



Wireless Communication Enabled Interactive Robot with Embedded Voice Assistance and Health Monitoring

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ABSTRACT

The current paper proposes the development of an artificial intelligence-based smart service robot that includes voice interaction, wireless mobility, and real-time health monitoring capabilities. In this regard, the current paper proposes an architecture that includes an artificial intelligence module, known as Thinker VC-02, to provide voice interaction capabilities to respond to a series of predefined questions. Furthermore, an HC-05/HC-06 module is utilized to provide wireless mobility capabilities to the proposed architecture, whereas a DHT11 temperature sensor and pulse sensor are utilized to provide real-time health monitoring capabilities to the proposed architecture, with a 16x2 LCD interface being utilized to provide real-time output to the user. In addition, the proposed architecture utilizes a motor driver module to provide smooth locomotion capabilities, with a DC motor being utilized to provide smooth locomotion capabilities to the proposed architecture, with the proposed architecture being utilized to provide waiter-based robotic assistance in healthcare and hospitality environments.

Keywords: *Wireless, Artificial Intelligence; Smart Robot; Bluetooth Navigation; Health Monitoring*

INTRODUCTION

The increase in demand for advanced assistance platforms has resulted in significant advances in embedded robotic systems that have capability to carry out interaction, monitoring and navigation functions. Low-cost robotic systems have been extensively utilized for health care assistance, education and other smart service applications. Recent developments in microcontrollers and communications technologies have made it possible to develop multi-functional robotic systems with enhanced operational simplicity and compact design [1], [2].

Another critical feature in smart robotic systems is wireless navigation which increases the efficiency of service in many applications including indoor robotics. Motor drivers with communication modules and controller unit based on Bluetooth technology offer wireless navigation capabilities using handheld devices. Wireless robotic platforms can be used for carrying out various assistance operations in healthcare, smart houses, etc. Effective motor driving and reliable communication are crucial for achieving successful navigation in embedded robotic systems [3].

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Embedded sensor acquisition systems have also been developed for physiological monitoring purposes in embedded robotic applications. Temperature and pulse sensing modules can constantly collect data related to health condition of patient which can be shown locally on displays. Embedding of sensor acquisition systems with displays in robotic systems makes it possible to monitor patients' health condition without cloud infrastructure and additional equipment [4].

One important component of current robotic systems is voice-based interaction mechanism that allows improved usability and simplicity in controlling robotic systems. Robots controlled by voice commands offer hands-free interaction capabilities that can be used by older generation individuals, physically disabled people and assistive robots. Voice recognition units embedded with microcontroller based systems allow simple execution of predefined commands without using other computers for computation processes. Such a combination allows for simple and efficient design for smaller scale robotic applications [6].

Despite the number of systems that perform healthcare monitoring, wireless navigation and interactive communications, most of current solutions are focused on separate components rather than compact multifunctional designs. Most of existing solutions are based on the IoT architecture, require external computing devices and cloud computing infrastructure, increasing their complexity and power consumption. Moreover, many current systems do not include local display interface and compact coordination between communication, sensors and navigation [13], [17].

This project involves development of a multifunctional voice interactive robotic platform with embedded capabilities of speech interaction, Bluetooth wireless navigation, physiological monitoring and local displays. The novelty of proposed robotic system is its ability to provide all above features in an embedded design that does not involve cloud computing and external devices for carrying out functions. Proposed solution aims at offering a low-cost and compact embedded robotic platform for healthcare assistance, education and robotic research.

The novelty of the presented research is that all of the above components have been integrated into one system on the basis of an affordable Arduino microcontroller, which does not require a cloud connection to be realized.

RELATED WORK

In recent studies conducted on embedded robotic devices, a lot of effort was made to develop sensing systems, wireless communication systems, and autonomous assistance systems in order to enhance patient monitoring applications. The smart healthcare robots embedded with monitoring systems have been designed using temperature sensors, pulse monitoring systems, and embedded controllers. These robotic systems have provided efficient health data acquisition in a real-time

environment. Wireless communication interfaces have also been used to support remote monitoring and healthcare assistance applications [1].

Wireless robotic navigation systems using Bluetooth and embedded motor control architectures have also been extensively used for indoor robotic service applications. The embedded robotic systems comprising of HC-05 communication modules, motor driver systems, and DC motors have achieved efficient wireless navigation performance when combined with mobile device-based direction systems. The use of Pulse Width Modulation technique has improved the directional accuracy in the compact robotic systems [3].

The use of voice-based interactive robotic devices has gained popularity since they provide better accessibility and facilitate interaction between human users and machines. Speech command-based robotic devices having embedded voice recognition modules have effectively provided predetermined command processing. Voice based interactive healthcare robots and elderly assistance systems have been implemented using voice-based interface systems in order to facilitate easy operation and convenient human-robot interactions [6], [10], [12].

