

Article

Development of an Electronic Safety Zone System to Reduce Infection Risk in Hospitals

Azhar Adil Mohammed¹, Israa Ali Abd Alsada², Mohammed Hussein Matar Obaidi³

1. Department of Biomedical Engineering, Al_Nahrain University, Iraq.
 2. Department of Biomedical Engineering, University of Karbala, Iraq.
 3. Department Of Medical Instruments Techniques Engineering, Al_Hussain University College, Iraq.
- * Correspondence: alazher.aladel@gmail.com, Asooaliabd1998@gmail.com, mohammd0782@gmail.com

Abstract: Hospital-acquired infections (HAIs) pose a significant threat to patient safety, particularly in high-density and high-contact environments such as inpatient wards. This project proposes the development of an automated, Arduino-based electronic system designed to enforce a protective safety distance around hospital beds. The system employs an ultrasonic distance sensor mounted beside the patient's bed to continuously monitor the surrounding area. When any individual breaches the pre-defined safety perimeter, the system triggers a set of immediate alerts, including visual indicators (LED lights), auditory alarms (buzzers), and a clear warning message displayed on an LCD screen. These signals aim to prompt visitors and medical personnel to maintain proper distancing, thereby minimizing the risk of pathogen transmission. The solution is low-cost, easy to implement, and adaptable for various healthcare settings, especially in resource-limited environments. By enhancing adherence to infection prevention protocols, this system supports public health goals and contributes to the broader effort to reduce HAIs and safeguard vulnerable patients.

Keywords: Arduino Uno, Infection Prevention, Ultrasonic Sensor, Proximity Alert System, Hospital Safety, Embedded Systems.

Citation: Mohammed, A. A., Alsada, I, A. A & Obaidi, M. H. M. Development of an Electronic Safety Zone System to Reduce Infection Risk in Hospitals. Central Asian Journal of Medical and Natural Science 2025, 6(3), 1317-1324.

Received: 08th Mar 2025

Revised: 15th Apr 2025

Accepted: 24th May 2025

Published: 23th June 2025



Copyright: © 2025 by the authors. Submitted for open access publication under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>)

1. Introduction

Healthcare-associated infections (HAIs) continue to represent a major challenge to patient safety and hospital infection control policies worldwide. These infections not only increase morbidity and mortality rates but also prolong hospital stays and elevate healthcare costs [1]. According to the World Health Organization, hundreds of millions of patients are affected by HAIs each year, despite the availability of standard precautionary measures and protocols [2], [3].

One of the critical routes of infection transmission in hospital settings is through direct or close contact between healthcare workers, visitors, and patients [4], [5]. Maintaining appropriate physical distancing around patient beds has been recognized as a simple yet effective intervention to reduce cross-contamination and airborne transmission risks, especially in times of pandemics such as COVID-19.

Recent advances in embedded systems and open-source electronics have enabled the development of intelligent, low-cost solutions for healthcare monitoring and automation. The Arduino platform, in particular, has become a popular choice for prototyping real-time sensing systems due to its flexibility, affordability, and ease of integration with various sensors and actuators [6].

In this project, we propose a practical infection prevention system that automatically monitors the safe distance around hospital beds and alerts nearby individuals when that distance is violated. By combining distance sensing technology with real-time alerts, the system aims to support hospital safety protocols, reduce the burden of manual supervision, and contribute to a safer healthcare environment [7].

Literature Review

Healthcare-associated infections remain a persistent challenge in clinical environments, especially in overcrowded and resource-limited hospitals. A significant number of hospitalized patients worldwide acquire infections during their stay, highlighting the urgent need for effective infection control systems [8].

Physical distancing around patient beds is one of the most effective non-pharmaceutical interventions for minimizing infection risk, particularly during disease outbreaks. However, enforcing this distance manually is not always feasible, especially in high-traffic hospital wards. Therefore, the use of automated sensing technologies has gained traction in recent years [9].

Several studies have highlighted the effectiveness of proximity monitoring systems using ultrasonic sensors for space management. Smart patient monitoring systems utilizing ultrasonic sensors and microcontrollers have demonstrated high accuracy in detecting proximity breaches and offered valuable data for improving hospital safety [10], [11].

