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Integrated Autonomous Mobile Robotic System For Vital Signs Surveillance And Automated Pharmacy Services In Healthcare Facilities

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Abstract
Autonomous mobile humanoid robots represent the transformative solution to healthcare's dual crises of nursing shortages and infection control demands. This paper presents an integrated autonomous mobile robotic system for vital signs surveillance and automated healthcare assistance in smart hospital environments. Unlike existing healthcare robotic solutions that primarily focus on isolated functionalities such as navigation, physiological sensing, or communication, the proposed framework combines autonomous navigation, RFID-based patient identification, physiological monitoring, real-time healthcare communication, emergency alert generation, and electronic health record (EHR) synchronization within a unified Robot Operating System (ROS)-based architecture. The proposed system incorporates a Raspberry Pi 4 and Arduino Mega control architecture integrated with LiDAR, IMU, RFID, temperature, and pulse oximetry sensors to enable autonomous patient localization, identification, and contactless acquisition of body temperature, heart rate, and oxygen saturation (SpO_2). Autonomous navigation is achieved through SLAM, sensor fusion, and ROS navigation frameworks, while wireless communication enables real-time transmission of healthcare information to a centralized monitoring server. An intelligent alert generation mechanism continuously evaluates physiological measurements against predefined clinical thresholds and automatically notifies healthcare personnel when abnormal conditions are detected. The obtained results validate the effectiveness of the proposed system for intelligent patient surveillance, continuous remote healthcare monitoring, and rapid clinical decision support, thereby contributing toward safer, more efficient, and human-centered smart healthcare environments.

Keywords: Autonomous Mobile Robot, Healthcare Robotics, ROS, RFID Patient Identification, Vital Signs Monitoring, Sensor Fusion, LiDAR Navigation, Electronic Health Records, Emergency Alert System, Smart Healthcare.

I. INTRODUCTION

Autonomous mobile robots have gained popularity in recent years due to their adaptability and potential applications used in today's world. The capacity of an independent versatile robot to explore an environment without any outside direction, such as physical or electro-mechanical direction expanded its potential. The early independent route frameworks utilized two-dimensional sensors, such as laser rangefinders, to explore without human intercession. For an independent portable to perform its errands, a huge number of natural sensors are required. These sensors are either joined to the robot or work as outside sensors. [1-2]. Everything became more challenging amid widespread scenarios, including overseeing waste and having face-to-face intuitive with patients. Figure 1 shows the structure of an autonomous mobile robot. By analyzing the feasibility and challenges encountered during the deployment of the autonomous mobile robot (AMR), this study provides valuable insights and recommendations for the continued development, optimization, and adoption of autonomous robotic systems in healthcare environments. The increasing demand for resilient and contactless healthcare solutions, particularly highlighted during the COVID-19 crisis, has accelerated the integration of autonomous robotic systems within clinical environments. Such systems play a crucial role in reducing direct human interaction, supporting patient care in isolation scenarios, and enhancing operational safety and efficiency in hospitals [1]. Recent developments in robotic communication and control, including the use of visible light–based systems, have further improved the reliability and precision of autonomous mobile platforms operating in complex indoor healthcare settings [2].

At the same time, the expansion of telemedicine has enabled continuous patient monitoring and remote clinical decision-making, reducing the need for physical presence while maintaining care quality [3]. The incorporation of IoT-enabled sensing technologies, particularly RFID-based solutions, facilitates real-time tracking of patients, medical assets, and vital parameters, thereby strengthening data-driven healthcare management systems [4]. Moreover, research on multi-robot coordination and scheduling has demonstrated significant improvements in hospital logistics, ensuring efficient and timely delivery of medicines and essential supplies [5].

In this evolving technological landscape, the convergence of autonomous robotics, intelligent sensing, and advanced communication frameworks is paving the way for next-generation smart healthcare systems. These systems are expected to operate with increased autonomy, adaptability, and minimal human intervention. In this context, the proposed integrated autonomous mobile robotic system is designed to enable continuous vital signs surveillance alongside automated pharmacy services, contributing to safer, more efficient, and human-centric healthcare facilities aligned with modern smart hospital requirements.

II. LITERATURE REVIEW

The adoption of autonomous robotic systems in healthcare has accelerated significantly, particularly in response to the operational constraints highlighted during the COVID-19 pandemic. Robotic assistance has been widely explored as a means to reduce direct human interaction while maintaining continuity in patient care. Systems designed for isolated patient support have demonstrated the ability to minimize infection risks, enhance safety for healthcare personnel, and ensure uninterrupted service delivery in high-risk environments [1]. These developments have laid the groundwork for contactless and automated healthcare solutions.

Communication technologies play a crucial role in enabling reliable operation of autonomous robots within hospital settings. Advanced frameworks utilizing visible light communication have been proposed to improve the precision and robustness of robot control in indoor environments. Such approaches offer advantages over conventional wireless systems by reducing signal interference and enhancing localization accuracy, which is essential for coordinated robotic operations in complex healthcare infrastructures [2]. These improvements contribute to more dependable navigation and task execution.

Parallel to robotic advancements, telemedicine has emerged as a transformative component of modern healthcare systems. Remote consultation and monitoring capabilities enable continuous patient supervision without requiring physical presence, thereby improving accessibility and reducing system burden [3]. When integrated with robotic platforms, telemedicine facilitates real-time data exchange and remote intervention, forming a comprehensive framework for intelligent healthcare delivery.

