IoT-Based Smart Weather Station for Real-Time Environmental Monitoring

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***Abstract* — This research document delivers a description of how the IoT-based Smart Weather Station develops and implements environmental observation via immediate sensors. The Arduino UNO uses sensor information from temperature, gas, ultrasonic & wind speed sensors to process data obtained by environmental measurements. The station's users get warning notifications according to dangerous situations like hot weather combined with hazardous gas leaks that prompt visible LCD displays and audible buzzer alarms. The technology supports Sustainable Development Goal targets by uniting environmental education features with security advancements that makes it compliant with the climate action and sustainable cities and good health charter requirements. This research investigates current IoT-based weather monitoring systems and assesses upcoming possibilities for enhanced precision through AI-machine learning collaborations and quantum-computing-based automatic sensor network development. Further development of the system must tackle space storage problems and make progress on precise sensor requirements and network connection solutions. Reliability and scalability at high levels become possible when LoRaWAN wireless technology merges with a cloud storage service that performs AI predictive analysis. The implementation of real-time environmental data-based infrastructure monitoring in smart cities makes possible support for various climate-resilient planning activities at affordable prices.**

Keywords — IoT (Internet of Things); Arduino UNO; Sensor Integration; Smart Weather Station;

I. Introduction

A smart weather station is a state-of-the-art device that continuously monitors and analyzes environmental parameters like temperature, humidity, atmospheric pressure, air quality, and rainfall using sensors and the Internet of Things (IoT). These stations offer precise, up-to-date data for a range of uses, including scientific research, agricultural planning, and weather forecasting. Because of their capacity to interface with cloud platforms, automated systems, and mobile devices, smart weather stations have grown in popularity as easily accessible and incredibly effective weather monitoring instruments (Sullivan, 2021).

Smart weather stations offer many useful uses in day-to-day living. They give homeowners the option to keep an eye on both interior and outdoor weather, which helps with energy management, adjusting the heating or cooling system in the house, and creating ideal conditions for gardening. For example, farmers can improve crop irrigation and yield forecasts by using these stations to track weather and soil moisture (Miller et al., 2020). Smart weather stations are also used by environmental scientists and urban planners to track pollution levels, monitor air quality, and create plans to lessen the effects of climate change (Johnson & Lee, 2019).

The capabilities of smart weather stations have been considerably enhanced by the increasing integration of AI and machine learning. These technologies improve decision-making and risk mitigation by increasing forecast accuracy and the capacity to identify early indicators of extreme weather events (Patel & Sharma, 2022).

II. Literature Review

Several research studies have explored IoT-based weather monitoring systems. This section reviews relevant papers in the field of IoT, smart weather monitoring, and technology.

1. *IOT*

IoT devices transmit data by utilizing their wireless connectivity to connect with cloud-based sensors. The Internet of Things has successfully enhanced automated processes as well as data acquisition operations in multiple production sectors. LoT-enabled weather monitoring systems increase environmental data collection efficiency through sensors which track temperature fluctuations and measure air moisture and atmospheric pressure to carry out instant data sharing (Čolaković & Hadžialić, 2018). The combination of sensors within monitoring systems produces improved environmental data by tracking all measurements including temperature and humidity and pressure and air quality. pressure, and air quality sensors with real-time data transmission (Čolaković & Hadžialić, 2018). These Automatic data recording in monitoring systems enhances both disaster forecasting precision for weather-related threats and precise control of agricultural procedures. logging and remote access. Users can access smart weather station information remotely because of smart weather station connections to loT technology. Users who access remote monitoring data before its collection deadline obtain positive environmental effects. awareness (Khanna & Kaur, 2020).

2. *IoT in Weather Monitoring*

- Research papers highlight the rapid growth of IoT applications in environmental monitoring. The integration of cloud computing and wireless networks enhances data accessibility and automation (Gubbi et al., 2013).
- Studies on edge computing for IoT devices demonstrate the importance of localized data processing for efficiency and accuracy (Shi et al., 2016).

3. *Smart Weather Systems*

- Studies discuss various implementations of smart weather stations using microcontrollers and wireless transmission (Kodali et al., 2016).
- IoT-based weather stations have been developed using LoRaWAN and GSM communication protocols for real-time data transmission (Adelantado et al., 2017).

4. Current Trends:

The integration of IoT, artificial intelligence (AI), and big data analytics is transforming weather monitoring systems. Smart weather stations now feature wireless sensor networks (WSN), real-time alerts, and cloud-based dashboards for improved accessibility (Xing, 2020). Emerging trends include the use of AI-powered weather prediction models, which analyze vast datasets to enhance forecast accuracy (Shafique et al., 2020). Additionally, the deployment of 5G networks is improving data transmission speeds, allowing for more efficient and responsive weather monitoring systems (Khurpade, Rao & Sanghavi, 2018).

5. Future Predictions:

Future developments in smart weather stations focus on self-sustaining sensor networks, advanced nanotechnology-based weather sensors, and quantum computing for climate modeling (Zikria et al., 2021). The rise of autonomous drone-based weather stations is expected to enhance remote climate monitoring, especially in disaster-prone areas (Ahmad et al., 2021). Additionally, AI-driven predictive analytics will enable highly precise weather forecasting, benefiting agriculture, aviation, and emergency response systems (Nur-A-Alam et al., 2021).

III. Methodology

The **Smart Weather Station** continuously monitors environmental conditions using sensors for rainfall, wind speed, temperature, and gas levels. It reads data from these sensors and compares the values to predefined thresholds. If any condition exceeds the threshold—such as high rainfall, strong winds, high temperature, or a dangerous gas level—the system triggers an alert, displaying the warning on an LCD and sounding a buzzer with different frequencies for each alert. In between alerts, the system displays real-time sensor readings on the LCD. This setup ensures constant monitoring, prioritizing critical alerts like gas detection while providing feedback on environmental conditions.

1. *Flowchart Overview*

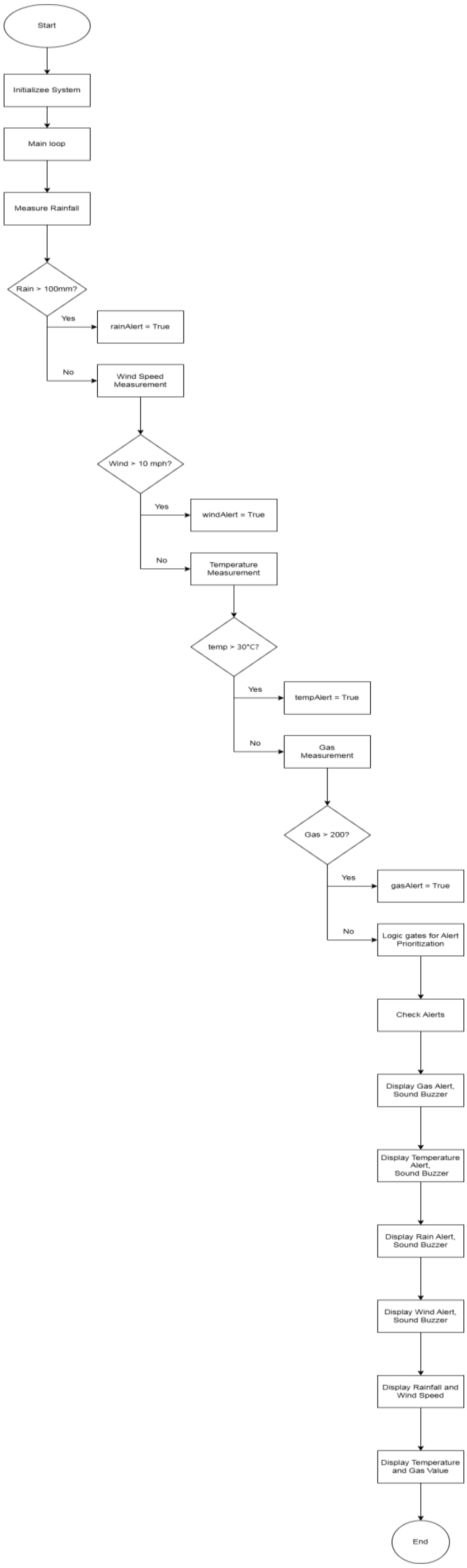


Fig: Flowchart of System

2. *Components Used*

- *Microcontroller*: Arduino Uno (compatible board).

- *Sensors*:
    - Temperature Sensor: Analog sensor (e.g., LM35).
    - Gas Sensor: MQ-series (e.g., MQ-2 for smoke/LPG).
    - Ultrasonic Sensor (HC-SR04): Repurposed for rainfall measurement.
    - Wind Speed Sensor: Potentiometer-based anemometer.

- *Output Devices*:
    - I2C LCD: 16x2 display with I2C interface.
    - Buzzer: For audible alerts.

- *Miscellaneous*:
    - Potentiometer (for LCD contrast adjustment).
    - Resistors, jumper wires, and a breadboard.

