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TRANSVYA: Autonomous Document Delivery System

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Abstract

This paper presents the design and implementation of an autonomous file-transfer robot for secure and efficient document delivery within office environments. The proposed system integrates Bluetooth communication for wireless task assignment and status monitoring, along with RFID-based authentication to ensure secure access to sensitive documents. The robot operates on a wheeled platform and navigates predefined indoor paths using infrared (IR) sensors for line tracking and ultrasonic sensors for obstacle detection and avoidance. RFID tags positioned at designated workstations facilitate precise pick-up and delivery operations, while a servo-controlled locking mechanism secures the file compartment, permitting access only after successful authentication. A single RFID reader, interfaced via a logic-level converter, is shared efficiently across compartments, reducing hardware costs without compromising reliability. Experimental evaluation demonstrates the system's capability for autonomous navigation, secure document handling, and seamless wireless communication in controlled indoor settings. The proposed approach provides a scalable, low-cost, and practical solution for smart office automation, reducing manual intervention, enhancing operational efficiency, and ensuring confidentiality in document transfer processes.

Keywords: Autonomous Robot, RFID, Wi-Fi Communication, Obstacle Avoidance, File Delivery, Automation.

1. Introduction

In today's rapidly advancing world, automation is transforming industrial, commercial, and institutional operations, driven by Industry 4.0 and intelligent systems that shift tasks from human-dependent processes to automated solutions. Despite these advancements, the transfer of physical documents between departments remains largely manual, time-consuming, and prone to inefficiency. Manual handling consumes valuable resources and exposes sensitive information to human error, delays, and security risks, which can disrupt critical workflows in large organizations. Autonomous file-transfer robots address these challenges by integrating robotics, RFID-based authentication, advanced sensors, Wi-Fi communication, and IoT-enabled control. These systems streamline workflow, reduce reliance on human intervention, and enhance security. They perform precise, repeatable tasks, follow predefined routes accurately, detect and avoid obstacles, and ensure that only authorized personnel can access secure compartments, making document delivery both efficient and safe.

Beyond improving operational efficiency, autonomous document-delivery robots provide economic and environmental benefits. They reduce labor costs, increase delivery speed, minimize downtime, and optimize resource allocation, while their energy-efficient operation lowers overall power consumption and carbon footprint compared to manual delivery methods. Features such as real-time tracking, remote monitoring, and IoT-based control enhance transparency, accountability, and workflow management, allowing organizations to monitor progress and adjust priorities dynamically. By automating internal logistics, these robots not only enhance efficiency, reliability, and security in offices, hospitals, and campuses but also pave the way for broader adoption of intelligent systems across sectors seeking faster, safer, and smarter service delivery. Ultimately, autonomous file-transfer robots are revolutionizing internal document management, combining advanced technology, sustainability, and operational excellence to meet the demands of modern organizations.

2. Objective:

The primary objective of this research is to design and develop an autonomous file-transfer robot capable of securely and efficiently delivering documents within an office environment. The system aims to integrate intelligent navigation, wireless communication, and security mechanisms to minimize human intervention, reduce operational errors, and enhance workplace productivity.

To achieve this goal, the following specific objectives have been formulated:

1. **To develop** an autonomous robotic system for efficient and reliable document delivery within office premises.
2. **To automate** the file transfer process in order to minimize manual effort and human dependency.
3. **To ensure** document security and confidentiality using RFID-based authentication and servo-controlled locking mechanisms.
4. **To design** a user-friendly, adaptable, and robust system suitable for practical workplace implementation.
5. **To implement** intelligent navigation using infrared (IR) and ultrasonic sensors for accurate path-following and obstacle avoidance.
6. **To evaluate and optimize** the overall system performance for improved operational efficiency, safety, and reliability in real-world environments.

3. Methodology:

The methodology for developing the Autonomous File-Transfer Robot follows a rigorous and sequential process, broken down into distinct phases to ensure thorough research, design, development, and validation.