The IoT-based robotic platforms have further extended the capabilities of monitoring systems by incorporating remote connectivity systems along with distributed monitoring systems. Many systems utilize sensor acquisition, cloud communication systems, and data logging systems in order to perform efficient real-time supervision tasks. Nevertheless, these kinds of systems require infrastructure facilities and increased computational capacity, thus making them complicated to implement in compact robotic systems [17].

According to the existing literature, it is clear that most of the embedded robotic systems concentrate either on physiological monitoring, wireless mobility or voice interaction separately. However, little emphasis is being given towards development of multi-functional compact systems having capabilities of speech interaction, wireless navigation, physiological sensing and local display mechanisms all together in one system. Thus, the proposed study will focus on developing a compact multi-functional robot using an embedded Arduino based system architecture.

Proposed Work

The implementation of the artificial intelligence-enabled smart service robot is divided into a modular embedded architecture that integrates sensing, interaction, communication, and actuation subsystems. In this regard, the control unit is implemented using an Arduino UNO microcontroller that manages all data acquisition, command interpretation, and motor control operations. All the peripheral modules, including the AI Thinker VC-02 voice module, Bluetooth communication interface, DHT11 temperature sensor, pulse sensor, motor driver module, and 16x2 LCD display,

are interfaced with the control unit using designated digital and analog I/O pins. This ensures that there is synchronized communication between all subsystems, including low power consumption and compact structural design.

The artificial intelligence-enabled smart service robot is implemented with a voice module, including the AI Thinker VC-02 voice module, that is programmed to recognize pre-defined commands and answer questions accordingly. In this regard, the voice module is implemented to process audio signals received from the environment using an embedded speech recognition engine that sends command information to the control unit via serial communication. The control unit is programmed to constantly check for valid command strings in the serial communication buffer that are then processed accordingly. A pre-defined response library is implemented in the control unit to ensure that there is structured interaction with the environment, thus optimizing the efficiency of the control unit in processing information at an embedded level.

The artificial intelligence-enabled smart service robot is implemented with a wireless navigation subsystem that utilizes an HC-05/06 Bluetooth communication module in slave mode to enable communication with a mobile device that sends command information to control the navigation of the robot in different directions, including forward, backward, left, right, and stop. In this regard, the HC-05/06 Bluetooth communication module is implemented to establish a serial communication channel with the control unit using a UART interface that sends command information from the mobile device to the control unit. All commands are processed accordingly, including generating digital outputs to control the motor driver module to enable navigation in different directions.

The motor control system employs the use of a dual-channel motor driver module, which is used to interface the microcontroller with the DC motors. The motor driver module receives low-power logic-level inputs from the Arduino microcontroller, boosting them to levels sufficient to drive the DC motors. The use of Pulse Width Modulation is also incorporated to control the speed of the motors, allowing smooth transitions between different directions of movement. The wheeled chassis design provides stability to the system, ensuring smooth movement over flat surfaces.

The physiological monitoring system employs the use of a DHT11 temperature sensor module and a pulse sensor module. The DHT11 temperature sensor module uses single-wire communication protocols to transmit digital temperature readings to the microcontroller. The pulse sensor module, on the other hand, employs photo plethysmography to detect changes in blood volume, generating analog voltage levels corresponding to heart rate activity. The microcontroller processes analog voltage levels using its internal Analog-to-Digital Converter, applying peak detection algorithm techniques to calculate beats per minute.

The system employs the use of a 16×2 LCD module, which is interfaced with the microcontroller

using parallel digital communication protocols. The 16×2 LCD module continuously displays sensor readings, system status, and user prompts, ensuring the user remains informed about system activities without relying on additional devices for monitoring purposes. The refresh rate of the LCD module is optimized to prevent flickering, ensuring smooth updates without affecting other system processes.

Fig. 1 shows the overall system architecture of the proposed smart service robot. In this architecture, the Arduino UNO is used to act as a central processing unit that can interact with all modules in the proposed system architecture. In addition, the proposed architecture integrates the AI Thinker VC-02 voice module, which is used to provide voice input signals to the controller for command recognition and interaction with the proposed system architecture. Furthermore, the proposed architecture integrates a Bluetooth module, namely HC-05/HC-06, that is used to enable wireless communication between the proposed smart service robot and a mobile phone application to control the direction of the proposed smart service robot.

