Project Report On

Project 2
Home Security Based on Ultrasonic Sensor and 4x4 Matrix Keypad

For The Subject Term Work Submission Of

CPE – 556 Computing Principles for Mobile and Embedded Systems

By

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Abstract:

This project presents the development of a smart access control system powered by the STM32L476RG microcontroller. The system combines ultrasonic sensing, a keypad interface, OLED graphical feedback, and serial communication to create an interactive and secure user authentication mechanism. The ultrasonic sensor detects when a person approaches the system, triggering a prompt on the OLED display for PIN entry. A 4-digit code is then entered using a 4x4 matrix keypad, with real-time visual feedback. If the entered code matches the pre-defined password, access is granted and a welcome message is shown. If the code is incorrect, an alert is issued, simulating an intruder warning. This system is designed using bare-metal C programming and low-level register access, making it efficient and well-suited for embedded applications.

Introduction:

Access control systems are essential in safeguarding environments such as homes, offices, and industrial facilities. With the growth of embedded technologies, such systems have evolved to be more compact, responsive, and feature rich. This project demonstrates a complete embedded access control solution built on the STM32L476RG, a Cortex-M4-based microcontroller. Unlike software-heavy platforms that rely on extensive libraries, this implementation emphasizes bare-metal programming using direct register manipulation for precise control over hardware. Key peripherals including GPIOs, timers, USART, and I2C are used to interface with external components like ultrasonic sensors, OLED displays, and keypads. The system highlights fundamental principles of embedded design: real-time responsiveness, hardware-software integration, and efficient resource utilization. Its modular structure also provides a scalable foundation for future enhancements such as wireless connectivity, EEPROM password storage, and enhanced user feedback mechanisms.

