VIET NAM MINISTRY OF EDUCATION AND TRAINING

FPT UNIVERSITY HA NOI

GROUP 3 – SE1925

SMART ALCOHOL DETECTION AND WARNING SYSTEM

IOT102 SUBJECT PROJECT
INFORMATION ASSURANCE

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DECLARATION

We hereby declare that the data and research results presented in this course project are truthful. All assistance in the completion of this graduation project has been acknowledged, and all cited information has been clearly sourced and properly authorized for publication.

Project Team

Group 3 – SE1925 SP25

INTRODUCTION

1. Problem Statement

In recent years, traffic accidents caused by alcohol consumption have become a significant societal issue, posing serious threats to public safety. Controlling and detecting drivers who exceed the legal blood alcohol concentration (BAC) limit remains a major challenge due to constraints in time, resources, and measurement accuracy. Given this situation, the demand for an efficient, rapid, and highly applicable alcohol detection solution has become increasingly urgent.

A research team consisting of three undergraduate students with a foundational background in IoT technology has proposed and developed the **" Smart Alcohol Detection and Warning System."** This system leverages sensor technology and microcontrollers to measure alcohol concentration in exhaled breath, display real-time results, and provide intuitive alerts. The system is designed with an MQ-3 alcohol sensor for BAC analysis, an Arduino microcontroller as the central processing unit, and supporting components such as a buzzer (alarm), LEDs (visual indicators), and a 16x2 LCD screen.

When a user exhales into the sensor, the system immediately measures the alcohol concentration and displays the results. If the BAC exceeds the legal threshold, the system activates an alarm through sound and LED signals, facilitating the identification of violations. Conversely, if the BAC remains within the permissible limit, the system provides a confirmation signal indicating compliance.

Although the project is still in the testing and refinement phase, the research team envisions expanding its capabilities, such as integrating IoT connectivity to transmit data to a monitoring center or incorporating mobile applications for enhanced management. With its high practical applicability, this research not only contributes to technological solutions for BAC violation detection but also lays the groundwork for future intelligent traffic monitoring systems.

2. Research Objectives

The primary objective of this research is to develop a Smart Alcohol Concentration Warning System using IoT technology to enhance awareness and promote responsible alcohol consumption, thereby contributing to traffic safety. The system is designed to provide an efficient and practical solution for measuring and monitoring blood alcohol concentration (BAC) through breath analysis, offering real-time feedback and alerts.

3. Research Content

- Overview of the effects of alcohol on driving ability and traffic safety
- Legal regulations regarding blood alcohol concentration (BAC) limits in breath analysis
- Principle of operation of alcohol sensors (MQ-3) and other measurement methods
- Application of IoT in alcohol concentration monitoring and intelligent traffic management

4. Research Methodology

This study was conducted through the collection and analysis of relevant literature on the effects of alcohol on driving ability, existing legal regulations, the operating principles of the MQ-3 alcohol sensor, and the application of IoT in traffic monitoring. Based on the gathered theoretical foundation, the research team designed and assembled an alcohol detection system using an Arduino microcontroller, an MQ-3 sensor, an LCD display, a buzzer, and LED indicators. After completing the hardware setup, the team developed a control program to process sensor data, display measurement results, and activate alerts when the alcohol concentration exceeds the permissible threshold.

The system was tested by measuring alcohol levels under various conditions to evaluate its accuracy and stability. The obtained results were compared with those from standard alcohol detection devices to calibrate the data processing algorithm. After the testing phase, the team analyzed the results, assessed the system's performance, and proposed improvements to enhance accuracy and practical applicability. This methodology ensures the system operates effectively, contributing to alcohol level control and improving traffic safety.

5. Expected Results

- Thesis Report
- Prototype Model

6. Project Structure

The project consists of three main chapters:

Chapter 1: Overview, Current Situation, Research Objectives

Chapter 2: Design and Development of an Alcohol Monitoring System Using MQ-3 Sensor.

Chapter 3: Experimentation, System Performance Evaluation

Chapter 4: Conclusion & Recommendations

CHAPTER 1: OVERVIEW, CURRENT SITUATION, RESEARCH OBJECTIVES

1.1. OVERVIEW OF ALCOHOL-RELATED TRAFFIC VIOLATIONS AND CONSEQUENCES

1.1.1. Traffic Accident Situation in Vietnam

In 2020, a total of approximately 14,510 traffic accidents were reported nationwide, of which 313 cases were directly attributed to excessive alcohol consumption. According to Cand.com.vn, these 313 cases accounted for approximately 2.16% of the total traffic accidents. Although a simple calculation ($313/14{,}510 \times 100 \approx 2.16\%$) confirms this percentage, official statistics from law enforcement agencies indicate that the actual proportion ranges from 2% to 4%. This variation arises due to differences in statistical scope, which may include only severe accidents or be limited to specific geographical areas.

In 2021, as the COVID-19 pandemic significantly impacted traffic volume, the total number of traffic accidents nationwide decreased to approximately 11,454 cases. While detailed data on alcohol-related accidents was not fully published, preliminary estimates suggested around 280 cases were directly linked to excessive alcohol consumption. This corresponds to an estimated rate of 2.44% ($280/11{,}454 \times 100$). Although not officially confirmed, this trend indicates no significant spike compared to 2020, partly reflecting the effect of mobility restrictions during the pandemic.

In 2022, the total number of traffic accidents was recorded at 11,457 cases. According to the National Traffic Safety Committee ,as reported on Dangcongsan.vn, alcohol-related accidents accounted for approximately 2%, equivalent to 229 cases. Despite the high number of alcohol violations handled (308,508 cases, representing 11.01% of total traffic violations), only a small proportion (2%) resulted in serious traffic accidents.