The heart rate data suggest that a conversation between a robot and a patient can reduce stress. The results show that verbal interactions have a greater impact on trust than gestural ones [22]. Creating a medical aid solution that provides a variety of non-invasive diagnoses performed by an autonomous robot whose mobility can also be controlled manually via a mobile application or voice command [23, 24]. Real-time visual feedback on the outcomes of actions could be used in future safety-critical human-robot interactions, including remote patient examinations. The transfer of human capabilities to robots is a pressing concern for human-cyber robotic systems. The fundamental problem for a mobile medical rescue robot is how to safely transport patients or medical supplies, especially in confined spaces [25-27]. In hospitals, the robot must perform challenging tasks both indoors and outdoors, in addition to some extensive assembly work [28]. Using optical navigation, multi-arm robotic maxillofacial surgery is being introduced as an alternative to conventional manual surgery [29]. There are excellent applications for robotic orthopedic surgery, and the accuracy of the robot is critical to the success of the procedure [30, 31]. It was noted that there is a need to support increasing workloads, including inventory monitoring, waste disposal, meal and medication delivery, and emergency communications, including patient emergency communications and medical staff emergency communications [32]. The safety rules for navigation must be followed by both humans and robots working in the same space [33].

The integration of Internet of Things (IoT) technologies has further strengthened the functionality of healthcare systems. RFID-based sensing mechanisms enable efficient tracking of patients, medical equipment, and pharmaceuticals, providing real-time visibility into hospital operations [4], [15]. These systems enhance data acquisition and support automated decision-making processes. Furthermore, advancements in RFID sensor design have improved sensitivity and scalability, making them suitable for large-scale healthcare deployments [16]. Secure communication protocols have also been developed to address privacy concerns, ensuring that sensitive medical data is protected within interconnected environments [17].

Efficient logistics management remains a critical aspect of hospital operations, where autonomous robots have shown considerable potential. Multi-robot scheduling techniques have been investigated to optimize task allocation and reduce delivery delays, particularly in environments with high demand for timely service [5]. Advanced optimization strategies for automated drug dispensing systems have further improved order picking efficiency and resource utilization, highlighting the importance of intelligent coordination between robotic agents and human operators [10], [11]. These approaches contribute to streamlined workflows and enhanced service reliability.

Fundamental research in mobile robot control has provided the theoretical basis for autonomous navigation in healthcare environments. Control strategies for non-linear robotic systems have enabled stable path-following and precise motion control, which are essential for safe operation in dynamic and constrained spaces [6]. Building on these principles, practical implementations have incorporated localization techniques based on signal strength and sensor fusion, enabling robots to accurately identify patient locations and deliver targeted services [19].

Automated medicine dispensing systems have evolved as a key component of smart healthcare infrastructure. Early designs focused on reducing human error and improving medication management through automated dispensing units [7]. Subsequent developments introduced integrated reminder systems to enhance patient adherence to prescribed treatments [8]. Scalable and remotely manageable dispensing platforms have also been proposed, enabling centralized control and monitoring of medication distribution processes [9].

Recent research has increasingly focused on combining dispensing systems with mobile robotic platforms. Autonomous dispensing robots capable of delivering medications directly to patients have been developed, demonstrating improved efficiency and reduced dependency on manual intervention [12], [14]. IoT-enabled semi-autonomous robots with obstacle detection capabilities have further enhanced safety and adaptability in real-world hospital environments [13]. These systems represent a significant step toward fully automated pharmacy services.

The safety and operational efficiency of robotic dispensing systems have been systematically evaluated, with findings indicating a reduction in medication errors and improvements in workflow performance [18]. Such systems not only enhance accuracy but also contribute to better resource management within hospital pharmacies. Additionally, RFID-based health monitoring systems have been proposed to enable continuous tracking of patient conditions, further supporting real-time healthcare delivery [20].

Despite substantial progress, several challenges remain in achieving fully integrated healthcare robotic systems. Issues related to interoperability between heterogeneous subsystems, real-time data synchronization, and robust operation in dynamic environments continue to require further investigation. Moreover, the seamless integration of vital signs monitoring, robotic navigation, and automated dispensing into a unified platform presents significant technical complexities.

Overall, the existing body of research demonstrates a clear trajectory toward intelligent, automated healthcare systems driven by the convergence of robotics, IoT, and advanced communication technologies. While individual components have been extensively studied and validated, there remains a critical need for a holistic solution that integrates these functionalities into a single cohesive system. Addressing this gap, the proposed work focuses on the development of an integrated autonomous mobile robotic system capable of performing both vital signs surveillance and automated pharmacy services, thereby advancing the realization of efficient, safe, and human-centric smart healthcare environments.

III. METHODOLOGY

The proposed Integrated Autonomous Mobile Robotic System for Vital Signs Surveillance and Automated Pharmacy Services in Healthcare Facilities is designed to provide contactless patient monitoring and intelligent healthcare data management. The system integrates autonomous navigation, physiological sensing, wireless communication, emergency alert generation, and electronic health record synchronization into a unified healthcare framework. The methodology is organized into four major modules: Autonomous Patient Monitoring, Healthcare Communication and Vital Signs Upload, Emergency Alert Generation and Clinical Decision Support, and Electronic Health Record Management and Data Synchronization.

Figure 1 illustrates the complete hardware architecture and subsystem integration of the proposed Integrated Autonomous Mobile Robotic System for Vital Signs Surveillance and Healthcare Assistance. The system consists of seven major subsystems: navigation and localization, patient identification, vital signs monitoring, main control, secondary control, motor driving, and power management. The operational workflow begins with the navigation and localization subsystem, where LiDAR (RPLiDAR A2) and IMU (MPU6050) sensors continuously collect environmental and orientation data to support autonomous navigation and localization within healthcare facilities. Simultaneously, the patient identification subsystem employs an MFRC522 RFID reader and patient-specific RFID tags to authenticate patient identity before initiating physiological monitoring. Following successful verification, the vital signs monitoring subsystem acquires body temperature, heart rate, and blood oxygen saturation (SpO_2) using integrated biomedical sensors, including the MAX30205/MLX90614 temperature sensor and MAX30102 pulse oximeter sensor. The acquired physiological data, along with localization and identification information, are transmitted to the Raspberry Pi 4-based main controller, which performs sensor fusion, navigation computation, healthcare data processing, communication management, and server synchronization. To reduce computational load on the main controller, an Arduino Mega is incorporated as a secondary controller responsible for low-level sensor interfacing, encoder processing, and actuator management. Motion control is achieved through a motor driving subsystem consisting of an L298N motor driver, differential-drive DC motors, and wheel encoders, enabling precise movement and trajectory tracking. The entire robotic platform is powered through a dedicated power management subsystem comprising a lithium-ion battery pack, battery management system (BMS), DC–DC voltage converters, and regulated power distribution circuits. Through the integration of sensing, control, communication, and monitoring modules, the proposed system enables autonomous patient localization, physiological data acquisition, real-time healthcare monitoring, and intelligent healthcare service delivery in smart hospital environments. This architecture provides a scalable and reliable framework for reducing healthcare workload while improving patient monitoring efficiency and operational safety.

