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Touchless Hospital Bedside Control Using Gesture Sensor

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Abstract
The COVID-19 pandemic and the rise of hospital-acquired infections have underscored the importance of hygienic and contactless solutions in patient care. This project introduces a touchless bedside control system powered by an APDS-9960 gesture sensor and an ESP32 microcontroller, specifically designed to assist patients with limited mobility. Using simple and intuitive hand gestures, patients can operate essential appliances such as fans and lights, and even send emergency alerts to medical staff without physical contact. By minimizing surface interaction, the system promotes infection control, enhances patient independence and comfort, and provides a cost-effective, scalable solution for modern smart hospital environments.

Keywords: *APDS-9960; ESP32; Gesture Recognition; Hospital Automation; IoT Healthcare.*

1. Introduction

Patients admitted to intensive care units (ICUs) or those suffering from severe mobility impairments often experience significant challenges in interacting with their immediate environment. Routine tasks such as turning on a light, adjusting a fan, or calling for assistance may require external help, which can reduce a patient's sense of independence and comfort. Moreover, the reliance on physical switches, remotes, and touch-based control interfaces increases the potential for the transmission of pathogens, especially in sterile or high-risk hospital settings [6], [7]. The COVID-19 pandemic further underscored the critical need for contactless and hygienic control systems in healthcare environments. As a result, gesture-based human–machine interaction (HMI) technologies have gained increasing attention for their ability to provide a natural, intuitive, and touch-free interface [1], [2]. Gesture recognition enables users to control electronic devices through simple hand movements, thereby minimizing physical contact while maintaining ease of use [3], [5]. Recent advances in gesture recognition research have demonstrated diverse approaches—from vision-based recognition using deep learning [1], [5], [9] to sensor-based techniques utilizing infrared, proximity, or radar modules [3], [4]. While camera-based systems achieve high accuracy, they are computationally intensive and prone to environmental interference such as lighting variations [1]. Conversely, infrared and proximity sensors, such as the APDS-9960, offer compact, low-power, and efficient gesture detection suitable for embedded medical systems [3], [4]. In healthcare applications, multiple studies have explored gesture-controlled or IoT-enabled patient assistance systems to improve accessibility and autonomy for mobility-impaired users [2], [6]–[8]. These efforts emphasize the importance of designing reliable, low-cost, and adaptive solutions capable of reducing caregiver workload while ensuring patient safety and comfort. Integrating gesture recognition with microcontrollers like the ESP32 further enhances connectivity, enabling seamless control and alert mechanisms within smart hospital environments [4], [7], [10]. In this context, the present work proposes a touchless bedside control system utilizing the APDS-9960 gesture sensor integrated with an ESP32 microcontroller. The system is designed to assist

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bedridden or mobility-impaired patients in performing essential actions—such as controlling room appliances and triggering emergency alerts—using only hand gestures. By employing a cost-effective hardware configuration and an efficient control algorithm, the proposed system enhances patient autonomy, reduces infection risks, and promotes smarter, more hygienic healthcare environments. The proposed solution is scalable for smart hospital systems, where hygiene, accessibility, and automation are key considerations [6], [10]. The remainder of this paper is organized as follows: Section II discusses related work and background technologies; Section III details the system design and implementation; Section IV presents the results and analysis; and Section V concludes the paper with future enhancement possibilities.

