and implementation of an autonomous secure delivery robot that uses a Raspberry Pi 4 as its control unit. The system includes ultrasonic sensors for detecting obstacles, a four-wheel drive mechanism for controlled movement, and a keypad-based authentication system with a servo motor lock to ensure secure access to parcels. The proposed design emphasizes simplicity, cost efficiency, and reliable operation in indoor spaces.

Experimental tests showed that the robot can navigate structured areas, avoid obstacles, and securely deliver items with minimal human help. The motion control system provided stable and accurate movement, while the security mechanism effectively prevented unauthorized access. The power

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management and control setup ensured that the system operated continuously without interruption.

Overall, the prototype confirms the effectiveness of using embedded computing platforms for autonomous delivery tasks. The system is especially suitable for controlled environments like schools, offices, and hospitals. Future improvements could aim to enhance navigation accuracy, extend the operational range, and add localization and communication features to boost scalability and practical use in real-world settings.

Future Scope:

While the current implementation performs well in controlled settings, several improvements could enhance its real-world use:

- AI-Based Vision Recognition: Adding deep learning models for face verification and obstacle classification to improve authentication accuracy.

- Cloud and Mobile Integration: Creating a mobile app for real-time robot tracking, OTP management, and delivery status monitoring.

- Solar-Powered Operation: Using solar panels and dynamic power management for longer outdoor runtime. - Swarm Coordination: Implementing communication protocols for multiple robots to coordinate group deliveries in industrial areas.

- Blockchain Authentication: Utilizing distributed ledger technology for secure transaction and delivery record validation.

- Voice-Enabled Control: Integrating natural language and speech interfaces to improve user accessibility. These future directions will boost the scalability, intelligence, and sustainability of autonomous delivery systems. They will help create fully intelligent, theft-proof logistic networks for smart cities.

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