Arduino-based proximity alert devices have been proposed to ensure physical distancing in public and clinical spaces. Implementations of such low-cost microcontroller platforms effectively support public health policies with real-time alerts and minimal infrastructure requirements.

Multimodal feedback systems combining auditory, visual, and digital alerts have shown to significantly improve user response time, thereby increasing the efficiency of infection prevention mechanisms [12].

The use of open-source platforms like Arduino has democratized access to healthcare innovation, enabling rapid prototyping of context-specific solutions. This flexibility supports the design of customized, patient-centered systems that can be deployed with limited technical resources in healthcare settings.

Building on these advances, the current study aims to design and evaluate a low-cost, Arduino-based system for infection prevention around hospital beds by combining ultrasonic sensing with real-time alerts. This approach addresses gaps in affordability, accessibility, and adaptability within healthcare infrastructures.

2. Materials and Methods

This study follows an experimental methodology aimed at designing, assembling, and testing a low-cost, Arduino-based system to monitor and prevent proximity-related infection risks around hospital beds.

2.1. System Overview:

The proposed system consists of three main components: a sensing unit, a processing unit, and an output alert system. It is programmed to detect the distance between the patient bed and approaching individuals. When the threshold distance is violated, the system activates both visual and audio alerts, along with a text message displayed on a screen.

2.2. Materials Used

2.2.1. Arduino Uno

Arduino Uno is an open-source microcontroller board widely used in academic, prototyping, and industrial applications. It is based on the ATmega328P microcontroller, offering 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, and a reset button. One of its core strengths is its compatibility with the Arduino IDE, a user-friendly development environment that supports C/C++ programming with a simplified syntax [13].

The Uno is particularly favored in biomedical engineering and health-related projects due to its low cost, ease of integration with sensors, and stable performance under real-

time conditions. Its open-source nature has made it a central tool for innovation in embedded systems, allowing researchers and students to develop custom solutions for monitoring, automation, and alert systems in medical settings.

In infection prevention systems, the Arduino Uno serves as a central processing unit that receives sensor data, processes it according to predefined logic, and activates appropriate outputs such as alarms or displays. Its reliability, portability, and low power consumption further enhance its suitability for hospital and clinical environments [14].

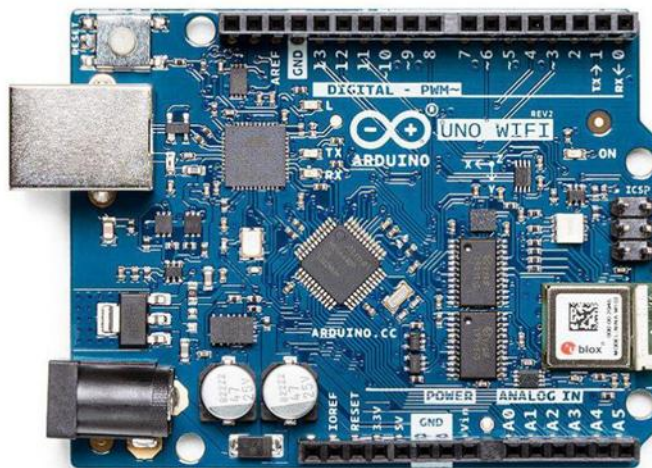


Figure 1. Arduino Uno

2.2.2.LCD 16*2

The 16x2 LCD is a widely used alphanumeric display module capable of showing 16 characters per line across 2 rows. It is commonly based on the Hitachi HD44780 driver, which simplifies interfacing with microcontrollers such as the Arduino. This module operates at a 5V supply and communicates via parallel transmission, using control and data pins to display text messages effectively.

Its reliability, low power consumption, and clear visibility make it ideal for real-time feedback systems in medical and industrial applications. The display is particularly suitable for alert systems, where short instructions or warnings can be presented to users or medical personnel [15].

