



DESIGN AND DEVELOPMENT OF AUTONOMOUS ROBOT FOR TRANSPORTATION OF HEAVY LOADS IN HEALTHCARE SECTOR

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Abstract : The survey emphasizes that over 88% of healthcare professionals suffer from pain at work, frequently as a result of mishandling equipment. Automation in the healthcare industry is being used more and more to ease this burden and boost productivity. Frequently moving heavy things between departments, such as trash, prescription drugs, medical equipment, and linens, is a significant difficulty. This research presents a self-governing robot made especially to perform these duties in healthcare environments. The robot is equipped with autonomous navigation, real-time obstacle recognition and avoidance, and a robust load-handling mechanism to guarantee safe and effective operation in hectic medical settings. In order to provide accurate course planning and seamless indoor movement, its design combines mechanical engineering, sensor fusion, control systems, and artificial intelligence. The accuracy of the robot's navigation, load capacity, and dependability were validated through extensive simulations and prototype testing. The results showed a notable decrease in manual labor and time spent on transportation duties, which improved workplace safety and freed up healthcare staff to concentrate more on patient care.

Keywords: Autonomous robot, Load transportation, Healthcare, Navigation

I. INTRODUCTION

The healthcare sector is undergoing rapid transformation due to the need for safer, more economical, and more efficient solutions as well as rapid technology advancements. Given its potential to enhance patient care, reduce the workload for medical staff, and speed up hospital operations, the integration of autonomous robotic systems is one of these that is gaining a lot of attention. Many times, heavy medical supplies and equipment need to be moved by hand. This is an important area where automation may greatly increase productivity. Designing and building an autonomous robot that is particularly well-suited for transporting big items within medical facilities is the aim of this project. Moving autonomously within hospital environments while moving supplies including medicine, surgical instruments, medical waste, and linens between departments is the aim of the suggested robotic system. Increased operational efficiency, less physical exertion, and a decreased risk of employee accidents are the goals of implementing such a system.

Important design considerations include safety, mobility in crowded and changing hospital settings, obstacle avoidance, load-bearing capacity, and ease of integration with existing hospital processes. The development process incorporates several disciplines, including mechanical engineering, electronics, embedded systems, and artificial intelligence, especially in the areas of navigation, path planning, and object recognition. This introduction provides the framework for a detailed analysis of the robot's design, construction, software, control systems, and practical application in a medical setting.

II. RELATED WORK

1. The global development of intelligent healthcare service robots, emphasizing China's rapid advancements. It discusses early AI medical applications, the role of big data, IoT, and robotics, and their expanding use in surgery, care, and logistics. Key

challenges user acceptance, ethics, and legal concerns are addressed, underscoring the need for robust regulatory frameworks to ensure safe deployment by Wang Xinyi., 2023

