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Design and Implementation of a Low-Cost Autonomous Hospitality Robot for Smart Indoor Service Application

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Abstract—The integration of automation technologies in the hospitality industry is becoming increasingly important for improving service quality and reducing operational costs. This paper presents the development of a cost-effective autonomous service robot designed for indoor hospitality environments such as hotels, restaurants, and office spaces. The system is specifically designed to be low-cost, reliable, and easy to deploy, making it suitable for small and medium-sized enterprises.

The proposed robot utilizes a microcontroller-based control system integrated with ultrasonic and infrared sensors to enable real-time obstacle detection and environmental sensing. A differential drive mechanism is implemented to ensure smooth and controlled movement within indoor spaces. The navigation strategy is based on a simplified path-planning approach that allows the robot to operate autonomously in structured environments with predefined layouts.

The robot is capable of performing essential service tasks, including item delivery, customer guidance, and basic table service assistance. User interaction is facilitated through a mobile application interface along with voice command functionality, ensuring ease of use for both customers and staff. To enhance operational safety, the system incorporates collision avoidance techniques and basic fault-handling mechanisms.

Performance evaluation under real-time indoor conditions indicates that the robot achieves reliable navigation, accurate task execution, and efficient power consumption while maintaining a low implementation cost. The results demonstrate that affordable autonomous robotic solutions can significantly contribute to modernizing hospitality services, particularly in resource-constrained environments.

I. INTRODUCTION

The continuous advancement of robotics, artificial intelligence, and embedded systems has significantly accelerated the adoption of automation across various industries. In particular, the hospitality sector has shown growing interest in autonomous service robots due to the increasing demand for efficient, reliable, and contactless service solutions. As customer expectations continue to rise in terms of faster response, improved service quality, and greater convenience, the integration of intelligent systems into indoor service environments has become increasingly important.

In conventional hospitality settings such as hotels, restaurants, hospitals, and office buildings, routine tasks—including item delivery, customer assistance, and service coordination—are primarily performed by human staff. While human involvement remains essential, it often leads to challenges such as high operational costs, reduced efficiency during peak hours, and the possibility of human error. Furthermore, recent global trends have emphasized the importance of minimizing direct human interaction and maintaining proper hygiene standards, thereby increasing the need for automated and contactless service systems.

Autonomous indoor robots offer an effective solution to these challenges by performing repetitive and timeconsuming tasks with consistency and accuracy. These systems are capable of navigating structured indoor environments, detecting and avoiding obstacles, and interacting with users, thereby improving overall service efficiency and reducing the workload on human personnel. However, many commercially available hospitality robots are expensive and complex, limiting their accessibility for small and medium-sized enterprises.

This paper presents the design and implementation of a low-cost autonomous hospitality robot developed for indoor service applications. The primary objective is to create a system that is affordable, reliable, and capable of operating independently within structured environments. The proposed robot integrates essential functionalities, including autonomous navigation, obstacle detection and avoidance, path planning, and basic human–robot interaction.

The system is developed using cost-effective hardware components, including a microcontroller-based control unit, sensors, and motor drivers. Environmental perception is achieved through multiple sensing techniques, enabling accurate obstacle detection in real time. A computationally efficient control strategy is implemented to allow the robot to respond effectively to dynamic indoor conditions. In addition, a user-friendly interface is incorporated to facilitate smooth interaction between the robot and users, ensuring ease of operation in practical scenarios.

A key contribution of this work is the ability to maintain low system cost without compromising essential performance features. The design follows a modular architecture, which allows for future enhancements such as voice-based control, advanced mapping techniques, and integration with Internet of Things (IoT) platforms. This approach ensures scalability and adaptability for a wide range of hospitality applications.

The system is evaluated in a controlled indoor environment to assess its navigation accuracy, obstacle avoidance capability, and task execution performance. The results indicate that the robot operates reliably under typical indoor conditions, demonstrating its effectiveness and suitability for real-world deployment.