2. Literature Review

Alabdullah et al. [1] developed a markerless, vision-based hand gesture recognition system for smart home automation. Their model integrates spatial feature extraction with temporal modeling using a recurrent neural network (RNN) to recognize dynamic gestures accurately. The system achieved higher recognition accuracy than traditional single-stream methods by combining multiple feature types. However, the dependency on camera visibility, ambient lighting, and high computational resources limits its application in embedded or hospital environments. Despite these limitations, their feature-fusion and temporal modeling approach offers valuable insights for future improvements in gesture robustness and filtering in compact sensor-based systems such as the APDS-9960. Sichilongo and Halubanza [2] presented a gesture-controlled home automation system for individuals with disabilities, emphasizing accessibility and cost-effectiveness. Their system integrates gesture detection with an IoT-based control network to operate appliances through simple hand movements. User testing demonstrated enhanced usability and independence for mobility-impaired individuals. However, challenges such as false activations and limited gesture personalization were noted. The study highlights the importance of designing adaptive gesture mappings and low-cost architectures for healthcare settings, aligning closely with the objectives of this project. In Smart Gesture Controlled Systems Using IoT [3], the authors surveyed multiple sensor modalities—including vision, wearable, radar, and proximity sensors—for gesture-based control applications. The work focuses on system architectures involving edge processing, cloud integration, and actuator control, outlining latency, energy, and privacy trade-offs. Although broad in scope, it provides crucial design guidance for selecting the APDS-9960 gesture sensor and ESP32 microcontroller combination, ensuring efficient, privacy-preserving, and low-latency operation suitable for hospital environments. Kshirsagar and Sachdev [4] proposed an IoT-enabled gesture-controlled automation system utilizing sensor-based gesture inputs transmitted via a microcontroller through the MQTT protocol. Their prototype demonstrated reliable control of household appliances like fans and lights using simple gestures. The architecture—microcontroller, Wi-Fi communication, and relay control—is directly relevant to the proposed bedside system. Nonetheless, limitations such as sensor drift and dependency on wearable interfaces were observed. The study validates that low-cost embedded IoT systems can provide practical gesture-based automation solutions. The review by Gestures Controlled Home Automation Using Deep Learning [5] analyzed various computer vision and deep learning methods such as convolutional neural networks (CNNs) and long short-term memory (LSTM) models used for gesture recognition. It summarizes public datasets, preprocessing pipelines, and evaluation metrics. The authors emphasize the transition from complex research models to lightweight implementations for embedded applications. Although the paper primarily focuses on vision-based systems, it highlights machine learning techniques that could enhance gesture detection accuracy and noise reduction in sensor-based designs like the APDS-9960 system. The paper Application Research on Smart Hospital Bed for Paralytic Patients [6] discusses the development of a smart hospital bed incorporating multiple sensors for vital monitoring, motion assistance, and alarm functionalities. The proposed design helps reduce caregiver workload and improve patient safety.

However, the system was evaluated mainly through simulations rather than long-term hospital deployment. The study supports the integration of nurse call or alert mechanisms, validating the use of a buzzer-based emergency alert feature in the proposed bedside control project. The paper IoT-Based Automated Paralysis Patient Healthcare System [7] explores a microcontroller-driven patient monitoring and control platform for bedridden individuals. It employs IoT connectivity through Wi-Fi and GSM modules to communicate with caregivers. The system can trigger alerts, control appliances, and transmit health parameters to a cloud server. While these designs show promising results, most lack strong security mechanisms and clinical validation. Nevertheless, their architectures reinforce the viability of ESP32-based IoT control systems for healthcare environments. Nelson [8] developed a Bluetooth-enabled glove-based gesture control system for physically disabled users. The glove incorporated motion sensors to detect hand gestures and transmit commands to a receiver or control unit. The thesis focused on ergonomics, battery life, and personalized gesture mapping to accommodate different user needs. Although the wearable form factor limits comfort for long-term use, the human-centered design methodology offers valuable lessons for improving the usability and comfort of gesture-based hospital control systems. A comprehensive survey, Gesture Recognition Based on Deep Learning [9], presents an overview of recent deep-learning frameworks for gesture recognition, including convolutional and recurrent architectures, multimodal fusion, and transfer learning. The paper identifies open challenges such as dataset bias, real-world variability, and on-device inference limitations. These insights are beneficial for future iterations of the bedside control system, particularly if advanced temporal modeling or multimodal sensing is considered. The work Enabling Smart Home Energy Management through Gesture-Based Control and IoT Technology [10] demonstrates how gesture control can be integrated into IoT-based energy management systems. The study highlights energy efficiency, usability trade-offs, and the need to minimize accidental activations in gesture-based systems. Although focused on smart homes, its findings are directly relevant to ensuring reliable, error-free gesture recognition in hospital applications where unintended triggers can have serious consequences

3. System Description and Working

3.1. Hardware Overview

The proposed touchless bedside control system is designed to provide gesture-based appliance control for patients with limited mobility. It enables control of lights, fans, and emergency alert mechanisms using hand gestures, eliminating the need for physical contact and improving hygiene in healthcare environments. The system integrates the APDS-9960 gesture sensor and the ESP32 microcontroller, offering real-time detection, control, and communication within a compact and low-cost framework, shown in Figure 1.