- *Software Used:*
    - Arduino IDE for programming
    - C++ for embedded coding

- *Truth Table*

1. Boolean Equation for the Buzzer (B)

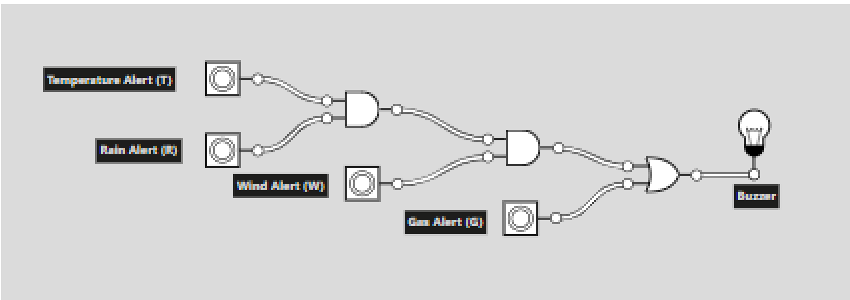


Fig 1. Logic Gate configuration for Buzzer

T	R	W	G	B
0	0	0	0	0
0	0	0	1	1
0	0	1	0	0
0	0	1	1	1
0	1	0	0	0
0	1	0	1	1
0	1	1	0	0
0	1	1	1	1
1	0	0	0	0
1	0	0	1	1
1	0	1	0	0
1	0	1	1	1
1	1	0	0	0
1	1	0	1	1
1	1	1	0	1
1	1	1	1	1

Boolean Expression:

$$B = G + (T \times R \times W)$$

Where:

- **D** = Display Alert
- **T** = Temperature
- **R** = Rain
- **W** = Wind Speed
- **G** = Gas Sensor

2. Boolean Equation for Display Alert (D)

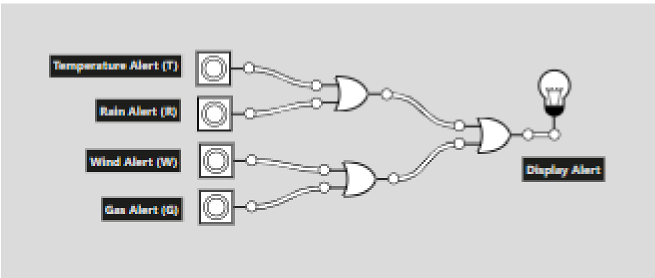


Fig 2. Logic Gate configuration for Display Alert

Truth Table:

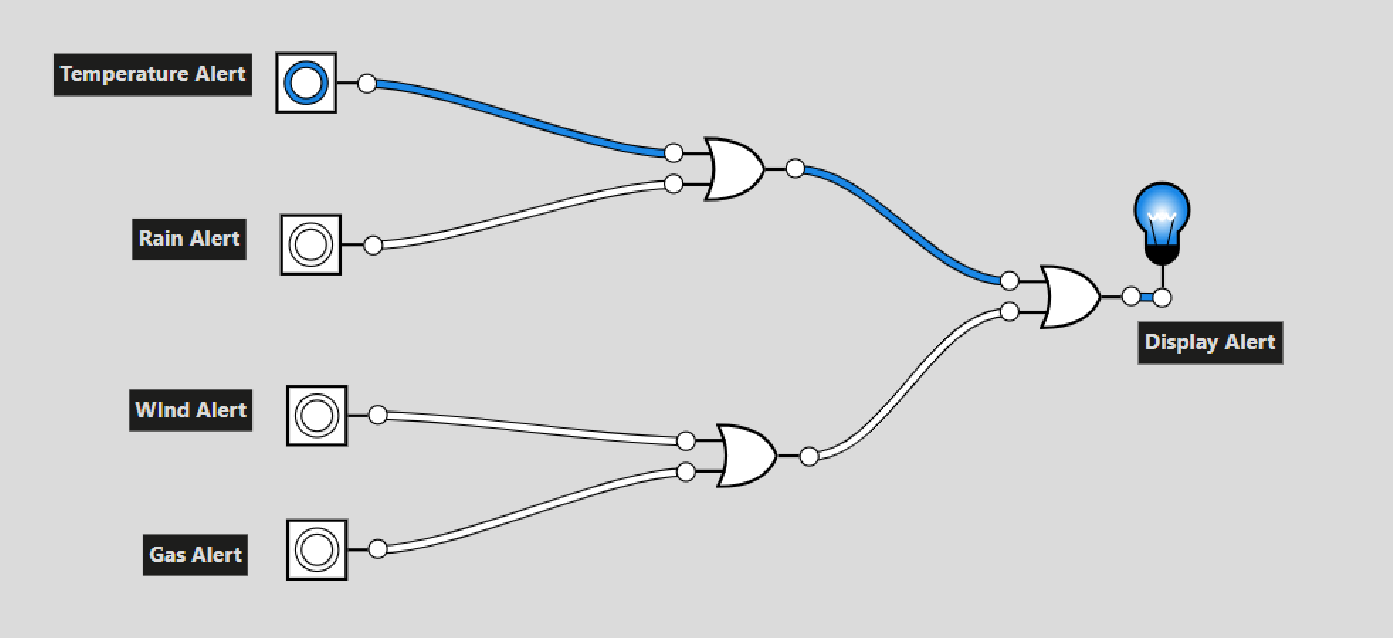
T	R	W	G	D
0	0	0	0	0
0	0	0	1	1
0	0	1	0	1
0	0	1	1	1
0	1	0	0	1
0	1	0	1	1
0	1	1	0	1
0	1	1	1	1
1	0	0	0	1
1	0	0	1	1
1	0	1	0	1
1	0	1	1	1
1	1	0	0	1
1	1	0	1	1
1	1	1	0	1
1	1	1	1	1

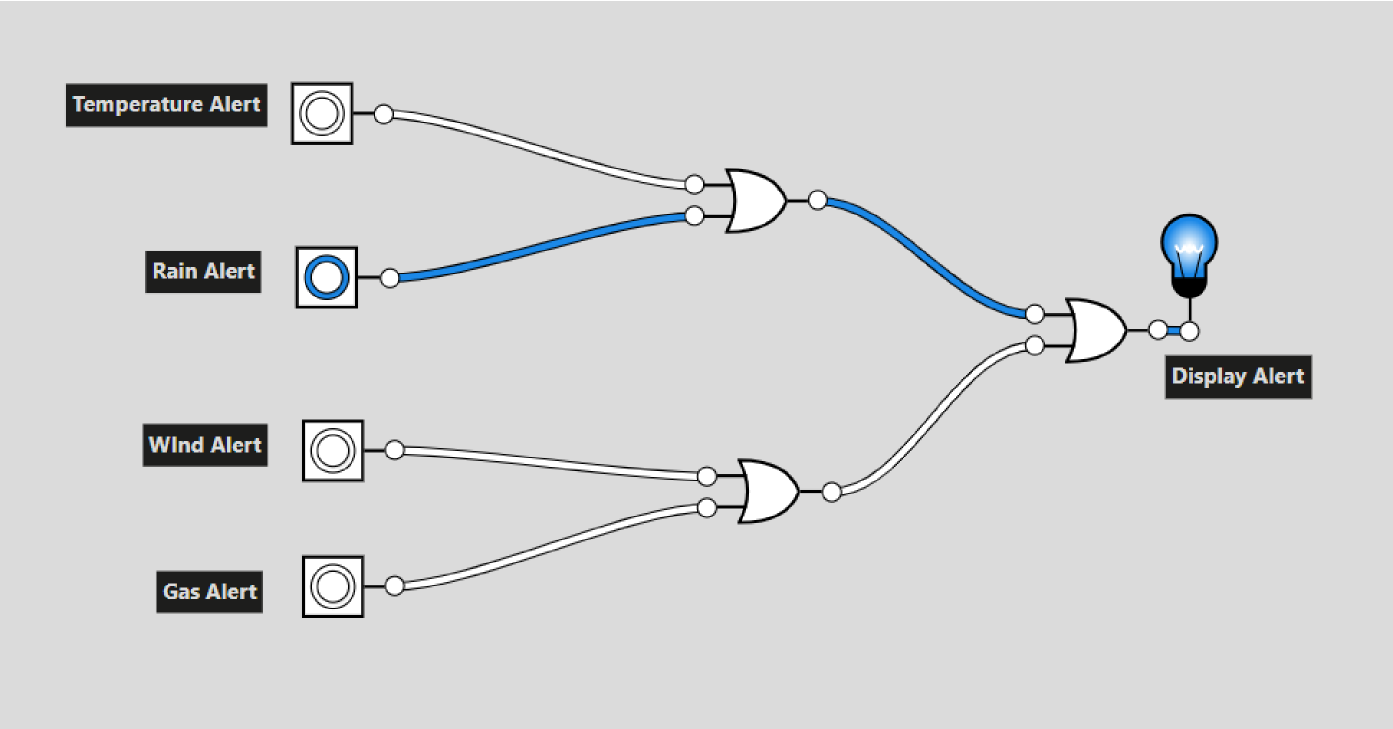
Boolean Expression:

$$\mathrm{D} = T + R + W + G$$

Where:

- **D** = Display Alert
- **T** = Temperature
- **R** = Rain
- **W** = Wind Speed
- **G** = Gas Sensor


