Design and Implementation for Smart Medical Alert Device

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***Abstract*—With the increasing emergence of Internet of Things (IoT) systems and devices, the concept of a real-time monitoring system, especially targeted towards the elderly, has existed for quite a long time. Most commonly, many elderly patients are typically at high-risk of experiencing a sudden medical emergency within an isolated room. As a result, various monitoring systems have been proposed which involve a wearable type of technology, or utilize a vision-based system in conjunction with a camera, which raises concerns of violations of one's privacy within their own home. As such, there has been a concentrated effort towards the construction of a system that has the capability for effective real-time monitoring of patients, while also being minimally invasive and non-wearable. Through the utilization of a wide combination of ambient sensors in conjunction with Bluetooth IoT technology, this system is designed to be non-invasive while still being proficient at the task of real-time monitoring of the patient's status within a room.**

Keywords*—*IoT, Non-Invasive, Ambient Sensors, Real-time Monitoring, Health, Wellness, Care

I. Introduction

One of the main overarching goals of real-time monitoring systems is to ease the burden on potential caretakers of patients by making the process of monitoring easier and more automated. With an assistive monitoring system in place, caretakers are able to focus on other household tasks while still having the ability to monitor their patients. In the case of wearable technologies, it is often considered an annoyance and discomfort to the patients and users of the system who have to be constantly wearing the device on their person. Additionally, patients commonly forget to wear the device entirely. However, through the use of IoT technologies such as Bluetooth, many monitoring systems have emerged that seek to provide such functionality while being non-wearable.

In particular, as the percentage of the elderly population increases every year, from 9% in 2010 to an expected 16.5% in 2025 [1], the demand for effective remote monitoring systems is becoming increasingly important, especially with many elderly individuals who live alone who are naturally at high risk of sudden death due to various causes associated with age. With an expected increased surge of elderly individuals throughout the world by 6.1% in comparison to 2008 by 2030, and an estimated 110-190 million elderly people suffering from illnesses [2], remote IoT monitoring systems will have a crucial impact in the years to come in terms of health care for those who are unable to afford proper hospitalization. More importantly, the trend of an increasingly aging population is not projected to halt anytime soon. By 2050, predictions state that there will be 2 billion individuals over the age of 60 at the minimum [3]. IoT remote monitoring systems will offer a viable and low-cost solution at home that will vastly increase the quality of life for both the elderly and caregivers.

Within the design employed by this study, the system will be able to detect the movement of an individual within the room, and the length of time since movement was last detected in situations where there is no movement. The design is targeted towards those who are elderly, especially individuals who are predisposed to life-threatening medical conditions, who may need constant supervision to ensure they do not experience a sudden medical emergency while within the room. Specifically, medical emergencies that would cause the individuals to collapse suddenly and cease movement. In such a case, the designed system will be able to detect the lack of movement, and should it continue for an extended period of time, is then capable of alerting any corresponding caregivers or other emergency personnel.

II. System Design

For the implementation of the system, which involves several hardware and software components, the sensors that will be used for presence detection within a room will involve an HC-SR501 passive infrared motion sensor, an HC-SR04 ultrasonic sensor, a BH1750 light sensor module, and an ADXL345 accelerometer. Each individual sensor is intended to detect a different aspect of presence within the room, which in conjunction with a majority voting algorithm among the sensors, will be effective in reducing the number of false positive detections while simultaneously being applicable to a wide range of situations. As for the software, the Arduino IDE will be used to work with the ESP32 module, as it has plenty of custom libraries and support for the ESP32 available, making it perfectly suited for such a task and great ease of use. In terms of the Android application, it is built using Google's Android Studio IDE, which provides all of the tools and documentation necessary for creating a GUI and implementing the core functionality of the remote monitoring and emergency alert application.

The design of the system is shown in Fig. 4, where the HC-SR501 PIR motion sensor, HC-SR04 ultrasonic sensor, BH1750 light sensor module, and ADXL345 accelerometer are connected to a central ESP32 microcontroller unit, which will be powered by a battery with a capacity of 20,000 mAh. Sensor readings pulled from all 4 devices will be used to determine whether or not an individual has been detected in the room. Upon detection of 2 or more sensors active, the system will conclude that there is a person currently present within the room, and this conclusive result will be sent through the built-in Bluetooth module of the ESP32 to an external Android application to be displayed as a status. The specific Bluetooth technology used for communication is Bluetooth Low Energy (BLE). Bluetooth Low Energy as a communication protocol, is perfectly suited for the system due to its low power consumption compared to traditional Bluetooth communication.

