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A unified artificial intelligence-enabled intelligent home assistant robot for smart automation and safety

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ABSTRACT

Intelligent home assistant systems are increasingly required to enhance safety, efficiency, and user convenience in smart environments. This paper presents LUNA, a unified artificial intelligence (AI)-enabled home assistant robot designed for smart automation and safety in indoor settings. The system integrates autonomous navigation, You Only Look Once version 8 (YOLOv8)-based object detection, gesture-based interaction, real-time gas and fire hazard detection, mobile application control, and automated floor cleaning within a single low-cost embedded platform. Unlike existing systems that focus on isolated functionalities, the proposed approach combines perception, mobility, safety monitoring, and user interaction in a coordinated framework suitable for real-world applications, particularly for elderly and disabled users. The system is implemented using Arduino, Raspberry Pi, and ESP32 to enable efficient sensing, processing, communication, and actuation. Experimental results demonstrate robust performance, achieving 93.5% navigation accuracy, 91.2% object detection accuracy, 2.5 s emergency response time, 1.2 s control latency, and 88.7% cleaning efficiency. These results indicate that LUNA is an effective and practical solution for next-generation smart home assistance.

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1. INTRODUCTION

The rapid advancement of artificial intelligence (AI), robotics, and internet of things (IoT) technologies has accelerated the development of intelligent systems capable of enhancing comfort, safety, and efficiency in smart homes [1]. In this scenario, home assistant robots are promising solutions to support daily activities, especially for elderly individuals and people with special needs [2]. AI robotics has rapidly evolved to transform home automation and assistive technologies. The estimate for the year 2050 is that there will be 2.1

billion elderly people aged 60 years and above, while those over 80 years of age will reach 426 million [3]. This growing demographic identified the urgent need to design affordable intelligent systems that ensure reliable assistance to the elderly and disabled while perpetuating their safety along with their independence in daily life and preserving their quality of life. Research shows the healthcare industry and domestic environment require more assistive robots because of workforce shortages and the spike in chronic diseases [4]. Standalone robotic solutions have become more important than ever because the coronavirus disease 2019 (COVID-19) pandemic demands equipment for limiting human contact during essential service delivery [5]. The market has seen substantial advancement in robotic home automation with the development of robotic vacuum cleaners and smart home devices. These robotic systems work on individual capabilities which hampers their value for multiple purposes.

The extensive deployment of robotic systems faces difficulties because they are expensive to produce and cannot easily interact with other systems while also generating privacy-related issues [6]. LUNA is a multipurpose robot system since it is capable of executing multiple operations simultaneously, thereby delivering a whole solution to a variety of household needs. LUNA is able to execute the detection of gas and fires, as well as object recognition, to deliver essential solutions for convenience assessment. Currently, robotics research is centered on the development of intelligent robots at a lower price. Literature has shown that cheaper robotics is able to facilitate assistance for elderly patients, especially when implementing rehabilitation plans for areas with poor medical facilities [7]. The usage of machine learning algorithms, such as You Only Look Once (YOLO), enables robots to execute navigation with great precision, according to this technology's integration [8]. LUNA further improves other robotic developments, bearing in mind its reduced-cost design for robotic technologies. This paper discusses LUNA's development and implementation, focusing on its advanced functionalities and affordable design. This paper makes the following contributions: (i) a unified assistive robotic system integrating navigation, intelligent perception, safety monitoring, human-robot interaction, and smart home control within a single platform; (ii) design and implementation of a multi-controller embedded architecture using Arduino, Raspberry Pi, and ESP32 for efficient sensing, processing, communication, and actuation; and (iii) experimental evaluation of system performance in terms of navigation accuracy, object detection accuracy, emergency response time, smart home control latency, and cleaning efficiency in a real-world indoor environment.

The proposed LUNA system integrates intelligent home assistance functionalities, including autonomous navigation, AI-based object recognition, gesture interaction, real-time hazard detection, mobile application control, and automated cleaning within a low-cost platform. Unlike existing systems that focus on isolated functionalities, the proposed framework introduces a coordinated multi-controller architecture that enables real-time interaction between perception, mobility, and safety subsystems, ensuring synchronized and efficient operation in dynamic indoor environments. This unified design allows seamless coordination among sensing, processing, and actuation modules, improving system responsiveness and operational efficiency. Furthermore, the system is validated through experimental evaluation in real-world indoor environments, demonstrating its practical applicability for elderly and disabled users. The remainder of this paper is structured as: recent related work is discussed in section 2. Section 3 comprehensively analyzes the proposed method and implementation details of the system. Section 4 evaluates the system's outcomes and performance, and section 5 presents the conclusion and future direction of this work.

