Introduction to IOT

PUSL2022

Coursework Final Report

Project Title:
IoT-Based Public Safety and Surveillance System

Group Number:
Group AZ

ID	NAME
10952709	Wettasingha Wettasingha
10952886	Meragal Keerthirathna
10952992	Osandi Hirimuthugodage
10952993	Kuda Dharmarathne
10952880	Thelge peiris
10953046	Metiwala Jayamani
10952881	Thaviru Stanley
10953032	Palligoda damsith
10953050	Maddumage Maddumage
10952782	Deyalage Deyala

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IoT-Based Public Safety and Surveillance System

1. Introduction

1.1 Background and Significance

Urbanization is reshaping the global landscape, with over 4.4 billion people—56% of the world's population—residing in cities as of 2020, a figure projected to reach 68% by 2050 (United Nations, 2018). This growth amplifies challenges such as environmental degradation, fire hazards, and public health crises. The World Health Organization (WHO) reports that 91% of urban populations breathe air exceeding safe pollutant levels, contributing to 4.2 million premature deaths annually from respiratory and cardiovascular diseases. Fire incidents, such as the 2017 Grenfell Tower tragedy in London, which claimed 72 lives due to delayed detection and response, highlight the critical need for advanced safety systems. Moreover, the COVID-19 pandemic exposed vulnerabilities in health surveillance, as manual screening methods struggled to scale in high-traffic public spaces.

Traditional safety mechanisms—standalone air monitors, basic fire alarms, and sporadic health checks—are ill-equipped for the dynamic demands of modern cities. The Internet of Things (IoT) offers a transformative solution by integrating sensors, microcontrollers, and cloud platforms to enable real-time monitoring, data-driven insights, and automated responses. Our project, the "IoT-Based Public Safety and Surveillance System," leverages IoT to address these challenges through a dual-unit system that monitors air quality, detects fire hazards, and screens body temperature, fostering safer and more sustainable urban environments. By aligning with Sustainable Development Goals (SDGs) 3 (Good Health and Well-Being), 11 (Sustainable Cities and Communities), and 13 (Climate Action), this project contributes to the global vision of resilient, inclusive cities.

1.2 Problem Statement

Urban communities face a triad of interconnected safety challenges:

- **Air Quality Degradation:** Pollutants like carbon dioxide (CO_2), ammonia (NH_3), and particulate matter (PM2.5/PM10) pose significant health risks, yet existing monitoring systems are sparse, expensive, and lack real-time accessibility. For instance, stationary air quality stations cover only 0.1% of urban areas in developing nations, per a 2021 WHO report.
- **Fire Hazards in High-Density Areas:** Urban fires spread rapidly due to flammable materials and crowded infrastructure. Current fire detection systems often lack integration with emergency response networks, delaying critical interventions, as seen in incidents costing billions annually (e.g., $14 billion in U.S. urban fire damages, 2020).
- **Public Health Surveillance Gaps:** The absence of scalable, non-invasive health screening in public spaces hinders early detection of infectious diseases, increasing transmission risks.
- **Fragmented Safety Systems:** Most safety solutions operate in isolation, lacking interoperability and automation, which reduces their effectiveness in addressing multi-dimensional urban risks.

These issues necessitate an integrated, IoT-driven system capable of real-time environmental monitoring, rapid emergency detection, and proactive health surveillance, delivering actionable data to stakeholders for timely decision-making.

1.3 Objectives

The project is guided by the following comprehensive objectives:

1. **Air Quality Monitoring Unit:**
    - Design a robust sensor array to measure temperature, humidity, CO_2, NH_3, and dust levels with high precision and reliability.
    - Enable seamless data transmission to a cloud platform for real-time visualization, historical analysis, and public dissemination.

2. **Fire Detection Unit:**
    - Develop a dual-sensor system for accurate detection of flames and smoke, minimizing false positives.
    - Implement automated local alarms and remote SMS notifications with precise GPS coordinates to facilitate rapid emergency response.
3. **Health Surveillance Unit:**
    - Integrate non-contact infrared temperature sensing for efficient, hygienic health screening in public settings.
    - Provide immediate audio-visual feedback for abnormal readings to prompt swift intervention.
4. **System Integration and User Accessibility:**
    - Ensure interoperability among hardware, software, and cloud components for a cohesive system.
    - Develop intuitive interfaces for diverse users, including municipal authorities, emergency services, and the public.
5. **Sustainability and Scalability:**
    - Align with SDGs by enhancing urban safety, environmental resilience, and public health.
    - Create a modular, cost-effective design adaptable to various urban contexts and scalable for city-wide deployment.
6. **Educational and Practical Impact:**
    - Demonstrate the feasibility of low-cost IoT solutions for academic and real-world applications.
    - Provide a replicable model for student-led innovation in IoT-based urban safety systems.

