Ministerul Educației și Cercetării al Republicii Moldova

Universitatea Tehnică a Moldovei

Facultatea Calculatoare, Informatică şi Microelectronică

Departamentul Inginerie Software și Automatică

Report

Laboratory work nr. 6.1

Control comportamental cu Automate Finite: ***Button-Led***

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Checked by:

Martîniuc Alexei, *university assistant*

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1. OBJECTIVES

Main purpose of the work:

To design and implement a modular microcontroller-based application that controls an LED using a finite state machine (FSM). The system transitions through OFF, ON, and BLINKING states based on user input from a push-button. The control flow and system state are observable in real time via serial output using STDIO.

The objectives of the work:

- To understand the use of Finite State Machines (FSM) in embedded applications.
- To develop modular code by separating hardware abstraction (LED, Button) from control logic (FSM).
- To apply debouncing techniques for reliable push-button input detection.
- To implement serial communication using STDIO for real-time feedback and debugging.
- To demonstrate a simple state-driven behavior using a user interface (button) and output interface (LED).
- To promote reusability and clarity through structured module design.
- To lay the foundation for more advanced control systems, such as ON-OFF hysteresis logic.

PROBLEM DEFINITION

System Description:

The project implements a basic Finite State Machine (FSM) to control an LED based on user interaction through a button. The system cycles through the following states:

- **OFF**: The LED is off.
- **ON**: The LED is turned on.
- **BLINKING**: The LED toggles on and off at a fixed interval.

Each press of the button transitions the system to the next state. The system ensures accurate button

press detection using a software debounce mechanism. State changes and current state information are displayed via the serial interface using printf, enabled through a custom STDIO redirection.

Hardware Involved:

- Microcontroller: Arduino Uno
- LED: Connected to digital pin 13
- Button: Connected to digital pin 2, using internal pull-up
- Serial Communication: Via USB, 9600 baud

Key Features:

- Debounced button input
- FSM with three distinct states
- LED control logic encapsulated in a class
- Button input encapsulated in a class
- STDIO redirection for using printf with the serial monitor

Use Case:

The application serves as a demonstrative tool for embedded systems learners to understand state machines, modular design, and serial communication. It provides a hands-on example of how a microcontroller can react to user input and change behavior in a predictable, testable manner.

2. DOMAIN ANALYSIS

3.1 Application Domain:

This project falls under the domain of **Embedded Systems** and **IoT (Internet of Things)**. It specifically addresses user-interactive systems that rely on real-time input and output, such as smart appliances, sensor systems, or control interfaces.

3.2 Related Concepts:

- **Finite State Machine (FSM):** A computation model used to design systems with a limited number of specific states and predictable transitions. Common in embedded applications for managing states like OFF, ON, and BLINK.
- **Modular Programming:** The practice of dividing code into independent modules or classes (e.g., LED, Button) that improve reusability and readability.
- **Button Debouncing:** A technique to eliminate false triggers due to mechanical bouncing in push-buttons.
- **Serial Communication & STDIO Redirection:** Redirection of printf to serial output, allowing debugging and feedback without Serial.print().

3.3 Target Users:

- Embedded systems students and developers.

- Engineers developing control systems or real-time embedded applications.
- Educators demonstrating FSM-based microcontroller behavior.

3.4 Constraints:

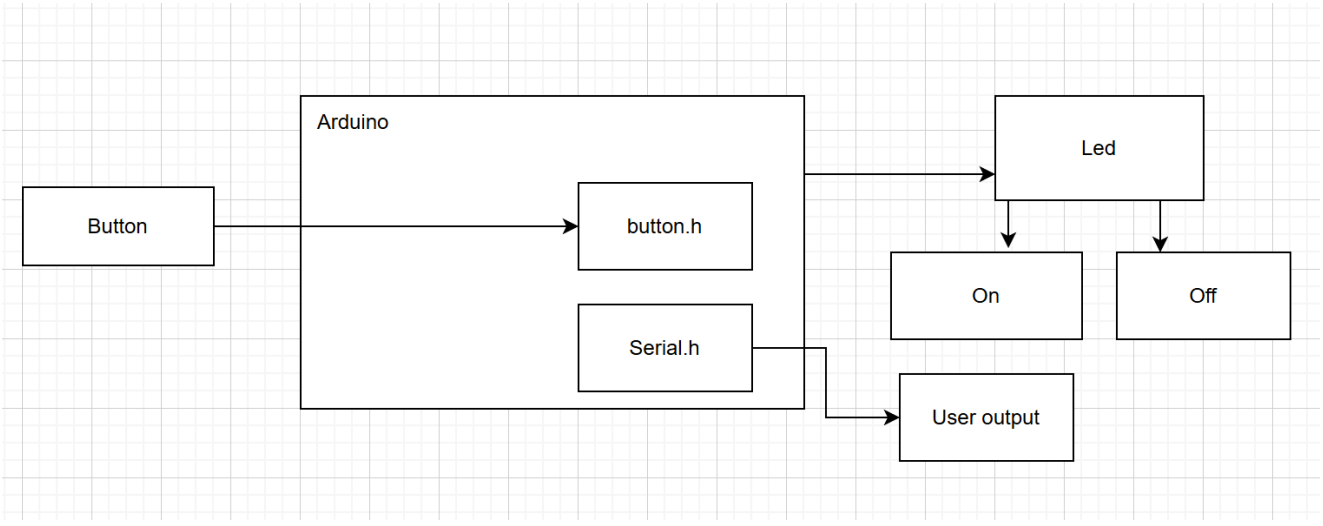
- The Arduino Uno has limited memory and processing power.
- The system assumes only one input device (button) and one output device (LED).
- Serial communication is limited to 9600 baud in this setup.