Temperature Alert
Rain Alert
WInd Alert
Gas Alert
Display Alert


Temperature Alert
Rain Alert
WInd Alert
Gas Alert
Display Alert

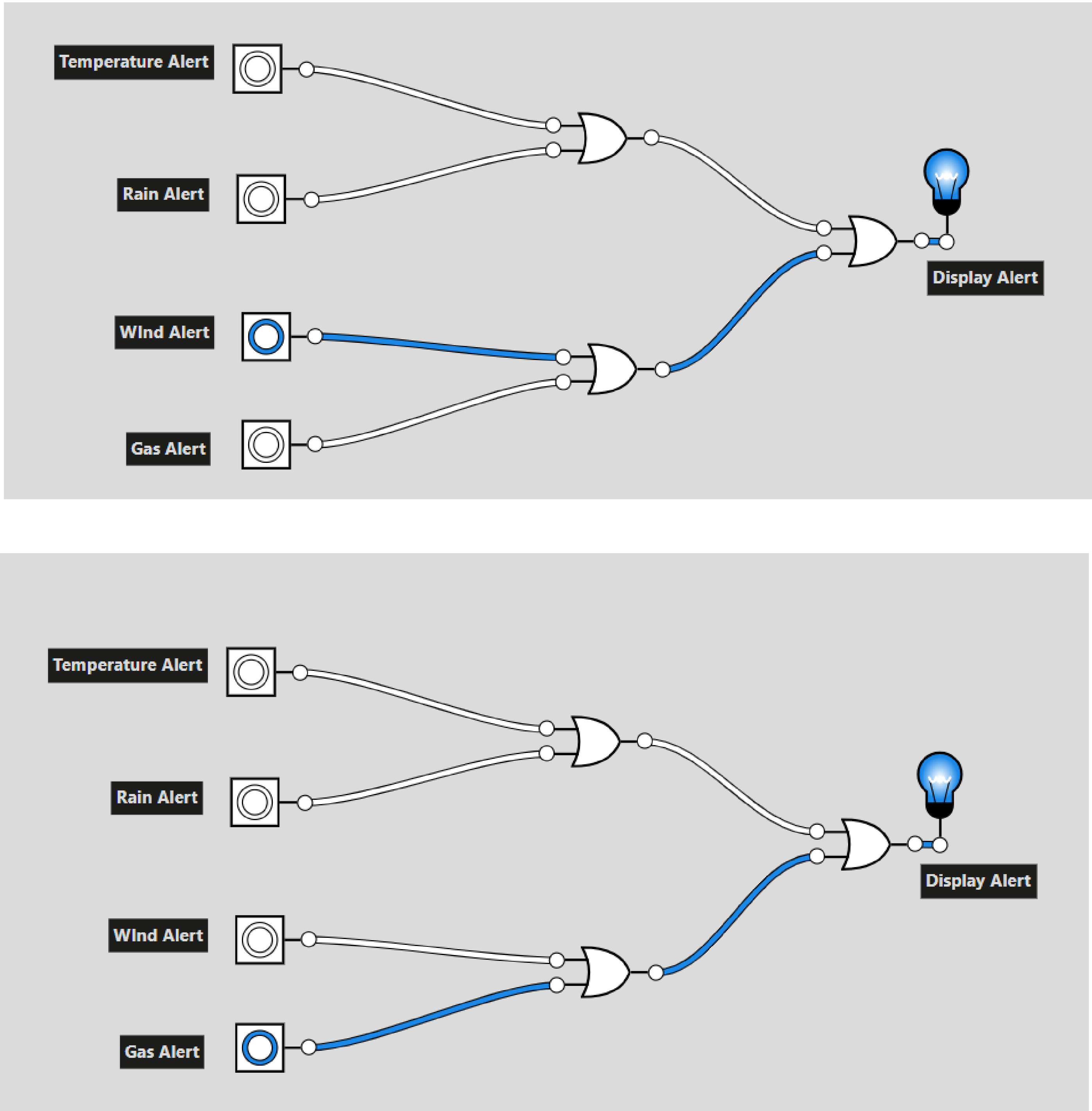
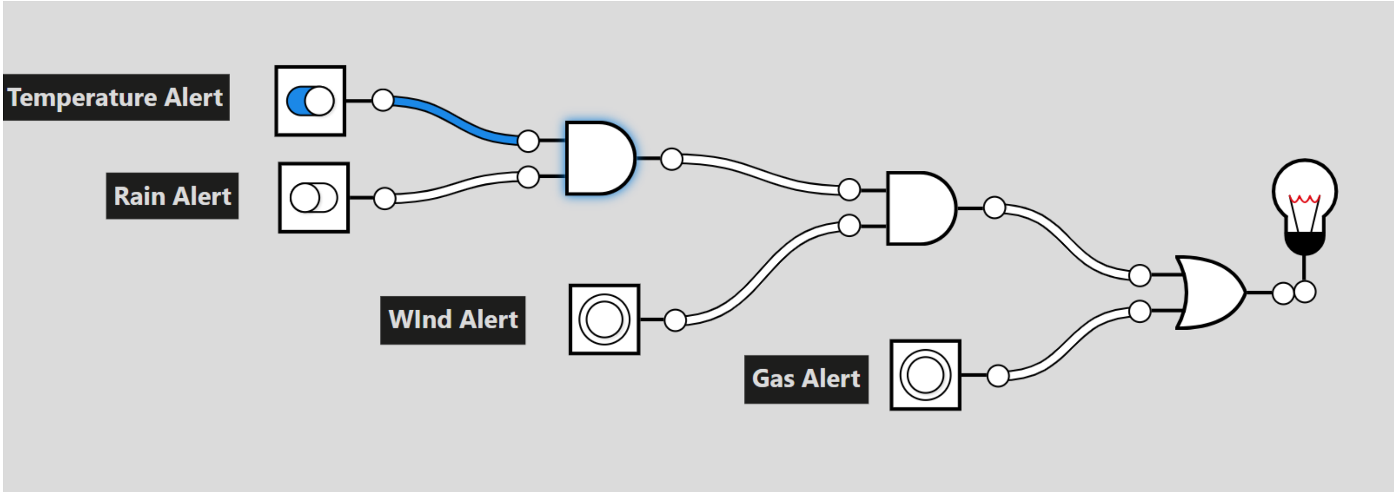
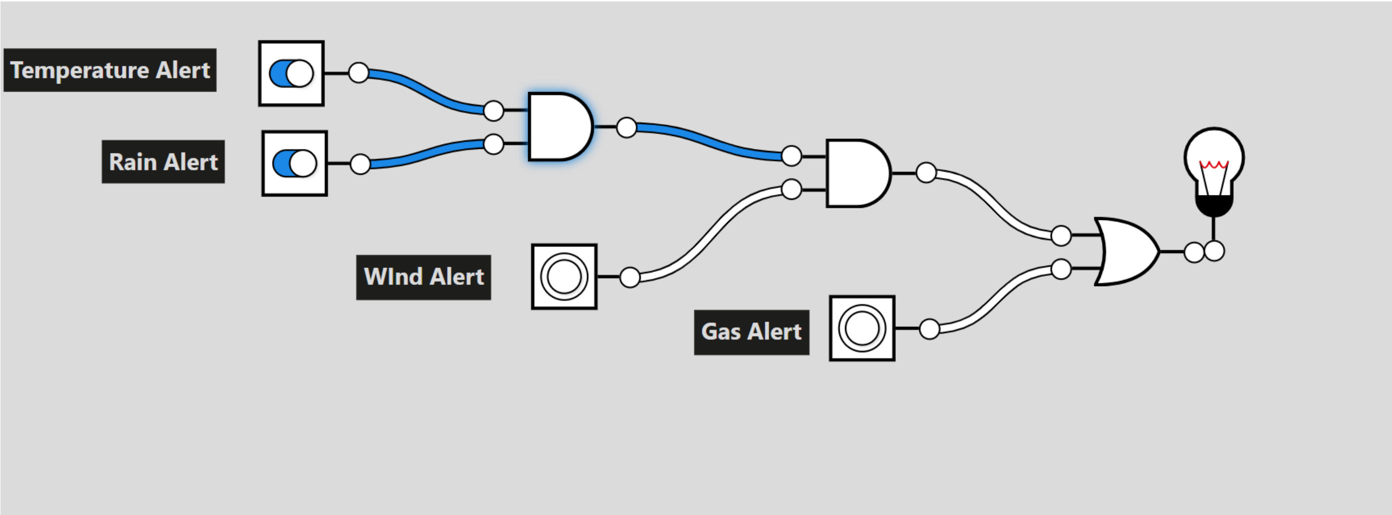
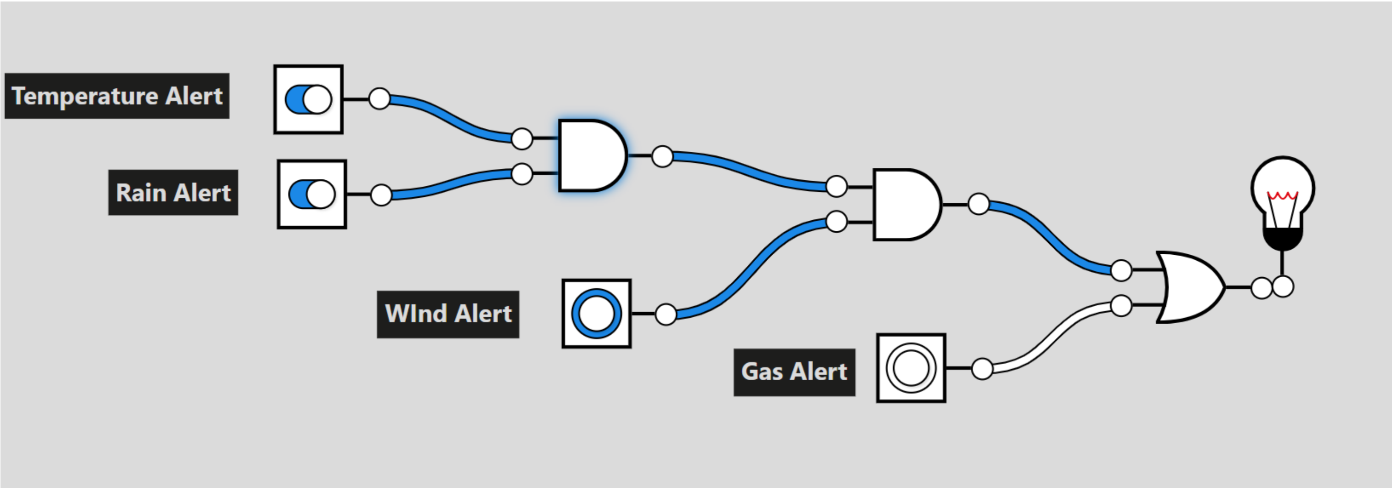
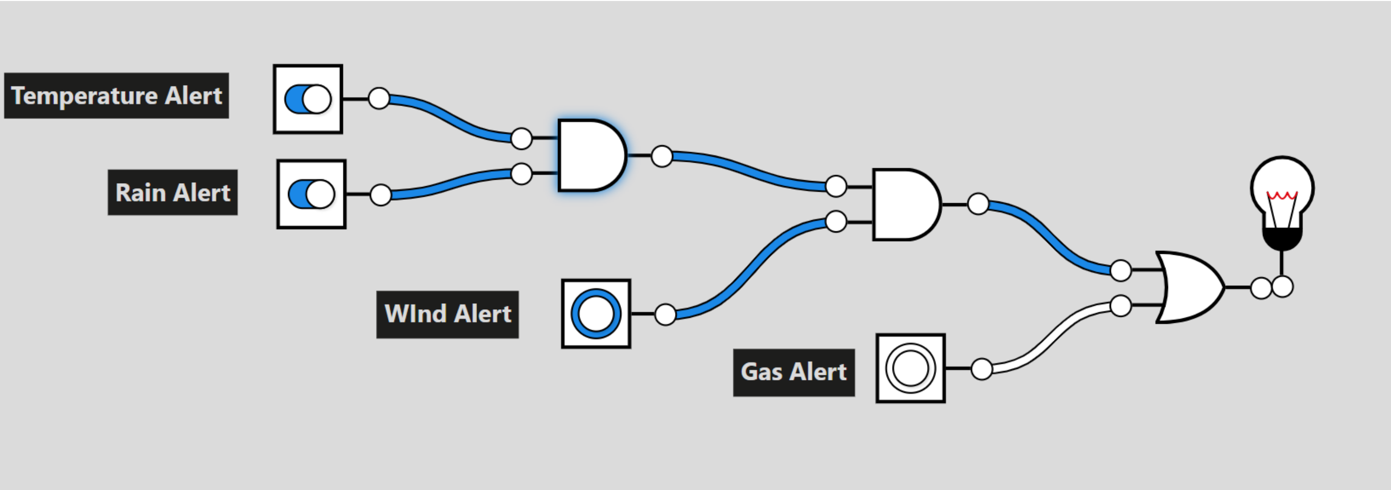