Proposed System Methodology

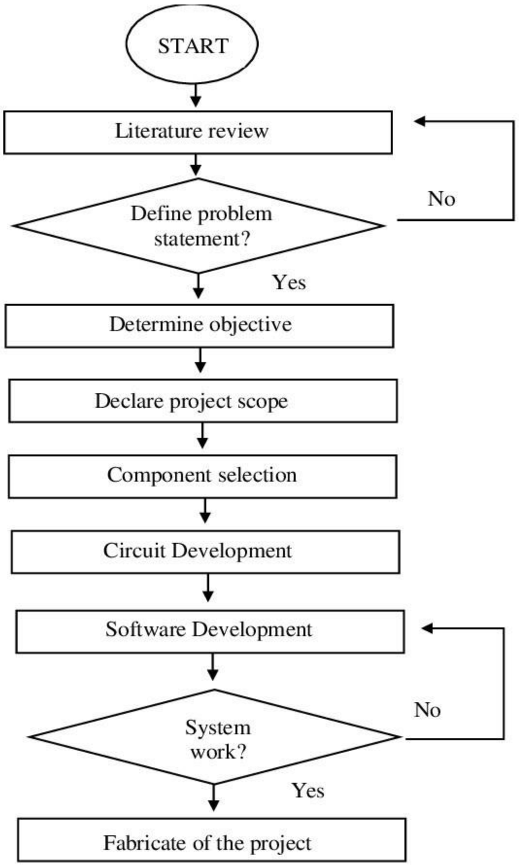

Figure 3.1 Iterative Development Process Flowchart

A. Planning and Definition

The initial phase involves extensive planning supported by a detailed literature review of existing robotic systems, navigation algorithms, and security mechanisms. This review helps in identifying research gaps and establishing a clear problem statement that highlights the need for a secure and autonomous document delivery system within office environments. Based on this analysis, the project defines its specific objective—to achieve reliable, secure, and autonomous file transfer—and outlines the scope of the system, including its operational boundaries, communication framework, and performance expectations. This phase forms the theoretical foundation for subsequent design and implementation activities.

B. Design and Development

The second phase focuses on the design and development of both hardware and software subsystems, which progress-concurrently.

On the hardware side, appropriate components are selected, including the microcontroller unit (MCU), RFID module, infrared and ultrasonic sensors, and motor drivers. This is followed by circuit development, integration of control electronics, and the mechanical fabrication of the robot's chassis and secure document compartment.

In parallel, the software development process includes programming the navigation logic, implementing RFID-based authentication for controlled compartment access, and developing Wi-Fi–based communication protocols to enable user command inputs and confirmation feedback. The coordination between hardware and software ensures efficient system operation and modular expandability.

C. Testing and Validation

The final and most crucial phase is testing and validation, where the integrated system is rigorously evaluated to determine its performance and reliability. Each subsystem—navigation, authentication, and communication—is tested under controlled conditions to verify that it meets the defined functional requirements. In cases where system errors occur, such as failed authentication, obstacle detection errors, or navigation inconsistencies, the methodology incorporates an iterative refinement loop, returning to the development phase for debugging and performance optimization. This iterative process continues until the robot achieves complete operational stability and reliability.

Once all objectives are successfully met, the final prototype is fabricated and prepared for deployment in real-world office environments.