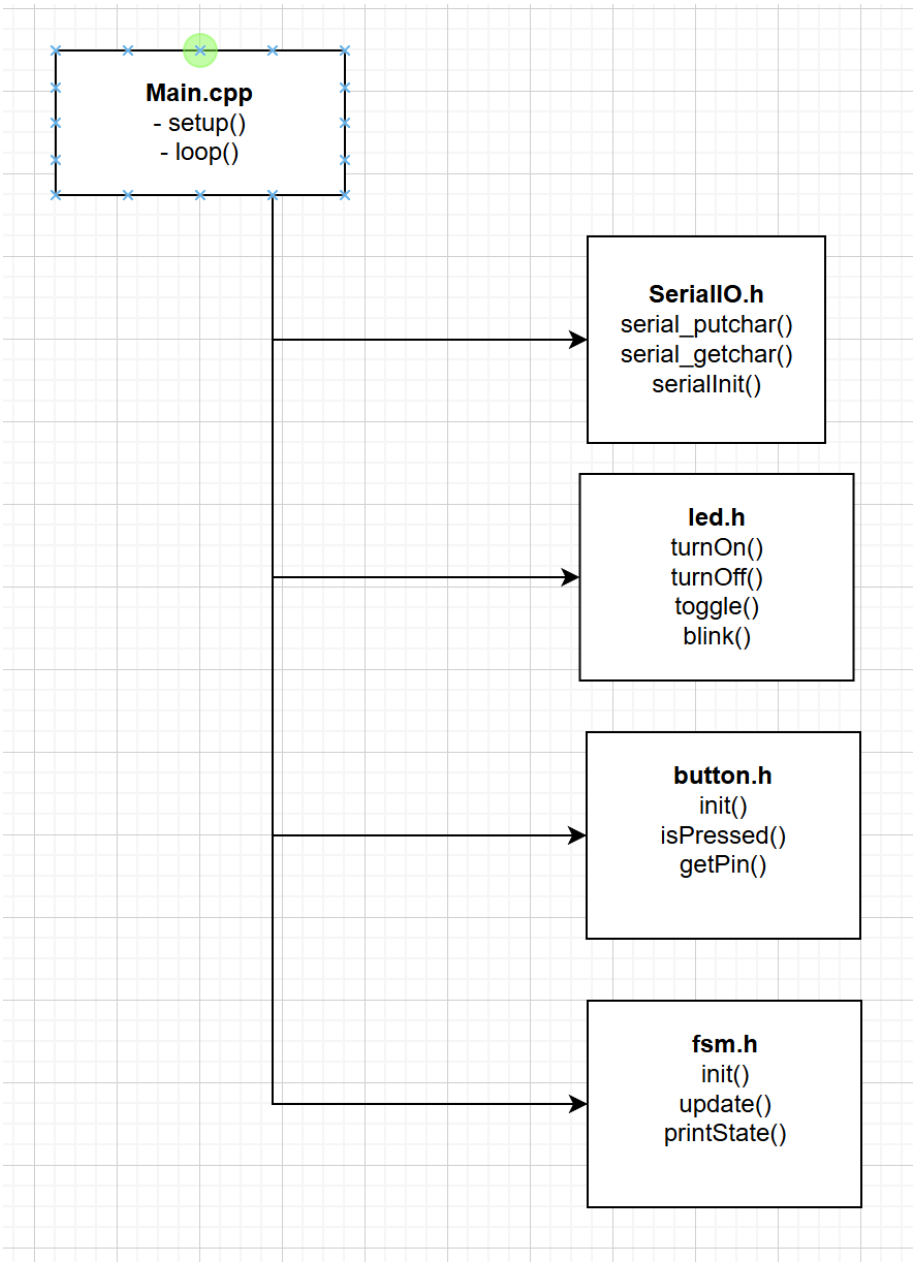
Architectural Design

The architectural design emphasizes modularity, reusability, and real-time interaction. Each component of the system is encapsulated in its own module:

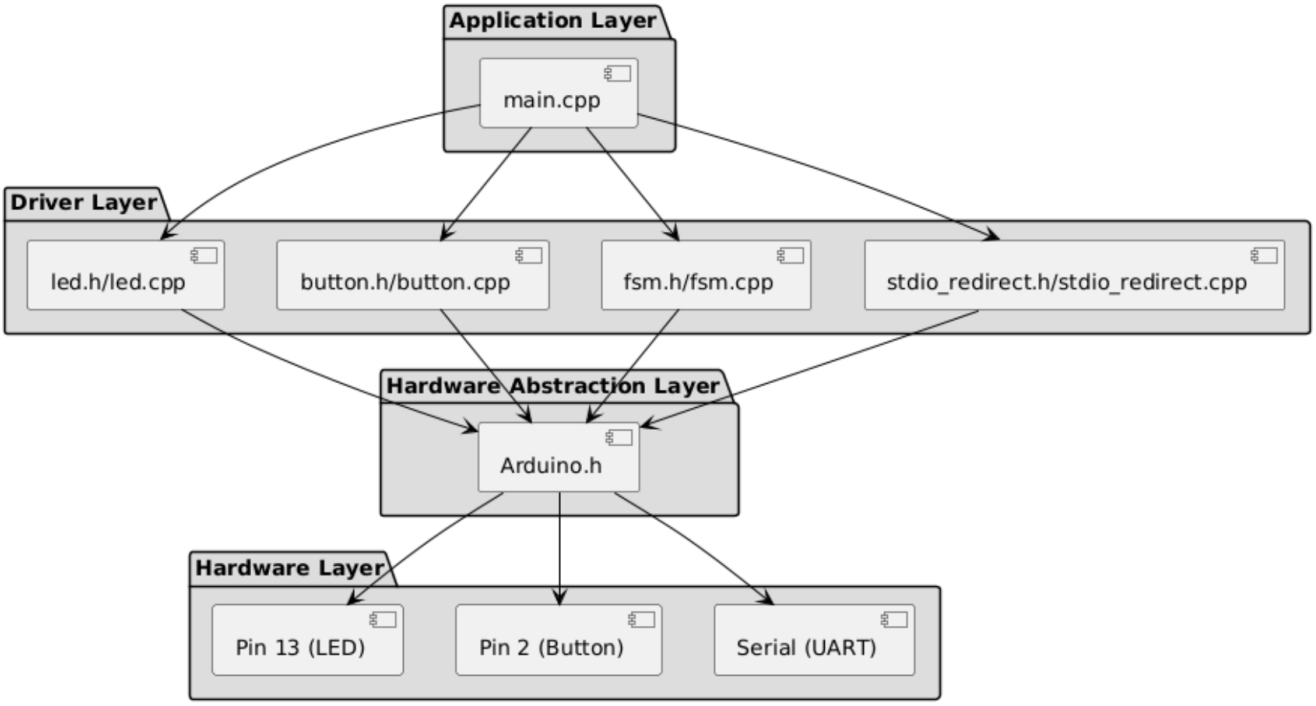
- **MCU Core**: Manages overall logic, reads sensor input, processes control algorithms, and updates outputs.
- **Sensor Module**: Reads environmental or positional data (e.g., DHT22 or potentiometer), returning processed values.
- **Control Module**: Implements ON-OFF logic with hysteresis, calculates thresholds, and determines output state.
- **Actuator Module**: Controls relay or motor via L298 driver based on control output.
- **Interface Module**: Displays current and set values on LCD and allows interaction via serial (STDIO) or physical controls (buttons/keypad).