The proposed architecture integrates a DHT11 temperature sensor that is used to provide temperature information to the proposed smart service robot, whereas a pulse sensor is used to provide heart rate information to the proposed smart service robot. In addition, the proposed architecture integrates a 16x2 LCD module to provide information to the proposed smart service robot. Furthermore, the proposed architecture integrates a motor driver module that is used to control DC motors that are attached to the proposed smart service robot, whereas a battery power supply is used to provide power to all components in the proposed architecture.

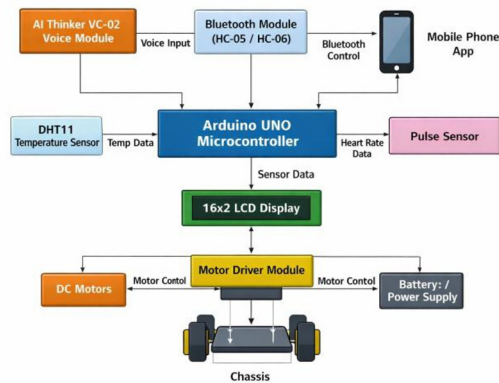


Fig. 1: Block Diagram

The proposed architecture of the intelligent service robot is shown in Fig. 1. Here, the Arduino UNO acts as the central controller embedded system that manages the communication between sensors, actuators, and motors. This architecture allows parallel operations for speech recognition,

Bluetooth navigation, physiological monitoring, and display update operation in an embedded environment.

The power management system has been developed to provide support to stable multi-module operation with a regulated battery supply. The voltage regulation circuits are used to provide a stable voltage supply to the microcontroller, sensors, and communication modules. The grounding and isolation of the power management system are also considered to minimize interference with the motor actuation circuit and sensor input.

The integrated control logic is developed using structured embedded programming methodologies. The firmware is structured in modular routines, including initialization, command processing, sensor acquisition, motor control, and display management. Interrupt-driven serial communication handling is incorporated to provide timely responses to voice commands and Bluetooth communication. The task scheduling is achieved using non-blocking delay methodologies to facilitate simultaneous sensor acquisition, communication, and motor control.

Another form of functionality enhancement of the proposed technique is the incorporation of adaptive operational prioritization between interaction and mobility functions. The suspension of motor control routines during voice command processing is achieved to provide stability in speech processing without interference from communication processes. The sensor acquisition periods are also dynamically adjusted during high-mobility phases to provide computational efficiency.

RESULTS

The experiment was done by testing the developed smart service robot on an indoor operating environment for validating its communication stability, sensor acquisition reliability, navigation efficiency, and multitasking ability. The indoor test environment was selected because of the closed room, which had standard noise conditions. Also, there was a maximum communication distance between the mobile application and the robot platform ranging from 5-8 meters.

The performance of the voice interaction module was tested using 50 predefined speeches commands on varying speaking conditions. Response accuracy and delays were used to determine its stability. The Bluetooth navigation of the robot was evaluated by sending the directional instructions continuously for 20 operational cycles.

In addition, the DHT11 temperature sensor and pulse sensor were continuously checked for real-time physiological monitoring. Values were acquired and compared with respect to their stability on repeated measurements. Moreover, multitasking ability was tested through simultaneously sensing, voice processing, and motor controlling processes.

The analysis of the proposed system performance was carried out by analyzing several performance metrics.

The developed smart service robot has been evaluated under various operating scenarios to test

responsiveness to interaction, control of robot mobility, and sensor reliability. The voice-based command recognition system using the AI Thinker VC-02 has been successful in decoding predefined sets of instructions under normal indoor acoustic conditions. The system has been able to process command inputs and execute corresponding control routines without any observable delays. The serial communication protocol has been consistent between the voice-based command recognition system and the Arduino UNO. There has been no observable overflow of commands or incorrect interpretation of commands during repeated execution cycles.

The Bluetooth-based navigation system has been tested by continuously controlling the robot's directions using a mobile application. The HC-05/HC-06 has been successful in maintaining consistent connectivity under normal indoor operating conditions. The transmission of commands such as moving forward, backward, left, right, and stop has been smooth. The motor driver has been successful in executing consistent responses to Bluetooth-based instructions without jerks or changes in directions. The Pulse Width Modulation has been successful in varying the speed of the robot's motors in a controlled manner.



Fig. 2: Prototype Image

Fig. 2 shows the developed prototype model of the robot. The design of the prototype includes all the required embedded hardware elements such as sensors, motors, and displays mounted on a wheeled robotic platform. The DHT11-based temperature sensor has been successful in obtaining consistent real-time data under controlled environmental conditions. The digital output from the sensor has been sampled at regular intervals without any observable communication issues. The fluctuations in temperature corresponding to changes in indoor conditions have been observed with high accuracy. The optimization of sampling intervals has been successful in preventing unnecessary delays.