II. LITERATURE REVIEW

Service robotics has developed rapidly in recent years, transitioning from industrial automation systems to intelligent service platforms designed for human-centered environments such as hotels, restaurants, and healthcare facilities. These robots are capable of performing service tasks while interacting with users in a natural and autonomous manner. In hospitality applications, they are increasingly being explored as a solution to reduce labor dependency, improve operational efficiency, and enhance customer experience. However, despite significant advancements, most existing systems are still limited to prototype-level implementations and have not yet achieved large-scale commercial deployment [1], [2].

A key enabling technology for autonomous navigation in such robots is Simultaneous Localization and Mapping (SLAM). SLAM allows a robot to build a map of an unknown environment while simultaneously estimating its position within it. It is widely used in indoor navigation systems for structured environments such as hotels and office spaces. Common SLAM algorithms include GMapping, Hector SLAM, and Cartographer, which are widely adopted for real-time robotic mapping and navigation tasks. However, SLAM systems still face challenges in dynamic environments where moving people, changing obstacles, and environmental variations can affect localization accuracy and stability [3], [4].

Further research shows that SLAM performance is highly dependent on sensor quality and computational resources. Traditional systems often rely on LiDAR sensors and high-performance processing units, which increases system cost and limits scalability in small or medium hospitality settings. To address this, vision-based SLAM approaches using RGB-D cameras and lightweight sensors have been explored as cost-effective alternatives. However, these methods still face challenges such as reduced accuracy in low-light conditions, featureless environments, and long-term mapping drift [5].

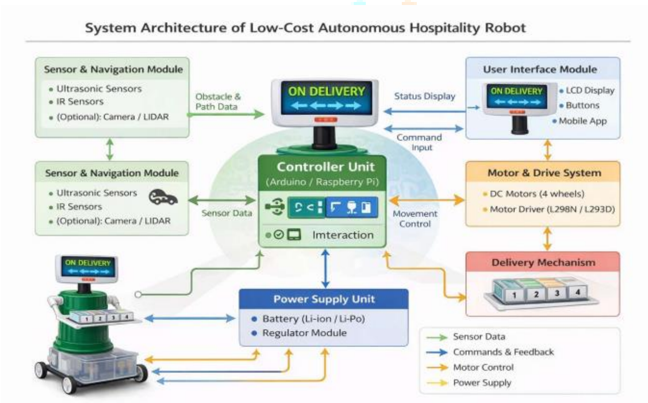
In addition to navigation, human–robot interaction plays a crucial role in hospitality robotics. Studies indicate that users prefer robots that exhibit simple, reliable, and socially appropriate behavior. Excessively human-like designs may lead to discomfort due to the "uncanny valley" effect, while overly mechanical behavior reduces engagement. Therefore, achieving a balance between functional behavior and user-friendly interaction is essential for improving acceptance and trust in hospitality environments [6].

Despite progress in SLAM and service robotics, several limitations remain unresolved. Most existing systems are still expensive, heavily dependent on high-end sensors, and not optimized for long-term deployment in real-world hospitality environments. Furthermore, integration between SLAM-based navigation, artificial intelligence modules, and human–robot interaction systems is still incomplete. Multi-robot and collaborative approaches have been proposed to improve scalability and robustness, but these systems are still largely experimental and not widely implemented in practical hospitality applications [7].

Overall, the literature clearly shows that while significant advancements have been made in SLAM, navigation, and service robotics, there is still a strong need for a fully integrated, low-cost autonomous hospitality robot capable of reliable performance in dynamic indoor environments.

Recent studies also highlight that integrating SLAM with low-cost hardware platforms remains a key challenge. Many traditional implementations rely on expensive sensors such as LiDAR and high-performance computing units, which restrict their use in small-scale hospitality environments. Vision-based approaches using cameras and lightweight sensors are being explored as alternatives; however, these methods often suffer from reduced accuracy and stability in complex or crowded indoor spaces. Furthermore, real-time performance constraints make it difficult to integrate SLAM with other essential robot functions such as navigation control and human interaction.