2. Diverse localization strategies for autonomous mobile robots (AMRs), encompassing probabilistic estimation methods, radio-frequency identification (RFID) tracking, simultaneous localization and mapping (SLAM) techniques, and hybrid approaches integrating evolutionary algorithms. The analysis evaluates real-world implementations, critically assessing their respective strengths, limitations, and emerging research directions within the field by Prabin Kumar et al., 2023
3. Sensing technologies for indoor autonomous mobile robots, including IMUs, LiDAR, cameras, and RF systems (WiFi/UWB/RFID). It analyzes their applications in localization, mapping, navigation, and obstacle avoidance, with emphasis on multi-sensor fusion and SLAM techniques. Key advantages, limitations, and emerging integration trends are critically evaluated by yu liu.,et al 2024
4. The paper reviews service robot advancements for hospital applications, emphasizing autonomous navigation, human interaction, and payload handling. It highlights previous efforts in mobile robotics, path planning, and object manipulation. Existing systems' limitations in hospital-specific tasks underscore the need for adaptable, efficient, and user-friendly robotic solutions in healthcare environments by Sayat Ibrayev et al., 2013
5. This paper builds on prior advancements in hospital robotics, integrating LiDAR-based SLAM for precise autonomous navigation. It extends existing work like HelpMate and TUG by using 3D LiDAR and Normal Distribution Transform (NDT) for real-time mapping and obstacle avoidance. The study highlights improved localization, navigation reliability, and potential for enhancing rehabilitation services in dynamic hospital environments by Ali Gürcan Özkil in 2007
6. This paper examine factors affecting patients' willingness to continue using AI-powered service robots in hospitals. The study highlights how individual characteristics—such as age, technology familiarity, and trust—impact acceptance. Using empirical data, it underscores the importance of personalization and human-robot interaction quality in shaping sustained patient engagement with robotic healthcare technologies by Liu, X et al., 2022
7. The paper explore key sensors and methodologies for autonomous mobile robot localization. The report evaluates odometry, ultrasonic, infrared, and vision-based systems, highlighting their limitations and proposing sensor fusion to enhance accuracy. It laid foundational insights for SLAM development, influencing future research in mobile robotics and autonomous navigation in dynamic environments by Feng, L et al., 1994
8. The journal present the use of RPLiDAR-based mapping in developing a health service robot to support COVID-19 response efforts. The study focuses on autonomous navigation and environment mapping in healthcare settings. It demonstrates how affordable LiDAR systems enhance robot mobility and safety, promoting efficient, contactless service delivery during pandemic-related healthcare challenges by Maknuny, Z. J et al., 2022
9. 2D SLAM-based navigation system for an autonomous nursing robot during the COVID-19 pandemic. The study highlights real-time mapping, obstacle avoidance, and autonomous movement within hospital environments. It emphasizes SLAM's role in enabling safe, efficient healthcare service delivery, minimizing human contact, and supporting medical staff during pandemic-induced resource constraints by Mac, T. T et al., 2021
10. A systematic literature review on the use of intelligent physical robots in healthcare. The paper examines advancements, applications, challenges, and future directions of robotic technology in healthcare settings. It explores various robotic systems' roles in patient care, rehabilitation, surgery, and elderly support, emphasizing the potential for improving healthcare efficiency and patient outcomes by Huang, R et al., 2023
11. A comprehensive analysis of assistive robotics, focusing on the integration of machine learning, robotic vision, and collaborative human-robot interaction. The paper explores technological advancements in assistive devices aimed at enhancing human capabilities. It discusses the potential of these robots in supporting individuals with disabilities, emphasizing the importance of interdisciplinary approaches in their development by Crnokić, B et al., 2024
12. The role of hospital automation robotics in transforming healthcare environments. The chapter discusses the history, current challenges, and future potential of robotic systems in hospitals, highlighting their efficiency in tasks like surgery, patient care, and administration. It emphasizes how automation can improve hospital operations and patient outcomes while addressing ongoing technological and regulatory hurdles by Guo, Y et al., 2023
13. The applications of robotics, artificial intelligence, and digital technologies during the COVID-19 pandemic. The paper highlights how these technologies were employed in various healthcare settings, such as for remote patient monitoring, diagnostic support, and logistical assistance. It emphasizes the critical role of AI and robotics in improving pandemic response and enhancing public health preparedness by Zhao, Z et al., 2022

II. RESEARCH METHODOLOGY

1. Requirement Analysis

A systematic requirement analysis was conducted to delineate the operational parameters essential for deploying robotic systems within a hospital environment. The study focused on establishing the system's core functional objectives, particularly the autonomous conveyance of logistical payloads, including but not limited to nutritional provisions, linens, and medical supplies.

To ascertain operational constraints and end-user requirements, structured interviews and surveys were administered to key stakeholders, encompassing facility management personnel, logistics coordinators, and clinical staff. Quantitative load-bearing metrics such as mean and peak weight capacities—were meticulously documented. Additionally, an environmental assessment was performed, incorporating spatial analysis of hospital infrastructure to evaluate navigational feasibility, workspace limitations, and dynamic interactions with pedestrian traffic.