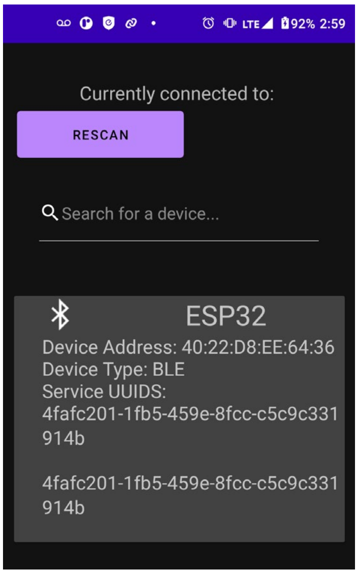

Fig. 1. Android Application scanning for devices

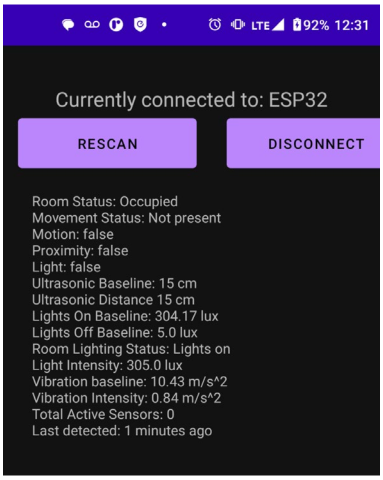

Fig. 2. Android App connected to central ESP32

The unit, involving the ESP32 microcontroller and battery, is placed within a custom 3D-printed enclosure that contains openings for the sensors. Sensors such as the HC-S501 PIR motion sensor, HC-SR04 ultrasonic sensor, and BH1750 light sensor module are all designed to protrude out of the enclosure, in order to ensure correct operation. The ADXL345 accelerometer, which is serving as an accelerometer for the unit, is placed inside the enclosure.

Fig. 3. Top view of the system enclosure

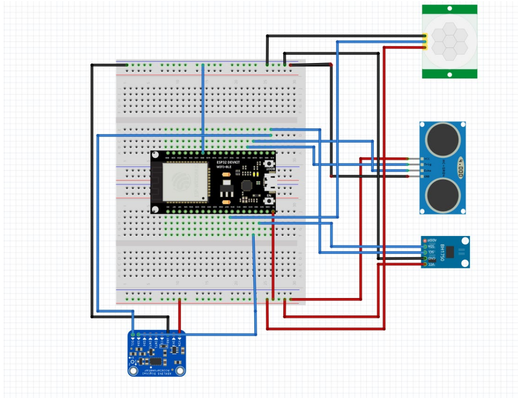

Fig. 4. System schematic

A. HC-SR501 Passive Infrared (PIR) Motion Sensor

Within the system, the HC-SR501 Passive Infrared (PIR) motion sensor will serve as one of the primary sensors used for detection of movement within the room. The HC-SR501 produces a simple digital output, either high when motion is present, or low when there is a lack of motion. When the output is high, the system will increment the number of active sensors by 1, contributing to the majority voting algorithm between the 3 combined ambient sensors.

Fig. 5. An individual HC-SR501 unit

B. HC-SR04 Ultrasonic Sensor

Another sensor incorporated into the overall system is the HC-SR04 ultrasonic sensor, as seen in Fig. 6. The HC-SR04 ultrasonic sensor is most popularly used for measuring distances between objects. Other common use cases include an array of modules that are linearly placed in order to extrapolate the speed and direction of a moving object. In the case of this system, an ultrasonic sensor such as the HC-SR04 can be used as a simple detection sensor by having a set, calibrated value (or distance) initially, which will be compared in a continuous loop with the current distance reading. If the current distance reading and calibrated value differ by a notable offset, this means that an object (such as a person) has passed in front of the ultrasonic sensor.