However, in 2023, a notable shift occurred. The total number of traffic accidents decreased to 10,814 cases, but 814 cases were confirmed to be directly linked to alcohol consumption. This represents a 7.53% rate ($814/10{,}814 \times 100$), marking a significant increase compared to previous years. According to Colonel Nguyễn Quang Nhật, Head of the Traffic Accident Investigation and Propaganda Department of the Traffic Police Department , among these 814 cases, there were 400 fatal accidents and 619 cases resulting in injuries. Additionally, in 2023, Traffic Police Force's handled 770,679 cases of alcohol violations, showing a substantial rise in enforcement compared to prior years.

These statistics are compiled based on the Traffic Police Force's statistical criteria and processed in accordance with administrative sanctions in the road and railway traffic sectors, along with additional directives and guidelines from the Ministry of Public Security and the Ministry of Transport. Enhancing monitoring and enforcement of alcohol-related violations is considered a key measure in minimizing traffic accident consequences and ensuring road safety for all road users.

1.1.2. Consequences of Drunk Driving

Vietnam enforces strict laws on drunk driving, based on the Law on Prevention and Control of Harmful Effects of Alcoholic Beverages (2019). This regulation establishes administrative penalties for traffic violations, including driving under the influence (DUI), with a zero-tolerance policy—meaning that any alcohol concentration in the blood or breath is considered a violation.

- Legal consequences:

Number of Violations:

In 2023, the national traffic police force handled 770,679 cases of drunk driving violations, accounting for 23.04% of all traffic violations.

Specific Fines:

In the first 15 days of 2020, 6,279 drivers were fined a total of 21 billion VND, highlighting the strict enforcement of DUI laws.

License Suspension and Imprisonment:

In addition to fines, offenders may face license suspension ranging from 1 to 4 months. In cases involving serious accidents, violators may face criminal prosecution, which could lead to imprisonment.

- Personal and Social Consequences:

Increased Accident Risk: Drunk driving significantly raises the likelihood of traffic accidents. According to the WHO (2018), at least 6,500 fatalities or injuries were caused by alcohol-related driving. In 2022, drunk driving accounted for 40% of all traffic accidents and 11% of fatalities in these incidents.

Personal Impact: Drunk drivers may suffer permanent disabilities, psychological trauma, and financial burdens due to medical expenses and lost income. In cases of fatal accidents, offenders may experience lifelong guilt and face serious legal consequences.

Social Behavior Changes: More people now use ride-hailing services like Grab or taxis instead of driving after drinking. Since 2020, alcohol sales have declined by at least 25%, and restaurant revenues have dropped by up to 80%, reflecting a shift in consumer behavior due to stricter enforcement.

1.2. CURRENT STATUS OF ALCOHOL BREATHALYZER DEVICES IN TRAFFIC ENFORCEMENT

Currently, there are many types of alcohol breathalyzer devices, but most only display blood alcohol concentration (BAC) levels on the device without the ability to automatically store BAC data and driver information. This storage function is crucial not only for law enforcement agencies to accurately and quickly compile statistics on the number of drivers exceeding the legal alcohol limit but also for violators to review their past offenses. By allowing drivers to reflect on their violations, automatic data storage serves as a tool for promoting responsible behavior and raising awareness about the consequences of drunk driving.

Tên máy	Thông số tính năng	Giá thành	Hình ảnh
M&MPRO ATAMT126	Nguyên lý: màng oxit bán dẫn. Sai số: 10 % Thang đo: 0.000 – 2.000 mg/l	606,736 VND	
ATAMT199	Nguyên lý: Màng oxit bán dẫn. Sai số: 10% Thang đo: 0.000 – 2.000 mg/l	1,500,000 VND	
M&MPRO ATAMT8600	Nguyên lý: Pin nhiên liệu Sai số: 1 % Thang đo: 0.000 – 2.500 mg/l	61,000,000 VND	

Figure 1.1: Some Smart Alcohol Breathalyzers on the Market

1.3. CONCLUSION OF CHAP 1

Providing an overview of alcohol-related traffic violations and their consequences serves as a foundation for researching technological solutions to support BAC monitoring and enforcement in traffic control.

Specifically, this chapter aims to:

Analyze the current state of alcohol-related traffic accidents: Summarize and evaluate statistical data from 2020 to 2023 to identify trends in the increase or decrease of alcohol-related accidents.

Assess the consequences of drunk driving: Clarify the legal, personal, and societal impacts of violating BAC regulations, emphasizing the severity of the issue.

Examine the current state of alcohol breathalyzer devices: Review existing BAC measurement devices and identify their limitations in enforcement and violation management.

Through this chapter, the study establishes a foundation for proposing more effective technological solutions for measuring, storing, and managing BAC-related data, contributing to improved monitoring and traffic safety.