2. LITERATURE REVIEW

Assistive robotics and smart home automation systems have evolved significantly to support elderly and disabled individuals through intelligent monitoring [9], gesture-based control, environmental sensing [10], and AI-driven interaction. Prior studies have explored various aspects of assistive technologies, including smart path following for restaurants and hospitality [11], gesture recognition for home automation [12]-[14], socially assistive robotic frameworks for elderly care [15]-[17], nursing-support robotic systems [18]-[20], healthcare-oriented automation platforms [21], [22], and IoT-based multipurpose home assistants with object detection capabilities [23]-[25]. These studies have shown significant developments in the integration of various sensors, AI, and distant communication technology systems. However, some of these systems may have limitations when it comes to their multifunctionality, cost-effectiveness, scalability, autonomous mobility, and thorough hazard detection. Some of the robots have been more focused on addressing social interactions [15], health monitoring [21], and gesture-based controls [12], others have addressed limitations such as system complexity

[18], [23]. Nevertheless, the use of multi-robot systems for emotional and household support was also explored [26]. Yet, the necessity of a cost-effective, integrated, and safe intelligent assistant remains a requirement. Henceforth, the LUNA system proposed in the paper bridges the gaps, integrating a cost-effective and safe framework that implements object recognition using AI, autonomous navigation, human following, environmental hazard detection, a cleaning feature, and mobile-based remote control. To well illustrate the gap in the existing system and the proposed system, Table 1 summarizes the comparison of the current work and proposed LUNA robot system. As shown in the table comparing the LUNA proposed robot and the existing work, the intelligent robot proposed is observed to integrate object recognition using AI, autonomous navigation, human following, gas and fire hazard detection, a cleaning feature, and mobile remote control within a unified and cost-effective framework.

Table 1. Summary of related works compared with the proposed LUNA system

Key aspect	[12]	[15]	[18]	[21]	[23]	LUNA
Gesture recognition	Yes	Limited	No	Yes	Yes	Yes
AI-based object detection	No	Partial	No	Partial	Yes (YOLOv8)	Custom YOLOv8
Autonomous navigation	No	No	Yes	Limited	No	Yes
Health/social assistance	No	Yes	Yes	Yes	Partial	Yes
Gas/fire detection	No	No	No	Emergency only	Yes	Yes
Remote app control	No	Yes	Limited	Yes	Yes	Yes
Cleaning functionality	No	No	No	No	No	Yes
Cost-effective integrated design	Limited	Costly	Prototype	Needs validation	Moderate	Yes

3. METHODOLOGY

The proposed approach is an intelligent embedded platform using Arduino, Raspberry Pi, and ESP32 to provide sensing, automation, and remote communication. Arduino is used as the main controller, which controls gas and flame detection using sensors, turns on the buzzer, and sends emergency calls with a global system for mobile communications (GSM) module. It controls vacuum cleaning, supports human-following mobility with motor drivers, infrared (IR), and ultrasonic sensors, and provides Bluetooth-based control. The Raspberry Pi is used to enhance the system with a camera-based image and gesture recognition using YOLOv8 and provides servo-based actuations. The ESP32 is responsible for inbuilt mobile app integration, environmental monitoring through the digital humidity and temperature (DHT) sensor, and remote control of output devices. These all together support a coherent multifunctional smart automation system.

3.1. System achitecture

LUNA is intended to be a multifunctional IoT-based and AI-assisted assistant robot. In this device, various sensing, processing, and executing modules are integrated. The system includes an embedded controller module, environment sensing modules, a navigation module, and communication modules. The system architecture of the proposed system is shown in Figure 1.