Fig: Logic Diagram of Display Alert


Temperature Alert
Rain Alert
WInd Alert
Gas Alert


Temperature Alert
Rain Alert
WInd Alert
Gas Alert


Temperature Alert
Rain Alert
WInd Alert
Gas Alert



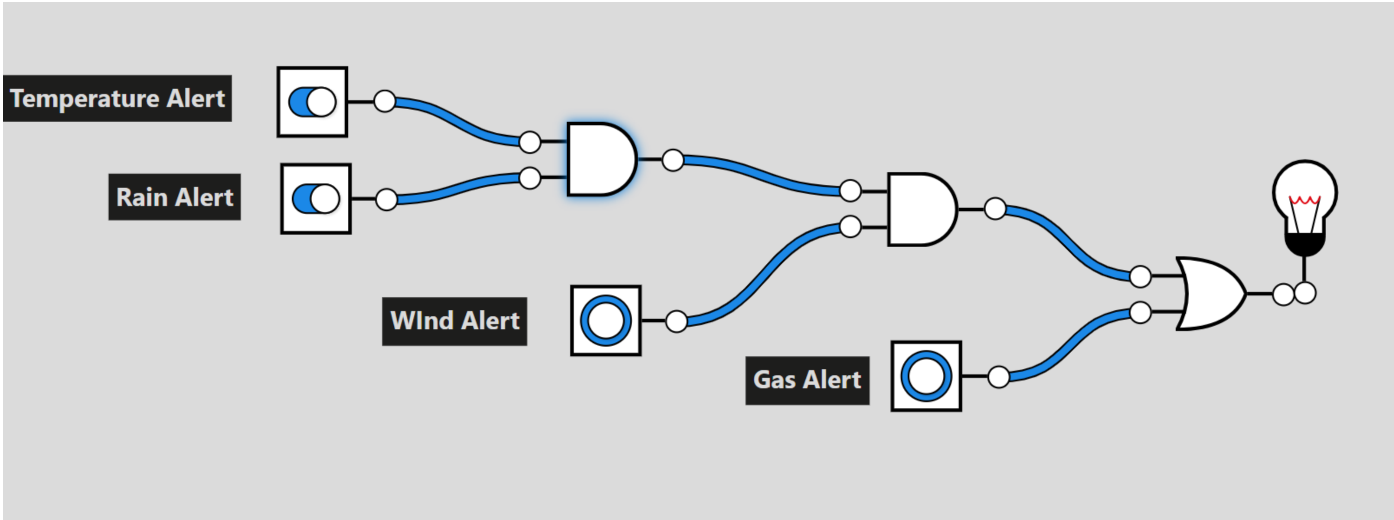


Fig: Logical Diagram of Buzzer

1. Sustainable Development Goals (SDG)s for Smart Weather Station

1. *SDG 3: Good Health and Well-Being*

The system monitors gas levels and temperature, which are critical for preventing health hazards such as gas leaks or extreme heat. By alerting users to dangerous conditions, it helps protect individuals from potential harm, promoting safer living and working environments.

2. *SDG 9: Industry, Innovation, and Infrastructure*

The code demonstrates the use of innovative technology, such as sensors and an LCD display, to create a monitoring system. This aligns with the goal of fostering technological advancements and resilient infrastructure, especially in areas prone to environmental risks.

3. *SDG 11: Sustainable Cities and Communities*

By monitoring environmental factors like rainfall, wind speed, and gas levels, the system contributes to creating safer and more sustainable communities. It helps cities and towns prepare for and respond to environmental challenges, reducing risks to infrastructure and residents.

4. *SDG 13: Climate Action*

The system tracks weather-related parameters such as rainfall and wind speed, which are essential for understanding and mitigating the impacts of climate change. By providing real-time data, it supports efforts to adapt to changing climate conditions and reduce vulnerabilities.

5. *SDG 15: Life on Land*

Monitoring environmental conditions like rainfall and wind can help protect ecosystems and biodiversity. For example, excessive rainfall or strong winds could harm natural habitats, and early warnings can help mitigate these effects.

6. *SDG 17: Partnerships for the Goals*

The code represents a small-scale implementation of technology that can be scaled up through partnerships between governments, industries, and communities. Collaborative efforts can expand such systems to broader applications, enhancing global sustainability efforts.

2. System Setup and Resources

Laptop Specification:

Device name	RjungThapa
Processor	11th Gen Intel(R) Core(TM) i7-1165G7 @ 2.80GHz 2.80 GHz
Installed RAM	8.00 GB (7.71 GB usable)
Device ID	E01E4C9B-FCB4-437D-B4F0-4E79CF2EF627
Product ID	00327-35909-69319-AAOEM
System type	64-bit operating system, x64-based processor
Pen and touch	No pen or touch input is available for this display

Windows Specification:

Edition Windows 11 Home Single Language

Version 24H2

Installed on 04/12/2024

OS build26100.3194

Experience Windows Feature Experience Pack 1000.26100.48.0

3. Hardware Component

The provided image outlines a list of components used in an environmental monitoring system, which includes an **Arduino Uno R3** as the main microcontroller, a **Temperature Sensor (TMPS6)** for measuring temperature, a **Gas Sensor** for detecting hazardous gases, and an **Ultrasonic Distance Sensor** for measuring rainfall or distance. Additional components like a **Piezo buzzer** for alerts, resistors (**1 kΩ and 325 kΩ**), a **250 kΩ potentiometer** for calibration, a **Voltage Multimeter** for measuring electrical values, and a **PCF8574-based LCD 16x2 (I2C)** for displaying data are also included. This setup is designed to create a comprehensive system that monitors environmental conditions such as temperature, gas levels, and rainfall, providing real-time alerts and data visualization to ensure safety and sustainability.

Name	Quantity	Component
U1	1	Arduino Uno R3
U2	1	Temperature Sensor [TMP36]
PIEZO1	1	Piezo
GAS1	1	Gas Sensor
R3	1	1 kΩ Resistor
DIST1	1	Ultrasonic Distance Sensor (4-pin)
R5	1	325 kΩ Resistor
Rpot1	1	250 kΩ Potentiometer
Meter1	1	Voltage Multimeter
U5	1	PCF8574-based, 39 (0x27) LCD 16 x 2 (I2C)

Fig: Hardware Components

A. Each component and its function:

1. **Arduino Uno R3 (U1)**: The main microcontroller board that processes sensor data and controls the system.
2. **Temperature Sensor [TMPS6] (U2)**: Measures ambient temperature and sends the data to the Arduino for processing.
3. **Piezo (PIEZO1)**: Acts as a buzzer to sound alerts when dangerous conditions are detected.
4. **Gas Sensor (GAS1)**: Detects gas levels in the environment and sends the readings to the Arduino.
5. **1 kΩ Resistor (R3)**: Likely used in the circuit to limit current or pull up/down signals.
6. **Ultrasonic Distance Sensor (DIST1)**: Measures rainfall by calculating the distance to water levels using ultrasonic waves.
7. **325 kΩ Resistor (R5)**: Possibly used in the sensor circuit to adjust voltage levels or signal conditioning.
8. **250 kΩ Potentiometer (Rpot1)**: May be used to calibrate or adjust sensor sensitivity.

9. **Voltage Multimeter (Meter1)**: Used for testing and measuring voltage levels in the circuit during setup or debugging.

10. **PCF8574-based, 39 (0x27) LCD 16 x 2 (I2C) (U5)**: Displays sensor readings and alerts to the user in real-time.