CHAPTER 2: DESIGN AND DEVELOPMENT OF THE ALCOHOL

2.1. OVERVIEW OF ALCOHOL DETECTION TECHNOLOGY

2.1.1. Arduino Uno R3

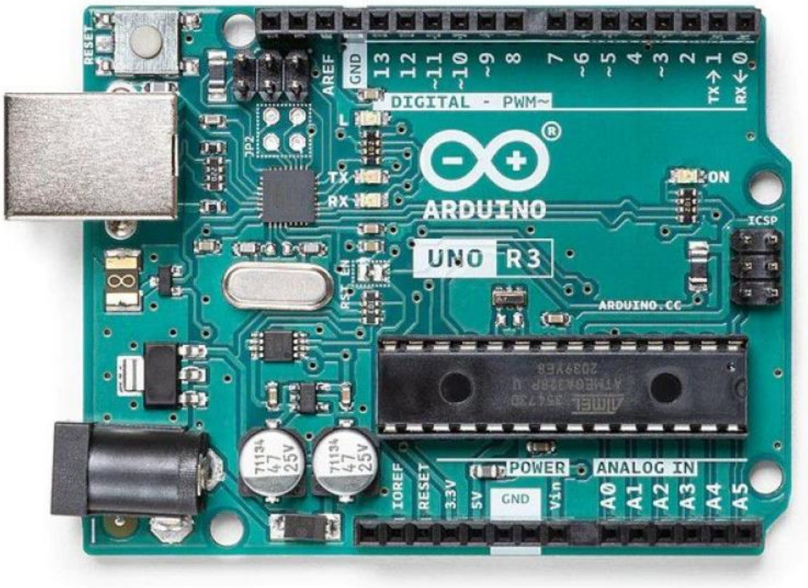

Figure 2.1: Arduino R3 Board Model

Arduino Uno R3 is a widely used microcontroller board in the embedded programming and DIY (Do It Yourself) community. It is the third revision (R3 - Revision 3) of the Arduino Uno series, utilizing the ATmega328P microcontroller from Microchip.

Key Specifications:

- Microcontroller: ATmega328P
- Operating Voltage: 5V
- Input Voltage: 7-12V (maximum 6-20V)
- Digital I/O Pins: 14 (including 6 PWM pins)
- Analog Input Pins: 6
- Flash Memory: 32KB (0.5KB reserved for bootloader)
- SRAM: 2KB
- EEPROM: 1KB
- Clock Speed: 16 MHz
- Communication Interfaces: UART, SPI, I2C
- Connector Port: USB-B (used for programming and power supply)

2.1.2. MQ-3 Sensor

The **MQ-3 sensor** is used to measure alcohol concentration. It is made of **SnO2 (tin dioxide)**, a material with low electrical conductivity in clean air but highly sensitive to alcohol vapors. In environments with higher alcohol concentrations, the sensor's resistance decreases.

The **SnO2** film is heated by an electric current to reach its operating temperature. When exposed to alcohol gas, the sensor's resistance changes, and this variation is measured and converted into an **analog or digital signal**.

The output signal amplitude varies according to the alcohol concentration, allowing the determination of alcohol levels
in the environment.

Figure 2.2 MQ-3 Sensor Model

Technical Specifications:

- **Dimensions:** 32 x 22 x 27 mm
- **Main Chip:** LM393
- **Operating Voltage:** 5V DC
- **Alcohol Detection Range:** 0.04 mg/L to 0.4 mg/L in air
- **Response Time:** Approximately 8 seconds when the sensor surface temperature reaches 60°C
- **Recovery Time:** ≤ 30 seconds
- **Power Consumption:** ≤ 900 mW

2.1.3. LCD

The LCD 16x2 is a small liquid crystal display used to show characters or numbers in the ASCII character set. The display used is a 16x2 blue text LCD, capable of displaying two lines with 16 characters per line. The characters appear in white on a bright blue background emitted by the LCD. The LCD 16x2 utilizes the HD44780 driver for control and data processing.

Figure 2.3: LCD I2C Model

Technical Specifications:

- **Operating Voltage:** 4.5 - 5V DC
- **Dimensions:** 86.96 x 60 x 13 mm
- **Current Consumption:** 2.0 – 5.0 mA
- **Main IC:** HD44780 Driver
- **Operating Temperature:** -10°C to 60°C
- **Maximum Display:** 16 characters per line

- **Interface:** 16-pin connection

The 16x2 LCD can communicate with a microcontroller using the I2C (Inter-Integrated Circuit) protocol, simplifying connections and conserving GPIO pins. Instead of using 6-8 wires like parallel communication, I2C only requires two wires: SDA (data) and SCL (clock). This makes wiring more compact and easier, especially for systems with limited pins such as Arduino. With the support of the PCF8574 module, the 16x2 I2C LCD can be easily controlled using the LiquidCrystal_I2C library, enabling quick and efficient display programming.

2.1.4. Other Components

Figure 2.4 LED

Light Emitting Diode (LED) is a type of semiconductor diode that emits light based on the principle of electroluminescence when an electric current passes through it. LEDs offer advantages such as energy efficiency, long lifespan (25,000 - 100,000 hours), compact size, and multi-color illumination. The operating voltage ranges from 1.8V to 3.6V, with a current range of 5mA to 20mA and a viewing angle of 20° - 140°. LEDs are widely applied in lighting, displays, decoration, and electronic devices.

A buzzer is an electronic component capable of generating sound when powered, operating based on the principle of diaphragm vibration or piezoelectric ceramic vibration. It is commonly used in alarm systems, clocks, and electronic devices. The buzzer operates at a voltage range of 3V - 12V, consumes a current of 5mA - 30mA, and produces sound with a frequency range of 1kHz - 5kHz and an intensity of 70 - 100 dB. Common buzzer sizes include 5mm, 9mm, 12mm, 15mm, and 27mm.

Figure 2.5 Buzzer

Figure 2.6 PIN 9V

Battery: The 9V battery is a common type, widely used in measuring devices, wireless microphones, and electronic toys. It has a rectangular design with two terminals on the top and comes in various types, including alkaline, carbon-zinc, NiMH, and Li-ion. The battery operates at 9V, has a capacity of 200mAh - 600mAh, dimensions of 48x26x17mm, and weighs between 30 - 50g.