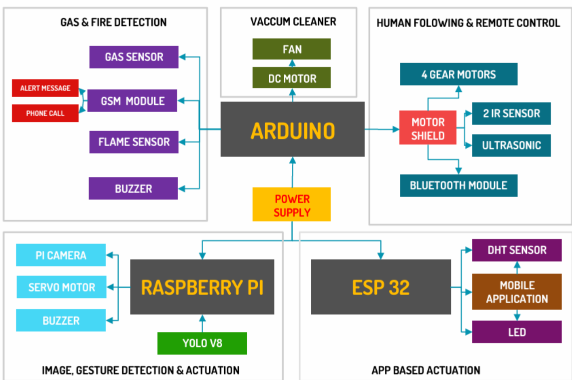


Figure 1. System architecture of the proposed intelligent home assistant robot showing sensing, processing, and communication modules

3.2. Hardware and software components

A comprehensive list of the essential hardware and software components, as well as the various costs, is provided in Table 2. This table reintroduces and combines various microcontrollers, sensors, actuators, as well as communication modules, with a focus placed on software. Integration of embedded software and mobile applications enhances their usability, while AI-powered object detection will further strengthen the capability of the system. This functional prototype cost can be estimated to be around 177.49 United States dollar (USD), thus making it cost-effective. However, in the case of the operational prototype with similar configurations, it may increase.

Table 2. Detailed list of hardware components used in the proposed system with corresponding costs (USD)

Component category (Items included)	Cost (USD)
Microcontrollers (Raspberry Pi 5, ESP32, Arduino Uno)	130.34
Sensors (ultrasonic, IR, MQ2, flame)	5.50
Actuators (direct current (DC) motors, 2 servo motors)	5.00
Communication modules (GSM, wireless fidelity (Wi-Fi))	16.40
Other components (Pi camera, cables, chassis)	20.25
Total hardware cost	177.49

4. EXPERIMENTAL SETUP AND RESULTS

LUNA was tested in a controlled indoor environment designed to replicate real-world home conditions. The experimental setup consisted of a $3m \times 3m$ area furnished with household objects to evaluate navigation and object detection performance. As shown in Figure 2, a human subject was involved in trials to assess human-following capability. Simulated gas leaks and fire hazards were introduced to test the emergency alert system, and Wi-Fi-enabled home appliances were used to verify remote control functionalities. Each feature was tested under multiple scenarios to validate performance consistency and efficiency.

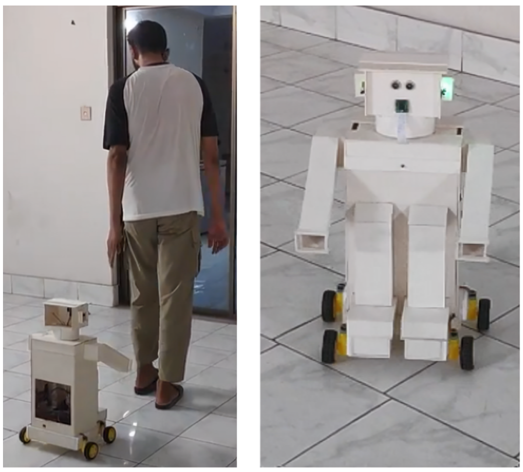


Figure 2. Path navigation and human-following performance of the robot in a controlled indoor environment

4.1. Human following and navigation

LUNA uses ultrasonic and IR sensors to detect human presence and track the user. The process is described in (1):

$$\text{Distance}_{\text{ultrasonic}} = \text{Speed of sound} \times \text{Time of flight} \tag{1}$$

This equation calculates the distance between the robot and the user based on the time it takes for the ultrasonic signal to travel. The system uses this distance to detect human presence.

$$\text{Angle}_{\text{IR}} = \arctan\left(\frac{\Delta y}{\Delta x}\right) \tag{2}$$

The IR sensor detects the user's position by calculating the angle based on the relative change in position. The robot then tracks and follows the user based on this angle and the distance from the sensors.

4.2. Object detection and gesture-based assistance

LUNA integrates both object detection and gesture-based assistance to enhance its functionality for smart home automation, the processes are as follows.

4.2.1. Object detection using YOLOv8 model

LUNA captures an image using its onboard camera and processes the image with the YOLOv8 model to detect household objects. The detection process is represented as (3).

$$\text{Object}_{\text{detected}} = \text{YOLOv8}(I_{\text{input}}) \tag{3}$$

Here, I_{input} represents the captured image, and the model processes the image to detect objects, resulting in $\text{Object}_{\text{detected}}$, which are the identified household objects. After processing the image, LUNA retrieves and recognizes the detected objects, assisting in locating them within the environment. Figure 3(a) shows the object detection outcome.