IV. Results

A. Arduino Board Overview

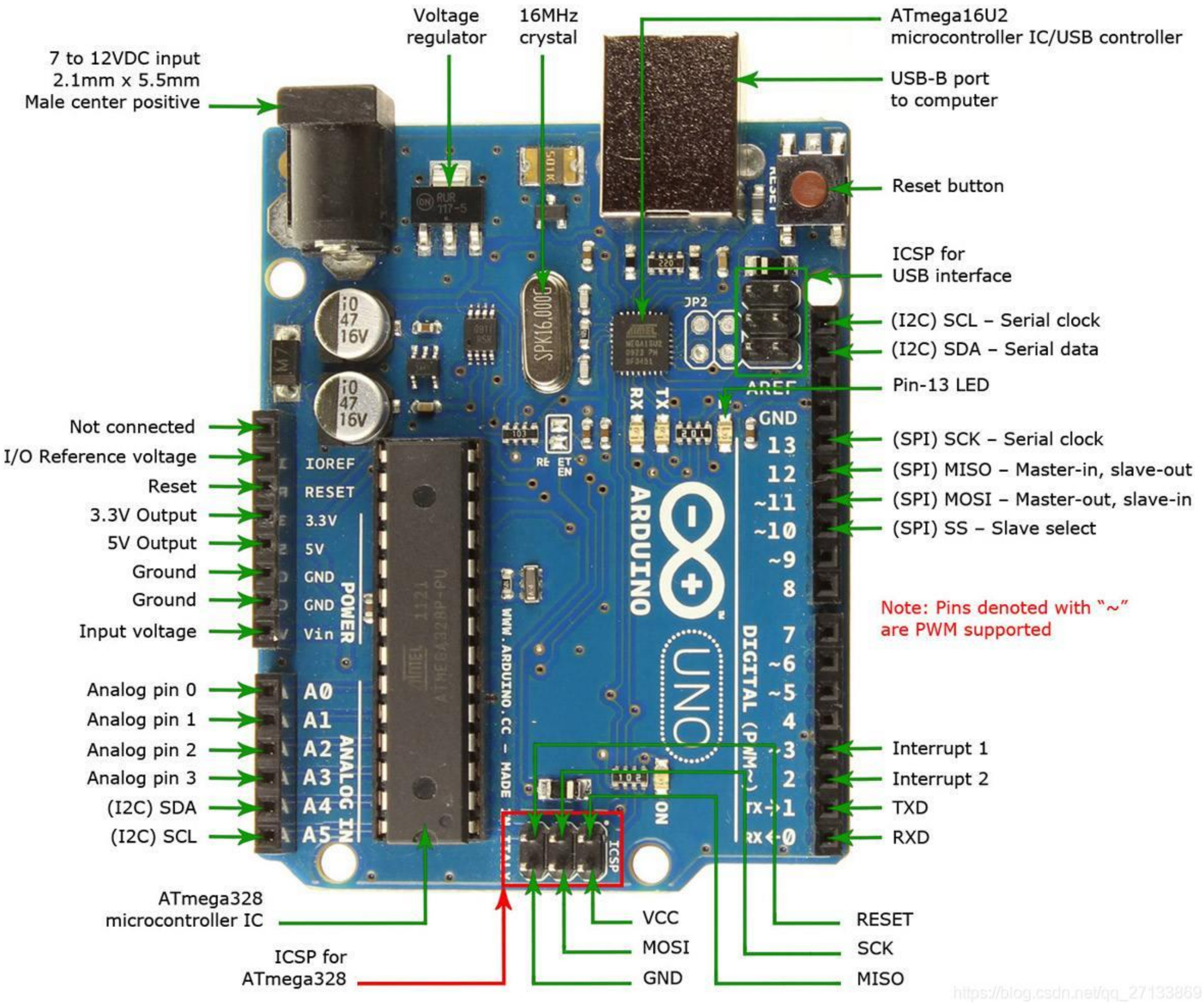


Fig: Labelled Arduino Board

B. Labelled Image

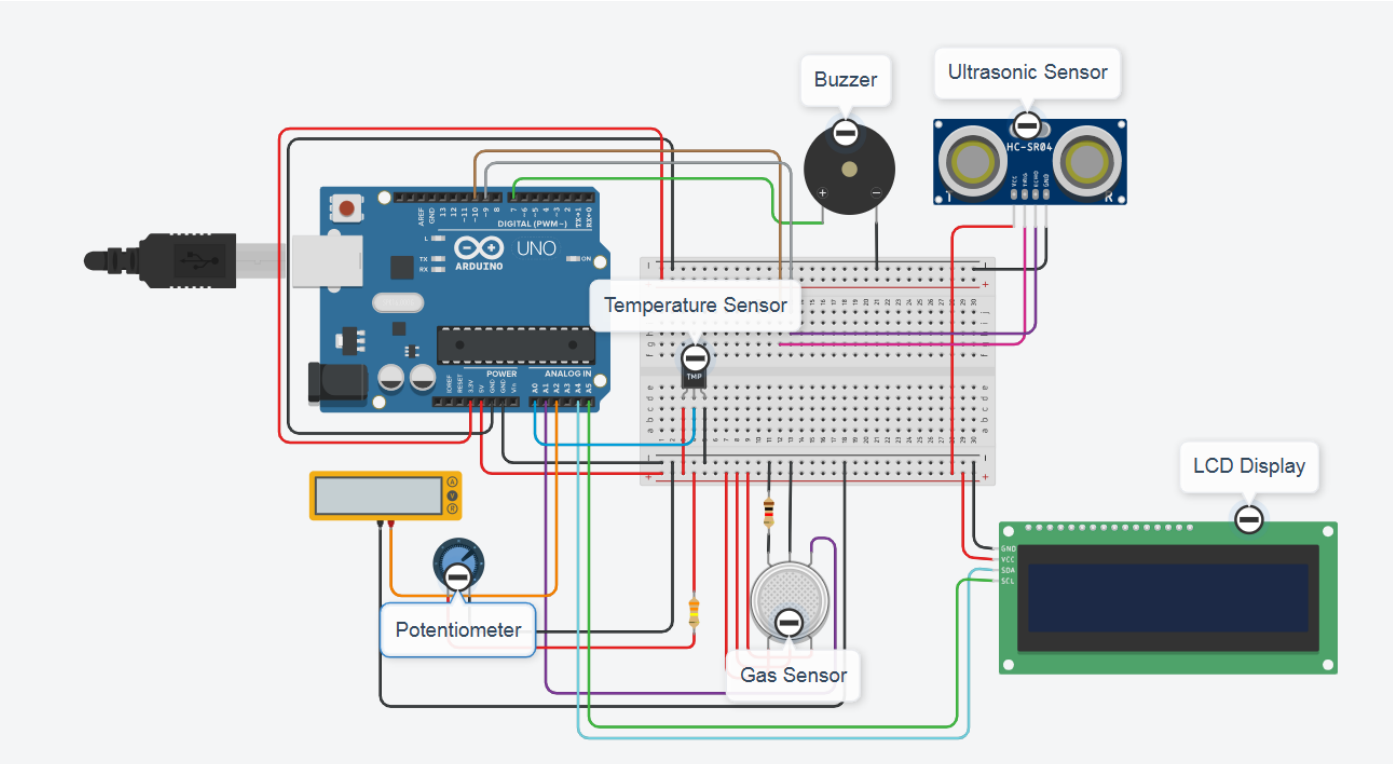