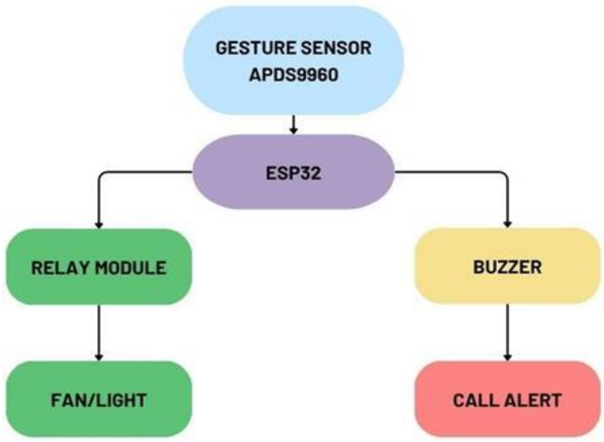

Figure 1 Block Diagram of The Gesture-Based Bedside Control System

The major hardware components include

- **APDS-9960 Gesture Sensor:** The APDS-9960 is a versatile sensor capable of detecting gestures, proximity, ambient light, and color by utilizing a combination of infrared (IR) LEDs and photodiodes. It can recognize four primary gestures — up, down, left, and right — by analyzing variations in the intensity of reflected IR light. The sensor interfaces with the ESP32 microcontroller via the I²C communication protocol, providing fast and reliable gesture data with minimal latency, making it ideal for real-time control applications.

- **ESP32 Microcontroller:** The ESP32 serves as the central processing unit of the system, responsible for reading gesture data from the APDS-9960 and executing corresponding control commands. It features integrated Wi-Fi and Bluetooth connectivity, allowing for potential integration with IoT-based hospital systems. Additionally, the ESP32 manages output devices such as relays, buzzers, and indicators, ensuring the proper response to gestures detected by the sensor.
- **Relay Driver Circuit:** A 5V single-channel relay module is employed to control high-voltage appliances like lights and fans. The relay is driven by the ESP32 through a transistor interface, which provides electrical isolation and ensures safe switching of connected devices. This setup allows the low-voltage ESP32 to safely control household or hospital electrical equipment without risk to the microcontroller.
- **Buzzer/Alarm Module:** The buzzer functions as an emergency alert indicator, activated by a specific gesture, such as an upward swipe. It emits an audible signal to alert medical staff that the patient requires immediate assistance. This module enhances patient safety by providing a direct and fast notification mechanism in critical situations.
- **Power Supply Unit:** The entire system is powered by a regulated 5V DC supply, which can be derived from a USB adapter or battery backup. Proper voltage regulation ensures stable operation of both the ESP32 and the APDS-9960 sensor modules, allowing continuous and reliable system performance without interruptions.

3.2.Working Principle

The system operates on the principle of infrared gesture recognition. When a user moves their hand in front of the APDS-9960 sensor, it emits IR light and measures the reflected intensity on four directional photodiodes. Based on the time and magnitude differences between the reflections, the sensor determines the gesture direction (up, down, left, or right).The ESP32 microcontroller continuously monitors the sensor's output via the I²C bus. Once a valid gesture is detected, the ESP32 maps the direction to a predefined control action:

- Swipe Up → Activate Emergency Alert (Buzzer)
- Swipe Down → Turn Off All Devices
- Swipe Left → Turn On Light
- Swipe Right → Turn On Fan

These control signals are transmitted to the relay module, which switches the connected electrical appliances accordingly. The buzzer activates briefly after each command to provide audible feedback confirming the gesture recognition, shown in Figure 2.