Hardware Diagram

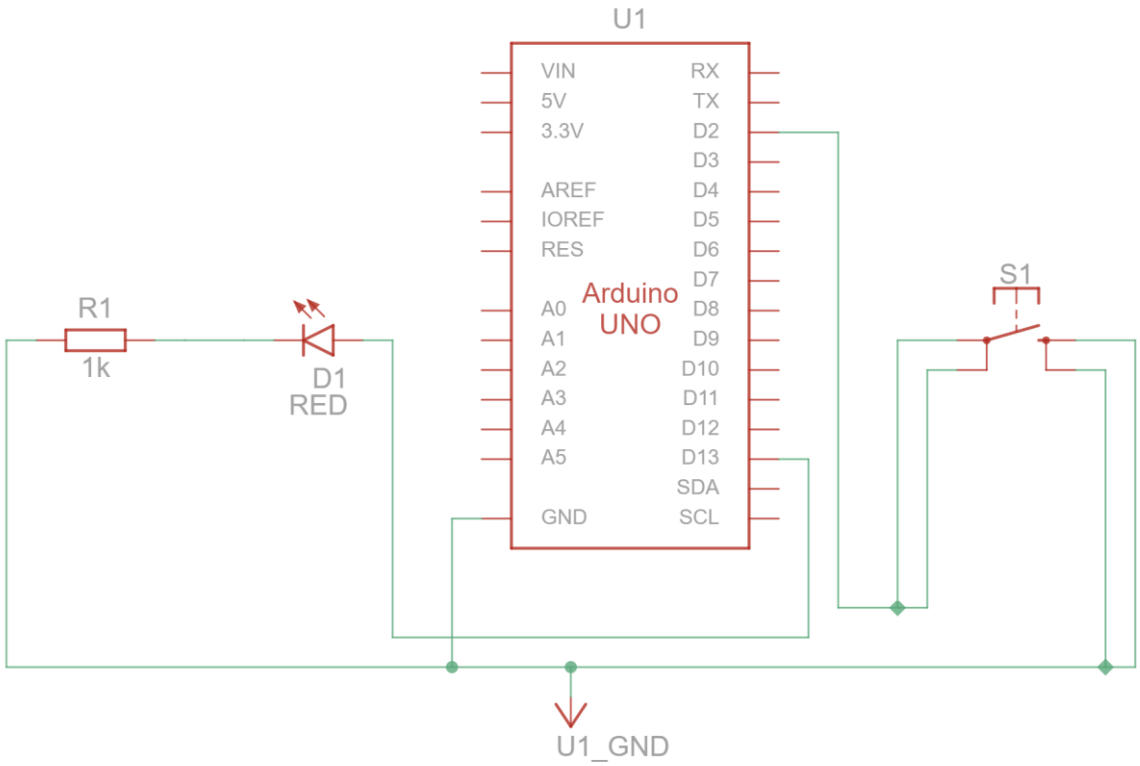


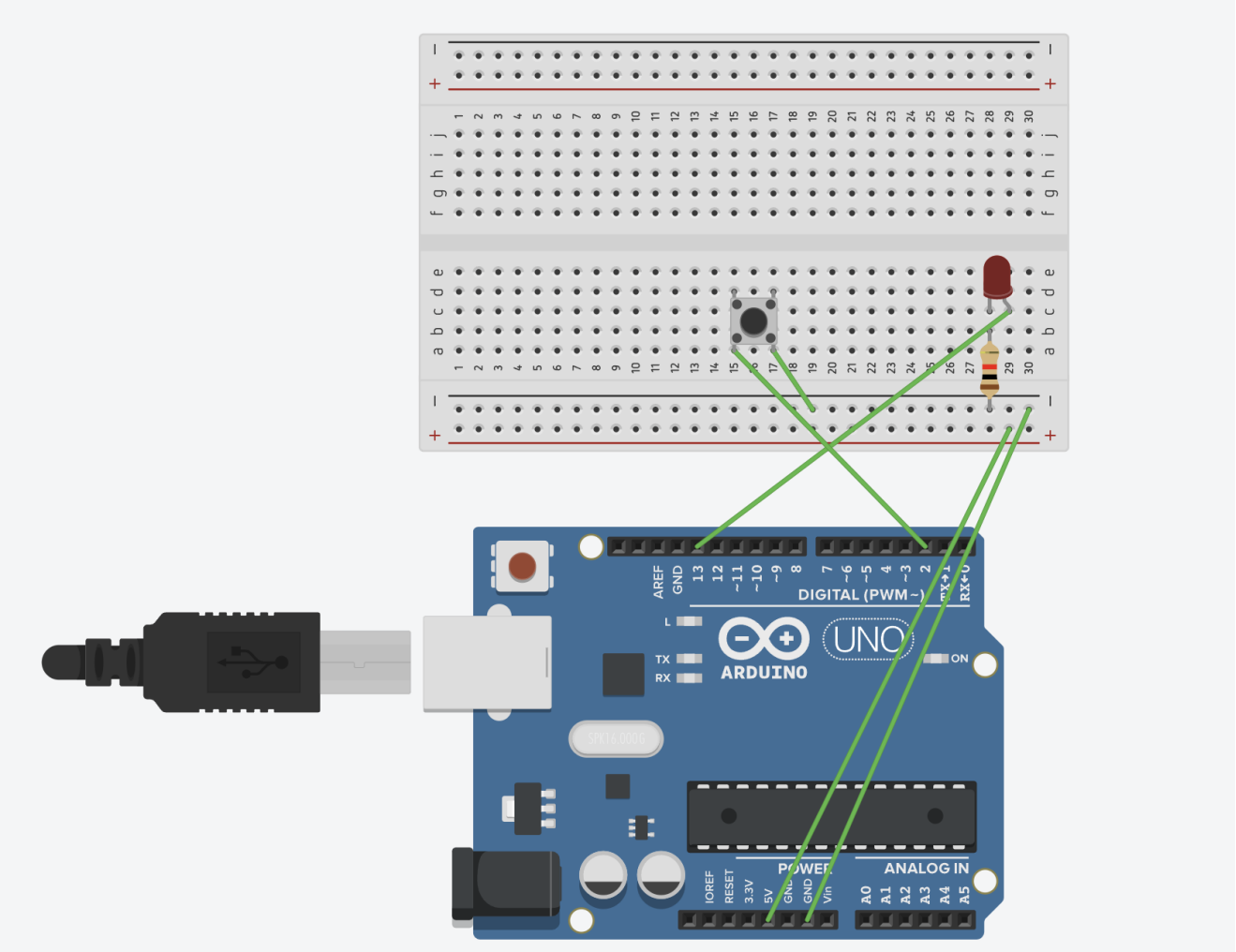

Main.cpp
- setup()
- loop()
SerialIO.h
serial_putchar()
serial_getchar()
serialInit()
led.h
turnOn()
turnOff()
toggle()
blink()
button.h
init()
isPressed()
getPin()
fsm.h
init()
update()
printState()