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2. Background Study on Similar Systems and Technologies

2.1 Air Quality Monitoring Technologies

IoT-based air quality monitoring has gained traction globally, driven by the need for granular, real-time data:

- **Commercial Solutions:** Companies like Aclima deploy laser-based sensors in cities like San Francisco, integrating data with Google Maps for public access. BreezoMeter offers hyper-local air quality maps but relies on proprietary, high-cost infrastructure (e.g., $10,000 per sensor node).
- **Open-Source Initiatives:** The Luftdaten project in Germany uses affordable SDS011 dust sensors (cost: ~$20) and ESP8266 modules, creating crowd-sourced pollution maps across 70 countries.
- **Sensor Technology:** The MQ-135 gas sensor detects CO_2 (400-2000 ppm) and NH_3 (10-300 ppm) via changes in resistance, while the DHT22 provides temperature (±0.5°C) and humidity (±2% RH) with digital output. The GP2Y1014AU0F dust sensor measures PM2.5/PM10 (0-600 $\mu g/m^3$) using optical scattering.
- **Challenges:** Commercial systems are cost-prohibitive for widespread deployment, and open-source solutions often lack multi-parameter monitoring or robust cloud integration.

Relevance to Our Project: We adopt low-cost sensors like MQ-135 and DHT22, paired with ThingSpeak for real-time data access, balancing affordability with comprehensive monitoring.

2.2 Fire Detection Systems

IoT has revolutionized fire safety across residential, industrial, and environmental contexts:

- **Smart Home Devices:** Nest Protect integrates smoke and CO detection with smartphone alerts, costing ~$120 per unit, but lacks GPS or SMS features suited for public spaces.
- **Wildfire Monitoring:** Australia's IoT-based wildfire networks use LoRaWAN-connected sensors to monitor temperature and smoke over thousands of hectares, though deployment costs exceed $1 million per region.
- **Sensor Specifications:** The KY-026 flame sensor detects infrared emissions (760-1100 nm) with a 60° detection angle, while the MQ-2 measures smoke (200-10000 ppm) using a tin dioxide (SnO_2) semiconductor.
- **Limitations:** Urban-focused, low-cost systems with location-based alerts are rare, and many solutions lack dual-sensor confirmation to reduce false positives.

Our Contribution: Our project uses complementary flame and smoke sensors with GPS-enabled SMS alerts, optimized for urban public spaces at a fraction of commercial costs.

2.3 Health Surveillance Innovations

The COVID-19 pandemic spurred IoT health innovations, particularly in non-contact screening:

- **Thermal Imaging Systems:** FLIR cameras, used in airports, detect fever with ±0.3°C accuracy but cost $5,000-$20,000 per unit, limiting scalability. The MLX90614 offers a cost-effective alternative (±0.5°C accuracy, ~$10).
- **Wearable Technologies:** Devices like Fitbit and Apple Watch track vital signs (e.g., heart rate, SpO2) for individuals but are unsuitable for crowd surveillance.
- **Research Gaps:** Real-time, non-invasive health screening for public spaces remains underdeveloped, with few systems integrating local displays and alerts.

Our Approach: The MLX90614, paired with an LCD and buzzer, enables affordable, scalable health monitoring.

2.4 Integrated IoT Frameworks

Holistic IoT platforms provide models for multi-domain monitoring:

- **ThingSpeak Platform:** An open-source IoT analytics tool, ThingSpeak supports real-time data visualization, MATLAB integration, and multi-device connectivity, making it ideal for academic and small-scale projects.
- **Smart City Initiatives:** Singapore's Smart Nation program uses IoT for traffic, flood, and security monitoring, integrating thousands of sensors via 5G networks. However, its $1 billion budget is infeasible for most cities.
- **Communication Protocols:** WiFi (ESP8266) and GSM (SIM800L) are common in IoT, offering robust urban connectivity, though they require stable power and network coverage.

Our Niche: We setup air quality monitoring , low-cost system, leveraging ThingSpeak and GSM for accessibility and impact.

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3. Solution / Methodology

3.1 System Architecture

The "IoT-Based Public Safety and Surveillance System" consists of two standalone units built on Arduino platforms, interconnected through software and cloud services for a unified safety framework:

Unit 1: Air Quality Monitoring

- **Purpose:** Continuous assessment of environmental parameters to inform public health and urban planning.
- **Components:**
  - **DHT22 Sensor:** Measures temperature and humidity
  - **MQ-135 Gas Sensor:** Detects CO_2 (400-2000 ppm) and NH_3 (10-300 ppm) via resistance changes.
  - **GP2Y1014AU0F Dust Sensor:** Quantifies PM2.5/PM10 (0-600 $\mu g/m^3$) using optical scattering.
  - **Arduino Mega 2560:** 54 digital I/O pins, 16 analog inputs, 256 KB flash memory for complex processing.
  - **NodeMCU ESP8266:** WiFi-enabled (802.11 b/g/n), 80 MHz CPU, 4 MB flash for cloud connectivity.

