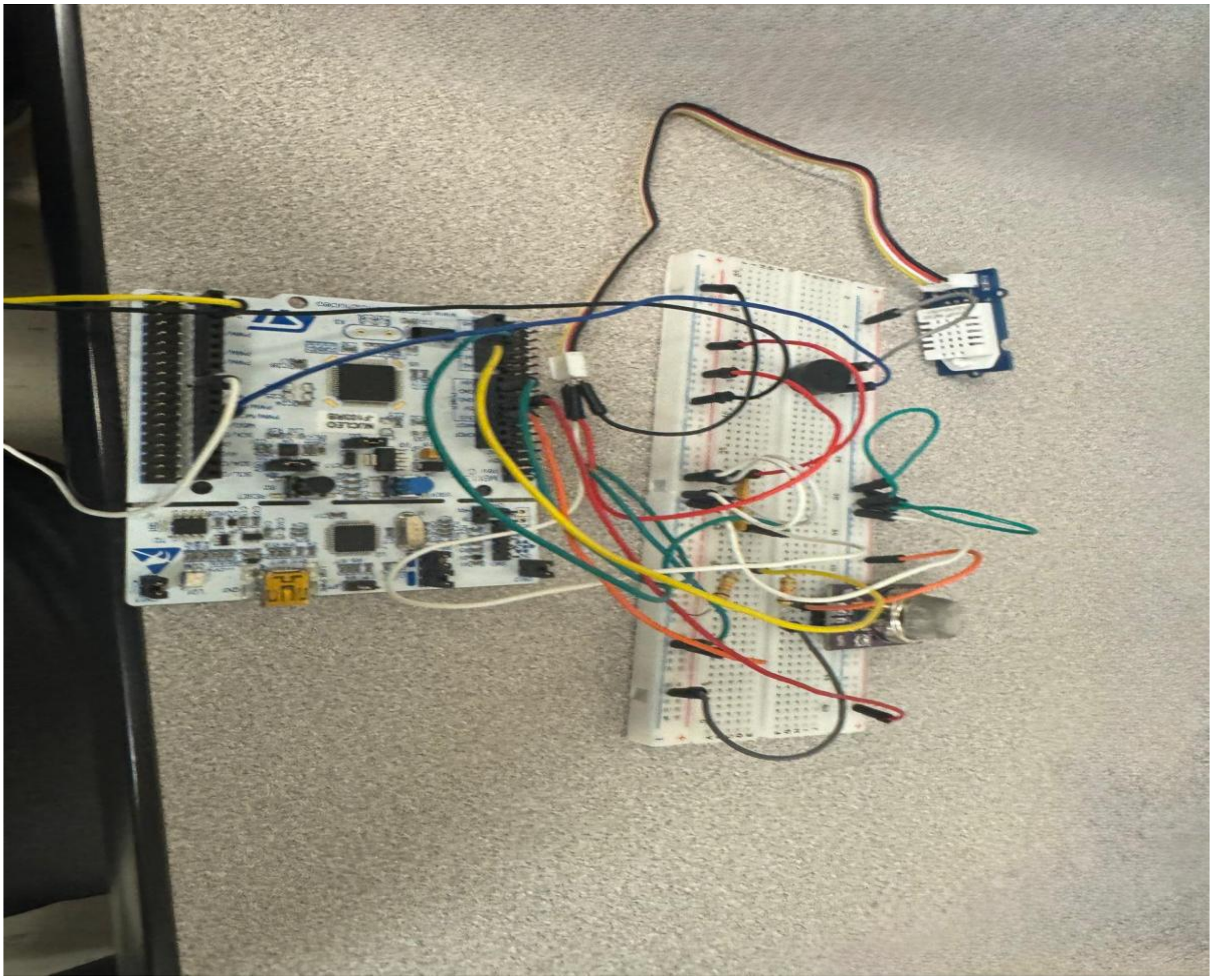
Design Report for MQ135/Buzzer and DHT22 Sensor System



1. Introduction

The goal of the project was to design an embedded system using an STM32F103RB microcontroller (running at 72 MHz) to monitor environmental conditions. The design was originally specified to include a 16×2 LCD display to show sensor readings, but difficulties in interfacing the LCD (e.g., persistent white squares likely due to contrast and wiring issues) necessitated a change. Instead, sensor data is output via the USART (to be viewed in a terminal like PuTTY). In addition to reading an MQ135 gas sensor (via an ADC input on PA0) for air quality monitoring, the design also includes a DHT22 sensor (connected on PA4) for temperature and humidity measurement. A buzzer is driven using a PWM output from TIM3 on PA6 to provide an audible warning when gas levels exceed a predefined threshold.

2. Functional Specification Versus Actual Implementation

2.1. Original Specification

Display: The initial plan was to use an LCD (TC1602A) in 4-bit mode to display sensor values and system status.

Sensors:

MQ135 Gas Sensor: To measure various gases using an analog signal scaled via a voltage divider.

DHT22 Temperature/Humidity Sensor: To measure ambient temperature and humidity using a single-wire digital interface.

Timing and Control:

Use SysTick for implementing delays and periodic sensor sampling.

Use basic timer modules for controlling the buzzer and delay functions.

Output Mechanism:

Provide real-time feedback on the LCD as well as debug output via USART.

2.2. Actual Implementation and Deviations

Display Change:

Issue: The LCD did not connect correctly (only white squares were seen), likely due to contrast (V0) and wiring challenges.

Deviation: The system was reconfigured to use USART (serial output via PA9/PA10) for reading the sensor values. This change simplified debugging and made it easier to verify sensor outputs through a terminal application such as PuTTY.