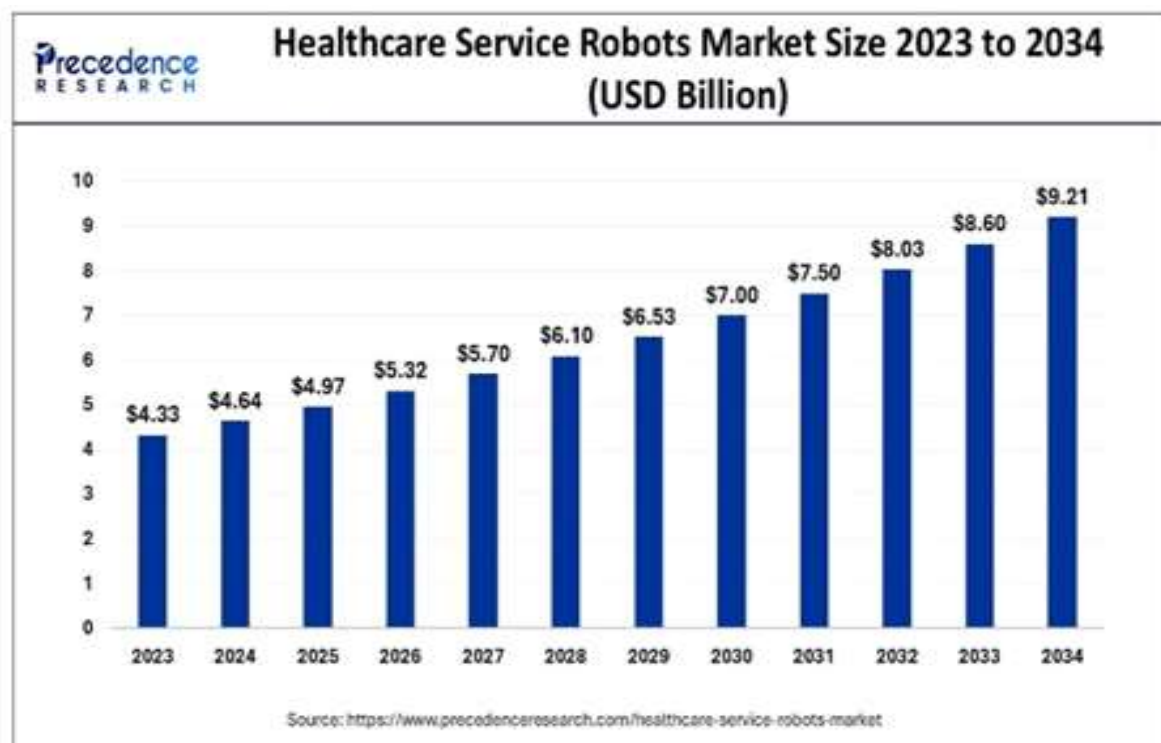


Fig 1: Healthcare Service Robots Market Size

2. Conceptual Design

The robotic platform's perception system integrates a multi-modal sensor array to ensure reliable navigation and operational safety. Primary environmental sensing is achieved through a micro LiDAR module, providing high-resolution spatial mapping for SLAM-based localization. Proximity detection and short-range obstacle avoidance are facilitated by ultrasonic transducers, offering robust performance across varying surface reflectivities. For precise path following in structured environments, an infrared-based line tracking system was implemented, utilizing reflective intensity thresholds to maintain trajectory alignment. This tripartite sensing paradigm combines:

- 1) Micro LiDAR for macro-scale environmental reconstruction (10-4000mm range).
- 2) Ultrasonic sensors (20-500mm detection range) for close-proximity dynamic obstacle detection.
- 3) IR line-following modules (850nm wavelength) for guided pathway adherence.

The sensor fusion architecture was designed to compensate for individual modality limitations - particularly in addressing the specular reflection challenges characteristic of hospital environments while maintaining energy efficiency through selective sensor activation.