Layer Diagram



Electrical Scheme

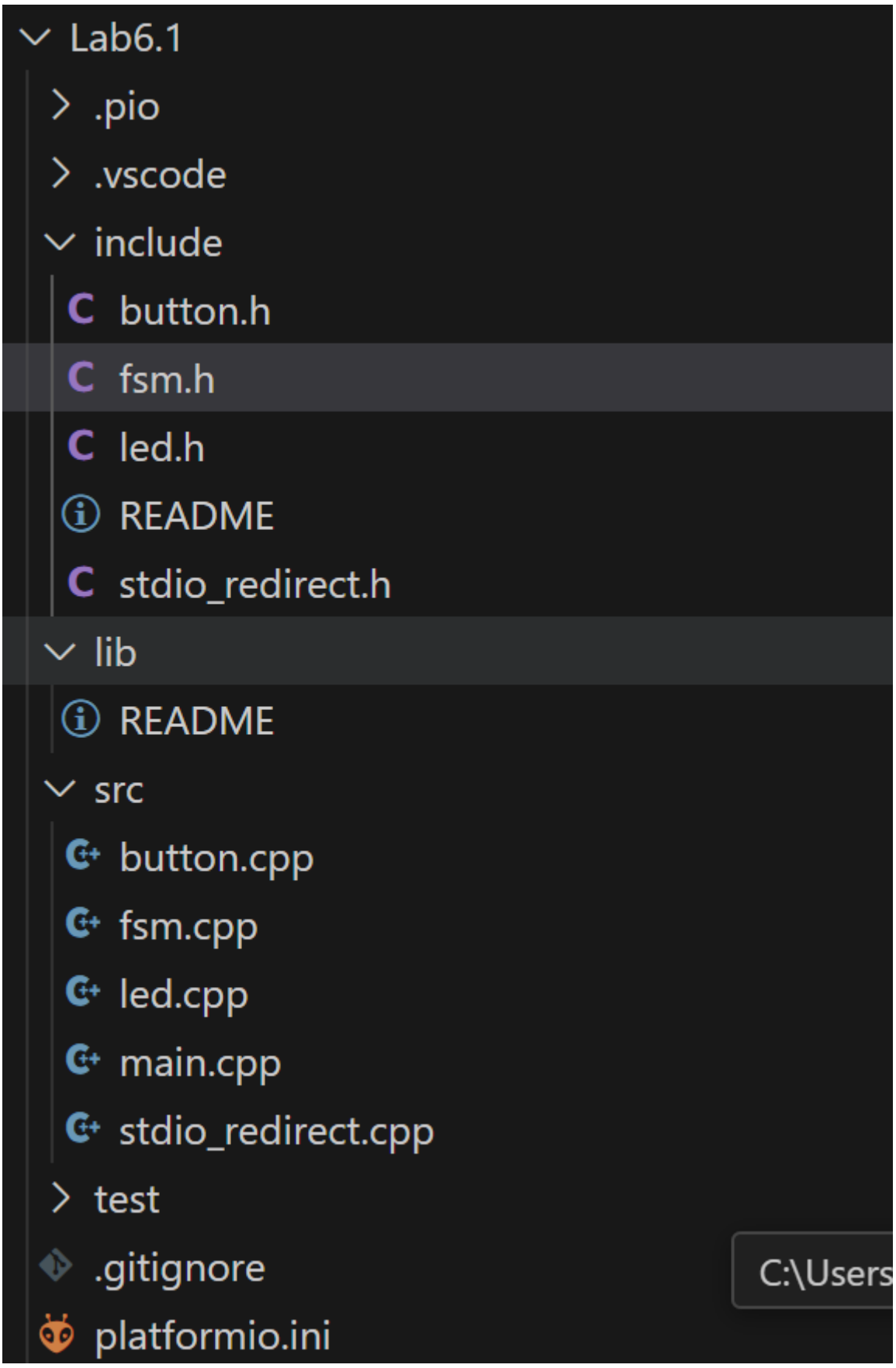




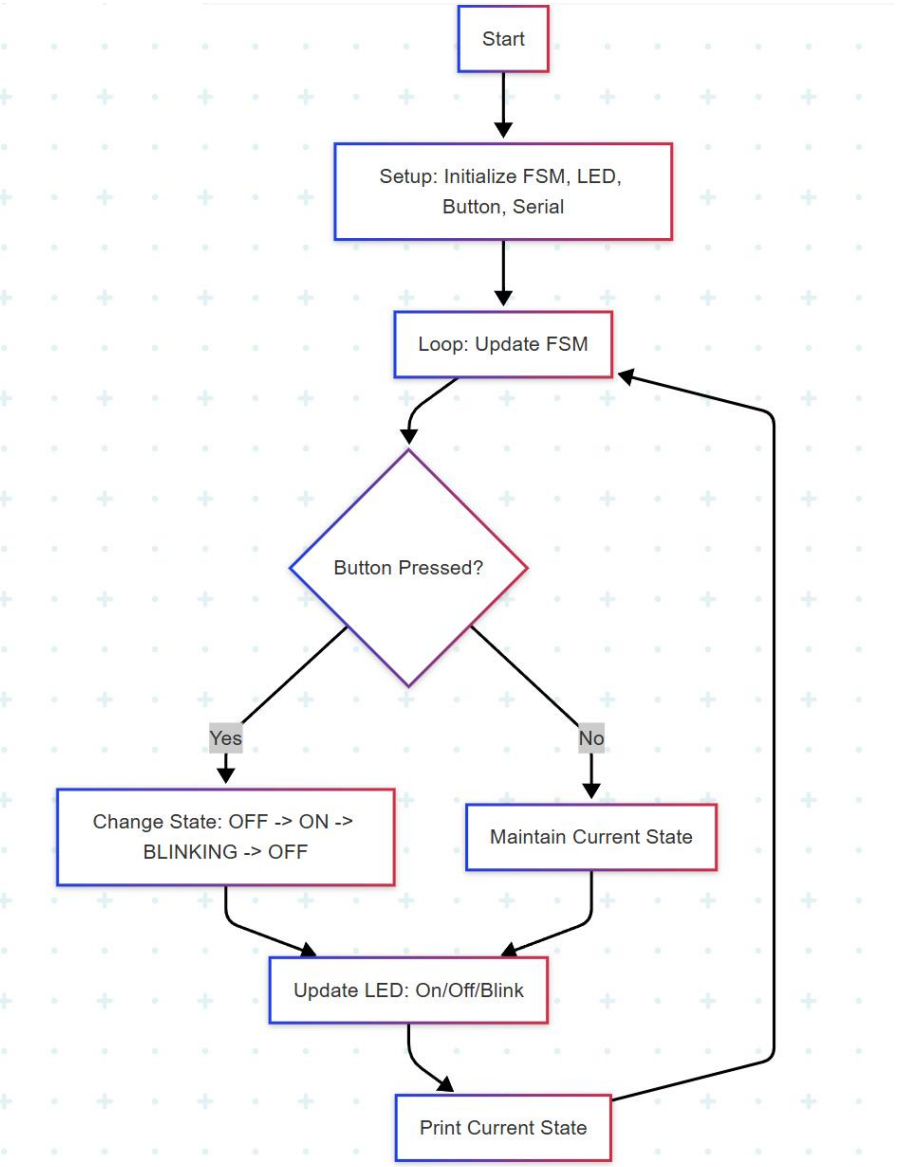
Project Structure and Modular Implementation

Table of states

State	Description	Transition Condition	Action Performed	Next State
STATE_OFF	LED is off	Button pressed	LED turned off, state printed	STATE_ON
STATE_ON	LED is steadily on	Button pressed	LED turned on, state printed	STATE_BLINKING
STATE_BLINKING	LED blinks at 500ms interval	Button pressed	LED turned off, state printed	STATE_OFF

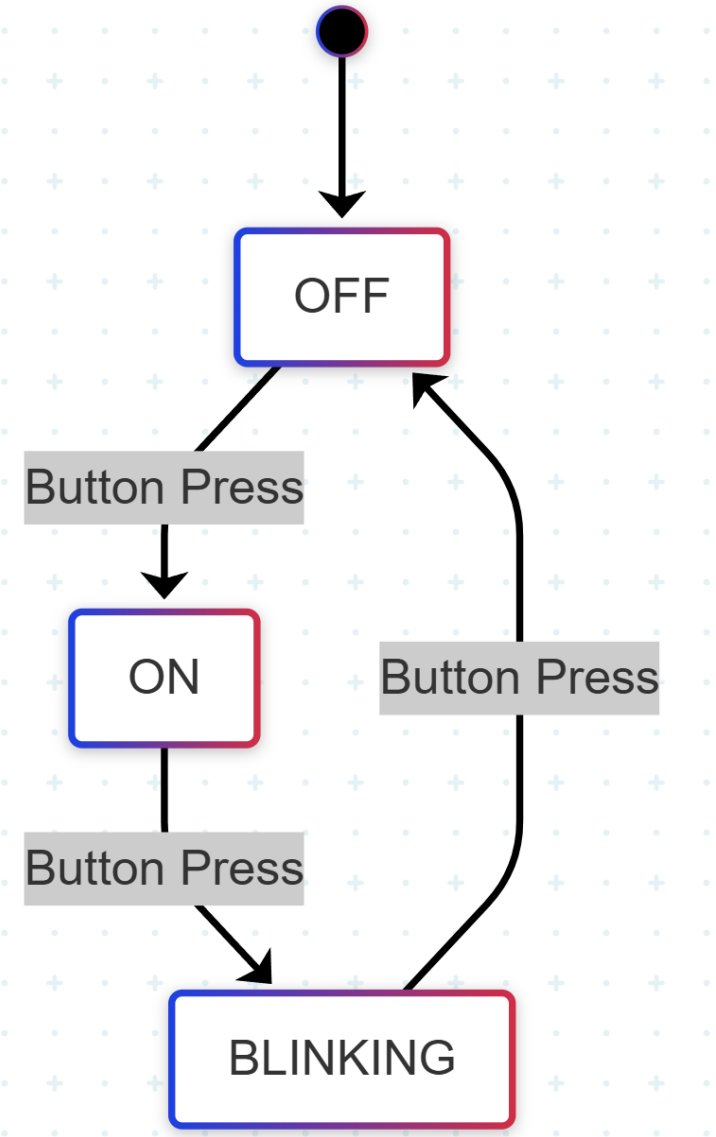

Lab6.1
.pio
.vscode
include
button.h
fsm.h
led.h
README
stdio_redirect.h
lib
README
src
button.cpp
fsm.cpp
led.cpp
main.cpp
stdio_redirect.cpp
test
.gitignore
platformio.ini
C:\Users

Block Diagram of System Behaviour



The general flowchart outlines the program's execution flow. In setup(), the FSM, LED, Button, and serial communication are initialized. The loop() continuously updates the FSM, checking for button presses. If a button is pressed, the FSM transitions to the next state (OFF → ON → BLINKING → OFF). Based on the current state, the LED is updated (on, off, or blinking). The current state is printed to the serial monitor, and the loop repeats.