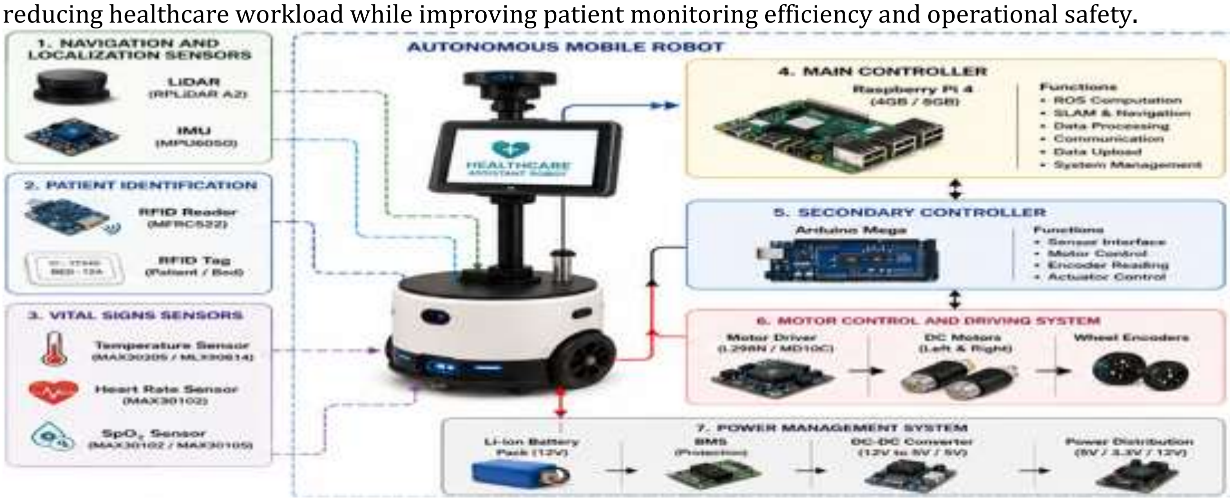

Fig. 1. Detailed architecture of the integrated autonomous mobile robot for vital signal surveillance

A. Autonomous Patient Monitoring Module

The Autonomous Patient Monitoring Module forms the first operational stage of the proposed healthcare robotic framework. This module is responsible for receiving monitoring requests, autonomously reaching the designated patient location, verifying patient identity, acquiring physiological parameters, and validating sensor measurements before further processing. The primary objective of this module is to reduce manual monitoring efforts while enabling continuous and reliable patient surveillance.

The monitoring process begins when the healthcare management server generates a monitoring request containing the patient identification number and bed location. The request is transmitted to the autonomous mobile robot through the wireless communication infrastructure. Upon receiving the request, the robot activates its navigation controller and retrieves the target location from the hospital database. The autonomous navigation subsystem then computes the optimal route toward the assigned patient location while considering environmental constraints and dynamic obstacles commonly encountered in hospital environments.

Upon arrival at the patient location, the robot initiates an identification procedure to ensure that physiological measurements are associated with the correct patient. Patient verification is performed using an RFID-based identification mechanism. Each patient is assigned a unique RFID tag containing identification information linked to the hospital database. The RFID reader integrated into the robotic platform scans the tag and validates the patient identity before monitoring activities commence.

After successful identification, the robot acquires physiological parameters using integrated biomedical sensing devices. The selected parameters include body temperature, heart rate, and blood oxygen saturation (SpO_2), which are widely recognized as essential indicators of patient health status.

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The physiological dataset is represented as

$$V_p = \{T, HR, SpO_2\}$$

Where;

- T = Body temperature
- HR = Heart rate
- SpO_2 = Oxygen saturation

The collected sensor readings undergo a validation process to eliminate erroneous measurements and transient fluctuations caused by environmental noise or sensor inaccuracies. Threshold-based filtering techniques are employed to verify the consistency and reliability of the acquired data. Only validated measurements are accepted for subsequent transmission and clinical evaluation.

The autonomous patient monitoring module significantly enhances healthcare service delivery by enabling continuous and contactless monitoring. Furthermore, the automation of physiological data acquisition improves measurement consistency, minimizes human recording errors, and supports rapid healthcare decision-making.

B. Healthcare Communication and Vital Signs Upload Module

The Healthcare Communication and Vital Signs Upload Module serves as the communication backbone of the proposed robotic system. This module facilitates real-time information exchange between the autonomous mobile robot and the centralized healthcare management server. Reliable communication is essential for transmitting patient physiological information, receiving monitoring requests, and maintaining synchronized healthcare records.

Following the validation of physiological measurements, the robot packages the acquired data into a structured healthcare data packet. The packet contains patient identification information, vital signs measurements, timestamps, and operational metadata required for healthcare record management.

The transmitted data packet is expressed as

$$D_t = \{PID, T, HR, SpO2, t\}$$

Where;

- PID = Patient Identification Number
- T = Body temperature
- HR = Heart rate
- SpO2 = Blood oxygen saturation

Once the data packet is generated, the communication module establishes a secure wireless connection with the healthcare server. The communication framework supports bidirectional information exchange, allowing the robot to upload physiological measurements while simultaneously receiving operational instructions from the monitoring center.