2.2. SYSTEM DESIGN

2.2.1. System Block Diagram

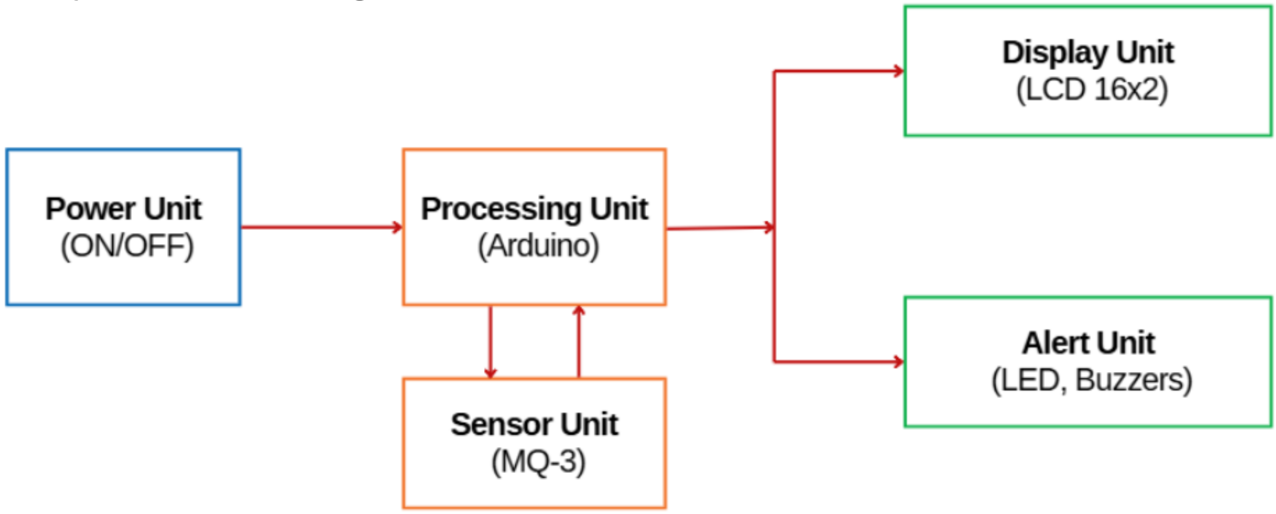

Figure 2.7. System Block Diagram

The block diagram describes a system consisting of five main components. The Power Unit supplies electrical power to the entire system. The Processing Unit (Arduino) receives data from the Sensor Unit (MQ-3), which detects environmental parameters and sends signals to the processor. After processing, the Arduino can display information on the Display Unit (LCD 16x2) or activate the Alert Unit (LEDs, Buzzers) to provide warnings when necessary. The system operates in a sequential process, ensuring timely monitoring and response to critical situations, thereby enhancing safety and operational efficiency.