Functional Block Diagrams

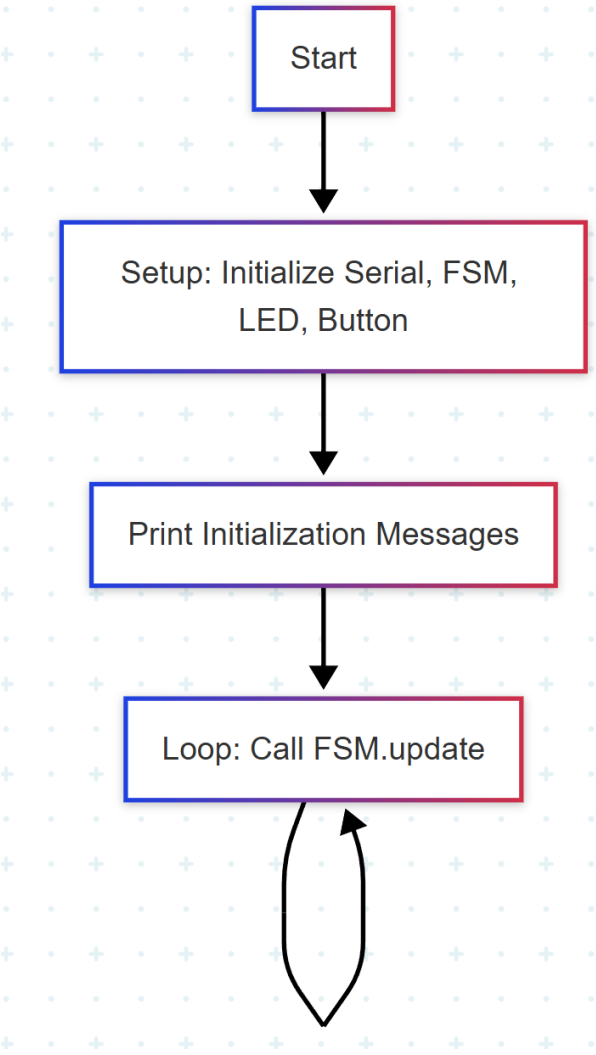


Description:

The Finite State Machine (FSM) diagram represents the state transitions of the system. The FSM starts in the OFF state. A button press transitions it to the ON state, where the LED is steadily on. Another button press moves it to the BLINKING state, where the LED blinks at a 500ms interval. A final button press returns it to the OFF state, turning the LED off. This cycle repeats with each

Code flowchart:

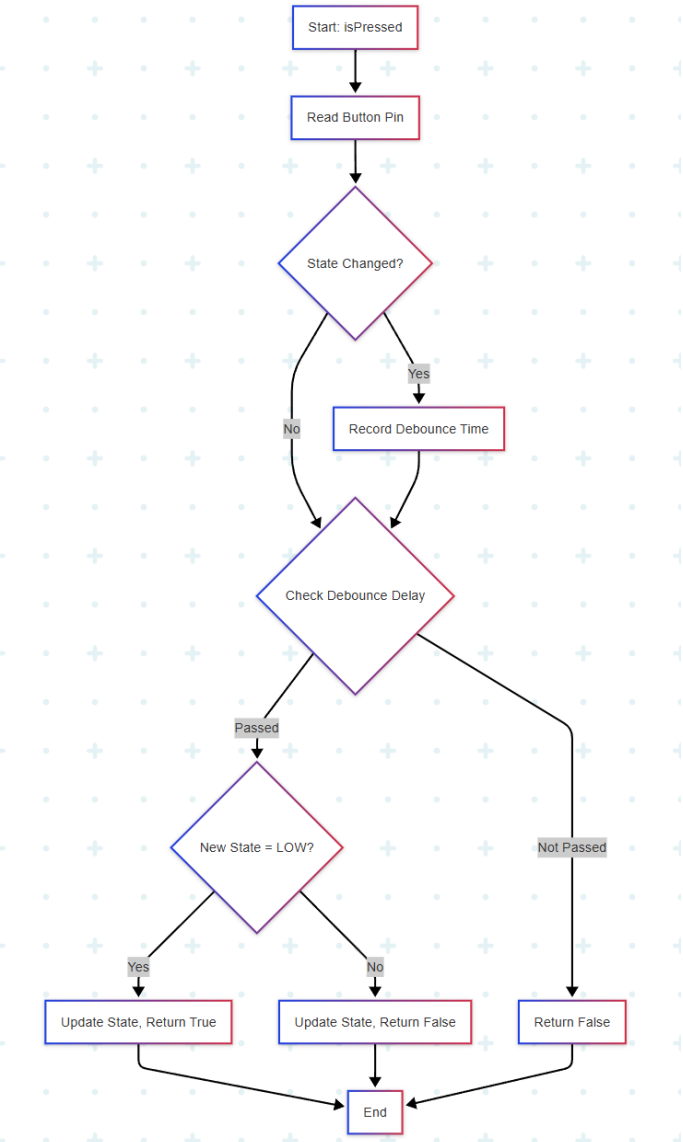
Main.cpp



Description:

The main.cpp flowchart is simple. In setup(), serial communication, the FSM, LED, and Button are initialized, and initialization messages are printed. The loop() continuously calls fsm.update() to run the FSM, driving the program's core functionality.

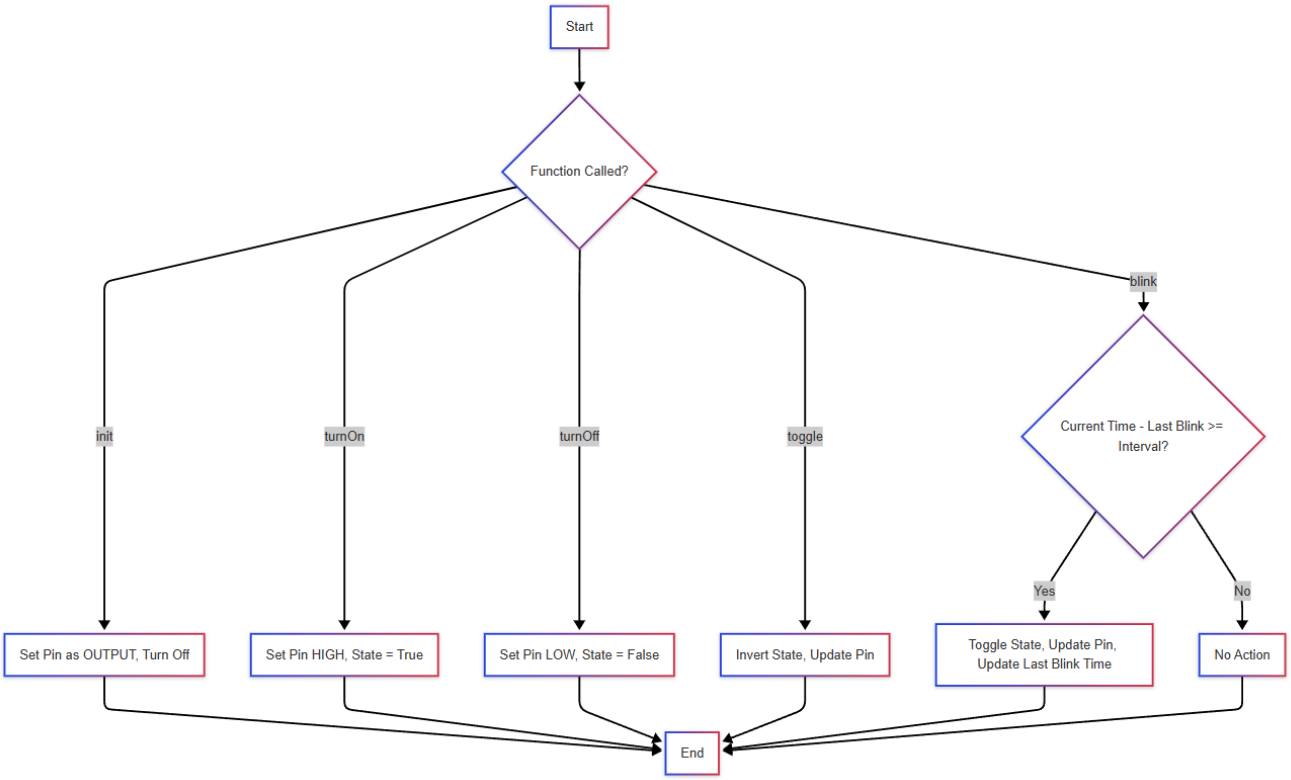
button.cpp



Description:

The isPressed() method in button.cpp implements debounced button reading. It reads the button pin and checks if the state has changed. If so, it records the debounce time. After ensuring the debounce delay (50ms) has passed, it updates the button state. If the new state is LOW (button pressed with INPUT_PULLUP), it returns true; otherwise, it returns false.