After establishing communication, the robot uploads the packaged physiological information to the healthcare database. The server acknowledges successful reception of the data and confirms transmission completion. This confirmation mechanism ensures communication reliability and prevents information loss during transmission.

The communication infrastructure enables healthcare personnel to remotely access patient information through a centralized monitoring dashboard. Real-time visualization of physiological measurements allows clinicians to assess patient conditions without requiring physical presence. This capability is particularly beneficial in high-dependency wards, infectious disease units, and large healthcare facilities where continuous monitoring is necessary.

Furthermore, communication reliability is enhanced through packet verification procedures and transmission confirmation protocols. These mechanisms ensure that physiological data are accurately delivered to the server without corruption or duplication. The communication module also supports future integration with cloud-based healthcare platforms, enabling large-scale patient monitoring and remote healthcare services.

The implementation of a robust communication framework contributes significantly to healthcare efficiency by enabling continuous data exchange between robotic systems and healthcare professionals. As a result, patient conditions can be monitored in real time while reducing delays associated with manual data collection and reporting procedures.

C. Emergency Alert Generation and Clinical Support Module

The Emergency Alert Generation and Clinical Decision Support Module is responsible for evaluating patient physiological conditions and identifying abnormal health situations that require immediate clinical attention. This module enhances patient safety by enabling rapid detection of critical physiological events and automatically notifying healthcare personnel.

Following successful data transmission, the uploaded physiological parameters are compared against predefined clinical threshold values established according to healthcare guidelines. The comparison process allows the system to distinguish between normal and abnormal physiological conditions.

The alert generation condition is defined as

$$A_e = \begin{cases} 1, & Vp > Vth \\ 0, & otherwise \end{cases}$$

Where;

- A_e = Alert status
- V_p = Measured biological data
- V_{th} = Clinical Threshold value

If the acquired measurements exceed or fall below predefined limits, the system classifies the patient's condition as abnormal. Examples include elevated body temperature, irregular heart rate, or reduced oxygen saturation levels. Upon detecting such conditions, the emergency alert subsystem automatically generates an alert notification.

The generated alert contains critical information including patient identification, measured physiological values, timestamp, and alert severity level. The notification is transmitted immediately to the healthcare monitoring dashboard and made available to medical personnel for rapid intervention.

The alert management framework supports multiple alert categories, including warning-level notifications and critical emergency notifications. Warning alerts indicate early physiological deviations that require observation, whereas critical alerts indicate potentially life-threatening conditions requiring immediate medical response.

In addition to alert generation, the module supports clinical decision-making by providing healthcare professionals with real-time physiological trends. Historical monitoring data can be analyzed to identify patient deterioration patterns and support preventive medical interventions. This capability contributes to improved patient outcomes through proactive healthcare management.

The integration of automated alert generation significantly reduces response times compared with conventional manual monitoring procedures. Furthermore, continuous surveillance ensures that abnormal physiological conditions are detected even when healthcare personnel are occupied with other clinical responsibilities. Consequently, the proposed system enhances patient safety, improves clinical efficiency, and supports intelligent healthcare decision-making within smart hospital environments.

D. Electronic Health Record Management and Data Synchronization Module

The Electronic Health Record (EHR) Management and Data Synchronization Module constitutes the final stage of the proposed healthcare robotic framework. This module is responsible for maintaining accurate patient records, updating healthcare databases, and ensuring continuous synchronization of clinical information across healthcare systems.

Following physiological data analysis and alert generation, the robotic platform updates the patient's electronic health record with newly acquired information. The updated record includes physiological measurements, monitoring timestamps, alert notifications, and operational logs associated with the monitoring session.

The record updating process can be represented as

$$R_u = R_p + D_n$$

Where;

- R_u = Updated patient record
- R_p = Existing patient record
- D_n = Newly acquired healthcare information

The update mechanism ensures that healthcare professionals have immediate access to current patient information. By maintaining a continuously updated electronic record, the system eliminates delays associated with manual documentation and improves overall healthcare efficiency.

Data synchronization plays a critical role in ensuring consistency between the robotic platform and the central healthcare database. Whenever new patient information is generated, synchronization procedures automatically update all connected healthcare systems. This process prevents discrepancies between local and centralized records and ensures that clinicians access the most recent patient information.

The synchronization framework also supports historical data storage and long-term patient monitoring. Continuous accumulation of physiological measurements enables trend analysis, disease progression monitoring, and predictive healthcare analytics. Such capabilities support evidence-based clinical decision-making and improve treatment planning.

To maintain data integrity and confidentiality, secure synchronization protocols are employed during information exchange. Authentication mechanisms verify authorized access, while encrypted communication channels protect sensitive healthcare information from unauthorized disclosure. These security measures ensure compliance with healthcare data protection requirements.

The implementation of automated electronic health record management offers several advantages over conventional manual record-keeping approaches. These include reduced documentation errors, improved data accessibility, enhanced record consistency, and greater operational efficiency. Furthermore, automated synchronization minimizes administrative workload, allowing healthcare personnel to focus on patient care activities.

Overall, the Electronic Health Record Management and Data Synchronization Module establishes a comprehensive healthcare information management framework that supports continuous patient monitoring, real-time clinical decision-making, and intelligent healthcare service delivery within modern smart hospital environments.

IV. SYSTEM IMPLEMENTATION

A. Hardwqre Architecture and Mobile Robotic Platform

The proposed healthcare monitoring system was implemented using an autonomous mobile robotic platform designed to perform patient monitoring operations within indoor healthcare environments. The hardware architecture consists of a differential-drive mobile robot integrated with sensing, processing, communication, and identification modules. The primary objective of the hardware subsystem is to provide reliable autonomous mobility while supporting physiological data acquisition and patient identification.