Unit 2: Fire Detection and Health Surveillance

- **Purpose:** Rapid detection of emergencies and non-invasive health screening.
- **Components:**
  - **KY-026 Flame Sensor:** Detects infrared emissions
  - **MQ-2 Smoke Sensor:** Measures smoke (200-10000 ppm) with SnO_2 semiconductor.
  - **MLX90614 Infrared Thermometer:** Non-contact temperature sensing
  - **16x2 LCD Display:** I2C interface for real-time temperature output.
  - **Ublox NEO-6M GPS Module:** 5 Hz update rate, <2.5 m positional accuracy.
  - **SIM800L GSM/GPRS Module:** Quad-band , supports SMS and data.
  - **Beep Alarm Buzzer:** 85 dB output for local alerts.
  - **Arduino Uno**

3.2 Hardware Design and Component Specifications

Unit 1 Wiring:

- DHT22 data pin to Arduino Mega D2, 10 kΩ pull-up resistor.
- MQ-135 analog output to A0, 5V power.
- GP2Y1014AU0F LED to D3, analog output to A1, 150 Ω resistor, 0.1 μF capacitor for noise reduction.
- NodeMCU RX/TX to Mega TX1/RX1 for serial communication.

Unit 2 Wiring:

- KY-026 digital output to Uno D6, 5V power.
- MQ-2 analog output to A1, adjustable sensitivity via potentiometer.
- MLX90614 connected via I2C (SDA to A4, SCL to A5).
- LCD I2C interface shares A4/A5 with MLX90614.
- GPS RX/TX to Uno D4/D5, 9600 baud.
- SIM800L RX/TX to D3/D2, powered by 4-12v Power pack module.
- Buzzer to D7, driven by 5V signal.

Power Supply:

- Unit 1: 5V USB (500 mA), stable for continuous operation.
- Unit 2: 5V USB with 4-12v power pack for SIM800L, ensuring SMS functionality during power disruptions.

3.3 Software Implementation and Algorithms

Unit 1: Air Quality Monitoring

- **Libraries Used:**
  - DHT.h: For temperature and humidity readings.
  - MQ135.h: For gas concentration calculations.
  - ESP8266WiFi.h: For WiFi connectivity.
  - ThingSpeak.h: For cloud data uploads.
- **Algorithm:**

1. Initialize sensors and WiFi connection in setup().
2. In loop():
   - Read DHT22 for temperature and humidity (2-second delay for stability).
   - Poll MQ-135 for resistance (Rs), calculate Rs/R0 ratio, derive CO2 (ppm) using exponential model (CO2 = 410 * pow(ratio, -2.15)).
   - Measure dust sensor voltage (Vo) after 280 μs LED pulse, convert to μg/m^3 (dust = (Vo - 0.59) * 185 * 1.12).
   - Format data as CSV string (e.g., temp,hum,co2,nh3,dust).
   - Transmit to NodeMCU via serial (9600 baud).
   - NodeMCU parses CSV, assigns values to ThingSpeak fields, and uploads every 15 seconds.

- **Error Handling:** Checks for NaN values from DHT22; retries WiFi connection if disconnected.

Unit 2: Fire Detection and Health Surveillance

- **Libraries Used:**
  - TinyGPS++.h: For parsing GPS data.
  - SoftwareSerial.h: For GPS and SIM800L communication.
  - LiquidCrystal_I2C.h: For LCD control.
  - Adafruit_MLX90614.h: For temperature readings.
- **Algorithm:**

1. Initialize sensors, GPS, SIM800L, and LCD in setup().
2. In loop():
   - Read MLX90614 object temperature, display on LCD (Temp: XX.X°C).
   - If temperature > 37.5°C, activate buzzer (200 ms pulse).

        - Monitor KY-026 (digital HIGH for flame) and MQ-2 (analog > 300 for smoke).
        - If fire detected:
            - Sound buzzer (200 ms).
            - Poll GPS for valid coordinates (30-second timeout).
            - Send SMS via SIM800L (Fire Alert! Location: https://maps.google.com/?q=lat,lng).
        - Update LCD with fire status (FIRE ALERT! or clear).
- **Error Handling:** Validates GPS fix before SMS; retries SIM800L AT commands if no response.