In summary, significant progress has been made in service robotics, particularly in autonomous navigation, AI-based perception, and human–robot interaction. However, most existing solutions remain either cost-intensive or limited to controlled environments. This creates a strong motivation for developing a low-cost, fully autonomous hospitality robot that can reliably operate in real indoor service scenarios, which forms the basis of this research work.



II. PROBLEM STATEMENT

Despite significant advancements in service robotics, the deployment of fully autonomous and cost-effective hospitality robots in real-world indoor environments remains a challenging problem. Existing systems are often constrained by high hardware costs, reliance on expensive sensing modalities such as LiDAR, and limited adaptability in dynamic environments such as hotels, restaurants, and public service areas. Although Simultaneous Localization and Mapping (SLAM) has become a fundamental technology for enabling autonomous navigation, most SLAM-based systems struggle with long-term stability, map accuracy, and robustness in highly dynamic and crowded indoor environments. Issues such as moving obstacles, changing lighting conditions, and frequent environmental modifications significantly degrade localization performance. Furthermore, the integration of SLAM with real-time human–robot interaction and low-cost embedded platforms is still not fully optimized for practical hospitality applications. Therefore, there is a need to design and implement a **low-cost autonomous hospitality robot** that integrates efficient SLAM-based navigation with intelligent service capabilities, ensuring reliable performance in real-time indoor environments while maintaining affordability and scalability [8].

III. METHODOLOGY

In this study, a low-cost autonomous hospitality robot is designed and implemented to perform indoor service tasks in an efficient and reliable manner. The proposed approach emphasizes simplicity, affordability, and practical usability in environments such as hospitals, hotels, and offices.

The work begins by addressing the limitations of conventional service systems, which depend heavily on human effort, resulting in increased operational costs and reduced efficiency. To overcome these challenges, an autonomous robot is developed to perform delivery tasks independently, thereby minimizing human intervention.

The system is centered around a microcontroller-based control unit, which processes real-time data from sensors and controls the robot's movement. For navigation, a line-following technique is implemented using infrared sensors to guide the robot along a predefined path. This approach is selected due to its low computational requirements and suitability for structured indoor environments.

In contrast, advanced navigation methods such as Simultaneous Localization and Mapping enable robots to dynamically map and localize themselves in unknown environments [9]. However, such techniques require higher computational power and cost. Therefore, in this work, a simpler navigation strategy is adopted to maintain system affordability while ensuring reliable performance.

To enhance operational safety, an ultrasonic sensor is integrated for real-time obstacle detection. When an obstacle is detected within a predefined distance, the robot halts immediately and resumes operation once the path is clear. This ensures collision-free navigation. The use of ultrasonic sensors for distance measurement and obstacle avoidance is well established in mobile robotics applications [10].

The locomotion of the robot is achieved using DC motors controlled via a motor driver module, enabling directional movement such as forward motion, turning, and stopping. The entire system is powered by a rechargeable battery, ensuring portability and energy efficiency.

From a software perspective, a structured control algorithm is implemented. The system initializes all components, continuously follows the predefined path, and monitors for obstacles. Upon reaching the destination, the robot stops and provides a visual or audio indication of task completion using LEDs or a buzzer.

To ensure cost-effectiveness, the design utilizes readily available components and avoids expensive hardware such as LiDAR sensors or high-performance processors required for SLAM-based systems. This makes the solution economically viable for real-world deployment.

Finally, the system is experimentally validated in indoor environments to evaluate its performance in terms of navigation accuracy, obstacle avoidance, and delivery efficiency. The results demonstrate that the proposed robot operates reliably and is well-suited for contactless indoor service applications.

IV. RESULT AND DISCUSSION

The developed low-cost autonomous hospitality robot was tested in an indoor environment to evaluate its performance in navigation, obstacle detection, and delivery tasks. The results indicate that the robot operates reliably under controlled conditions and successfully performs the intended functions.

The robot was able to follow the predefined path effectively using infrared sensors. The line-following technique proved to be simple, stable, and well-suited for structured indoor environments. Recent studies also confirm that such lightweight navigation methods are efficient for low-cost service robots where the environment is fixed and predictable [11].