2.2.2. Hardware Diagram

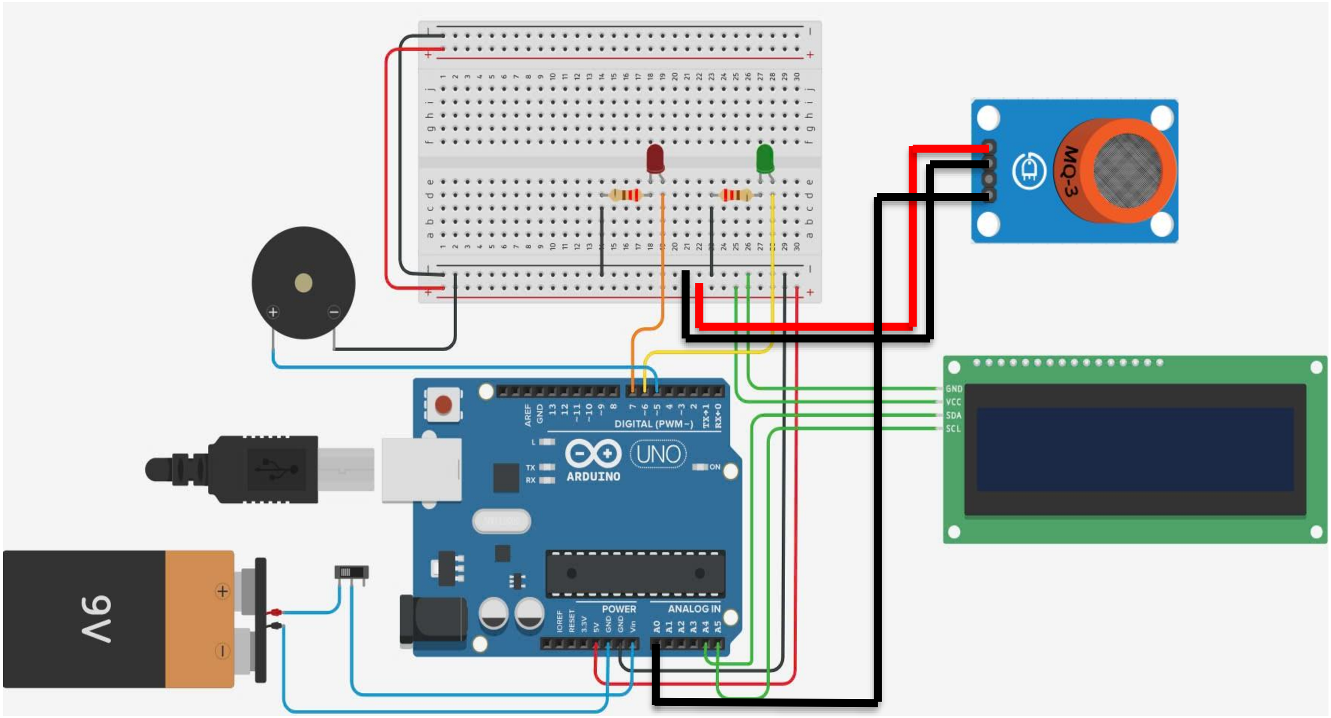

Figure 2.8. System Hardware Diagram

2.2.3. Circuit Schematic Diagram

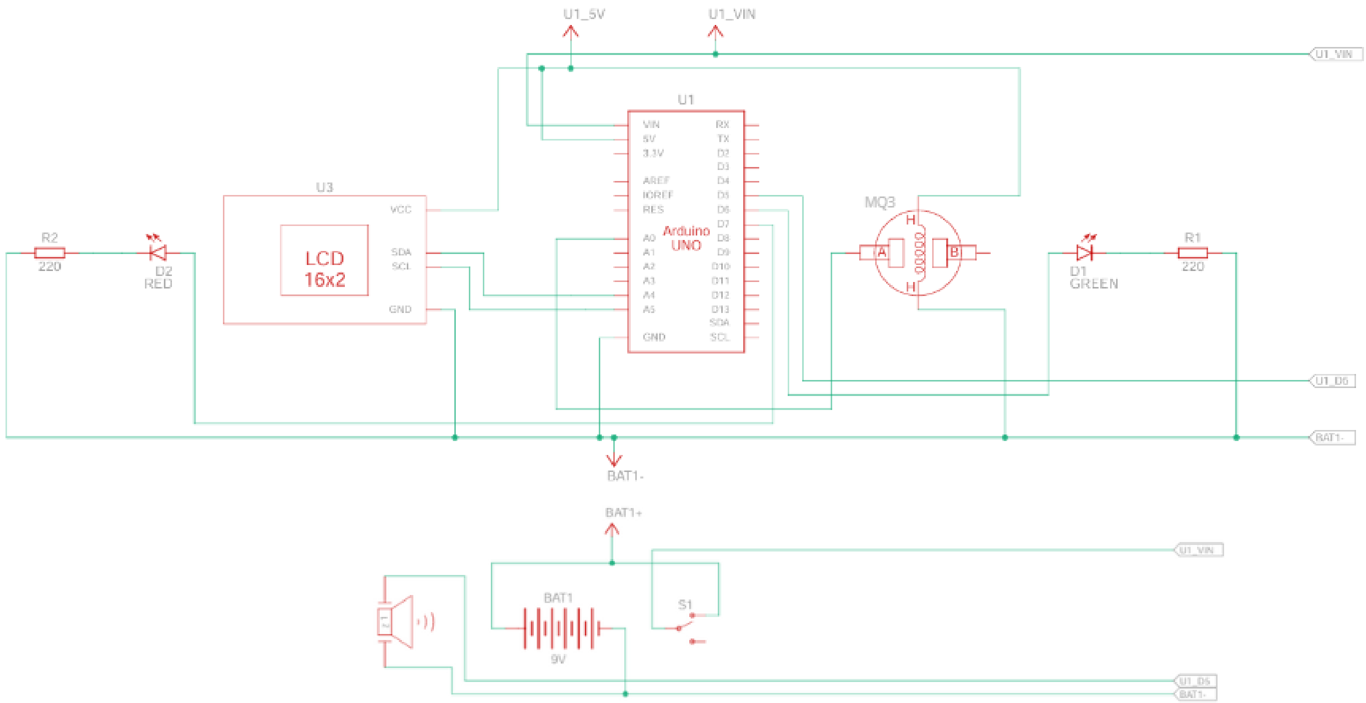

Figure 2.9. Circuit Schematic Diagram

In the circuit schematic diagram above, the Arduino UNO (U1) functions as the central controller. The A0 pin of the Arduino is connected to the MQ-3 sensor to receive measurement signals. The D5 pin is used to connect to switch S1 to activate the circuit. The D6 pin controls the green LED (D1) through resistor R1 (220Ω), indicating the system's operational status.

The 16x2 LCD display (U3) communicates with the Arduino via the I2C protocol, with the SDA and SCL pins of the LCD connected to the corresponding SDA and SCL pins on the Arduino. The power supply for the LCD and other components is drawn from the VCC and GND of the Arduino. Additionally, a red LED (D2) is connected in series with resistor R2 (220Ω) to indicate an alternative system state. The system is powered by a 9V battery (BAT1) through switch S1, with the positive terminal connected to the VIN of the Arduino and the negative terminal connected to the common GND of the circuit.

2.2.4. Flowchart

The flowchart illustrates the operational process of an alcohol concentration measuring device using the MQ-3 sensor. The process begins with device initialization (Initialize Device), followed by sensor warming (Warm Up Sensor) to ensure measurement accuracy. Once the sensor is ready, the system displays the "Ready To Test" status.

When the user exhales into the sensor, the system reads data from the MQ-3 sensor (Read Data from MQ3 Sensor). If no alcohol is detected (alcohol concentration $\leq$ 0.02 mg/L), the system returns to the standby state. If alcohol is detected, the system proceeds with measurement, updates the data, and displays the results on the LCD screen.

Next, the device compares the alcohol concentration against the threshold limit. If the concentration is below the allowable threshold, the system displays the result as "PASS," activates the green LED, and does not trigger the buzzer. If the alcohol concentration exceeds the predefined limit, the system displays the result as "FAIL," activates the red LED, and triggers the buzzer as an alert.