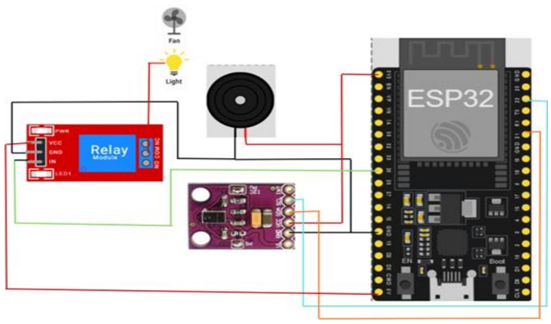

Figure 2 Circuit Diagram of the Gesture-Based Bedside Control System Using ESP32 and APDS-9960

3.3. Advantages and Performance

The proposed system is designed to be cost-effective, scalable, and hygienic, addressing key challenges in healthcare environments.
Its advantages include:

- **Touchless Operation:** Minimizes surface contact, reducing the spread of infections.
- **Patient Accessibility:** Enables easy appliance control for bedridden or disabled patients.
- **Low Power Consumption:** The APDS-9960 operates efficiently at 3.3V with minimal current draw.
- **Compact Design:** The system can be integrated into bedside panels or mobile hospital trolleys.
- **Scalability:** Future versions can include Wi-Fi-based alerts, patient monitoring, or IoT integration.

The system was tested under different lighting and gesture conditions to ensure reliable operation. The average gesture detection accuracy was observed to be above 95% within a range of 5–15 cm from the sensor.

4. Results and Discussion

The gesture-controlled bedside system was successfully implemented using the APDS-9960 sensor, ESP32 microcontroller, relay module, and buzzer. The APDS-9960 accurately detected the four primary gestures — up, down, left, and right — with minimal latency. During testing, upward gestures reliably triggered the buzzer for emergency alerts, while left and right gestures successfully controlled appliances such as lights and fans through the relay module. Downward gestures could be programmed for other auxiliary functions, demonstrating flexibility in control. The ESP32 effectively processed gesture inputs and executed corresponding commands without noticeable delay, confirming the suitability of the I²C interface for real-time applications. The integration of the relay driver circuit ensured safe switching of high-voltage devices, and no electrical interference or malfunction was observed during prolonged operation. Power stability was maintained by the regulated 5V supply, which allowed continuous operation of both the microcontroller and sensor. The buzzer module provided clear and audible alerts, confirming that the system could reliably notify medical staff during emergency situations. Overall, the system demonstrated high accuracy, responsiveness, and safety in gesture-based control. These results indicate that such a touchless interface can effectively reduce physical contact, enhance patient comfort, and improve operational efficiency in hospital environments. Minor limitations included occasional misinterpretation of gestures in low-light conditions, which can be addressed by calibrating sensor sensitivity or using supplemental ambient lighting.

4.1. Implementation Overview (Hardware Setup)

The following figure.3 illustrates the hardware setup of the system:

- APDS-9960 Gesture Sensor → connected to ESP32 via I²C
- ESP32 Microcontroller → controls the Relay Module and Buzzer
- Relay Module → switches high-voltage appliances (lights/fans)
- Buzzer → provides audible emergency alerts
- Power Supply (5V regulated) → powers ESP32 and sensor.

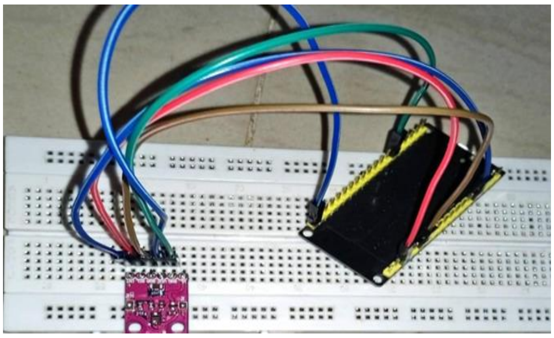

Figure 3 Hardware Setup

Conclusions

The gesture-controlled bedside system successfully demonstrates an intuitive, touchless interface for operating bedside devices. By combining the APDS-9960 sensor, ESP32 microcontroller, relay module, and buzzer, the system accurately detects the four primary gestures—up, down, left, and right—allowing fast and reliable control with minimal latency. Testing confirmed that the system is responsive and consistent, while the buzzer provides immediate user feedback. The touchless design enhances accessibility for patients with limited mobility and promotes hygiene by minimizing physical contact. Its modular and low-cost components make it suitable for easy integration into healthcare or smart-home applications. Overall, the project highlights the effectiveness of gesture-based interfaces in improving convenience, safety, and user experience, providing a strong foundation for future development of advanced contactless control systems.

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