Fig. 6. HC-SR04 unit

C. BH1750 Light Sensor

The BH1750 is a light sensor module that can be used to measure the intensity of light in any given environment. The BH1750 is a digital sensor that has excellent ease of use, as well as a wide range of detection in terms of light intensity, measuring from as low as 1 lux to 65535 lux [9]. Sensor readings from the BH1750 will be read through the utilization of the I2C communication protocol, which the ESP32 supports.

Regarding system design, the BH1750 will be used to determine whether the light in the room is on or off. In addition, objects or individuals who move past the BH1750 within a short radius of 1.5 feet also decrease the sensor's lux readings by a measurable amount (lux readings decreased by 30 lux) provided that the room is well-illuminated. This phenomenon is present in a dark room with the lights turned off as well, however, the effect on the lux readings is significantly less; lux readings decreased by 1 lux, and only if the individual directly moved past and blocked the ambient light within the room.

As such, the BH1750 can also double as a pseudo-motion sensor under certain lighting conditions capable of detecting movement within a room in a small radius all around the system, as opposed to the HC-SR501, which can detect motion from a much greater distance, however, only within a certain conal angle. To properly take advantage of such a use case, two baseline values were initialized; one representing the lux reading with lights active in a room, and the other, without any lights active.

Extensive testing with the BH1750 light sensor was conducted to establish typical lux values for rooms with lights on and lights off, allowing the BH1750 to correctly determine the room's lighting status consistently. Additionally, if the difference in lux readings arising from an individual passing by falls within the set threshold, the BH1750 will be marked as active, and increment the number of active sensors by one. A rolling average algorithm is also employed to adapt to varying ambient lighting conditions, where lux readings are added to separate arrays every 5 minutes and averaged every 30 minutes to update the baseline value.

Fig. 7. BH1750 unit

D. ADXL345 Accelerometer

The final sensor that will be part of the system design will be the ADXL345 accelerometer. As an accelerometer, the ADXL345 is capable of measuring acceleration in 3 axes. The ADXL345 is ideal for measuring both subtle and large vibrations. For example, a system involving an ADXL345 accelerometer [10] was developed with the goal of achieving fall detection by having individuals wear the system on their bodies. With the ADXL345, the system is able to detect rapid changes in orientation and acceleration, both of which occur when an individual falls. From the resulting body posture of a fall, data from the ADXL345 accelerometer is analyzed and fed into an algorithm that will determine whether or not a fall has taken place.

Fig. 8. ADXL345 unit

Within the present system, utilizing the I2C communication protocol, the ADXL345 will serve as an accurate measure for when the system is repositioned or relocated to a different part of the room. The magnitude of the acceleration is found using the formula below:

$$|\vec{a}| = \sqrt{(ax)^2 + (ay)^2 + (az)^2}$$

Variables a_x, a_y, and a_z represent the acceleration in the x, y, and z directions, which can be obtained from the ADXL345 accelerometer directly. Future magnitude values are then compared with the baseline value, whereby if the reading differs from the baseline by a set margin, the system will conclude that there is significant vibration present. Such significant vibration will indicate repositioning of the system, where a flag will then be set so that the existing baseline value for both the ultrasonic sensor and BH1750 will be reset and recalculated. With this approach, the system becomes much more adaptable and flexible, with the ability to be repositioned around a room as needed while retaining consistent functionality for its sensors.

E. Dedicated Subsystem for Room Presence Detection

Although the main system is capable of detecting movement within a room, it has no functionality for determining the occupation of the room. Without such capability, the main system is prone to sending false positives to emergency alerts in cases where the room is unoccupied.

As such, a simple, dedicated subsystem was developed for the purposes of detecting when an individual enters or exits the room. The subsystem consists of a basic design containing two ultrasonic sensors arranged in a horizontally linear fashion, where the direction in which an individual is traveling can be roughly extrapolated through the order in which the ultrasonics have been activated. Placement of the subsystem at main entrances into a room such as doors will allow for an accurate assessment of room occupation. The room occupation status will then be communicated back to the main system by leveraging the already existing usage of Bluetooth Low Energy within the system design.

Fig. 9. Frontal View of the Dedicated Subsystem

III. Experimental Setup and Results

A. Testing for Effective Sensor Ranges and Accuracy

Extensive testing and experimentation performed to discover the effectiveness and efficiency of each of the 4 individual sensors was performed.