Fig: Labelled Diagram of Smart Weather Station

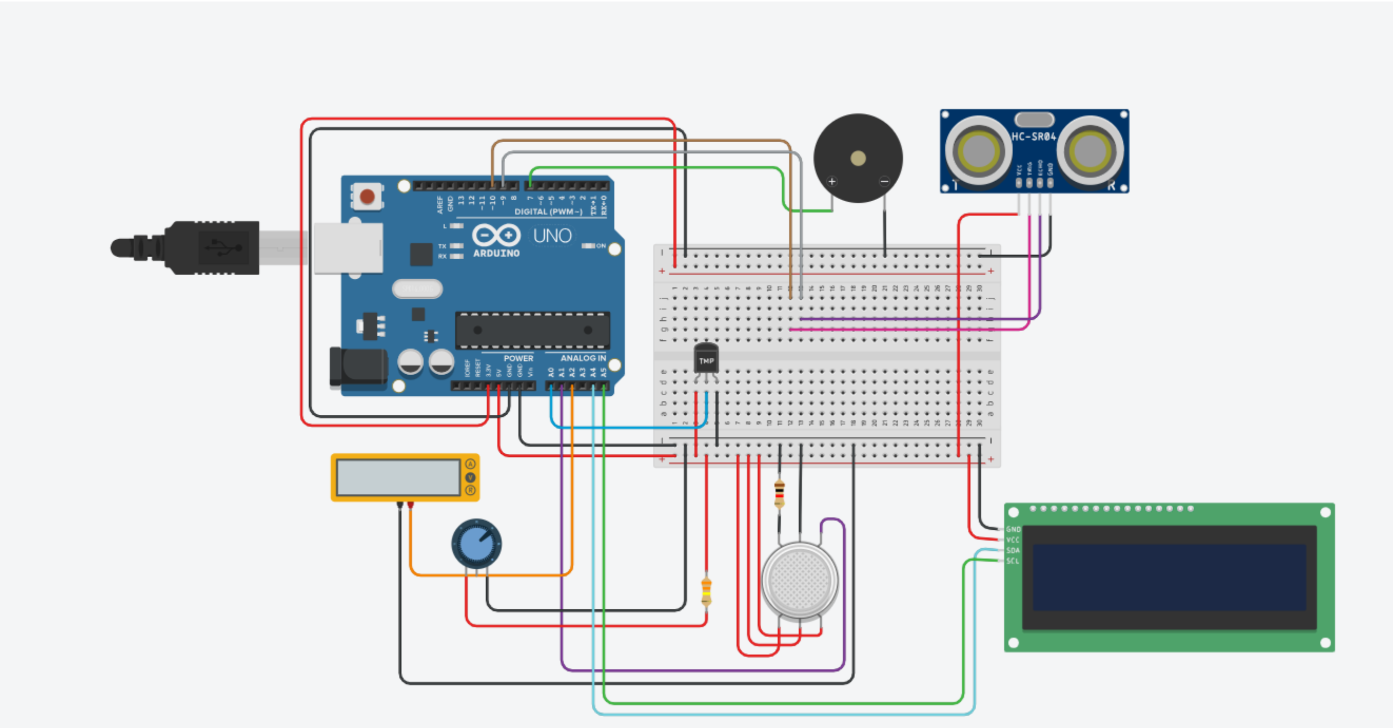
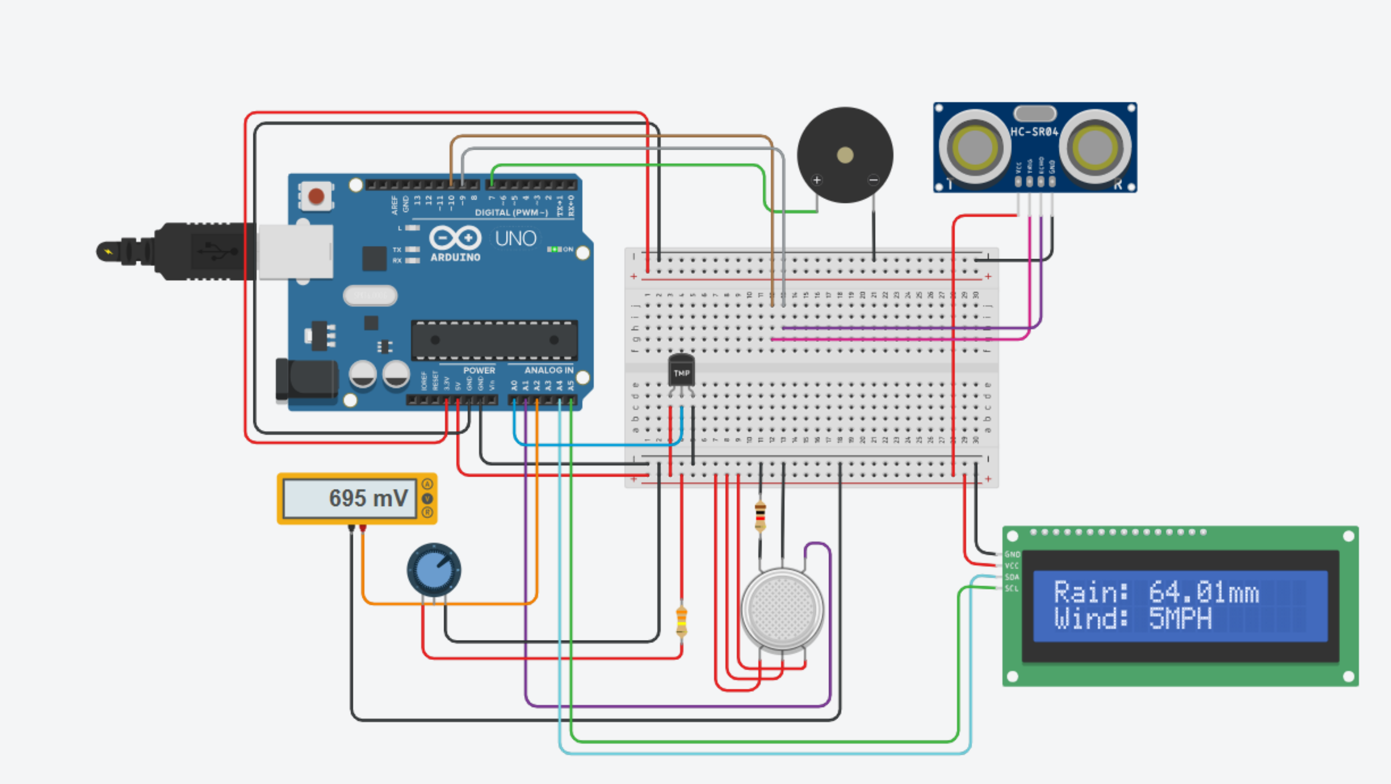
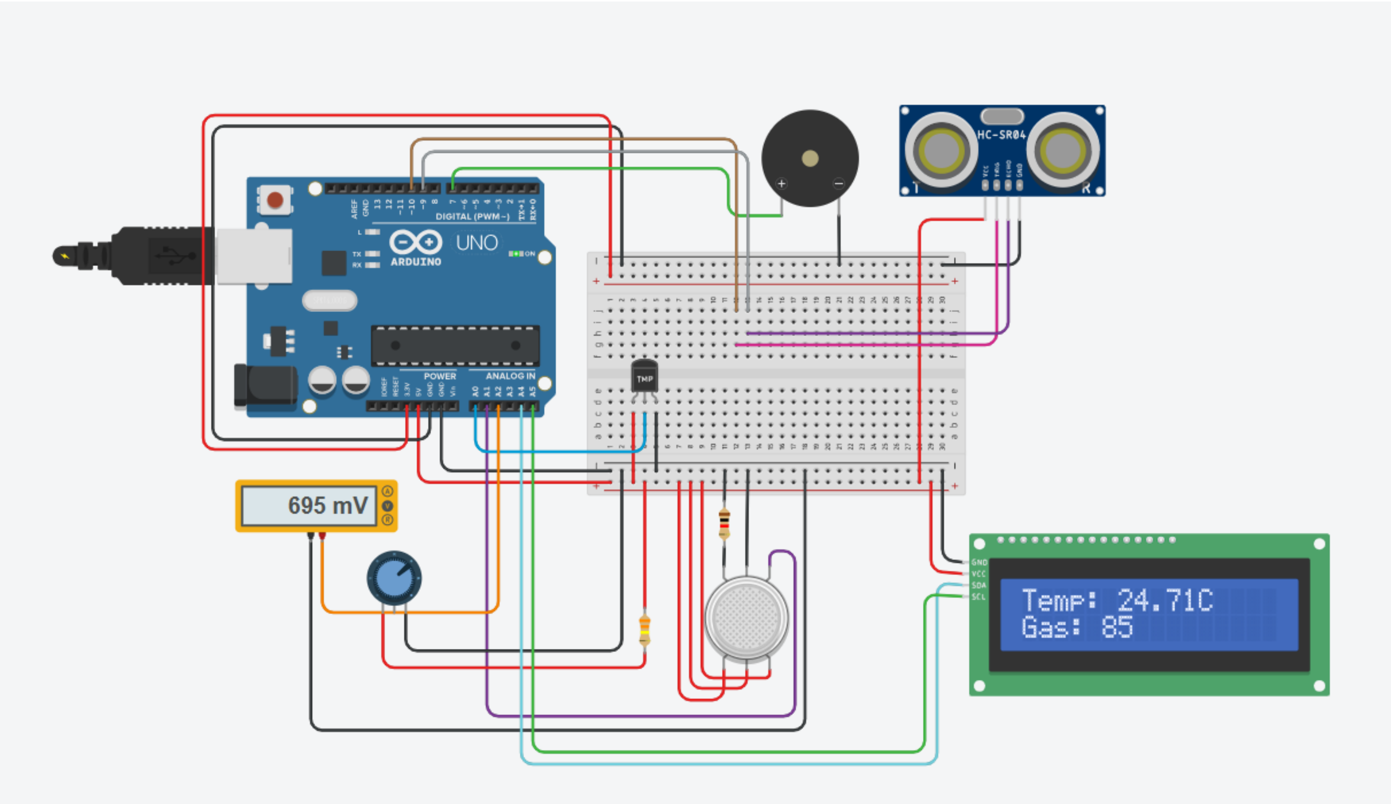
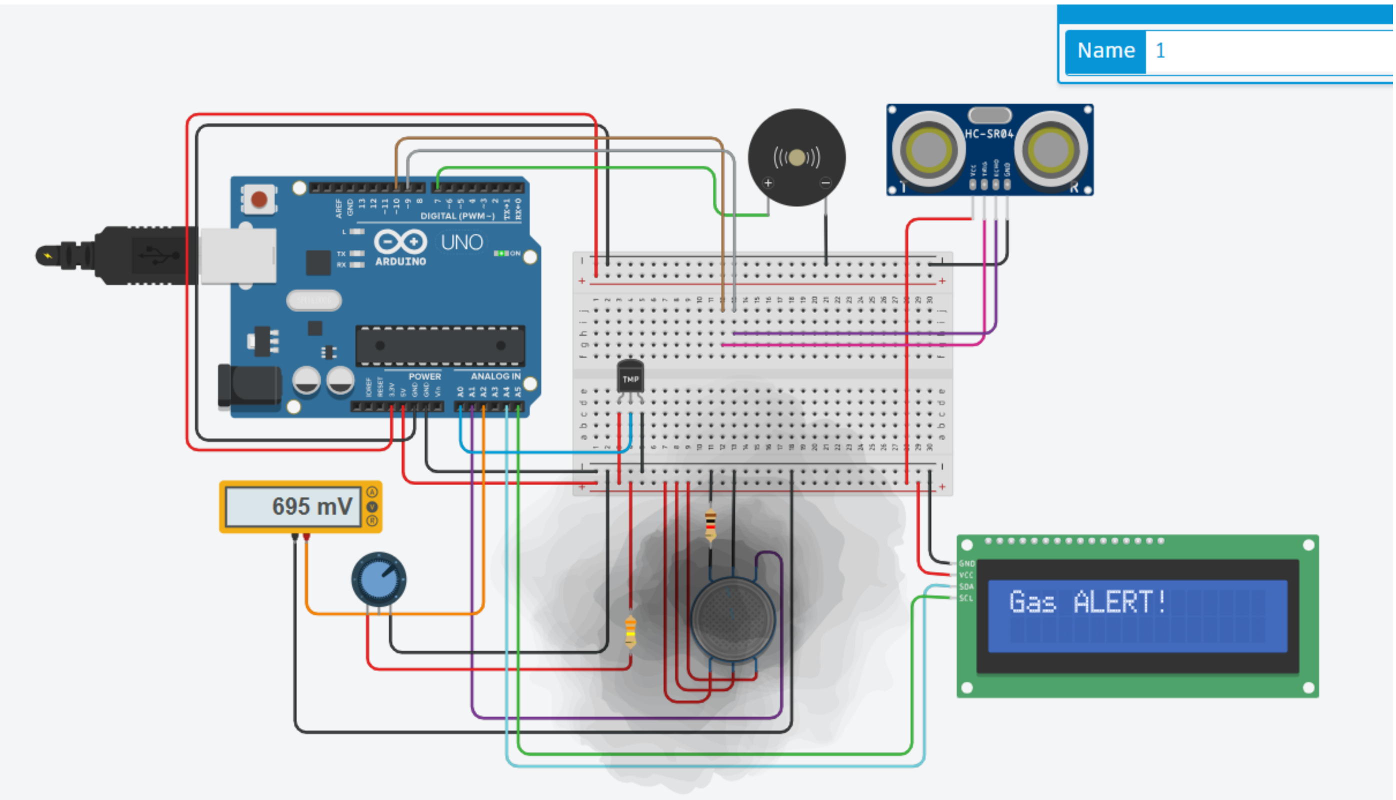