The robotic platform utilizes a Raspberry Pi 4 as the central processing unit responsible for coordinating navigation, sensing, communication, and data processing tasks. An Arduino Mega is employed as a secondary controller to manage low-level motor control and sensor interfacing operations. The motion subsystem consists of two DC geared motors, wheel encoders, motor drivers, and a rechargeable lithium-ion battery pack.

Environmental perception is achieved using a LiDAR sensor and an Inertial Measurement Unit (IMU). The LiDAR continuously scans the surrounding environment to identify obstacles and generate spatial information required for autonomous navigation. The IMU provides orientation and motion data that improve localization accuracy through sensor fusion techniques. Similar combinations of LiDAR and inertial sensing have demonstrated reliable navigation performance in autonomous hospital service robots and logistics platforms [2], [5], [19].

The patient identification subsystem is implemented using an RFID reader and RFID tags assigned to individual patients. RFID technology has become increasingly important in healthcare applications because it enables rapid and reliable patient identification while minimizing human error [4], [15], [16]. Upon arrival at a designated patient location, the RFID reader retrieves the patient identification information and verifies it against the centralized healthcare database.

Physiological monitoring is performed using biomedical sensors capable of measuring body temperature, heart rate, and blood oxygen saturation. The MAX30102 pulse oximeter sensor is employed for heart rate and SpO_2 measurements, while a non-contact temperature sensor is used to acquire body temperature data. The acquired measurements are processed locally before transmission to the healthcare server.

The integration of autonomous mobility, patient identification, and physiological sensing establishes a comprehensive robotic platform capable of supporting continuous healthcare monitoring in smart hospital environments.

B. Software Architecture and Autonomous Navigation Framework

The software architecture of the proposed system was developed using the Robot Operating System (ROS) framework, which provides a modular environment for sensor integration, navigation, communication, and data processing. ROS facilitates interoperability between hardware modules and simplifies the implementation of autonomous robotic functionalities.

The navigation framework consists of simultaneous localization and mapping (SLAM), localization, path planning, and obstacle avoidance modules. Environmental mapping is performed using LiDAR and IMU data to generate a two-dimensional occupancy grid map of the healthcare facility. The generated map serves as the reference environment for navigation and localization processes.

Localization algorithms continuously estimate the robot position within the mapped environment by combining LiDAR observations and inertial measurements. Sensor fusion methods have been shown to improve localization robustness and navigation accuracy in autonomous mobile robots operating in dynamic indoor environments [2], [6].

Following localization, the ROS navigation stack computes an optimal route between the robot's current position and the designated patient location. The navigation framework incorporates both global and local planning algorithms. The global planner determines the shortest feasible route, whereas the local planner dynamically adjusts robot movement according to environmental changes.

Table.1. presents the software architecture and development framework employed in the proposed healthcare robotic system. The implementation was developed using the Ubuntu 20.04 operating system and the ROS Noetic middleware, which provided a modular platform for integrating navigation, sensing, communication, and healthcare monitoring functionalities.

Table. 1. SOFTWARE COMPONENTS AND FUNCTIONALITIES

Software Component	**Tool/Framework**	**Function**
Operating System	Ubuntu 20.04	System platform
Middleware	ROS Noetic	Robot communication and control
Mapping	Hector SLAM	Environment mapping
Localization	AMCL	Robot position estimation
Navigation	ROS Navigation Stack	Path planning and obstacle avoidance
Database	MySQL/Firebase	Patient data storage
Programming Language	Python/C++	Algorithm implementation
Visualization	RViz	Real-time robot monitoring

Dashboard	Node-RED/Web Interface	Healthcare monitoring interface

Obstacle avoidance is achieved through real-time LiDAR scanning and local costmap generation. Detected obstacles are continuously incorporated into the navigation framework, allowing the robot to modify its trajectory and avoid collisions. This capability is particularly important in healthcare facilities where patients, medical staff, and equipment frequently move throughout the environment.

The integration of localization, mapping, path planning, and obstacle avoidance modules enables safe and reliable autonomous operation within hospital settings.

C. Healthcare Monitoring and Communication Infrastructure

The healthcare monitoring subsystem facilitates physiological data acquisition and real-time communication between the robotic platform and the centralized healthcare server. This subsystem forms the communication backbone of the proposed healthcare monitoring framework.

After patient verification, the physiological sensing subsystem acquires body temperature, heart rate, and blood oxygen saturation measurements.

To ensure measurement reliability, multiple sensor readings are collected and validated before transmission. The validated data are subsequently packaged into a structured healthcare information packet containing patient identification information, physiological parameters, and monitoring timestamps.

Wireless communication is established using a Wi-Fi-based infrastructure that enables secure data exchange between the robot and the healthcare server. IoT-enabled communication frameworks have demonstrated significant effectiveness in healthcare monitoring applications by supporting real-time data accessibility and remote supervision [15], [17], [20].

The transmitted data packet is expressed as

$$D_t = \{PID, T, HR, SpO2, t\}$$

where (PID) denotes patient identification and (t) represents the monitoring timestamp.

Table. 2. presents the physiological parameters monitored by the proposed autonomous healthcare robotic system along with the corresponding sensing devices, normal operating ranges, and measurement units.

Table. 2. Physiological Parameters Monitored by the System

Parameter	**Sensor Used**	**Normal Range**	**Unit**
Body Temperature	MLX90614	36.5 – 37.5	°C
Heart Rate	MAX30102	60 – 100	BPM
Oxygen Saturation (SpO_2)	MAX30102	≥ 95	%

Following successful transmission, the healthcare server stores the received information in the monitoring database and updates the healthcare dashboard. This architecture enables healthcare personnel to access real-time patient information from remote locations.

D. Emergency Alert and Clinical Decision Support Framework

The emergency alert subsystem was implemented to provide automated detection of abnormal physiological conditions and support rapid medical intervention. The subsystem continuously evaluates uploaded physiological measurements against predefined clinical threshold values.