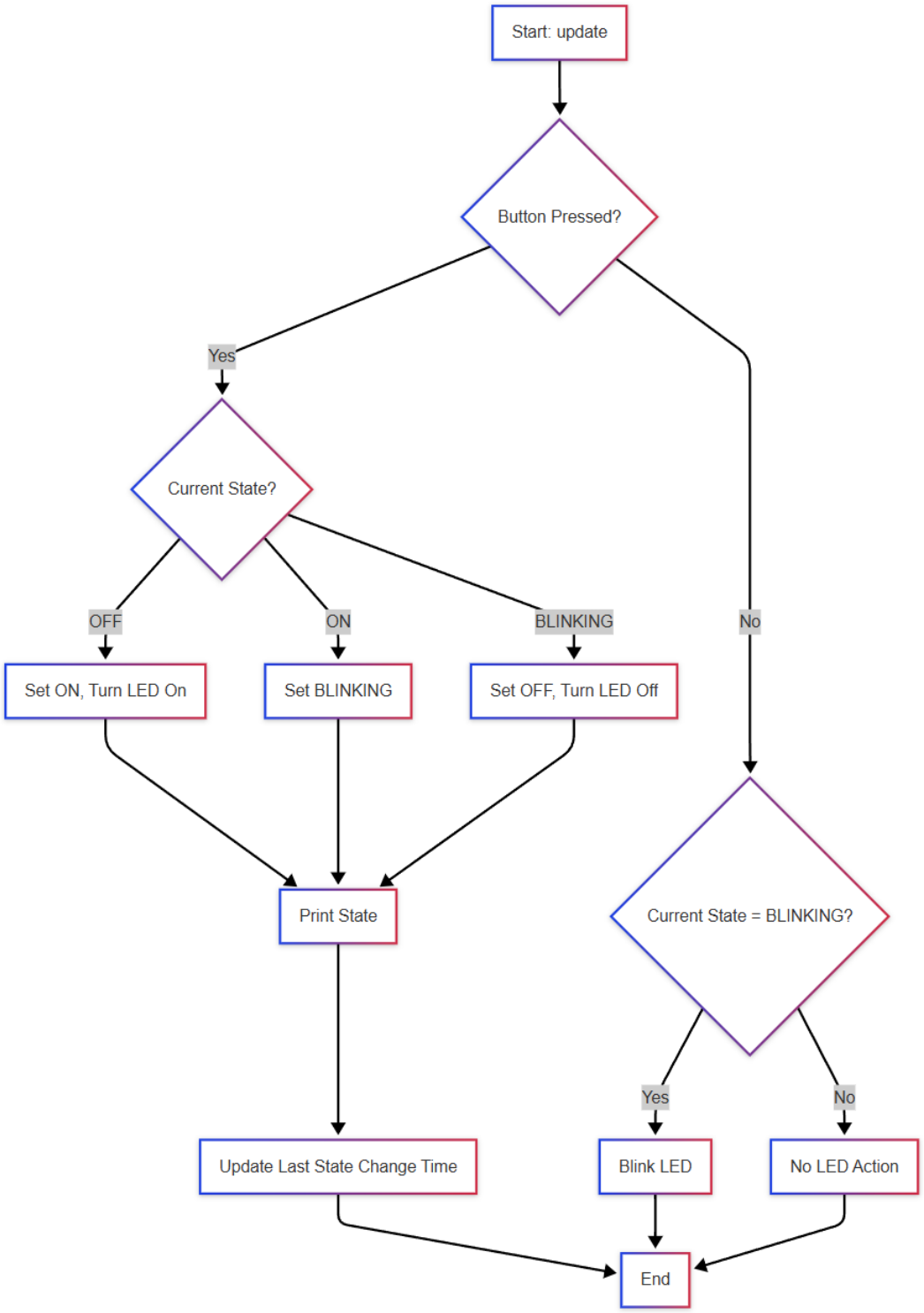
led.cpp



Description:

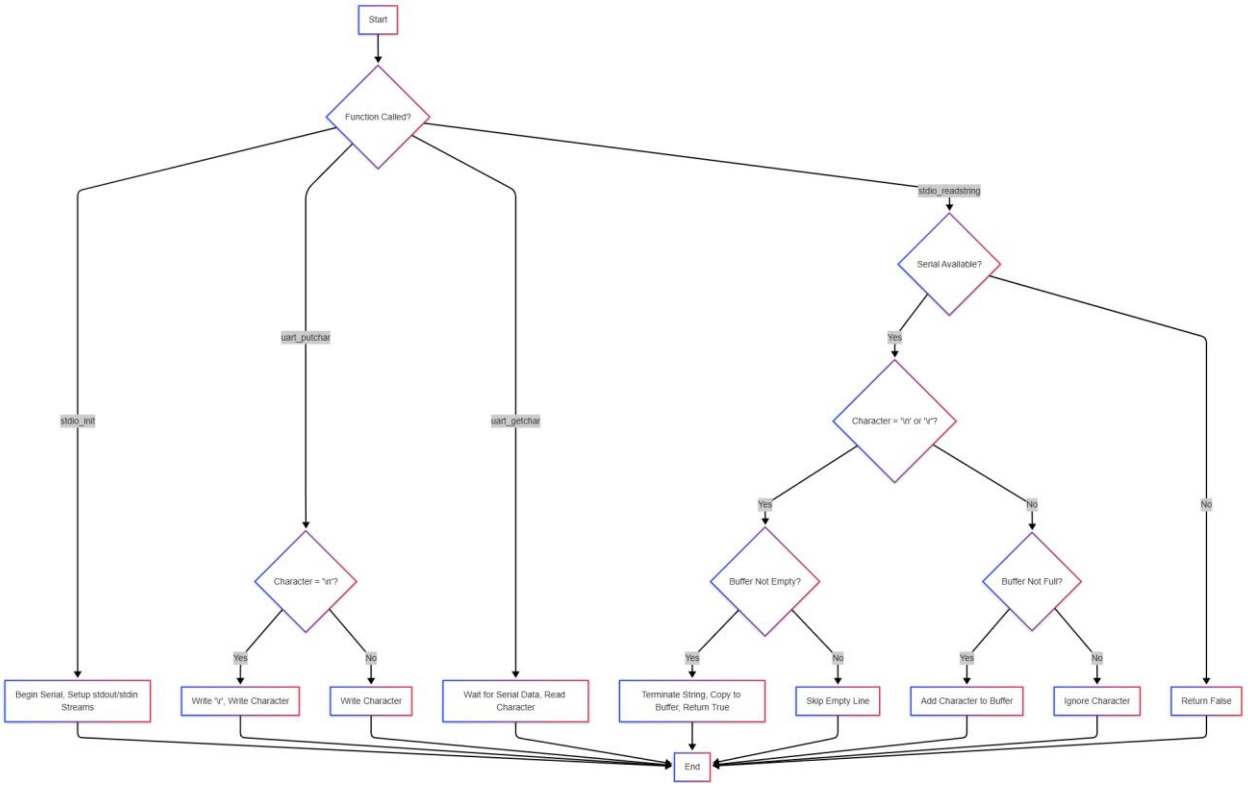
The led.cpp flowchart covers the LED class methods. init() sets the pin as OUTPUT and turns the LED off. turnOn() and turnOff() set the pin HIGH or LOW, updating the state. toggle() inverts the state and updates the pin. blink() checks if the specified interval has passed since the last blink; if so, it toggles the LED state and updates the pin and last blink time.