4.2.2. Gesture-based assistance using Raspberry Pi and Pi camera

LUNA employs a Raspberry Pi and Pi Camera to capture and recognize hand gestures for hands-free home control. The captured image I_{gesture} is processed using a gesture recognition model, expressed as (4).

$$\text{Gesture}_{\text{detected}} = \text{Gesture Model}(I_{\text{gesture}}) \tag{4}$$

where the identified gesture triggers the corresponding action, such as activating alarms or controlling appliances. This approach enables intuitive and touchless interaction. Object detection and gesture recognition performance is illustrated in Figures 3(a) and (b), respectively.

(a)

(b)

Figure 3. Object detection and gesture recognition results: (a) object detection results using the YOLOv8 model for real-time identification of household objects and (b) gesture recognition for user interaction using camera-based detection

4.3. Gas and fire detection

LUNA monitors environmental sensors to detect gas and fire hazards. The detection process can be described as follows.

4.3.1. Gas detection using MQ2 sensor

The MQ2 gas sensor detects the presence of gases by measuring the resistance change in the sensor. The gas concentration (C_{gas}) can be calculated based on the ratio of the resistance of the load resistor (R_{load}) to the resistance of the sensing material (R_{sensing}):

$$C_{\text{gas}} = \frac{R_{\text{load}}}{R_{\text{sensing}}} \tag{5}$$

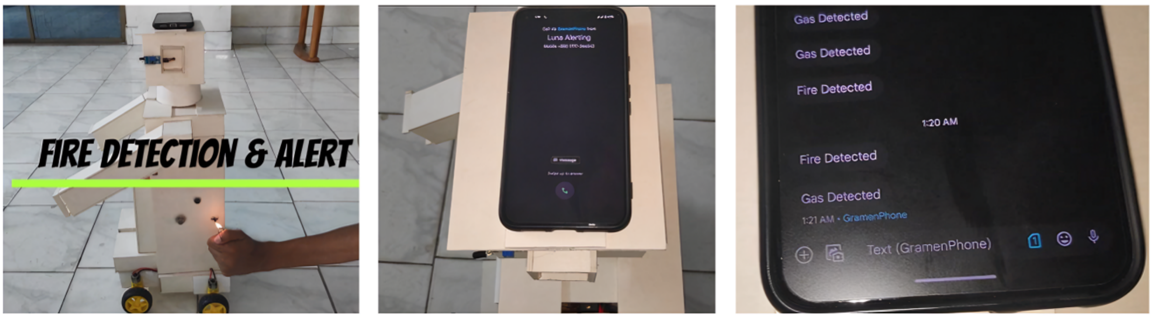
Here, R_{load} is the resistance of the load resistor, R_{sensing} is the resistance of the sensing material. If the gas concentration exceeds a predefined threshold, it indicates the presence of a gas leak.

4.3.2. Fire detection using flame sensor

The flame sensor detects fire by measuring the intensity of the light emitted by the flame. The output voltage (V_{flame}) from the sensor can be calculated as (6):

$$V_{\text{flame}} = I_{\text{flame}} \times R_{\text{sensor}} \tag{6}$$

Here V_{flame} is the voltage output from the flame sensor, I_{flame} is the current generated by the flame's light intensity, R_{sensor} is the resistance of the flame sensor. If the output voltage exceeds the threshold, it indicates the presence of fire. The fire detection process is demonstrated in Figure 4(a), where the flame sensor detects the presence of a flame on the robot. When either gas or fire is detected, the system immediately triggers an alert to notify the user, as shown in Figure 4(b). In addition, the system sends notifications through SMS and phone calls, as illustrated in Figure 4(c). This ensures that the user is promptly notified of the detected hazard.



(a) (b) (c)

Figure 4. Emergency detection system for gas and fire hazards with real-time alert response: (a) flame detection by the robot, (b) alert notification displayed on the smartphone, and (c) SMS notifications for detected gas and fire hazards

4.4. Smart home control via mobile app

LUNA helps the user control and interact with their respective smart objects such as lights, fans, and appliances via a bespoke mobile application, and at the same time, users will be able to enjoy the ability to observe their respective environments in real-time. As depicted in Figure 5, the major pages of the developed mobile application will be able to offer easy interaction with the robot's status, location, and conditions.