Whenever abnormal conditions are detected, the system automatically generates an alert notification containing patient identification information, physiological measurements, alert severity, and monitoring timestamps. The generated alerts are transmitted to healthcare personnel through the monitoring dashboard.

Historical physiological data are retained within the database to support trend analysis and clinical assessment. This functionality enables healthcare professionals to evaluate patient progression and identify early indicators of clinical deterioration.

Table. 3. presents the hardware components incorporated into the proposed autonomous healthcare robotic system along with their respective functions. The hardware architecture was designed to support autonomous navigation, patient identification, physiological monitoring, communication, and healthcare data management within a unified platform.

Table. 3. MATERIALS AND WEIGHT

Component	Model/Type	Function
Processing Unit	Raspberry Pi 4	Central system control and data processing
Microcontroller	Arduino Mega	Sensor interfacing and motor control
Navigation Sensor	RPLiDAR A1/A2	Environment mapping and obstacle detection
IMU Sensor	MPU6050	Orientation and motion estimation
RFID Reader	MFRC522	Patient identification
RFID Tag	Passive RFID Tag	Patient information storage
Temperature Sensor	MLX90614	Non-contact body temperature measurement
Pulse Oximeter Sensor	MAX30102	Heart rate and SpO_2 monitoring
Motor Driver	L298N	DC motor actuation
Communication Module	Wi-Fi (ESP32/Onboard Wi-Fi)	Data transmission to healthcare server
Power Source	Li-ion Battery Pack	Power supply for robotic platform

V. EXPERIMENTAL DESIGN

The experimental design was developed to evaluate the performance of the proposed Integrated Autonomous Mobile Robotic System for Vital Signs Surveillance and Healthcare Assistance under realistic healthcare operating conditions. The objective of the experiments was to validate the robot's capability to autonomously navigate within a healthcare environment, identify patients, acquire physiological parameters, transmit healthcare information, and generate emergency alerts when abnormal conditions were detected.

Unlike conventional healthcare monitoring systems that primarily focus on physiological sensing or communication infrastructure, the proposed framework integrates autonomous mobility, RFID-based patient identification, biomedical sensing, healthcare communication, and clinical decision support within a unified robotic platform. Therefore, the experimental evaluation was designed to assess the complete operational workflow rather than evaluating individual subsystems independently.

Initially, a virtual healthcare environment was developed using Gazebo and RViz within the ROS framework. The simulated environment consisted of hospital corridors, patient beds, healthcare workstations, and various static obstacles that represented real-world hospital infrastructure. The virtual environment was designed to replicate common navigation challenges encountered in healthcare facilities, including narrow pathways, multiple patient locations, and obstacle-rich operating conditions.

A. Hospital Environment Mapping and Navigation Evaluation

The first stage of experimentation focused on evaluating the autonomous navigation capability of the robotic platform. During the mapping process, the robot was manually teleoperated throughout the virtual healthcare environment to ensure complete exploration of all accessible areas. LiDAR and IMU measurements were continuously collected and processed using the Hector SLAM algorithm to generate a two-dimensional occupancy grid map of the environment.

The generated map served as the reference environment for autonomous localization and path planning. Following map generation, patient bed locations were designated as navigation goals within the ROS navigation framework. The robot was instructed to autonomously navigate toward assigned patient locations while avoiding static obstacles positioned throughout the environment.

The experimental evaluation measured navigation accuracy, obstacle avoidance performance, path completion success rate, and localization consistency. The navigation experiments verified the robot's capability to safely operate in healthcare environments while maintaining accurate positioning during patient monitoring tasks.

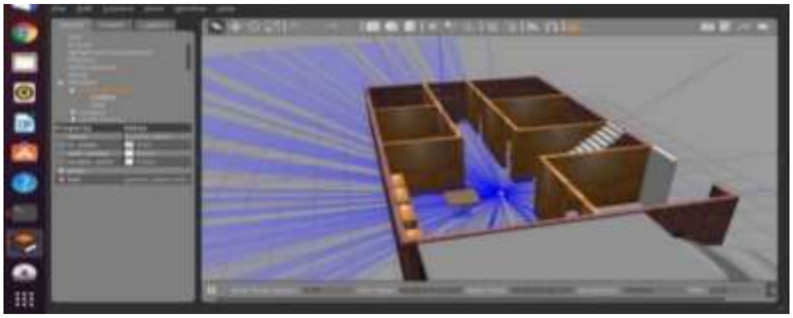

Fig. 2. Virtual environment for navigation

B. Patient Identification and Physiological Monitoring Evaluation

Following successful navigation, the second stage evaluated the patient identification and physiological monitoring capabilities of the robotic system. RFID tags were assigned to individual patient locations, and the robot was required to verify patient identity before initiating monitoring procedures.

Upon reaching the designated patient bed, the RFID reader scanned the patient tag and compared the retrieved identification information with records stored in the healthcare database. Successful verification triggered the physiological monitoring subsystem.

The monitoring subsystem acquired body temperature, heart rate, and oxygen saturation measurements using integrated biomedical sensors. Multiple measurements were collected to assess sensing stability and repeatability. Experimental observations included sensor response time, identification accuracy, measurement consistency, and monitoring reliability.

This experimental stage verified that the robotic platform could accurately associate physiological measurements with the correct patient and reliably acquire healthcare information without requiring manual intervention.

Figure 3. Autonomous Navigation, RFID Verification, and Vital Signs Acquisition Process

C. Healthcare Communication and Data Transmission Evaluation

The third stage focused on validating the communication framework responsible for transferring healthcare information between the robot and the centralized healthcare server. Following physiological data acquisition, patient information and vital sign measurements were packaged into structured healthcare data packets and transmitted through a Wi-Fi communication network.

The communication experiments evaluated packet delivery success rate, transmission latency, acknowledgment response time, and database synchronization performance. Data received by the healthcare server were automatically stored and visualized through a healthcare monitoring dashboard.

The communication evaluation demonstrated the system's capability to provide continuous remote patient monitoring while maintaining reliable information exchange between robotic and healthcare infrastructures.