TABLE I. HC-SR501 Operational Range and Angle

HC-SR501 PIR Motion Sensor	
Range	10 feet
Cone of Operation	150 degrees

As for the HC-SR04 ultrasonic sensor, the max distance at which it retains accuracy was 70 centimeters (0.7 meters). Beyond 0.7 meters, testing revealed that the distance readings were highly inconsistent and inaccurate, resulting in the distance readings obtained from the ultrasonic sensor often spiking up to values as high as 1190 centimeters for brief periods of time.

For the BH1750 light module, simple tests were performed in order to find common baseline lux values for various lighting scenarios in a room-based environment.

TABLE II. BH1750 Baseline Testing Results

BH1750 Light Sensor	
Lighting Environment	**Lux Reading**
Lights On	418 lux
Lights Off	5.83 lux
Lights On/Person passing by	392.43 lux
Lights Off/Person passing by	4.36 lux

B. Power Consumption and Total Battery Life

To obtain an accurate estimate of the battery life of the system, current draw of all of the sensors and ESP32 were measured. Below is a table of the results of current draw for each component:

TABLE III. Current Draw of Components

Component	Current Draw
ESP32	130 mA
HC-SR501	50 uA
HC-SR04	15 mA
BH1750	190 uA
ADXL345	150 uA
Total Current Draw of System	145.39 mA

$$Total\ Battery\ Life\ (hours) = \left(\frac{Battery\ Capacity}{System\ Total\ Current\ Draw}\right)$$

With a battery capacity of 20000 mAh, the calculation yields a result of 137.561 hours, or roughly 6 days, assuming the system is left on constantly and active.

C. Experimental Setup

Two lighting scenarios where the lights were on, and off, were accounted for in the tests. 4 trials in each lighting environment were performed to accurately extrapolate the overall accuracy of the system.

TABLE IV. Test Grouping #1 (Distance of 14 feet): Lights On

Motion	Ultrasonic	Light	Total
Active	Active	Inactive	2/3 Person Present
Active	Active	Inactive	2/3 Person Present
Active	Active	Inactive	2/3 Person Present
Active	Active	Inactive	2/3 Person Present

TABLE V. Test Grouping #1 (Distance of 14 feet): Lights Off

Motion	Ultrasonic	Light	Total
Active	Active	Inactive	2/3 Person Present
Active	Active	Inactive	2/3 Person Present
Active	Active	Inactive	2/3 Person Present
Active	Active	Inactive	2/3 Person Present

Under the ideal conditions above, the HC-SR501 and HC-SR04 were able to accurately detect motion and human presence at a distance of 14 feet each time in both light and dark environments, while the BH1750 light sensor was unable to detect any significant changes in lux readings due to the distance being too great.

TABLE VI. Test Grouping #2 (Distance of 2 feet): Lights On

Motion	Ultrasonic	Light	Total
Active	Active	Active	3/3 Person Present

Active	Active	Active	3/3 Person Present
Active	Active	Active	3/3 Person Present
Active	Active	Active	3/3 Person Present

TABLE VII. TEST GROUPING #2 (DISTANCE OF 2 FEET): LIGHTS OFF

Motion	**Ultrasonic**	**Light**	**Total**
Active	Active	Inactive	⅔ Person Present
Active	Active	Inactive	⅔ Person Present
Active	Active	Inactive	⅔ Person Present
Active	Active	Inactive	⅔ Person Present

As seen in the results above, the performance of the HC-SR501 and HC-SR04 were practically identical to the previous tests. In this particular set of trials however, it can be observed that the BH1750 was able to detect the subtle decreases in lux measurement resulting from the individual passing by the system due to the closer proximity of the individual. Testing reveals the BH1750 is capable of measuring decreases in lux measurements from passing individuals at a minimum distance of 2 feet, and can more than likely be increased even further if the threshold values for detection were set to be lower. Unfortunately, in room environments where there are low amounts of lighting or a complete lack of, the BH1750 was not able to detect any decreases in lux measurements with an individual closely passing by the system. Due to the already low amounts of lux within a dark room, an individual's body will not decrease the light readings by an impactful amount, therefore, the BH1750 will not be practical for detection of movement within dimly lit environments.