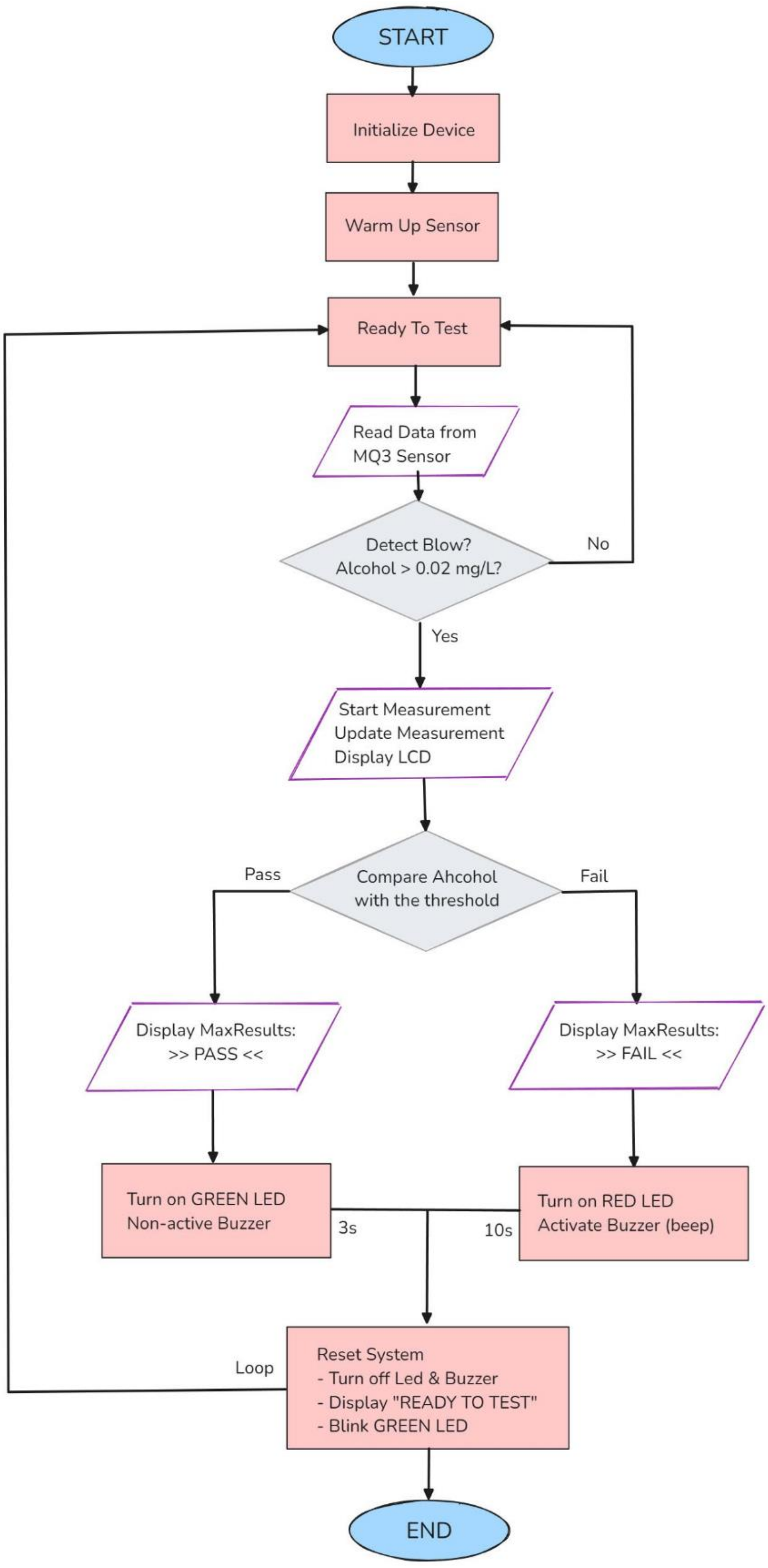

Figure 2.10 Flowchart

After displaying the results, the system maintains the display for 3 seconds in the case of a "PASS" result and 10 seconds for a "FAIL" result. It then resets by turning off the LED, deactivating the buzzer, displaying the "READY TO TEST" status, and blinking the green LED. The process then repeats, preparing the system for the next test

2.3. CONCLUSION OF CHAP 2

Chapter 2 provides an overview of alcohol concentration detection methods and the application of IoT in traffic monitoring. The core technologies researched and integrated into the system include:

Arduino Uno R3, functioning as the central processing unit, responsible for collecting, processing, and coordinating system components.

MQ-3 sensor, detecting alcohol concentration by measuring changes in the resistance of SnO_2 material upon exposure to alcohol vapor.

LCD 16x2, used for displaying information visually, allowing users to easily monitor measurement parameters.

Additional components, such as LEDs, buzzers, and power sources, providing alerts when alcohol concentration exceeds the safety threshold.

Additionally, this chapter presents the system design, including block diagrams, hardware schematics, and circuit schematics. The system operates in a sequential process, from data collection and information processing to display and alert generation, ensuring timely monitoring and response to hazardous situations.

The contents of this chapter serve as a crucial foundation for the implementation, testing, and evaluation of the system in the following chapter. Chapter 3 will focus on system testing and performance evaluation, including sensor accuracy, processing speed, and the effectiveness of alert mechanisms. Through real-world experiments, the system will be analyzed and optimized to ensure high applicability in practice.