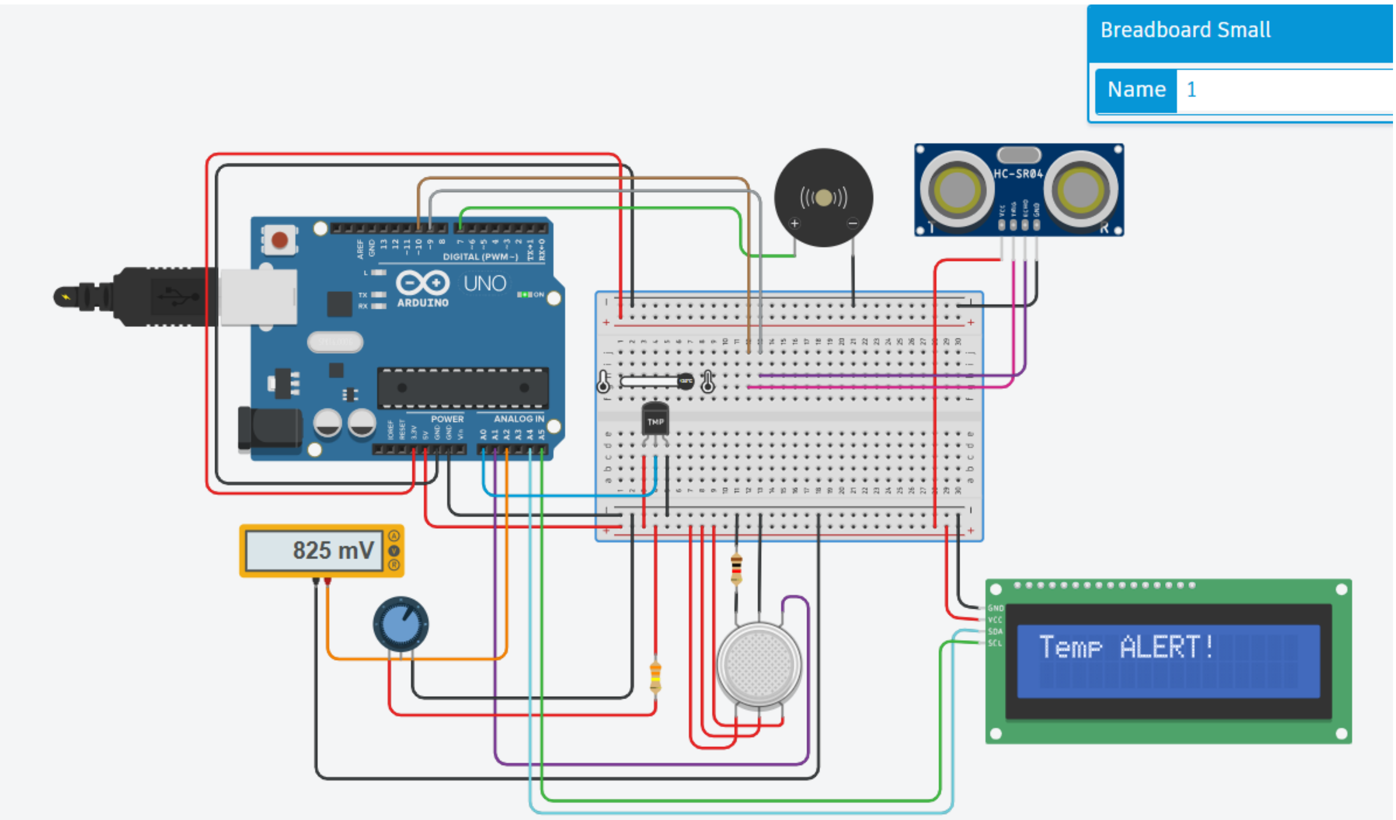
Fig: Normal Image of Smart Weather Station

C. Simulated Image of Smart Weather Station






Name 1
HC-SR04
UNO
ARDUINO
DIGITAL (PWM~)
POWER
ANALOG IN
695 mV
Gas ALERT!


Breadboard Small
Name 1
HC-SR04
UNO
ARDUINO
DIGITAL (PWM~)
POWER
ANALOG IN
825 mV
Temp ALERT!