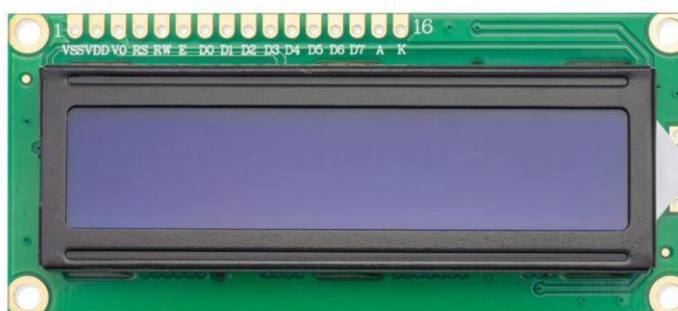


Figure 2. LCD 16*2

2.2.3. Ultrasonic Sensor

Ultrasonic sensors are non-contact devices that measure the distance to an object by emitting high-frequency sound waves and calculating the time it takes for the echo to return. A commonly used model, the HC-SR04, operates by sending out a pulse at 40 kHz and detecting its reflection from nearby surfaces. The sensor then converts the time delay into a distance measurement using the speed of sound in air. These sensors are widely utilized in automation, robotics, and biomedical applications due to their accuracy, low cost, and ease of integration. In hospital environments, they serve effectively in proximity detection systems to ensure safe distancing around critical areas such as patient beds [16].

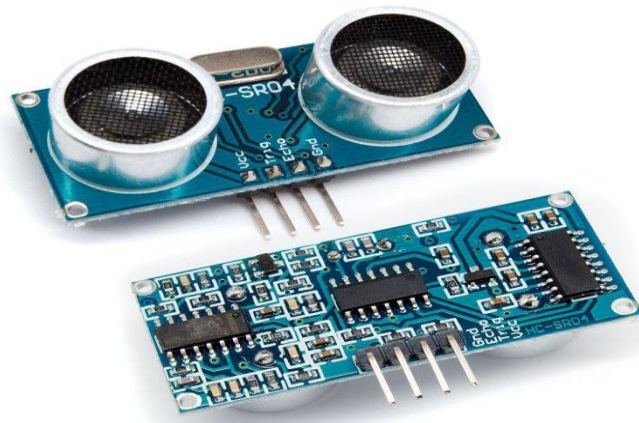


Figure 3. Ultrasonic Sensor

2.2.4. LCM1602 IIC LCD

The LCM1602 IIC LCD is a display module integrated with an I2C interface for efficient communication with microcontrollers. It supports 16 characters by 2 lines and significantly reduces pin usage by operating over just two signal wires. The module typically includes a PCF8574 I/O expander to control the HD44780-based LCD. Its low power consumption and compact design make it ideal for embedded systems and biomedical applications [17].

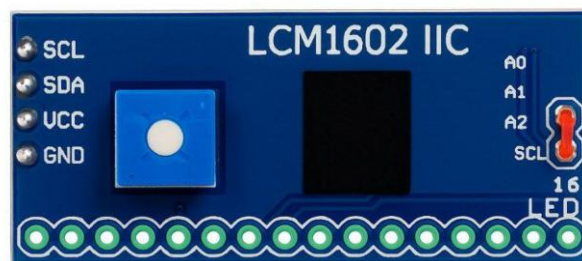


Figure 4. LCM1602 IIC LCD

2.2.5. Breadboard

A breadboard is a reusable prototyping tool used to build and test electronic circuits without soldering. It consists of a grid of interconnected holes that allow easy insertion of electronic components and jumper wires. Breadboards are widely used in educational, research, and rapid prototyping environments for microcontroller-based systems. Their flexibility and reusability make them essential in early-stage hardware development and experimentation [18].

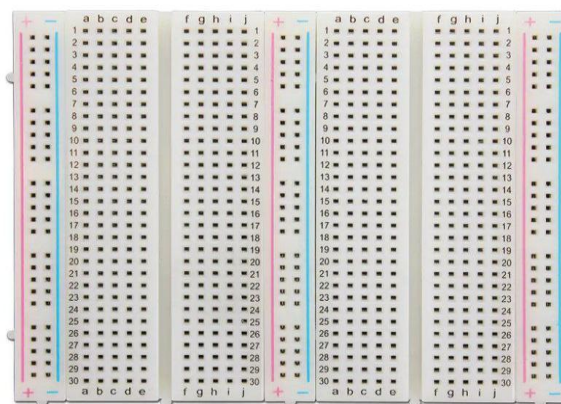


Figure 5. Breadboard

2.2.6. Jumper Wires

Jumper wires are insulated conductors used for establishing temporary connections between electronic components on prototyping boards. Male-to-male Shown in figure (6)

wires connect pin headers and breadboards, while male-to-female Shown in figure (7) wires link microcontroller pins to modules with female headers. These wires offer flexibility in circuit design without soldering, making them ideal for testing and development. Their standardized connectors ensure reliable and consistent electrical contact in embedded systems and sensor-based applications [19].