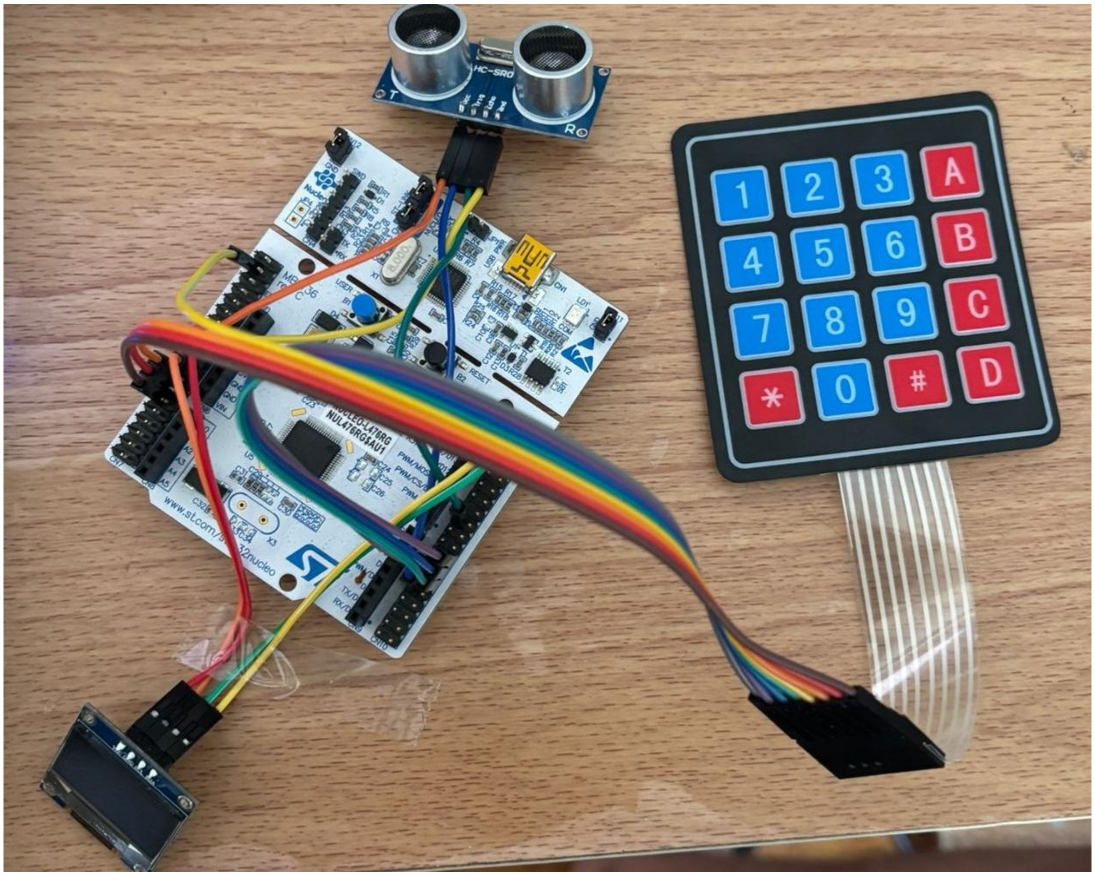

Figure 1: Hardware setup

Hardware

- STM32L476RG Nucleo Board
- HC-SR04 Ultrasonic Sensor
- 4x4 Matrix Keypad
- SSD1306 OLED Display (I2C Interface)
- USB-to-Serial for USART communication

Software Design

The software architecture follows a modular structure, with separate C files for each functional component. Key modules include Ultrasonic sensing, OLED handling via I2C, Keypad scanning, and USART communication. Initialization routines are defined for each peripheral using direct register access, ensuring full control over hardware behavior.
The main.c file acts as the system coordinator. It initializes all hardware components, continuously monitors the distance using the ultrasonic sensor, and triggers the keypad interaction sequence when presence is detected. The keypad handler reads one character at a time, masking the input on the OLED and transmitting feedback over USART. If the entered PIN matches the predefined value, a success message is shown; otherwise, a warning is displayed. Timers and busy-wait delays are used for debouncing and event timing.

System Workflow

1. Initialization Phase:
    - Configure GPIO pins for the ultrasonic sensor (PB5 as output, PB6 as input).
    - Set up GPIOs for 4x4 matrix keypad rows (PB10, PB13–15) and columns (PC12–15).
    - Initialize I2C1 on PB8 and PB9 for OLED communication.
    - Set up USART2 on PA2 for serial transmission.
    - Configure Timer 2 for microsecond-level pulse measurements.
2. Monitoring Phase:
    - Continuously generate a trigger pulse on the ultrasonic sensor.
    - Measure echo pulse width and calculate distance.
    - If distance ≤ 150 cm, activate the keypad and OLED UI.
3. Authentication Phase:
    - Prompt the user via OLED to enter a 4-digit passcode.
    - Capture and mask each digit from keypad input.
    - Display entered characters as # and transmit via USART.
4. Decision Phase:
    - Compare the entered code to the preset password (1048).
    - If matched, display a Welcome message.
    - If mismatched, display Intruder Alert.
5. Reset Phase:
    - Clear the screen and resume distance monitoring.

This structured workflow ensures a seamless interaction between hardware modules and provides real-time, context-sensitive feedback to users.

Conclusion

This project successfully demonstrates the application of embedded systems in access control solutions. By integrating multiple peripherals with the STM32L476RG microcontroller, a secure and responsive system was created that simulates a real-world smart lock. The use of ultrasonic sensing provides contactless presence detection, while the OLED display and keypad offer intuitive user interaction. Implementing the project using bare-metal programming not only ensures low-level hardware control but also reinforces understanding of the microcontroller's internal architecture. The modular and extensible nature of the design allows for easy scaling—such as incorporating additional sensors, wireless modules (like ESP8266), or EEPROM for dynamic passcode storage. This project serves as a robust foundation for students and engineers interested in building advanced security systems using embedded technology. The successful execution of this system reinforces key engineering principles: modularity, hardware-software co-design, and practical problem solving in resource-constrained environments.

Future Work

- EEPROM-based passkey storage
- Buzzer feedback