D. Emergency Alert and Clinical Response Evaluation

The final experimental stage assessed the effectiveness of the emergency alert generation subsystem. Controlled physiological scenarios were created by introducing predefined abnormal temperature, heart rate, and oxygen saturation values into the monitoring framework.

Whenever physiological measurements exceeded predefined threshold values, the system automatically generated emergency notifications and transmitted them to the healthcare dashboard. The generated alerts contained patient identification information, alert severity level, physiological measurements, and monitoring timestamps.

The experimental evaluation measured alert detection accuracy, notification latency, and database update performance. Additionally, the synchronization of generated alerts with patient electronic health records was verified.

The results demonstrated the capability of the proposed framework to provide continuous patient surveillance, rapid emergency detection, and timely clinical notification, thereby improving healthcare response efficiency and patient safety.

V. Result and Analysis

The experimental evaluation was conducted to assess the performance of the proposed autonomous healthcare robotic system in terms of navigation reliability, localization accuracy, and operational effectiveness within a hospital environment. Since healthcare facilities involve dynamic conditions, frequent human movement, and safety-critical operations, it is essential to evaluate the robot's ability to navigate accurately while maintaining reliable patient monitoring services.

The experiments focused on two key aspects of system performance: autonomous navigation success and localization accuracy achieved through sensor fusion techniques. Autonomous navigation was evaluated by measuring the robot's ability to successfully reach designated patient locations under realistic operating conditions. Additionally, the effectiveness of the proposed sensor fusion framework was assessed by comparing localization accuracy obtained from individual sensors, including GPS, IMU, and LiDAR, against the integrated multi-sensor approach.

Accurate localization and reliable navigation are fundamental requirements for healthcare robots because they directly influence patient safety, monitoring efficiency, and the overall quality of healthcare service delivery. Therefore, the obtained results provide valuable insights into the capability of the proposed system to perform autonomous healthcare tasks with minimal human intervention. The following subsections present a detailed analysis of navigation performance and sensor fusion accuracy, followed by a discussion of their implications for smart healthcare environments.

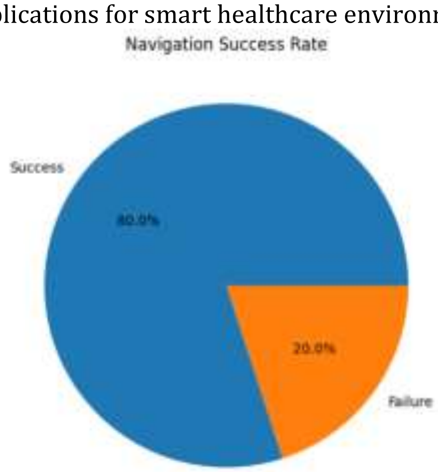

Figure 4. Autonomous navigation performance analysis

The navigation performance of the autonomous healthcare robot was evaluated by measuring the percentage of successful and unsuccessful navigation attempts during experimental trials. As illustrated in Figure 4, the robot achieved an overall navigation success rate of 80%, while 20% of the navigation attempts resulted in failure.

The high success rate indicates that the robot was capable of reaching designated patient locations in most experimental scenarios without human intervention. The successful navigation outcomes demonstrate the effectiveness of the integrated localization, obstacle detection, and path-planning mechanisms implemented within the robotic platform.

The observed failures may be attributed to factors such as:

- Dynamic obstacles introduced during navigation.
- Temporary localization drift.
- Sensor measurement noise.
- Environmental uncertainties within the hospital corridor.

Despite these challenges, the achieved success rate confirms that the proposed navigation framework provides a reliable foundation for autonomous healthcare service delivery.

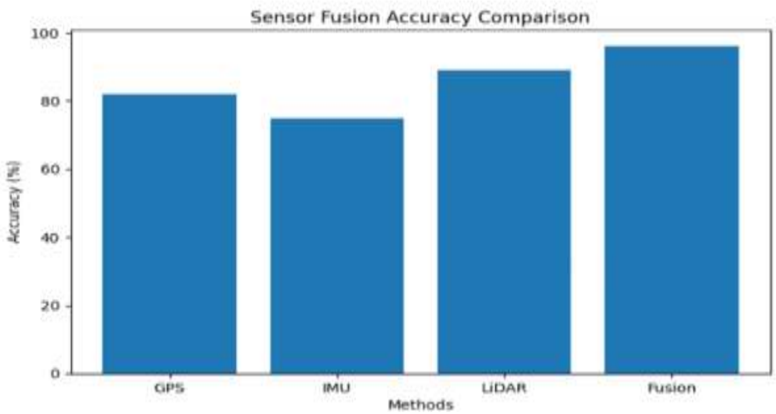

Figure 5. Sensor Fusion accuracy analysis

Figure 5. compares the localization accuracy achieved using individual sensing modalities and the proposed sensor fusion approach.
The IMU-based localization produced the lowest accuracy (75%) among the evaluated methods. Although IMUs provide continuous motion information, accumulated drift errors over time significantly reduce localization precision.
GPS achieved higher accuracy (82%) than the IMU due to its ability to provide global position estimates. However, GPS signals are often degraded in indoor hospital environments because of signal attenuation and multipath effects, limiting its effectiveness for precise navigation.
LiDAR demonstrated superior performance (89%) compared to GPS and IMU. The laser-based sensing mechanism enabled accurate obstacle detection and environmental mapping, resulting in improved localization accuracy. Nevertheless, LiDAR performance may still be affected by environmental complexity and map-matching uncertainties.
The proposed sensor fusion framework achieved the highest localization accuracy of 96%. By integrating information from GPS, IMU, and LiDAR sensors, the system effectively compensated for the limitations of individual sensing modalities.
The improvement can be attributed to:

- Reduction of IMU drift errors.
- Enhanced environmental perception through LiDAR.
- Global position correction from GPS measurements.
- Improved state estimation through multi-sensor data integration.