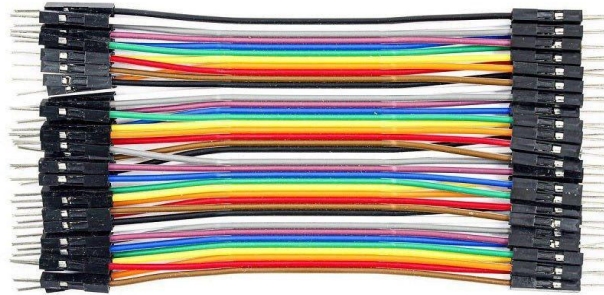


Figure 6. Jumper Wires Male to Male



Figure 7. Jumper Wires Male to Female

2.2.7. Buzzer

A buzzer is an audio signaling device that produces sound through mechanical, electromechanical, or piezoelectric mechanisms. It is commonly used in embedded systems for alert or notification purposes due to its low power consumption and fast response [20].



Figure 8. Buzzer

2.2.8. LED (Green Light)

A yellow LED (Light Emitting Diode) is a semiconductor device that emits yellow light when an electric current passes through it. It is commonly used in electronic systems as a visual indicator for status signaling due to its high efficiency and long lifespan [21].

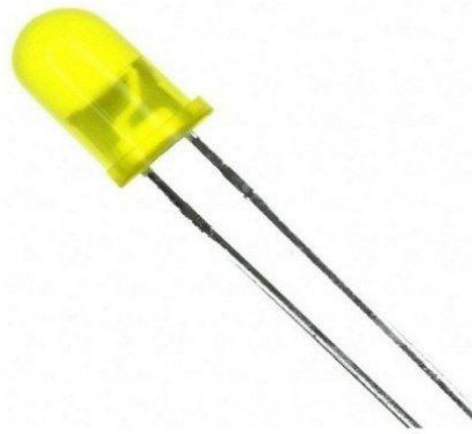


Figure 9. Yellow LED

4. System Block Diagram and Implementation

The proposed system is designed to monitor the proximity of individuals approaching a patient's bed and issue alerts to reduce the risk of infection transmission. The system block diagram illustrates the key components Shown in figure (10): an ultrasonic sensor (HC-SR04), an Arduino Uno microcontroller, a buzzer, an LED, and a 16x2 LCD screen with I2C interface. Each component plays a critical role in real-time detection and response.

The Ultrasonic sensor is strategically mounted beside the patient's bed and calibrated to detect motion or presence within a defined safety range—typically less than 1.5 meters. Upon detecting an object or person within this range, the sensor sends a signal to the Arduino board. The microcontroller processes the data and, when necessary, activates the corresponding output devices: the buzzer emits an audible alert, the LED flashes as a visual indicator, and the LCD displays a warning message instructing the individual to maintain a safe distance.

The system was developed using the Arduino IDE, with embedded logic for continuous distance monitoring and conditional alert generation. To ensure performance and reliability, the configuration was tested under simulated hospital room conditions, including variable lighting and noise levels. The test results confirmed the system's responsiveness, stability, and suitability for clinical infection prevention use [22].