CHAPTER 3: TESTING AND EVALUATION

3.1. EXPERIMENTAL MODE

3.1.1. Hardware

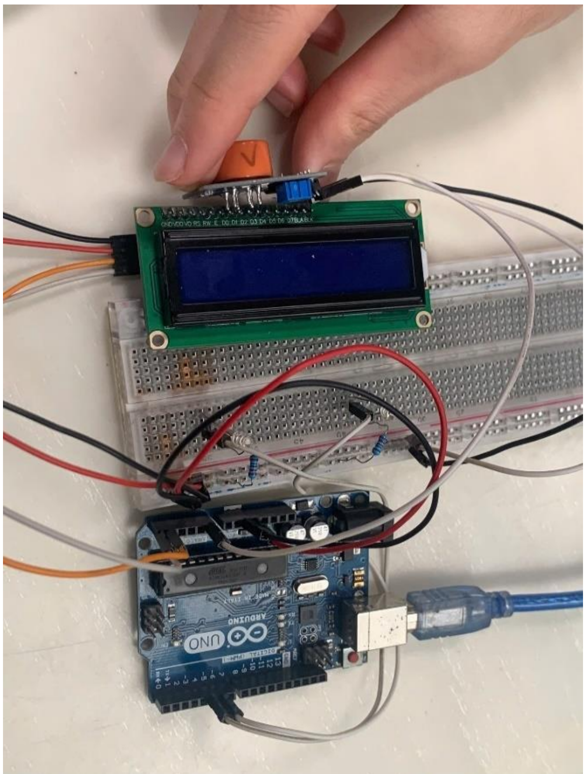

Figure 3.1 Raw Design Model

-**Arduino Uno**: A widely used microcontroller board that serves as the "brain" of the system, processing data from the sensor and controlling the LCD display.

-**I2C LCD Display**: Used to display information or results from the Arduino.

-**Breadboard**: An electronic prototyping board that facilitates easy connections between components.

-**MQ-3 Sensor**: Operates based on the change in resistance of a semiconductor material when exposed to alcohol vapors.

-**Jumper Wires**: Used to connect components on the breadboard to the Arduino and LCD.

-**Potentiometer**: A variable resistor, commonly used to adjust the contrast of the LCD display.

-**USB Cable**: Used for power supply and programming the Arduino..

3.1.2. Final Revision

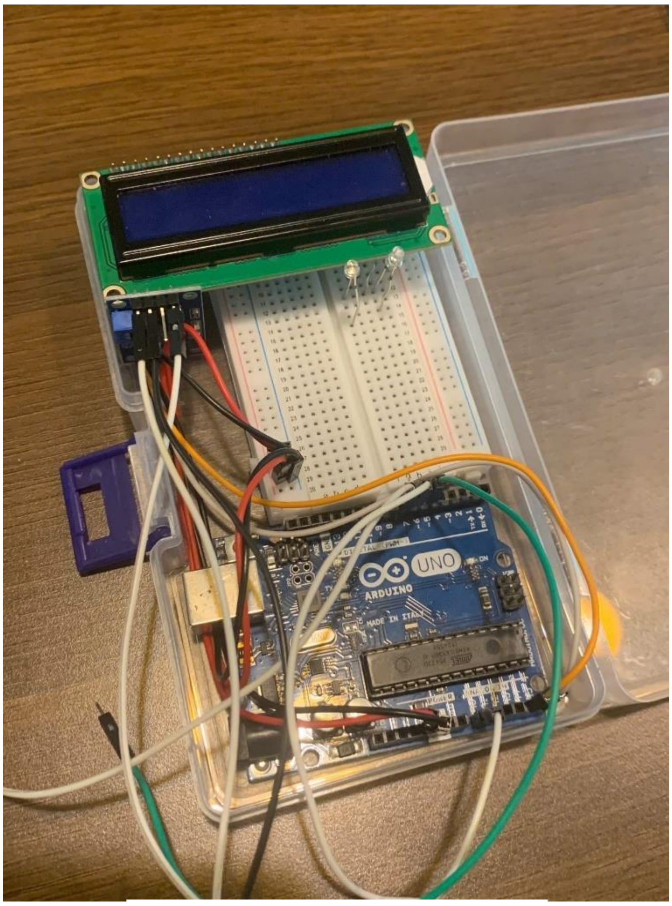

Figure 3.2 Preliminary Design

Figure 3.3 Final Design Model

3.2. TEST SCENARIOS

3.2.1. Test Scenario Table

STT	Code	Scenario TN	Note
1	T01	Testing with the alcohol concentration violation limit of 0.15 mg/L	
2	T02	Testing with the standard alcohol concentration violation limit of 0.25 mg/L	
3	T03	Testing with a calibrated breathalyzer	

3.2.2. Selected Test Scenarios

Test Scenario T01

Case 1: NO VIOLATION

Description: Verify if the system accurately detects low alcohol concentration levels?

Figure 3.4. Standby Screen Display

Step 1: Consume Hanoi vodka (5-10% alcohol) or approximately 0.3 cans of beer. Wait for 5-10 minutes for alcohol absorption into the bloodstream before testing.

Step 2: Power on the system; the LCD screen displays "READY FOR TEST"

Step 3: Blow steadily into the MQ-3 sensor for 3-5 seconds

Step 4: The system processes the data

Step 5: The LCD displays the measured data, and the green LED lights up, indicating a "PASS" result.

Figure 3.5. Display Screen for "Pass" Result

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RESULTS: 0.103

>> PASS <<

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Case 2: VIOLATION

Description: This test aims to evaluate whether the system can accurately detect alcohol concentration after alcohol consumption?

Figure 3.6. Standby Screen Display

Step 1: Consume Hanoi vodka (30-40% alcohol) and approximately 3-4 cans of beer. Wait for about 5-10 minutes to allow the alcohol to be absorbed into the bloodstream before conducting the test.

Step 2: Activate the system; the LCD screen displays “READY FOR TEST”.

Step 3: Exhale into the MQ-3 sensor for approximately 3-5 seconds while maintaining a steady breath.

Step 4: The system processes the acquired data

Step 5: The LCD screen displays the message "FAIL".The red LED blinks continuously to indicate a hazardous condition. The buzzer is activated to generate an audible alert.”