fsm.cpp


Start: update
Button Pressed?
Yes
No
Current State?
OFF
ON
BLINKING
Set ON, Turn LED On
Set BLINKING
Set OFF, Turn LED Off
Print State
Update Last State Change Time
Current State = BLINKING?
Yes
No
Blink LED
No LED Action
End

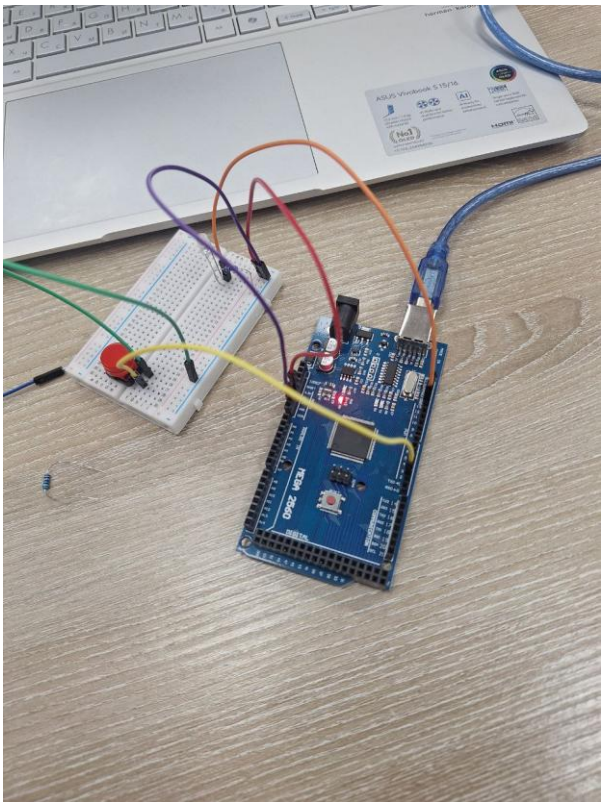
The update() method in fsm.cpp drives the FSM. If a button press is detected, it transitions the state: OFF → ON (turns LED on), ON → BLINKING, or BLINKING → OFF (turns LED off). The new state is printed, and the state change time is updated. If no button is pressed and the state is BLINKING, the LED blinks at the specified interval. Otherwise, no LED action is taken.

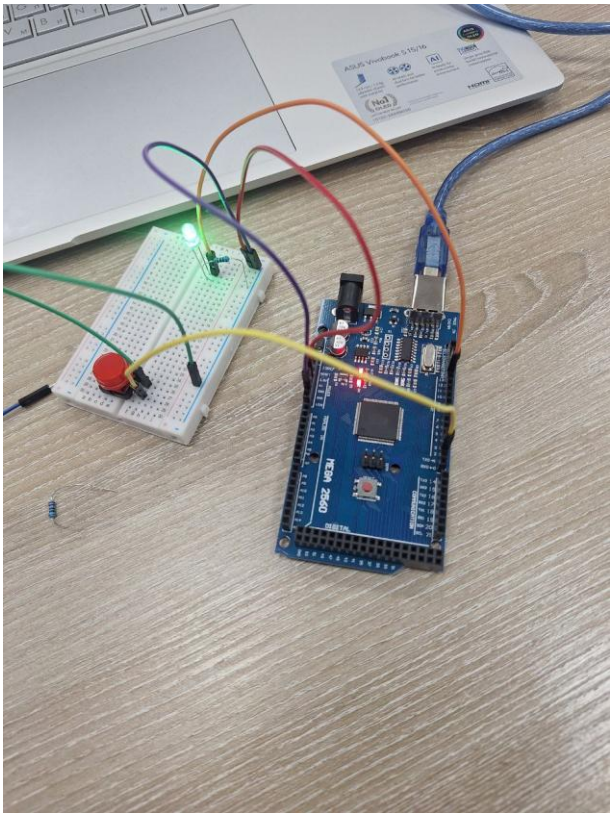
stdio_redirect.cpp



The stdio_redirect.cpp flowchart covers serial I/O functions. stdio_init() starts serial communication and sets up stdout/stdin streams. uart_putchar() writes a character to serial, adding a carriage return before a newline. uart_getchar() waits for and reads a serial character. stdio_readstring() buffers incoming characters until a newline or carriage return, then returns the string if the buffer isn't empty, or skips empty lines.

Results





Conclusion

In this project, we successfully designed and implemented an Arduino-based Finite State Machine (FSM) system to control an LED using a button with serial communication for state monitoring. The system integrates several core components: a button for user input, an LED for output, an FSM to manage state transitions, and a serial communication interface for real-time feedback. Each module was carefully developed and tested to ensure reliable performance in controlling the LED through distinct states (OFF, ON, BLINKING).

Key Highlights:

1. **Button Integration and Debouncing**: The Button class interfaces with a push button on digital pin 2, utilizing the Arduino's internal pull-up resistor to simplify the circuit. The debouncing mechanism, implemented with a 50ms delay, ensures accurate detection of button presses by filtering out noise, allowing the FSM to transition states reliably.
2. **LED Control Logic**: The LED class manages the LED on digital pin 13, providing methods to turn it on, off, toggle, and blink at a 500ms interval. This functionality supports the FSM's states: steady ON, OFF, and BLINKING. The implementation ensures smooth operation by updating the LED state based on the current FSM state and timing requirements.
3. **Finite State Machine Implementation**: The FiniteStateMachine class orchestrates the system's behavior, transitioning between OFF, ON, and BLINKING states with each button press. The FSM logic ensures predictable state changes, with the LED reflecting the current state (off, on, or blinking), providing a clear visual indication of the system's operation.
4. **Serial Interface for Monitoring**: The stdio_redirect module enables serial communication at 9600 baud, allowing real-time state updates to be printed to the serial monitor. This feature provides visibility into the system's operation, displaying messages like "Current State: OFF" after each state transition, enhancing user interaction and debugging capabilities.
5. **Modular Design**: The project's modular structure, with separate files for each component (led.cpp, button.cpp, fsm.cpp, stdio_redirect.cpp), promotes maintainability and scalability. Each module handles a specific task, reducing complexity and making it easier to modify or extend the system in the future. This design also supports code reusability for other Arduino projects.
6. **User Feedback**: The serial output provides clear feedback on the system's state, making it

easy for users to understand the current operation (e.g., whether the LED is off, on, or blinking). This transparency is crucial for verifying the system's behavior and troubleshooting any issues.

Challenges: Several challenges were encountered during the project:

- **Debouncing Accuracy**: Ensuring reliable button debouncing required fine-tuning the debounce delay (50ms). Initial tests showed occasional false positives, which were resolved by adjusting the timing and verifying the button state transitions.
- **Serial Output Synchronization**: Aligning serial output with state changes required careful timing to avoid delays in the main loop. Proper initialization and buffer management in stdio_redirect.cpp mitigated this issue.

Future Improvements:

- **Enhanced User Interaction**: Adding a more interactive serial interface to allow users to set the blink interval dynamically could improve flexibility.
- **Additional States**: Introducing more states (e.g., a FAST_BLINKING state with a shorter interval) could expand the system's functionality.
- **External Display**: Integrating an LCD or OLED display to show the current state visually, alongside serial output, would enhance user experience and make the system more standalone.