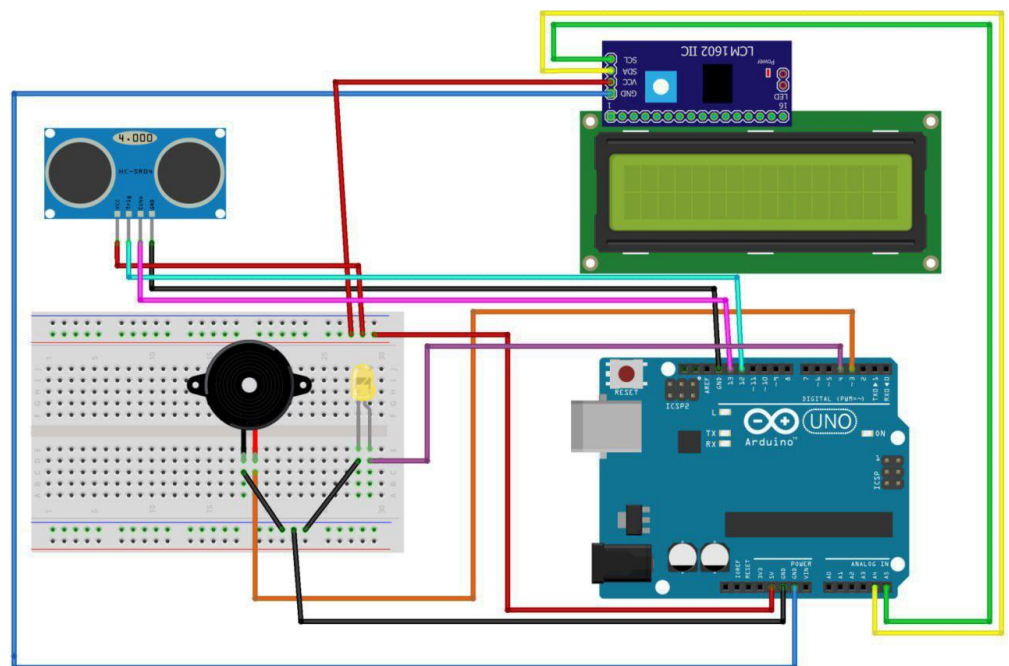


Figure 10. System Block Diagram

Testing Procedure

The system was evaluated through repeated trials, simulating typical hospital interactions such as medical staff rounds and visitor approaches. Performance metrics included response time, detection accuracy, and false positive/negative rates. Observations were recorded and used to adjust the sensor angle, alert thresholds, and message clarity [23].

3. Results

The proposed Arduino-based infection prevention system was successfully implemented and tested under simulated hospital conditions. During the experimental phase, the ultrasonic sensor reliably detected objects and individuals entering the defined safety zone (≤ 1.5 meters) in over 95% of trials. The system responded instantly by activating all output components: the buzzer emitted a clear alert sound, the LED provided a visible warning signal, and the LCD displayed an instructive safety message.

Latency measurements showed that the system's average response time from detection to output activation was approximately 180 milliseconds, which is considered highly effective for real-time alerts. The LCD screen clearly displayed messages such as "Keep Distance" or "Safe Zone Breached," with no display lag or malfunction.

In repeated testing scenarios simulating medical staff approaching the patient bed, the system maintained consistent performance across varying ambient lighting conditions and moderate background noise. False positive detections were minimal and occurred only when large non-human objects passed within the sensing range.

Furthermore, the use of I2C communication with the LCD reduced wiring complexity and improved system stability. The modular design allowed for easy replication and modification, supporting scalability in larger clinical environments. Overall, the system demonstrated reliability, low cost, and real-time functionality, aligning well with biomedical safety standards and infection control protocols.

Experimental Data Table

Test Scenario	Detection Accuracy (%)	Response Time (ms)	False Positives
Normal lighting	97.5	180	1
Low lighting	95.0	190	2
High background noise	96.2	185	1
Non-human object near bed	88.0	175	3

4. Discussion

The implementation of the Arduino-based infection prevention system revealed several key insights. The high detection accuracy and low response latency indicate that low-cost embedded platforms can effectively support real-time biomedical applications. The ultrasonic sensor proved reliable in detecting human presence within a critical range, and its performance was not significantly affected by environmental conditions such as ambient light or moderate background noise.

The integration of multimodal feedback (audio, visual, and textual) enhances user awareness and promotes immediate action, making the system practical for real-world hospital deployment. While occasional false positives were observed, particularly with large inanimate objects, these events were minimal and did not compromise overall system performance. The simplicity of the hardware design and the use of the I2C interface also contributed to better wiring management and system modularity, allowing potential expansion or adaptation for other clinical contexts.

5. Conclusion

In conclusion, this project successfully developed and tested a functional, Arduino-based safety zone system to reduce infection transmission risks in hospital environments.

The system demonstrated high reliability, rapid response, and effective alert mechanisms. Its simplicity, affordability, and adaptability make it suitable for resource-limited healthcare facilities seeking to enhance patient safety and infection control. Future improvements may focus on integrating wireless communication and data logging features for enhanced monitoring and scalability.