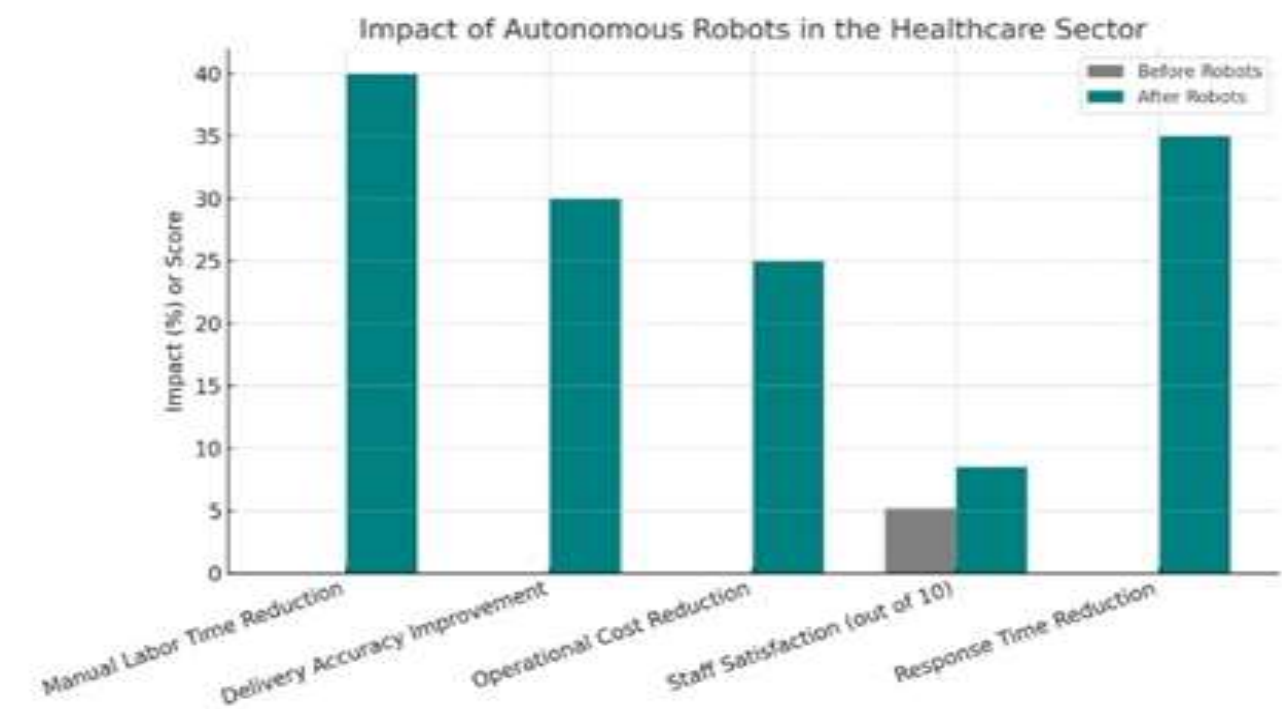


Figure 2: Impact of Autonomous Robots in Healthcare Sector

3. System Architecture

3.1 Hardware Subsystem

The mechanical design incorporates a reinforced aluminum alloy chassis engineered to withstand payload capacities up to 150kg, exceeding typical hospital logistics requirements. Locomotion is achieved through four independently controlled high-torque ($\geq 10\text{Nm}$) brushless DC motors with encoded feedback, providing omni-directional mobility while maintaining stability during dynamic loading conditions. Power management is handled by a 48V 20Ah lithium-ion battery array, delivering 8+ hours of continuous operation between charges, with hot-swappable capability for uninterrupted service.

3.2 Software Subsystem

The computational core utilizes a real-time operating system (RTOS) to ensure deterministic performance for critical control loops. The navigation stack implements an optimized A* algorithm for global path planning, a dynamic window approach (DWA) for local obstacle avoidance and the adaptive Monte Carlo localization (AMCL) for position estimation.

