Integrated Ultrasonic-Based Occupancy Detection System with Multimodal and Bluetooth Alerts using Arduino Uno and LCD Display

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***Abstract*—This paper describes the development and implementation of a real-time occupancy detection and monitoring. The system was built using an Arduino Uno microcontroller, a pair of ultrasonic sensors, RGB LEDs for visual indications, a buzzer for sound alerts, an LCD display for real time monitoring and Bluetooth communication for wireless alerts. By designing a state-machine based algorithm with debouncing, directional accuracy was ensured and experimental results confirmed reliable detection within a range of 3-15 cm with high accuracy and minimal false alarm. This effectively distinguished between entry and exits. The prototype demonstrates effective crowd management ability with multi-modal alerts depending on the capacity and solves a real-world need in monitoring spaces with restricted capacities such as laboratories, library and parking lots.**

Keywords — Ultrasonic sensing; multimodal alerts; wireless Bluetooth communication; real time occupancy monitoring

I. INTRODUCTION

Monitoring and managing occupancy levels in confined and restricted spaces is important for safety and efficiency. Traditional manual counting methods are outdated and are labor-intensive and often impractical for continuous monitoring. This paper describes the development of an automated monitoring system that would provide real time updates with minimal human intervention. Real-world challenges such as limits in laboratories, libraries and seminar rooms especially addressed in university campuses are addressed by this system [1]. This automated prototype provides accurate and continuous monitoring with necessary alerts which reduces human resources and efforts. Fundamental concepts of electrical engineering have been applied in building this prototype such as sensors interfacing, signal processing, microcontroller programming, state-machine design and wireless communication. The combination of all these elements results in a robust system capable of directional detection sensing both entry and exits as well as providing wireless remote alerts through Bluetooth.

II. INSTRUMENTS REQUIRED

The components required in building this model include An Arduino Uno Microcontroller, HC-SR04 Ultrasonic distance sensors (x2), a 16x2 LCD Display, an I2C module, a Common cathode RGB LED, a Piezoelectric buzzer (in GPIO board), 220 Ω resistors (x3), Breadboard (x2), jumper wires and a HC-05 Bluetooth module.

III. THEORY

The prototype shown in Fig 1 is designed using the concepts of Ultrasonic Distance Measurement, State Machine implementation, Debounce mechanism and Bluetooth communication.

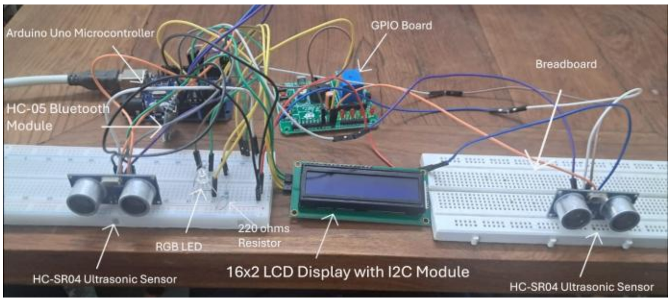

Fig. 1: Labelled photograph of the circuit of the monitoring system.

A. *Ultrasonic Distance Measurement*

The HC-SR04 ultrasonic sensor works on the concept of sound wave reflection. The sensor emits high frequency sound pulses around 40 kHz that travels and bounces back upon entering an obstacle. The time between the emission and reception of the wave is measured to calculate the distance. The speed of sound in air is approximately 343 m/s (0.034 cm/us) at room temperature.

B. *State Machine Implementation*

The key component of this model is the implementation of the finite state machine to ensure directional detection of entry/exit. The system has 3 states: 1) IDLE: At this state, the system waits for sensor activation (2) SENSOR1_TRIGGERED: In this state, the 1^{st} sensor has detected an object (3) SENSOR2_TRIGGERED: In this state the 2^{nd} sensor has detected an object. The transition between these states and the order of occurrence decides directional detection and reduces false detection.

C. *Debounce Mechanism*

Ultrasonic sensors can generate false triggers from various environmental factors. To avoid these situations, we incorporated spatial and temporal filtration techniques. Detections within 3-15 cm of range were considered valid along with a debounce delay of 800ms applied to avoid multiple triggers from a single passing event.

IV. PROCEDURE

The two HC-SR04 Ultrasonic sensors are connected to Arduino digital pins 6,7,8 and 9 with the respective echo and trigger pins. The common cathode RGB LED is connected to analog pins A0 (red), A1 (green), A2 (blue) to provide visual status indication. The piezoelectric buzzer in the GPIO board is connected to the buzzer pin and the A3 pin for audible alerts. The 5V and GND pins of the GPIO board were connected to the 5V and GND from the Arduino. The A4 and A5 pins of the Arduino Uno were connected to the SDA and SCL pins of the I2C 16x2 LCD Display. They were connected with the respective 5V and GND pins as well. The TX and RX pins of the HC-05 Bluetooth module were connected to the RX and TX pins of the Arduino Uno and the 5V and GND pins are connected with the respective pins on the Arduino Uno and operated at 115200 baud for wireless communication.