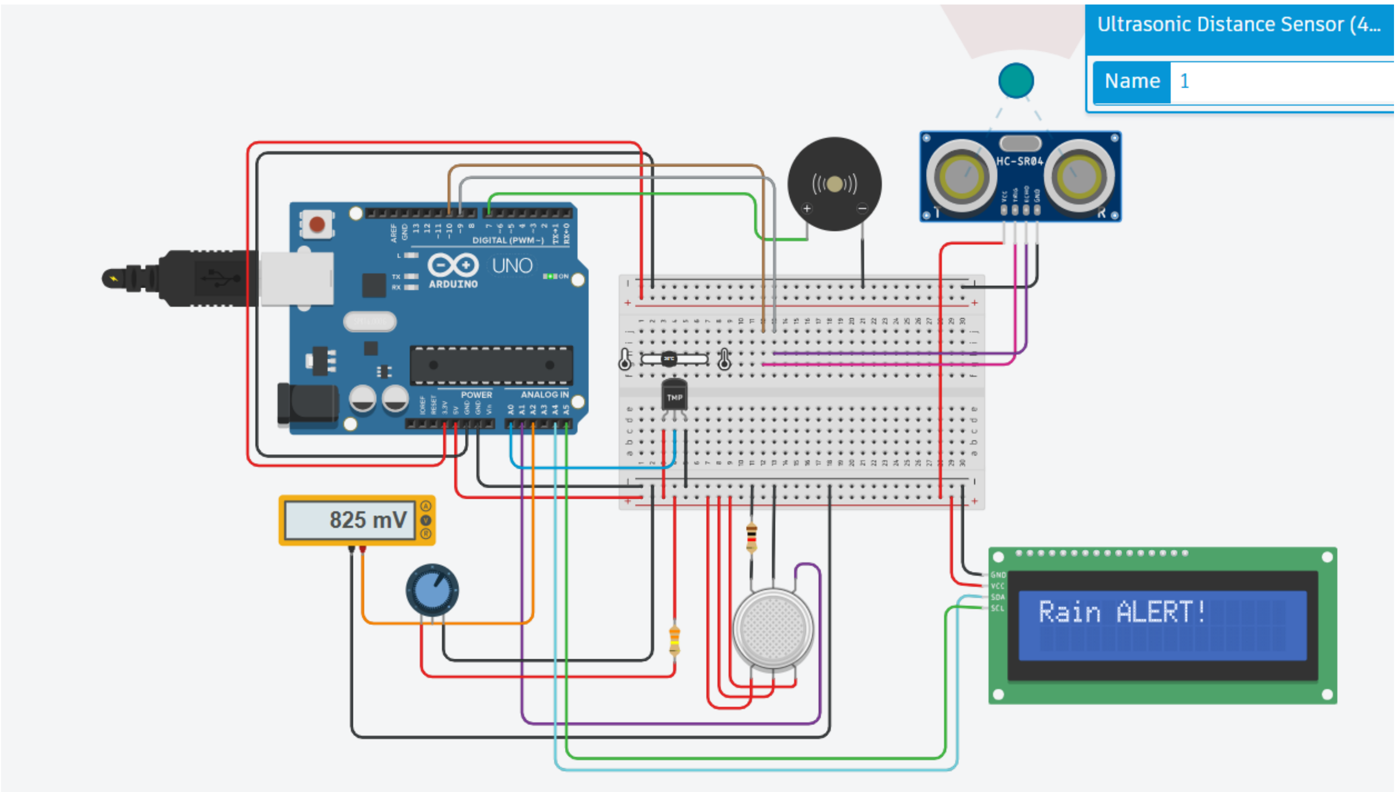


Fig: Simulated Image of Smart Weather Station

D. Schematic View of Smart Weather Station

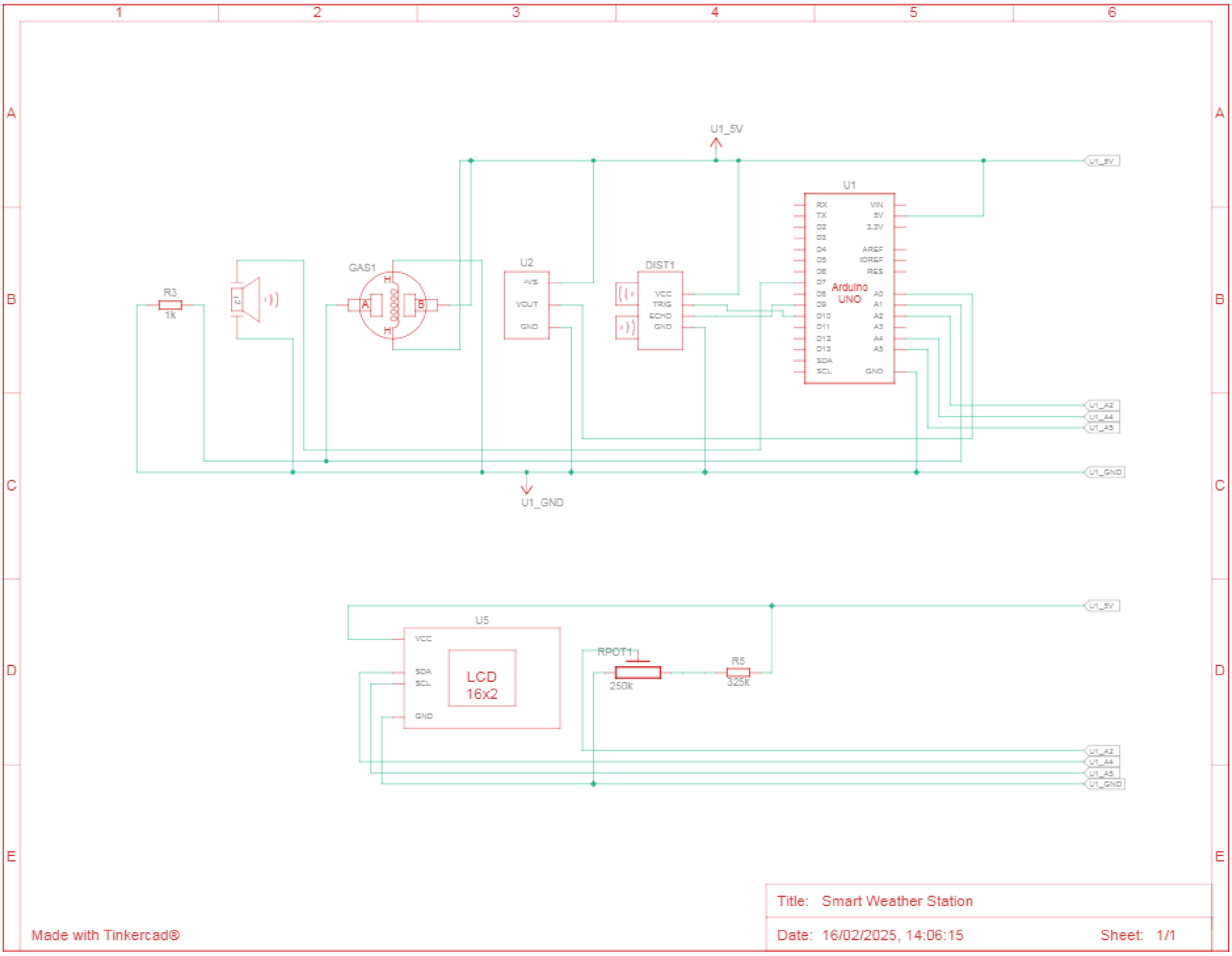


Fig: Schematic View of Smart Weather Station

E. Arduino Code of Smart Weather Station

```
#include <Wire.h>
#include <LiquidCrystal_I2C.h>  // Import the library for I2C LCD

// Sensor variables
float temp_vout, temp, voltage, rain, V_wind;
int gas_sensor_value, Windspeedint;
bool rainAlert = false, windAlert = false, tempAlert = false, gasAlert = false;

// Pin definitions
const int gas_sensor_port = A1;
const int triggerPin = 10;
const int echoPin = 9;
const int buzzerPin = 7;
const int temp_sensor_pin = A0;
const int wind_sensor_pin = A2;
```

```
// LCD initialization
LiquidCrystal_I2C lcd(0x27, 16, 2);

void setup() {
  pinMode(gas_sensor_port, INPUT);
  pinMode(temp_sensor_pin, INPUT);
  pinMode(wind_sensor_pin, INPUT);
  pinMode(triggerPin, OUTPUT);
  pinMode(echoPin, INPUT);
  pinMode(buzzerPin, OUTPUT);

  lcd.init();
  lcd.backlight();
  Serial.begin(9600);
}

void loop() {
  // Measure Rainfall
  digitalWrite(triggerPin, LOW);
  delayMicroseconds(2);
  digitalWrite(triggerPin, HIGH);
  delayMicroseconds(10);
  digitalWrite(triggerPin, LOW);
  long duration = pulseIn(echoPin, HIGH);
  rain = 0.01723 * duration;
  rainAlert = (rain > 100);

  // Measure Wind Speed
  V_wind = analogRead(wind_sensor_pin) * (5.0 / 1023.0);
  Windspeedint = (V_wind - 0.4) * 20;
  windAlert = (Windspeedint > 10);

  // Measure Temperature
  temp_vout = analogRead(temp_sensor_pin);
  voltage = temp_vout * 0.0048828125;
  temp = (voltage - 0.5) * 100.0;
  tempAlert = (temp > 30);

  // Measure Gas Level
  gas_sensor_value = analogRead(gas_sensor_port);
  gasAlert = (gas_sensor_value > 200);

  // Prioritize and Display Alerts
  if (gasAlert) {
    lcd.clear();
    lcd.setCursor(0, 0);
    lcd.print("Gas ALERT!");
    tone(buzzerPin, 1200, 2000);
    delay(2000);
  }
  if (tempAlert) {
    lcd.clear();
    lcd.setCursor(0, 0);
    lcd.print("Temp ALERT!");
    tone(buzzerPin, 600, 2000);
    delay(2000);
  }
```

```
  if (rainAlert) {
    lcd.clear();
    lcd.setCursor(0, 0);
    lcd.print("Rain ALERT!");
    tone(buzzerPin, 1000, 2000);
    delay(2000);
  }
  if (windAlert) {
    lcd.clear();
    lcd.setCursor(0, 0);
    lcd.print("Wind ALERT!");
    tone(buzzerPin, 800, 2000);
    delay(2000);
  }

  // Display Normal Readings
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("Rain: "); lcd.print(rain); lcd.print("mm");
  lcd.setCursor(0, 1);
  lcd.print("Wind: "); lcd.print(Windspeedint); lcd.print("MPH");
  delay(2000);

  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("Temp: "); lcd.print(temp); lcd.print("C");
  lcd.setCursor(0, 1);
  lcd.print("Gas: "); lcd.print(gas_sensor_value);
  delay(2000);
}
```

V. DISCUSSION

Smart weather stations have significantly advanced with IoT technology integration, enhancing accuracy, real-time data acquisition, and sustainability in weather monitoring. This discussion explores their key strengths, challenges, and future potential.

These modern stations utilize high-tech sensors, including temperature, humidity, wind speed, and air pressure measurement tools, to provide accurate weather predictions and optimize resource utilization. Addressing SDG 13 (Climate Action), smart weather stations supply location-specific data that help communities and industries mitigate climate change effects while reducing environmental impact. In agriculture, real-time weather data aids in irrigation scheduling, minimizing water waste (Smith et al., 2021).

Smart weather stations align with SDG 7 (Affordable and Clean Energy) by operating on renewable energy sources like solar power, reducing reliance on non-renewable energy. They also enhance smart grid efficiency through optimized data distribution, fostering sustainable energy systems on both regional and global scales (Jones & Patel, 2022).

These stations also contribute to SDG 3 (Good Health and Well-Being) by providing early warnings for natural disasters such as cyclones, floods, and heatwaves. Real-time alerts enable communities to prepare for evacuations and disaster response, minimizing casualties and property damage (Brown et al., 2020).

Despite these benefits, challenges persist. Many smart weather stations undergo testing in controlled environments that fail to replicate real-world conditions, affecting performance accuracy. High implementation and maintenance costs hinder widespread adoption, particularly in developing countries (Taylor et al., 2023). Additionally, environmental impact assessments must consider the entire lifecycle of electronic components, from production to disposal, to ensure net ecological benefits (Taylor et al., 2023).

Future research should focus on deploying smart weather stations in diverse environments to assess real-world performance. Machine learning and AI advancements can improve predictive analytics, enhancing disaster preparedness and resource management. AI algorithms analyzing historical weather data can refine forecasting accuracy (Williams et al., 2023).

Innovations in materials science can facilitate the development of sustainable sensors using biodegradable or recyclable components, promoting SDG 12 (Responsible Consumption and Production). Blockchain technology can further enhance data reliability and transparency, fostering trust in weather monitoring systems (Green et al., 2022).

Integrating smart weather stations with IoT-driven smart grids, agricultural systems, and urban infrastructure will create a more interconnected and efficient system (Harris et al., 2021). These advancements will improve environmental monitoring and broaden applications across various engineering fields.

Security considerations are crucial in ensuring the integrity and reliability of smart weather stations. Data transmission should incorporate end-to-end encryption to prevent cyber threats and unauthorized access. Firewalls must be properly configured to block malicious attacks, and IoT devices should implement secure boot mechanisms to ensure only verified firmware runs on the system. Additionally, user authentication and access control are essential in remote monitoring dashboards to restrict unauthorized data manipulation and system breaches. Robust security measures not only protect sensitive environmental data but also enhance the overall trustworthiness of smart weather systems (Lee & Chen, 2023).

VI. Conclusion

1. Conclusion

The implementation of the smart weather station demonstrates how Arduino-based sensor technology can establish affordable systems for real-time environmental monitoring. The established system successfully collects localized weather data yet holds potential to extend into broader uses which include smart city infrastructure implementation and climate-resilient planning.

2. Limitations

The system has three main drawbacks which consist of its limited data storage horsepower and its dependence on Internet access for remote operation and intermittent sensor performance precision issues. The system needs essential improvements to enhance its reliability together with scalability features.

3. Future Recommendations

The system would benefit from future development of wireless data transmission with LoRaWAN technology and cloud-based storage combined with AI models to predict weather and detect system anomalies. Security measures need implementation for protecting data integrity and user privacy should be considered part of the future plan. Smart weather stations will maintain their essential position as sustainable environmental monitoring solutions because of new advancements.

References

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