IV. CONCLUSION

This paper presents the idea and early prototype for a novel system that seeks to be able to effectively alert caregivers and other individuals when an individual within a room has collapsed suddenly due to a medical emergency, and is no longer moving. As such, IoT is a core principle within the design of the system, with the system using Bluetooth Low Energy to notify external devices of emergencies. There have been many, previous existing systems that have tackled the same issue, utilizing various peripherals devices such as cameras in combination with machine learning algorithms to accurately detect sudden falls. However, such systems raise concern for intrusions of privacy. This system aims to be as non-invasive as possible through the usage of ambient sensors, while retaining much of the functionality and accuracy of already existing solutions.

V. FUTURE WORK

In terms of future improvements, an ideal addition would be a sound sensor capable of detecting and measuring the amplitude of such resulting sounds within the room. By only measuring the amplitude and not directly recording audio, the overarching goal of the system to remain as non-invasive as possible will be preserved. A sound sensor would also be operable in both well-lit and dark environments, which would aid in supplementing the BH1750's ineffectiveness in dark rooms.

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REFERENCES

[1] M. Alwan et al., "A Smart and Passive Floor-Vibration Based Fall Detector for Elderly," 2006 2nd International Conference on Information & Communication Technologies, Damascus, Syria, 2006, pp. 1003-1007, doi: 10.1109/ICTTA.2006.1684511.

[2] K. Guizani and S. Guizani, "IoT Healthcare Monitoring Systems Overview for Elderly Population," 2020 International Wireless Communications and Mobile Computing (IWCMC), Limassol, Cyprus, 2020, pp. 2005-2009, doi: 10.1109/IWCMC48107.2020.9148446.

[3] I. Asghar, R. Ullah, M. G. Griffiths, G. Evans and J. Vermaak, "Skystrm: An Activity Monitoring System to Support Elderly Independence Through Smart Care Homes," 2023 6th Conference on Cloud and Internet of Things (CIoT), Lisbon, Portugal, 2023, pp. 119-126, doi: 10.1109/CIoT57267.2023.10084898.

[4] M. Alwan et al., "A Smart and Passive Floor-Vibration Based Fall Detector for Elderly," 2006 2nd International Conference on Information & Communication Technologies, Damascus, Syria, 2006, pp. 1003-1007, doi: 10.1109/ICTTA.2006.1684511.

[5] T. F. Tan, S. S. Teoh, J. E. Fow and K. S. Yen, "Embedded human detection system based on thermal and infrared sensors for anti-poaching application," 2016 IEEE Conference on Systems, Process and Control (ICSPC), Melaka, Malaysia, 2016, pp. 37-42, doi: 10.1109/SPC.2016.7920700.

[6] P. Jiru, "Design of Intelligent Monitoring System," 2013 Third International Conference on Instrumentation, Measurement, Computer, Communication and Control, Shenyang, China, 2013, pp. 407-410, doi: 10.1109/IMCCC.2013.93.

[7] M. D. Ahmad, S. Z. Mohammad Noor, N. F. Abdul Rahman and F. A. Haris, "Lux Meter Integrated with Internet of Things (IoT) and Data Storage (LMX20)," 2021 IEEE International Conference in Power Engineering Application (ICPEA), Malaysia, 2021, pp. 138-142, doi: 10.1109/ICPEA51500.2021.9417762.

[8] K. A. Raza and W. Monnet, "Moving objects detection and direction-finding with HC-SR04 ultrasonic linear array," 2019 International Engineering Conference (IEC), Erbil, Iraq, 2019, pp. 153-158, doi: 10.1109/IEC47844.2019.8950639.

[9] J. Gao, J. Luo, A. Xu and J. Yu, "Light intensity intelligent control system research and design based on automobile sun visor of BH1750," 2017 29th Chinese Control And Decision Conference (CCDC), Chongqing, China, 2017, pp. 3957-3960, doi: 10.1109/CCDC.2017.7979192.

[10] Y. Xiuping, L. Jia-Nan and F. Zuhua, "Hardware Design of Fall Detection System Based on ADXL345 Sensor," 2015 8th International Conference on Intelligent Computation Technology and Automation (ICICTA), Nanchang, China, 2015, pp. 446-449, doi: 10.1109/ICICTA.2015