V. EXPERIMENTAL RESULTS

The system successfully tracked entry and exits with high reliability over extended periods with multiple use cases. The key observations were that the system was able to detect entry and exits in quick succession as there was a delay of 800ms kept in the code between the two sensors to avoid multiple counts. It also detected between 3-15 cm of the sensors placed which was optimal as it removed other objects from being detected by the sensor. RGB visual LED alerts are an easy way to alert as the color coding effectively communicates the occupancy status with different colors being shown for occupancy levels as below 50%, between 50 and 90% or greater than equal to 90%. Buzzer alert was an effective way as it warned the occupants and the incomers about the approaching maximum capacity and a continuous buzzer at full capacity provided warning of a potential over-capacity situation. The integration of Bluetooth alerts enabled real-time remote monitoring and tracking for both the administrator or organizers and the visitors.

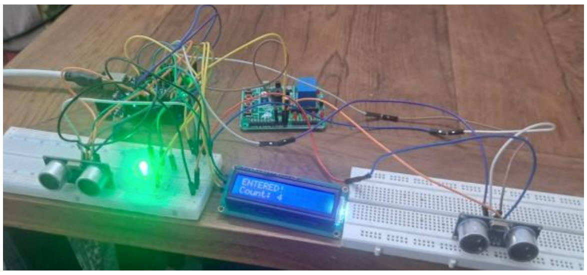

Fig. 2: LCD showing 'ENTERED' and the count with a Green LED.

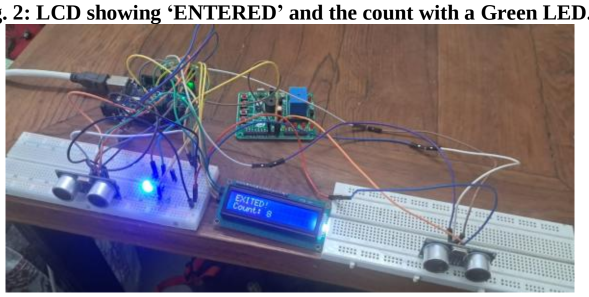

Fig. 3: LCD showing 'EXITED' and the count with a Blue LED.

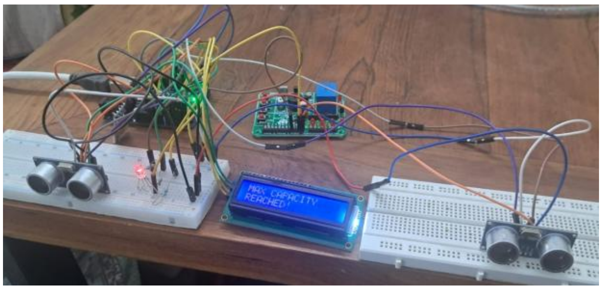

Fig. 4: LCD showing 'MAX CAPACITY REACHED' with a Red LED.

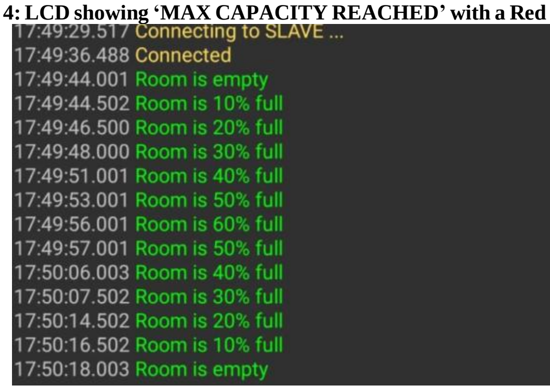

Fig. 5: Bluetooth terminal showing real time alerts.

VI. CONCLUSION

This paper presented the design and implementation of an automated entry-exit counting system based on various electrical components. It addressed the real-world challenge of monitoring space occupancy with high accuracy and low human intervention. By integrating sensors and alert mechanisms with wireless communication into a cohesive system, this demonstrated the applications of fundamental concepts of electrical engineering. The current prototype demonstrates feasibility via the breadboard and validates the core functionality and technical approach. However, it is easily scalable with the wiring complexity being reduced and making the product more compact to cater for more applications in retail and public facilities. The future enhancements can include Wi-Fi integration or a cloud-based platform which enables better data tracking and analytics for policy making.

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