This project demonstrates a robust implementation of a state-driven LED control system using Arduino, with a focus on modularity, reliability, and user feedback. The lessons learned provide a strong foundation for future enhancements and more complex Arduino-based projects.

During the preparation of this report, the author used Grok for generating/strengthening the content. The resulting information was reviewed, validated, and adjusted according to the requirements of the laboratory work.

References

1. IoT-24 : Lab 6.1. - https://www.youtube.com/watch?v=ODJjs82LrtM
2. Arduino Documentation about Seria - https://docs.arduino.cc/language-reference/en/functions/communication/serial/
3. PlatformIO Documentation - https://docs.platformio.org/en/latest/integration/ide/pioide.html

Appendix - Source Code

File name: button.cpp
text
Copy

```
#include "button.h"
#include <Arduino.h>

// Constructor
Button::Button(int buttonPin)
    : pin(buttonPin),
      lastButtonState(HIGH),
      buttonState(HIGH),
      lastDebounceTime(0),
      debounceDelay(50) // 50ms debounce time
{}

// Initialize the button
void Button::init() {
    // Use internal pull-up resistor
    pinMode(pin, INPUT_PULLUP);
}

// Check if button is pressed (debounced)
bool Button::isPressed() {
    int reading = digitalRead(pin);

    // Check for button state change
    if (reading != lastButtonState) {
        lastDebounceTime = millis();
    }

    // Check if debounce delay has passed
    if ((millis() - lastDebounceTime) > debounceDelay) {
        // If button state has changed
        if (reading != buttonState) {
            buttonState = reading;

            // Return true only on button press (LOW for INPUT_PULLUP)
            if (buttonState == LOW) {
                lastButtonState = reading;
                return true;
            }
        }
    }

    lastButtonState = reading;
    return false;
}
```

```
// Get current button pin
int Button::getPin() const {
    return pin;
}
File name: led.cpp
text
Copy
#include "led.h"
#include <Arduino.h>

// Constructor
LED::LED(int ledPin) : pin(ledPin), state(false) {}

// Initialize the LED
void LED::init() {
    pinMode(pin, OUTPUT);
    digitalWrite(pin, LOW);
}

// Turn LED on
void LED::turnOn() {
    digitalWrite(pin, HIGH);
    state = true;
}

// Turn LED off
void LED::turnOff() {
    digitalWrite(pin, LOW);
    state = false;
}

// Toggle LED state
void LED::toggle() {
    state = !state;
    digitalWrite(pin, state);
}

// Blink LED with specified interval
void LED::blink(unsigned long interval) {
    static unsigned long lastBlinkTime = 0;
    unsigned long currentTime = millis();

    if (currentTime - lastBlinkTime >= interval) {
        toggle();
        lastBlinkTime = currentTime;
    }
}

// Get current LED state
bool LED::getState() const {
    return state;
```

```
}

// Get LED pin number
int LED::getPin() const {
    return pin;
}
File name: fsm.cpp
text
Copy
#include "fsm.h"
#include "stdio_redirect.h"

// Constructor
FiniteStateMachine::FiniteStateMachine(LED& ledObj, Button& buttonObj)
    : currentState(STATE_OFF),
      lastStateChangeTime(0),
      blinkInterval(500),  // 500ms blink interval
      led(ledObj),
      button(buttonObj)
{}

// Initialize the FSM
void FiniteStateMachine::init() {
    // Initialize components
    led.init();
    button.init();

    // Initialize stdio
    stdio_init(9600);
}

// Update method to be called in main loop
void FiniteStateMachine::update() {
    // Check for button press
    if (button.isPressed()) {
        // State machine logic
        switch (currentState) {
            case STATE_OFF:
                currentState = STATE_ON;
                led.turnOn();
                break;
            case STATE_ON:
                currentState = STATE_BLINKING;
                break;
            case STATE_BLINKING:
                currentState = STATE_OFF;
                led.turnOff();
                break;
        }

        // Print state after change
```

```
        printState();

        // Update last state change time
        lastStateChangeTime = millis();
    }

    // Control LED based on current state
    if (currentState == STATE_BLINKING) {
        led.blink(blinkInterval);
    }
}

// Get current state
FSMState FiniteStateMachine::getState() const {
    return currentState;
}

// Print current state to serial
void FiniteStateMachine::printState() const {
    switch (currentState) {
        case STATE_OFF:
            printf("Current State: OFF\n");
            break;
        case STATE_ON:
            printf("Current State: ON\n");
            break;
        case STATE_BLINKING:
            printf("Current State: BLINKING\n");
            break;
    }
}
File name: stdio_redirect.cpp
text
Copy
/**
 * stdio_wrapper.cpp
 * Standard I/O wrapper implementation for Arduino
 */

#include "stdio_redirect.h"

// Create a FILE stream structure for stdin and stdout
static FILE uartout = {0};
static FILE uartin = {0};

// Buffer for reading serial input
#define BUFFER_SIZE 32
static char commandBuffer[BUFFER_SIZE];
static int bufferIndex = 0;

void stdio_init(unsigned long baud) {
```

```
    // Initialize serial
    Serial.begin(baud);

    // Wait for serial port to connect (needed for native USB port only)
    while (!Serial && millis() < 5000);

    // Setup stdout stream
    fdev_setup_stream(&uartout, uart_putchar, NULL, _FDEV_SETUP_WRITE);
    stdout = &uartout;

    // Setup stdin stream
    fdev_setup_stream(&uartin, NULL, uart_getchar, _FDEV_SETUP_READ);
    stdin = &uartin;
}

int uart_putchar(char c, FILE *stream) {
    // Optionally convert newline to carriage return + newline
    if (c == '\n') {
        Serial.write('\r');
    }
    Serial.write(c);
    return 0;
}

int uart_getchar(FILE *stream) {
    // Wait until character is available
    while (!Serial.available());
    return Serial.read();
}

bool stdio_available() {
    return Serial.available() > 0;
}

bool stdio_readstring(char* buffer, size_t max_length) {
    while (Serial.available()) {
        char c = Serial.read();
        if (c == '\n' || c == '\r') {
            if (bufferIndex > 0) {
                commandBuffer[bufferIndex] = '\0'; // Terminate the string
                bufferIndex = 0; // Reset for next command
                // Copy to output buffer, respecting max_length
                strncpy(buffer, commandBuffer, max_length - 1);
                buffer[max_length - 1] = '\0'; // Ensure null-termination
                // Debug: Print the buffer
                printf("DEBUG: stdio_readstring buffer: '%s'\n", buffer);
                return true;
            }
            // Skip empty lines
        } else {
            if (bufferIndex < BUFFER_SIZE - 1) {
```

```
            commandBuffer[bufferIndex++] = c;
          }
          // Ignore characters if buffer is full
        }
    }
    return false;
}
```

File name: main.cpp

text

Copy

```
#include <Arduino.h>
#include "led.h"
#include "button.h"
#include "fsm.h"

// Pin Definitions
const int BUTTON_PIN = 2;  // Button connected to digital pin 2
const int LED_PIN = 13;    // Built-in LED or external LED on pin 13

// Create hardware components
LED led(LED_PIN);
Button button(BUTTON_PIN);
// Custom printf function for serial output

// Create FSM instance
FiniteStateMachine fsm(led, button);

void setup() {
    // Initialize FSM
    fsm.init();
    // Initialize serial communication
    Serial.begin(9600);
    // Optional: Print initial message
    printf("Finite State Machine Initialized\n");
    // Initialize LED and button
    led.init();
    button.init();

    // Optional: Print initial state message
    printf("Initial State: OFF\n");
}

void loop() {
    // Update FSM in each loop iteration
    fsm.update();
}
```