4. Circuit Design:

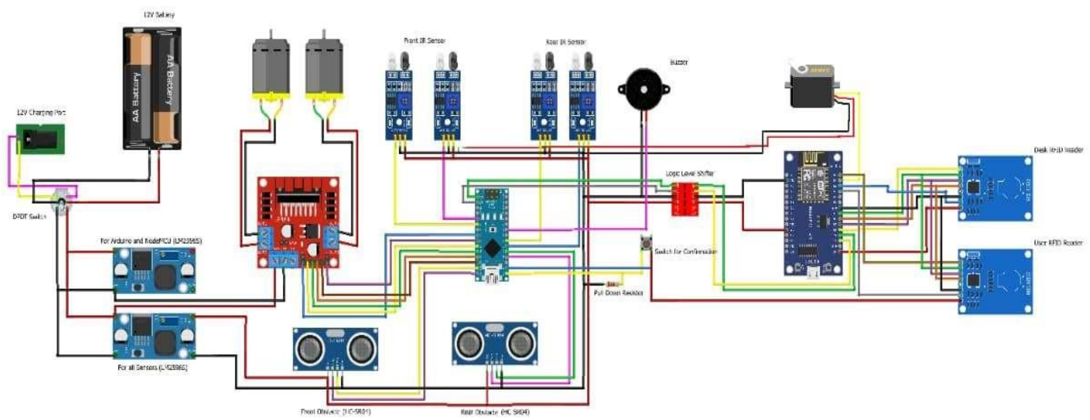

Figure 4.1 circuit design

5. Result and Discussion:

The developed Autonomous File-Transfer Robot is an innovative system designed to automate the physical transfer of documents within office environments, thereby minimizing human effort and enhancing workflow efficiency. The robot autonomously follows a predefined black line using infrared (IR) sensors and employs ultrasonic sensors for obstacle detection and avoidance. To ensure accurate destination identification, RFID technology is utilized for desk or department recognition. The control architecture is based on an Arduino Nano, which processes sensor inputs and manages motor operations, while the NodeMCU (ESP8266) handles data communication and RFID authentication. The system is powered by a 12V rechargeable battery, regulated through buck converters to supply suitable voltages to different modules.

All electronic components—including the power unit, controllers, motor driver, sensors, and RFID module—are compactly integrated within the robot's main unit, which also houses a secure compartment for document placement. The prototype demonstrates smooth navigation, stable communication, and reliable document delivery even in dynamic office environments. This implementation successfully integrates embedded systems, automation, and wireless communication technologies, presenting a practical and contactless solution for modern administrative workflows.

A. System Performance

The robot accurately follows designated paths, avoids obstacles efficiently, and ensures reliable document delivery using RFID-based verification. Testing results confirm consistent performance under standard office conditions.

B. Component Interaction

The Arduino Nano and NodeMCU coordinate effectively to manage sensor inputs, motor actuation, and power distribution. The system achieves seamless interaction between navigation, communication, and security subsystems.

C. Reliability and Efficiency

Experiments demonstrate consistent line-following, obstacle avoidance, and secure file delivery. The robot operates autonomously and contactlessly, contributing to improved safety and operational efficiency.

D. Practical Observations

System performance is influenced by factors such as surface conditions, ambient lighting, sensor alignment, and RFID tag placement. Stable performance is achieved with proper calibration and controlled environmental conditions.

E. Limitations

The system's performance depends on the clarity of path markings, limited RFID range, and motor driver load capacity. These constraints may affect operation in large or uneven office layouts.

F. Suggestions for Improvement

Future enhancements may include the integration of wheel encoders for precise odometry, IMU or vision-based navigation for redundancy, improved motor drivers, and a battery management system (BMS) for extended operation. These additions could enhance the robot's autonomy, accuracy, and overall robustness in real-world deployments.

6. Conclusion and Future Scope:

The proposed Autonomous File-Transfer Robot effectively demonstrates an innovative approach to automating the physical transportation of documents within organizational environments. By integrating infrared (IR) sensors for line-following, RFID technology for precise location identification, Bluetooth communication for wireless data exchange, and ultrasonic sensors for obstacle detection, the system ensures secure, efficient, and reliable document delivery. The inclusion of a servo-controlled locking mechanism further enhances data confidentiality, making the robot suitable for handling sensitive or classified materials. The developed system significantly reduces human intervention, minimizes delays, and improves overall workplace productivity, offering a cost-effective and practical solution for internal logistics automation.

In the future, the system can be enhanced through advanced navigation techniques such as vision-based path planning or LIDAR-enabled mapping to achieve greater autonomy and flexibility. Integration with IoT platforms can facilitate real-time tracking, remote monitoring, and performance analytics. The addition of voice recognition or AI-driven task scheduling can enable multi-delivery management and intelligent routing. Furthermore, scaling the design for larger infrastructures—such as corporate offices, hospitals, and government institutions—can expand its applicability. Incorporating cloud connectivity and data logging mechanisms will also support performance optimization, predictive maintenance, and enhanced security in future deployments.

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