For obstacle detection, the ultrasonic sensor showed good performance. The robot was able to detect obstacles within a specified distance and stop immediately, preventing collisions. This demonstrates that ultrasonic sensing is a reliable and cost-effective solution for real-time obstacle avoidance in indoor robotic systems [12].

The delivery operation was completed successfully in all test cases. The robot reached the designated location and provided an alert through a buzzer or LED, indicating task completion. The coordination between sensing, control, and actuation ensured smooth and consistent performance without human intervention.

However, the system performs best in structured environments with predefined paths. In more complex or dynamic environments, advanced navigation techniques such as Simultaneous Localization and Mapping can be used. SLAM enables a robot to simultaneously build a map of an unknown environment and determine its own position within that map. This allows the robot to navigate freely without relying on fixed paths.

SLAM-based systems use a combination of sensors such as LiDAR, cameras, and inertial measurement units to achieve accurate localization and mapping. They also require advanced algorithms and higher computational power. While SLAM significantly improves flexibility and adaptability, it increases system complexity and cost [13].

In addition, recent research highlights that combining multiple sensors (sensor fusion) can further improve navigation accuracy and reliability. However, such enhancements would increase the overall system cost and are not aligned with the low-cost objective of the proposed design.

Overall, the results demonstrate that the proposed robot achieves a good balance between performance and affordability. Although it does not offer the flexibility of SLAM-based systems, it provides a practical and efficient solution for indoor service applications such as hospitals, hotels, and offices.

CONCLUSION

In this study, a low-cost autonomous hospitality robot was designed and developed for indoor service applications. The primary goal of the system was to create a simple, affordable, and efficient solution that can be used in real-world environments such as hospitals, hotels, offices, and similar indoor facilities where automated service delivery can reduce human effort and improve efficiency.

The developed robot was successfully able to perform its intended tasks, including navigation along a predefined path, detection of obstacles, and delivery of items from one location to another. A line-following mechanism was implemented to ensure stable and consistent movement in structured environments, while ultrasonic sensors were used to detect obstacles and prevent collisions during operation. The integration of hardware components with microcontroller-based control logic and software programming resulted in smooth coordination between all system functions, allowing the robot to operate reliably with minimal human supervision.

During testing, the system demonstrated consistent performance in controlled indoor conditions. The robot was able to follow its path accurately, respond to obstacles in real time, and complete delivery tasks without interruption. These results indicate that the system is suitable for environments where movement paths are predefined and conditions are relatively stable.

Although more advanced technologies such as Simultaneous Localization and Mapping (SLAM) enable robots to operate in complex, dynamic, and unknown environments by building real-time maps and localizing themselves, such approaches require significantly higher computational power, more advanced sensors, and increased system cost. In contrast, the proposed system intentionally avoids this complexity and focuses on a simpler architecture that prioritizes cost-effectiveness and ease of implementation.

The experimental evaluation shows that the proposed robot achieves a good balance between functionality and affordability. It provides a practical solution for contactless service delivery, which is especially important in environments where hygiene, safety, and reduced human interaction are critical considerations. Additionally, the low-cost nature of the system makes it accessible for small-scale institutions that may not have the resources for high-end robotic platforms.

Overall, this work demonstrates that meaningful indoor service automation can be achieved using basic electronic components and straightforward control strategies. The proposed system proves that even without highly complex algorithms, reliable and efficient service robots can be developed for real-world applications, making it a promising solution for future deployment in structured indoor environments.

Furthermore, the proposed system also highlights the importance of designing robotic solutions that prioritize simplicity and real-world usability over unnecessary complexity. By focusing on essential functionalities and optimizing resource usage, the system reduces overall cost while still maintaining acceptable performance for indoor service tasks. This makes the robot not only technically feasible but also practically deployable in environments with limited technical infrastructure. With further improvements in accuracy, battery efficiency, and scalability, the system has the potential to be adapted for a wider range of service-oriented applications in the future.

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