The communication reliability of the healthcare robotic system was evaluated by measuring packet loss during ten consecutive communication trials. Figure 6 illustrates the packet loss percentage observed during data transmission between the robot and the healthcare monitoring server.
The packet loss values ranged between 1.5% and 2.5%, with an average packet loss of approximately 1.85%. The highest packet loss occurred during Trial 3 (2.5%), whereas the lowest packet loss was recorded during Trial 8 (1.5%).

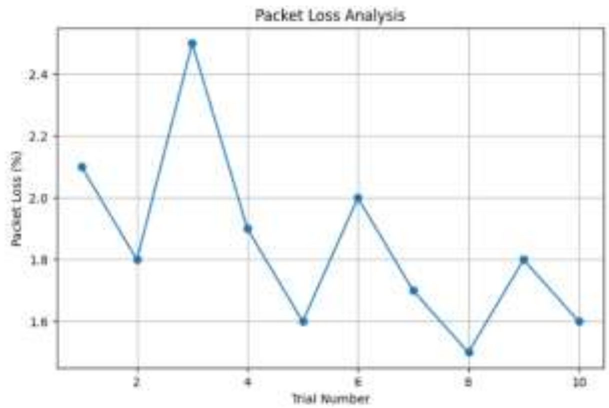

Figure 6. Sensor Fusion accuracy analysis

The communication results indicate that packet loss remained consistently below 3% throughout all experimental trials. Such low packet loss levels suggest that the Wi-Fi communication framework provides stable and reliable healthcare data transmission.

The minor fluctuations observed across trials can be attributed to:

- Temporary wireless interference.
- Network congestion.
- Environmental signal attenuation.
- Variations in communication distance.

Despite these variations, the overall packet delivery performance remained highly reliable, ensuring successful transmission of patient identification information, physiological measurements, and emergency alerts.

Table 4 presents a comparison between the proposed healthcare robotic system and previously reported healthcare monitoring and autonomous robotic platforms. In contrast, the proposed system combines all essential healthcare monitoring components within a unified ROS-based robotic framework. The system not only performs autonomous navigation and RFID-based patient verification but also acquires vital signs including body temperature, heart rate, and oxygen saturation. Furthermore, collected healthcare data are transmitted in real time to a centralized healthcare server, where patient records are automatically updated and synchronized. Therefore, compared with existing approaches, the proposed system offers a more comprehensive and intelligent healthcare solution by integrating navigation, patient identification, physiological monitoring, wireless communication, emergency response, and healthcare database management into a single autonomous platform. This integrated architecture enhances patient safety, improves healthcare monitoring efficiency, reduces manual workload, and supports the development of next-generation smart healthcare environments.

Table. 4. COMPARISON OF PROPOSED SYSTEM FUNCTIONALITIES WITH EXISTING METHODS

Features	[1]	[4]	[13]	[19]	Proposed System
Autonomous Navigation	✓	✗	✓	✓	✓
RFID Patient Identification	✗	✓	✗	✓	✓
Vital Signs Monitoring	✓	✓	✗	✗	✓
Real-Time Data Upload	✓	✓	✓	✗	✓
Emergency Alert Generation	✗	✗	✗	✗	✓
Electronic Health Record Update	✗	✗	✗	✗	✓
Integrated Healthcare Framework	✗	✗	✗	✗	✓

VI. Conclusion and Future work

This research presented the design and implementation of an autonomous healthcare monitoring robot based on the Robot Operating System (ROS) framework for intelligent patient monitoring and healthcare assistance applications. The proposed system integrates autonomous navigation, RFID-based patient identification, physiological monitoring, wireless healthcare communication, and emergency alert generation into a unified robotic platform capable of operating with minimal human intervention.

The developed system combines LiDAR sensing, IMU measurements, sensor fusion techniques, and PID-based motion control to achieve reliable indoor navigation and localization. Experimental evaluation demonstrated an autonomous navigation success rate of 80%, while the sensor fusion framework achieved a localization accuracy of 96%, outperforming individual sensing modalities such as GPS, IMU, and LiDAR. The obtained results confirm the effectiveness of multi-sensor integration for improving navigation reliability in dynamic healthcare environments.

The RFID-based patient identification subsystem successfully verified patient information prior to monitoring operations, ensuring that physiological measurements were correctly associated with the corresponding patient records. Furthermore, the integrated biomedical sensors consistently acquired body temperature, heart rate, and oxygen saturation measurements, demonstrating stable and reliable monitoring performance.

The communication framework provided efficient data transmission between the robotic platform and the centralized healthcare server. Communication experiments showed an average packet loss of approximately 1.85%, indicating reliable wireless information exchange and effective database synchronization. In addition, the emergency alert subsystem successfully detected abnormal physiological conditions and generated timely notifications, enabling rapid clinical response and continuous patient surveillance.

Overall, the experimental results validate the capability of the proposed healthcare robotic system to perform autonomous navigation, patient identification, physiological monitoring, healthcare data transmission, and emergency alert generation. The developed framework provides a practical foundation for intelligent healthcare assistance systems that can improve patient safety, reduce healthcare personnel workload, and support continuous remote monitoring in modern smart healthcare environments.

Future work can be focused on the following such as,

1. Integrate additional sensing technologies such as depth cameras, stereo vision systems, and visual-inertial odometry to further improve localization accuracy and robustness in complex indoor healthcare environments.
2. Incorporate ultrasonic, infrared, and RGB-D sensors to enhance real-time obstacle detection, enabling safer navigation in highly dynamic hospital environments with patients, visitors, and healthcare personnel.
3. Integrate machine learning and artificial intelligence algorithms for intelligent patient condition assessment, anomaly detection, and predictive healthcare monitoring based on historical physiological data.
4. Develop intelligent task allocation and scheduling mechanisms that allow the robot to autonomously prioritize patient visits and monitoring tasks according to urgency and clinical requirements.

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