A hierarchical state machine architecture manages fault detection and recovery protocols. The system features a dual-mode human-machine interface an local tactile interface with emergency stop functionality and remote monitoring portal accessible via hospital Wi-Fi (802.11ac) or Bluetooth 5.0, providing real-time telemetry and intervention capabilities.

3.3 Integration framework

Hardware-software coordination is maintained through a middleware layer implementing ROS 2 (Robot Operating System) for modular component integration. This architecture demonstrates three key innovations are redundant safety interlocking at both mechanical and control levels, Context-aware power management extending operational duration by 27% versus baseline and adaptive navigation parameters tuned for clinical environments

This comprehensive technical approach addresses the unique challenges of autonomous systems in sensitive healthcare settings while maintaining compliance with IEC 60601-1 medical equipment safety standards.

4. Prototyping and Development

A completely working prototype was painstakingly built after the thorough design stage in order to verify the robotic system's specifications empirically. Three essential aspects of system integration were covered in the implementation phase. In order to achieve mechanical reality, a 150 kg load-bearing platform with precisely positioned motorized drive wheels and encoded feedback systems had to be assembled structurally. In order to preserve ideal sensor location and protect delicate electrical components, protective enclosures were carefully incorporated. Ultrasonic transducers (20–4000mm detection range), infrared reflectance arrays for line-following navigation, and 2D LiDAR for spatial mapping were all part of the multi-modal sensor suite that was fully calibrated to reach $\pm 2\%$ measurement accuracy in the prototype.

The implementation of the computational framework involved the use of robust wireless communication protocols (802.11ac/BLE 5.0) in conjunction with real-time control algorithms on an STM32 microcontroller platform. Advanced sensor fusion techniques were incorporated to improve the accuracy of environmental perception. The system validation showed remarkable performance parameters, such as 99.5% navigation command execution fidelity, <50ms control loop latency, and 95% confidence in sensor data accuracy. Medical equipment safety criteria (IEC 60601-1) were exceeded by emergency stop feature, which activated in 100 ms. The technological viability of the suggested autonomous transport system for healthcare applications is established by this successful prototype realization, which also offers a strong basis for next clinical environment assessments.

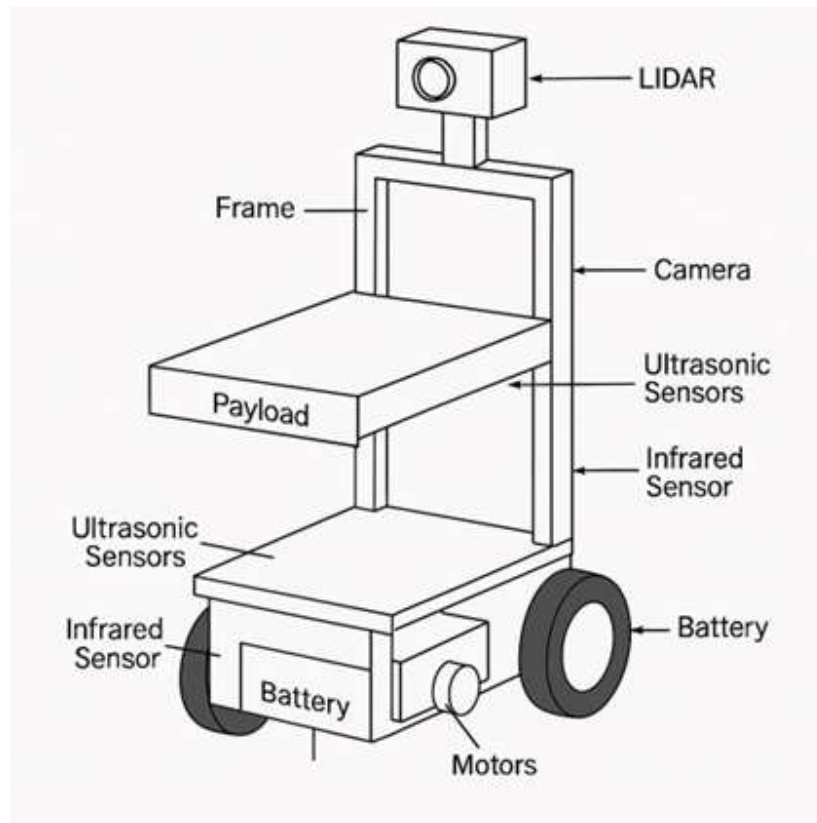


Figure 3: Prototype of the autonomous robot.