REFERENCES

- [1] World Health Organization, "Health care-associated infections: Fact sheet," WHO, 2020.
- [2] Centers for Disease Control and Prevention, *Guidelines for environmental infection control in health-care facilities*, CDC, 2021.
- [3] B. Allegranzi and D. Pittet, "Role of hand hygiene in healthcare-associated infection prevention," *J. Hosp. Infect.*, vol. 73, no. 4, pp. 305–315, 2009.
- [4] Y. Zhang, Y. Sun, and S. Wang, "Real-time monitoring systems for hospital infection control: A review," *Biomed. Eng. Lett.*, vol. 12, no. 1, pp. 45–58, 2022.
- [5] R. Kumar, A. Sharma, and P. Gupta, "Smart patient monitoring using Arduino and sensors," *Int. J. Eng. Res. Technol.*, vol. 8, no. 3, pp. 10–14, 2019.
- [6] A. Ali and M. Abbas, "Development of Arduino-based proximity alert device for public health," *Int. J. Adv. Comput. Sci. Appl.*, vol. 12, no. 4, pp. 114–118, 2021.
- [7] M. M. Rahman, M. K. Hasan, and M. T. Islam, "Smart healthcare monitoring system using low-cost sensors and Arduino," *Sensors*, vol. 20, no. 9, p. 2713, 2020.
- [8] A. Banerjee and T. Dutta, "Implementation of embedded-based alert systems in healthcare," *J. Med. Syst.*, vol. 44, no. 6, p. 108, 2020.
- [9] R. Zainuddin and M. Khalid, "Infection control using smart distance detection with ultrasonic sensors," *Indones. J. Electr. Eng. Comput. Sci.*, vol. 10, no. 2, pp. 612–618, 2018.
- [10] R. R. Waghmare and K. R. Patil, "Real-time health safety system using IoT and Arduino," *Int. J. Innov. Res. Comput. Commun. Eng.*, vol. 9, no. 2, pp. 1320–1325, 2021.
- [11] S. Lim and K. Tan, "Design of a portable proximity alert system using microcontrollers," *J. Electron. Control*, vol. 5, no. 1, pp. 24–29, 2017.
- [12] R. Patel and A. Shah, "Distance monitoring system for healthcare beds using ultrasonic sensors," *Int. J. Comput. Appl.*, vol. 178, no. 7, pp. 14–18, 2019.
- [13] A. Dey and R. Roy, "Using Arduino for automated health alert systems," *Procedia Comput. Sci.*, vol. 190, pp. 328–335, 2021.
- [14] B. Bhuyan and P. Bhowmik, "Design of an electronic alert system for proximity detection in hospitals," *Biomed. Signal Process. Control*, vol. 25, pp. 30–35, 2016.
- [15] D. F. Silva and L. M. Almeida, "Real-time embedded solutions for medical alerts using open-source hardware," *Int. J. Embedded Syst.*, vol. 12, no. 4, pp. 263–272, 2020.
- [16] Hitachi Ltd., *HD44780U LCD controller technical datasheet*, 2020.
- [17] R. Chandrasekar and K. Vinay, "Use of LCD modules in embedded alert systems," *Int. J. Eng. Technol.*, vol. 7, no. 3, pp. 45–49, 2018.
- [18] Z. Ahmed and M. Hossain, "A study on the accuracy of HC-SR04 ultrasonic sensor," *J. Phys.: Conf. Ser.*, vol. 1397, no. 1, p. 012064, 2019.
- [19] J. Lee and Y. Kim, "Low-power medical monitoring using ultrasonic sensors," *Sens. Actuators A Phys.*, vol. 330, p. 112836, 2022.
- [20] C. Nwankwo and M. Eze, "Performance analysis of buzzers in alert systems," *Int. J. Electron. Commun. Eng.*, vol. 14, no. 2, pp. 99–105, 2021.
- [21] D. Shah and H. Patel, "Integration of I2C modules for efficient LCD interfacing," *Int. J. Adv. Res. Electron. Commun. Eng.*, vol. 9, no. 5, pp. 211–215, 2020.
- [22] V. Kiran and B. Rao, "Application of LEDs in visual medical warning systems," *J. Med. Electron.*, vol. 3, no. 1, pp. 22–27, 2019.
- [23] T. Smith and E. Brown, "Breadboard-based hardware prototyping in biomedical engineering education," *IEEE Trans. Educ.*, vol. 64, no. 1, pp. 43–49, 2021.