The pulse sensor module, which was used to monitor the heart rate, generated stable analog signals corresponding to the physiological activities. The Analog-to-Digital Converter of the Arduino microcontroller was able to process the signals properly, and the peak detection algorithm was able to compute the beats per minute values correctly. Noise reduction techniques and grounding of the system ensured that there was no interference with the signals due to motor movement, hence providing efficient physiological data acquisition.

The 16 x 2 LCD display module was used to display the sensor data and other system status messages in real-time. The data refresh operations were carried out properly, and there was no flickering of the display or any corruption of the characters on the display. The interface was efficient in displaying temperature and heart rate data simultaneously, along with the status of the system, while still being responsive to voice commands and Bluetooth communication.

Table 1 shows the comparative benchmarking.

Table 1 Comparative Analysis with Existing Systems

System	Voice Interaction	Health Monitoring	Wireless Navigation	Local Display	Low-Cost Embedded Design
Existing Healthcare Robot	Yes	Yes	No	No	No
IoT Medical Assistant Robot	Limited	Yes	Yes	No	No
Social Healthcare Robot	Yes	Limited	No	Yes	No
Proposed System	Yes	Yes	Yes	Yes	Yes

Table 2 System Validation Matrix for Smart Service Robot

Test Module	Test Condition	Performance Indicator	Validation Outcome
Voice Recognition Module	Indoor predefined command input	Command decoding and execution stability	Successful
Bluetooth Control Module	Mobile app directional control	Communication reliability and response	Stable
Motor Driver & DC Motors	Continuous forward/reverse/turn motion	Smooth actuation without signal delay	Verified

Temperature Sensor (DHT11)	Ambient temperature variation	Real-time data acquisition consistency	Accurate
Pulse Sensor Module	Resting heart rate measurement	BPM computation and signal stability	Reliable
LCD Display Interface	Simultaneous sensor data update	Display refresh synchronization	Stable
Integrated System Operation	Concurrent voice + mobility + sensing	Task coordination without interruption	Validated
Power Management	Extended operational duration testing	Voltage stability and module performance	Consistent

The integrated system was tested for its functionality, and it was observed that all the modules of the system were able to work together properly. The adaptive nature of the system was able to maintain stability in the execution of tasks, even when all the modules were running simultaneously. The system was able to respond to voice commands, communicate wirelessly, and monitor physiological signals without any conflicts. The system was able to adjust the sampling of the sensors to maintain efficiency in its execution of tasks. The architecture of the system was able to maintain multitasking functionality within the limitations of the microcontroller. Table 2 presents the structured validation of all the functional modules integrated into the smart service robot enabled by the artificial intelligence system. The framework for the evaluation of the system is based on the module level performance evaluation of the system under specific operation conditions. The voice recognition module was tested under indoor predefined commands, where the stability of the commands was analyzed. The module was successful in interpreting the stored voice commands correctly without any misclassifications.

The stability of the system was tested by running it for extended periods of time. The voltage regulator was able to maintain voltage stability, ensuring that all the systems were able to function properly. There was no significant drop in voltage, which could have caused the system to shut down. The structural stability of the system was tested by running it on the wheels, which were able to distribute the weight of the system properly, ensuring smooth movement of the system.

The prototype system at present works solely with pre-set voice command sets and does not use any adaptive learning or cloud computing artificial intelligence. The navigation module mainly works indoors without any obstacle avoidance functionality. The biometric monitoring module only monitors the temperature and heart rate parameters at present. The future versions can include machine learning speech processing, IoT technology integration, and autonomous navigation capabilities.

Conclusion

In this paper, an interactive smart service robot using voice communication and Bluetooth-based navigation system together with physiological sensors has been designed and implemented using embedded hardware components. The proposed robotic system was able to incorporate speech recognition, wireless navigation, environmental sensing, and display system into its functionality using a compact and robust architecture based on the Arduino development board. Inclusion of the AI Thinker VC-02 voice module into the robotic system has been successful in carrying out stable operations of the pre-recorded voice commands, whereas the Bluetooth module (HC-05/HC-06) has performed well in terms of reliable wireless navigation within indoor environments. The temperature sensor (DHT11) and pulse sensor modules have been efficient in capturing physiological information such as body temperature and heart rate. This data has been continuously captured and displayed using the LCD display (16×2). The embedded control system architecture allowed for coordinated sensing, communication, and motor control without experiencing any significant interruption. The Pulse Width Modulation (PWM)-based motor control has been efficient in providing a smooth transition between movements. Based on experimental observations, it is possible to note that the proposed robotic platform can operate efficiently in repetitive test scenarios with stable communications and sensing capabilities.

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