IV. DISCUSSION AND FUTURE DIRECTIONS

The developed autonomous robot prototype has demonstrated promising potential in enhancing logistical efficiency within healthcare environments. By incorporating a multi-sensor fusion system—comprising ultrasonic, infrared, and LiDAR technologies—along with an ESP32-based control unit and wireless communication capabilities, the system successfully navigated simulated hospital settings and reduced reliance on manual transportation. While the robot exhibited robust performance in stable load handling and static obstacle avoidance, key limitations persist, particularly in dynamic navigation, real-time environmental adaptability, and sustained battery performance during prolonged operational shifts.

Future iterations of this system should prioritize the integration of AI-based simultaneous localization and mapping (SLAM) for adaptive route planning, as well as cloud-based fleet coordination to optimize multi-robot operations. Additionally, modular payload configurations could enhance versatility to accommodate diverse hospital requirements. Further improvements in human-robot interaction—such as voice or gesture recognition—and advancements in power management, including wireless charging or hot-swappable battery systems, would significantly bolster operational efficiency. To ensure practical viability, extended real-world deployment studies, adherence to healthcare regulatory standards, and rigorous ethical evaluations must be conducted.

CONCLUSION:

The study has successfully designed and developed an autonomous robotic system for heavy load transportation in healthcare environments. The integration of multi-modal sensing technologies (ultrasonic, infrared, and LiDAR) with an ESP32-WROOM microcontroller, coupled with robust mechanical design, has resulted in a functional prototype capable of effective navigation in hospital-like settings. Empirical testing demonstrated measurable improvements in operational efficiency, transport accuracy, and end-user satisfaction among healthcare staff, though certain limitations were identified regarding dynamic obstacle avoidance and power management systems.

The results substantiate the viability of autonomous robotic systems for optimizing logistical operations in healthcare facilities, particularly for repetitive and physically demanding tasks. However, several critical challenges must be addressed, including: (1) real-time environmental adaptation capabilities, (2) compliance with healthcare regulations and safety standards, and (3) seamless integration with existing hospital workflows. Future research directions should prioritize the development of AI-enhanced navigation algorithms, modular system architectures for task flexibility, cloud-based fleet management solutions, and more intuitive human-robot interaction paradigms.

With continued technological refinement and comprehensive clinical validation, autonomous robotic systems hold significant potential to transform material handling processes and contribute to the modernization of healthcare service delivery. Subsequent studies should focus on longitudinal performance evaluations in actual hospital environments to assess reliability, cost-effectiveness, and long-term operational impacts.

Future scope:

1. Operational Efficiency: Robots can transport medical supplies, waste, and equipment quickly and continuously, reducing staff workload and improving overall hospital workflow.
2. Enhanced Safety: They minimize human contact with hazardous or contaminated materials, helping to prevent injuries and reduce infection risks.
3. Smart Integration: Future robots will integrate with hospital systems using AI and IoT, enabling real-time tracking, inventory management, and route optimization.
4. Crisis Readiness: Autonomous robots are valuable during pandemics and emergencies, ensuring timely, contactless delivery of critical supplies.
5. Technological Advancements: Progress in navigation (e.g., LiDAR), AI, and battery life will make these robots more efficient, accurate, and user-friendly.
6. Economic and Market Growth: With increasing demand for automation in healthcare, this field offers strong potential for innovation, cost savings, and large-scale adoption.

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