Figure 3.7. Display Screen for “Fail” Result

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RESULTS: 0.181

>> FAIL <<

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3.3. EXPERIMENTAL EVALUATION

3.3.1. Test Scenario T01

Test scenario T01 was conducted under two conditions: Non-Violation and Violation, to evaluate the system’s ability to detect alcohol concentration using the MQ-3 sensor..

In the Non-Violation case, the experiment involved a small amount of alcohol consumption (0.3 cans of beer, vodka 5-10%). The results indicated that the system accurately detected a low alcohol concentration level (0.103) and did not trigger any alerts while displaying the “PASS” status. This demonstrates that the system can effectively differentiate between a permissible alcohol level that does not impair driving ability and a violation threshold.

In the Violation case, a higher alcohol intake (vodka 30-40%, 3-4 cans of beer) resulted in a recorded alcohol concentration of 0.181, exceeding the legal limit. The system responded accurately by activating the red LED warning, triggering the buzzer, and displaying the “FAIL” status. This confirms that the system can detect drivers with excessive alcohol levels and prevent vehicle ignition.

However, for a more precise evaluation, additional tests such as T02 (standard violation limit of 0.25 mg/L) and T03 (calibrated breathalyzer test) should be conducted to verify the absolute accuracy of the MQ-3 sensor. At present, test scenario T01 has provided valuable real-world data and demonstrated that the system functions according to its design. However, further comparative measurements are necessary to ensure its reliability.

3.3.2. Test Scenario T02

The objective of this experiment is to evaluate whether the system can accurately detect alcohol levels approaching the violation threshold. The test requires the consumption of a precisely calculated amount of alcohol to reach 0.25 mg/L in breath and verify whether the system responds correctly.

3.3.3. Test Scenario T03

To assess the accuracy of the MQ-3 sensor, this experiment compares the system’s measurements with a calibrated professional breathalyzer. This comparison will help determine the sensor’s margin of error and evaluate the system’s practical applicability.

3.4. CONCLUSION OF CHAP 3

Chapter 3 presented the testing and evaluation process of the alcohol concentration measurement system using the MQ-3 sensor. The test results from Scenario T01 demonstrate that the system can accurately detect alcohol levels in breath, distinguishing clearly between low concentrations and violation levels. The system responds promptly, displaying results intuitively on the LCD screen and issuing timely alerts, proving its feasibility for real-world application.

Additionally, the device operates stably with a simple testing procedure, making it easy for users to interact with. This indicates that the system has the potential to become a supportive tool for alcohol level control before driving, contributing to improved road safety.

However, to ensure higher accuracy, further tests T02 and T03 should be conducted. Scenario T02 will assess the system’s performance at the standard threshold (0.25 mg/L), while Scenario T03 will validate measurement accuracy by comparing results with a calibrated professional breathalyzer. Completing these experiments will help determine the error margin and optimize system performance, thereby reinforcing its practical applicability.

CHAPTER 4: CONCLUSION & RECOMMENDATIONS

4.2. CONCLUSION

The research and development project on the alcohol concentration measurement system using the MQ-3 sensor has yielded encouraging results, demonstrating the feasibility of a simple, cost-effective, and easily applicable alcohol monitoring solution. The system is built on the Arduino platform, featuring the ability to measure, process data, and display results in an intuitive manner. During experimental testing, the system exhibited sensitivity to variations in alcohol concentration, responded promptly, and provided appropriate warnings.

The test results indicate that the system can accurately differentiate between low alcohol levels and violation thresholds, allowing users to assess their condition before engaging in traffic. Specifically, in experimental scenario T01, the system successfully distinguished between two cases: non-violation (alcohol concentration below the regulatory threshold) and violation (alcohol concentration exceeding the allowable limit). The measured results were directly displayed on the LCD screen, while LED indicators and a buzzer were activated when the alcohol level surpassed the permitted threshold.

However, to ensure greater accuracy, the system needs to be tested under advanced scenarios such as T02 (standard threshold of 0.25 mg/L) and T03 (comparison with a calibrated professional measuring device). Conducting these experiments will help assess the error margin of the MQ-3 sensor, enabling appropriate calibration adjustments to enhance system reliability..

Despite its advantages in flexibility, low cost, and expandability, the system also has certain limitations. The MQ-3 sensor is affected by environmental factors such as temperature and humidity, which may cause measurement deviations in some cases.

In summary, the project has successfully developed a simple, easy-to-deploy alcohol concentration measurement system with high practical applicability. In the future, upgrading the system by integrating more precise sensors, incorporating calibration algorithms, and implementing data modeling will enhance reliability, paving the way for the development of intelligent traffic safety monitoring applications.

4.2. RECOMMENDATIONS

1. **Enhancing Internet Connectivity**: Suggest IoT integration methods for real-time data transmission, assess modern communication protocols (MQTT, CoAP, WebSocket), evaluate 5G/Wi-Fi 6 benefits, and recommend cloud-based data storage solutions.
2. **Upgrading Alcohol Sensor Accuracy**: Analyze alternative sensors (spectrophotometric, electrochemical, infrared), assess environmental factors affecting accuracy, propose AI/ML calibration techniques, and explore multi-point detection methods.
3. **Testing Under Realistic Conditions**: Develop test scenarios for diverse environments, conduct long-term durability tests, evaluate performance across different user demographics, and compare results with law enforcement-grade devices.
4. **Market Demand and Commercialization Potential**: Analyze competitors, assess market demand from key stakeholders (police, transport companies, private users), recommend a viable business model, and propose pricing and market expansion strategies.

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