Use of TIM2 and TIM3 Instead of SysTick:

Issue: Initial attempts to use the SysTick timer resulted in erratic readings from the DHT22 sensor (likely due to conflicts in sensor operation).

Deviation: TIM2 was implemented to generate microsecond delays (used by the DHT22 communication routine), and TIM3 was used to produce a PWM signal for controlling the buzzer. This provided more precise control over timing and improved sensor reliability.

Sensor Integration:

The MQ135 sensor output is scaled via a voltage divider. Originally, a voltage divider using a 10 kΩ and a 20 kΩ resistor was implemented, scaling a 5 V sensor output to around 3.33 V—this matches the ADC input range of the STM32F10x running at 3.3 V.

The DHT22 sensor is connected on PA4 and is read using a carefully timed digital protocol that relies on TIM2 for microsecond delays.

Buzzer Control:

The buzzer is driven by a PWM signal generated on PA6 (TIM3 channel 1). When the ADC reading from the MQ135 sensor exceeds a set threshold (defined as MQ135_THRESHOLD), the PWM output is switched to a 50% duty cycle (approximately 2 kHz), sounding the buzzer.

3. Design Process and Implementation Details

3.1. Hardware Setup and Pin Assignments

Microcontroller: STM32F103RB running at 72 MHz.

Sensors:

MQ135 Sensor:

Analog Output (AO) is connected to PA0 through a voltage divider (10 kΩ from sensor to PA0 and 20 kΩ from PA0 to Ground).

VCC connected to +5 V and GND to ground.

DHT22 Sensor:

Data line is connected to PA4 (configured initially as output for the start signal, then switched to input).

Power connections: VCC to +5 V and GND to ground.

Buzzer:

PWM signal generated on PA6 (TIM3 channel 1) drives the buzzer.

The other terminal of the buzzer is connected to ground.

Communication:

USART: Uses PA9 (TX) and PA10 (RX) for serial output to a PC terminal (configured to 9600 bps, 8N1).

3.2. Software Implementation

Delay Functions:

Busy-loop delays are implemented based on a 72 MHz clock.

TIM2 is used to produce microsecond delays required by the DHT22 sensor protocol.

USART Communication:

The code initializes USART1 for debug output. All sensor readings and system status (including the buzzer state) are printed to the serial terminal.

ADC Operation:

ADC1 reads the scaled analog output from the MQ135 sensor on PA0. Proper calibration and a dummy conversion are performed to ensure stable readings.

PWM for Buzzer:

TIM3 is configured for a PWM frequency of about 2 kHz. The buzzer is activated when the sensor reading exceeds the threshold.

DHT22 Sensor Reading:

A dedicated function handles the time-critical protocol for the DHT22 sensor. It sends a start signal (by driving PA4 low for 18 ms and then high for 30 µs), waits for the sensor's response, and then measures the length of high pulses to determine the data bits.

Temperature and humidity are calculated and printed via USART.

4. Testing Strategies and Procedures

4.1. Component-Level Testing

Voltage Measurements:

The voltage divider at PA0 was measured to ensure that the maximum sensor output (5 V) is scaled to approximately 3.33 V.

The DHT22 sensor's timing was verified using an oscilloscope where possible to check that the proper start pulse and response timings are observed.

Peripheral Initialization:

Each peripheral (USART, ADC, TIM3 PWM, and the DHT22 interface using TIM2 for delays) was tested separately. For example, a simple USART loop printed messages to PuTTY; ADC conversions were verified by applying known voltages; PWM output was observed on PA6 using a multimeter and oscilloscope.

4.2. System-Level Testing

Serial Output Verification:

The complete system was run, and sensor values (MQ135 ADC readings and DHT22 temperature/humidity measurements) as well as buzzer status were printed on PuTTY.

Test scenarios included both “clean air” and simulated gas exposure to verify threshold detection and buzzer activation.

Integration Testing:

The DHT22 sensor’s protocol was verified by reading temperature/humidity values at known environmental conditions.

The ADC reading from the MQ135 and its effect on the buzzer (turned ON when above the threshold) were also confirmed.

5. Deviations and Justifications

Switching from LCD to USART:

The original specification called for an LCD display. However, due to persistent wiring/contrast issues (white squares on the display despite proper V0 adjustment), the LCD interface was scrapped in favor of USART output. This ensured that sensor readings could be reliably monitored during development.

Replacing SysTick with TIM2 and TIM3:

Initial attempts using SysTick for delays interfered with the timing-critical DHT22 sensor protocol, resulting in unreliable sensor data. Therefore, TIM2 was used for microsecond delays, and TIM3 was used to generate the PWM signal for the buzzer. This change improved both sensors reading accuracy and overall system timing.

Inclusion of the DHT22 Sensor:

The DHT22 sensor was maintained in the design to capture temperature and humidity data. Its critical timing requirements necessitated the use of TIM2 for microsecond delays. The sensor data, along with the gas sensor readings, are output via USART.

6. Conclusion

In summary, the system now reliably measures air quality using the MQ135 sensor and environmental conditions using the DHT22 sensor. Due to hardware challenges with the LCD interface, the design was adapted to use USART for output. Additionally, timing challenges with the temperature sensor led to replacing SysTick with TIM2 (for microsecond delays) and TIM3 (for PWM generation), ensuring stable and accurate operation. This report outlines the overall design process, detailed testing procedures, and the rationale behind deviations from the original functional specification. Future work could include revisiting the LCD implementation with alternate hardware or further refining the voltage divider and contrast settings to get the LCD working reliably.