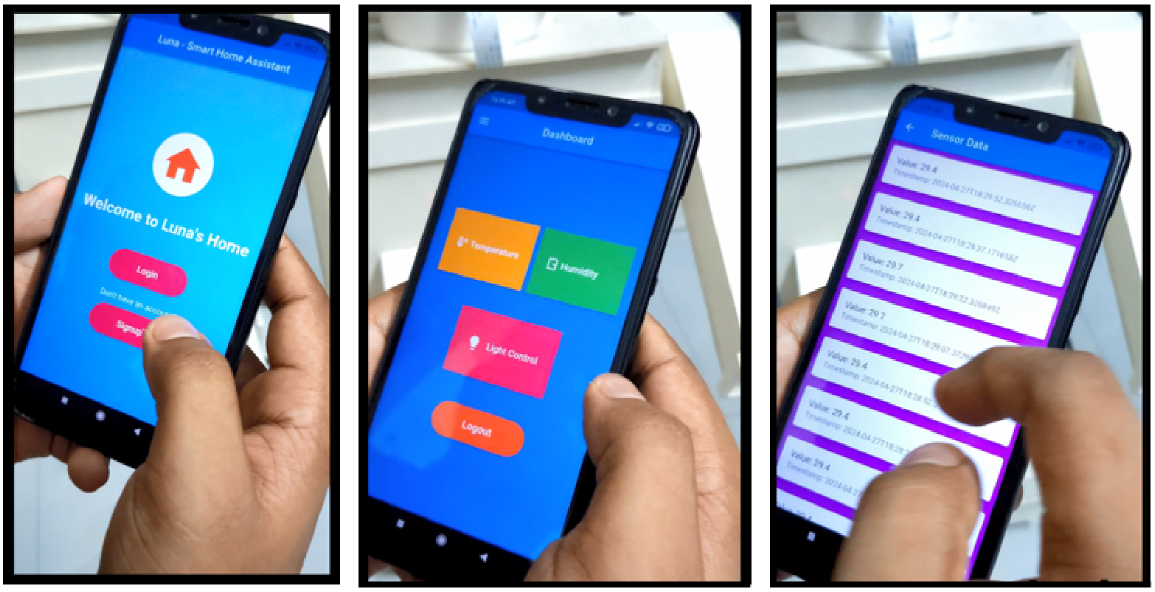


Figure 5. Mobile application interface for monitoring, control, and interaction with the robot

4.5. Automated floor cleaning

LUNA's vacuum cleaning system is powered by an Arduino Uno with a DC motor coupled with a fan to provide automated floor cleaning. The suction created from the DC motor sucks the dust and deposits it into a compartment. With the inclusion of a camera, the trolley can execute navigation with high precision. Moreover, this trolley can also be controlled using any mobile application. The system resulted in an average cleaning efficiency of 88.7%.

4.6. Comparative analysis of result

To highlight its effectiveness, LUNA is evaluated against existing smart assistant and static IoT-based home automation systems. Unlike fixed sensor-based solutions, LUNA offers dynamic environmental interaction through mobility. It achieves 91.2% object detection accuracy using YOLOv8 and 93.5% navigation accuracy, outperforming comparable low-cost robotic systems reported in prior studies. The system records a fast emergency response time of 2.5 seconds and a smart home control latency of 1.2 seconds, demonstrating superior responsiveness compared to conventional static detection systems. Table 3 represents performance evaluation of our developed intelligent home assistant robot LUNA. In general, the results confirm that LUNA provides efficient and intelligent home automation by integrating AI and IoT technologies.

Table 3. Performance evaluation of our developed intelligent home assistant robot LUNA

Metric	Value
Navigation accuracy	93.5%
Object detection (YOLOv8)	91.2%
Emergency response time	2.5 s
Home control latency	1.2 s
Cleaning efficiency	88.7%

5. CONCLUSION

The proposed LUNA system presents a unified home assistant robot that integrates navigation, perception, safety monitoring, and user interaction within a single low-cost platform. The system successfully combines multiple assistive functionalities, including object detection, human-following, hazard detection, and smart home control, demonstrating its applicability for real-world indoor environments. The experimental results confirm that the proposed approach provides reliable performance and practical applicability, particularly for elderly and disabled users. Despite its effectiveness, the system has certain limitations related to processing latency, power consumption, and multi-device complexity. Future work will focus on optimizing system architecture, improving real-time performance using advanced AI techniques, and incorporating cloud-based integration for enhanced scalability and data management.

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