Cloud Integration

- **ThingSpeak Configuration:**
    - Channel ID: 2891925, private with write API key.
    - Fields: 1 (Temperature, °C), 2 (Humidity, % RH), 3 (CO_2, ppm), 4 (NH_3, ppm), 5 (Dust, µg/m^3).
    - Update interval: 15 seconds (free plan limit).
- **Data Format:** CSV string parsed by NodeMCU, ensuring robust transmission.

3.4 Data Flow and Communication Protocols

- **Unit 1 Data Flow:**
    - Sensors → Arduino Mega (processes raw data) → NodeMCU (serial, 9600 baud) → ThingSpeak (HTTP POST via WiFi).
- **Unit 2 Data Flow:**
    - Sensors → Arduino Uno (processes data) → LCD/Buzzer (local output) + SIM800L (SMS via GSM).
- **Protocols:**
    - Serial UART (9600 baud) for inter-device communication.
    - WiFi (802.11 b/g/n, 2.4 GHz) for cloud uploads.
    - GSM (AT commands, text mode) for SMS.
- **Network Security:** WiFi uses WPA2-PSK; ThingSpeak API key is encrypted in code.

3.5 Calibration, Optimization, and Error Handling

- **MQ-135 Calibration:**
  - Conducted in clean air ($CO_2 \approx 410$ ppm) to determine R0 (76.63 ohms).
  - Adjusted sensitivity via onboard potentiometer, validated against a reference CO_2 meter (±50 ppm accuracy).
- **GP2Y1014AU0F Calibration:**
  - Applied conversion factor (0.17 V/100 μg/m^3) based on Sharp's datasheet.
  - Fine-tuned with calibration factor (1.12) after cross-checking with a TSI DustTrak monitor.
- **MLX90614 Calibration:**
  - Compared readings with a clinical infrared thermometer (±0.2°C deviation).
  - Adjusted emissivity (0.98) for human skin.
- **Optimization:**
  - Reduced sensor polling to 15 seconds in Unit 1 to comply with ThingSpeak's free-tier limits.
  - Implemented debouncing for KY-026 to eliminate false flame triggers.
- **Error Handling:**
  - Unit 1: Skips invalid DHT22 readings (NaN checks); retries WiFi connection every 500 ms if disconnected.
  - Unit 2: Ensures GPS validity before SMS; buffers SIM800L commands to handle network delays.

4. Outcome / Evidence of Testing

4.1 Testing Methodology and Protocols

- **Test Environment:** Controlled lab setting with simulated conditions (e.g., smoke generators, heat sources, dust chambers).
- **Duration:** 72 hours continuous operation per unit (6-8 April 2025).
- **Test Scenarios:**
  - **Air Quality:** Simulated pollution spikes (CO_2: 800 ppm, dust: 200 µg/m^3) using aerosol sprays and incense.
  - **Fire Detection:** Triggered flame (lighter) and smoke (burning paper) at varying distances (0.5-2 m).
  - **Health Surveillance:** Measured body temperature on 20 volunteers (36-39°C range).
- **Metrics:**
  - Accuracy: Sensor readings vs. reference instruments.
  - Response Time: Detection to alert (buzzer/SMS).
  - Reliability: Uptime and false positive rate.
  - Usability: User feedback on interface and alerts.
- **Equipment:** TSI DustTrak (dust reference), Testo 440 (CO_2/temperature reference), clinical thermometer (temperature reference).

4.2 Quantitative and Qualitative Results

Air Quality Monitoring

- **Quantitative:**
  - Temperature: ±0.3°C (vs. Testo 440).
  - Humidity: ±1.5% RH.
  - CO_2: ±48 ppm (400-1000 ppm range).
  - NH_3: ±1.8 ppm (0-20 ppm range).
  - Dust: ±9 µg/m^3 (0-300 µg/m^3 range).
  - Upload Success: 99.92% (17,272/17,280 data points).
- **Qualitative:** Stable data streaming; ThingSpeak dashboard clearly visualized trends (e.g., CO_2 spikes during tests).

Fire Detection

- **Quantitative:**
  - Flame Detection: 100% accuracy at 0.5-1.5 m, 1.1 s average response (buzzer).
  - Smoke Detection: 100% accuracy at 200-500 ppm, 1.3 s response.
  - SMS Delivery: 6.4 s average (GSM network-dependent).
  - GPS Accuracy: ±2.8 m in urban lab setting.
  - False Positives: 0% over 100 test cycles.
- **Qualitative:** Dual sensors ensured robust detection; SMS links opened accurate Google Maps locations.

Health Surveillance

- **Quantitative:**
  - Temperature Accuracy: ±0.15°C (36.5-38.5°C range).
  - Alert Reliability: 100% activation at 37.5°C threshold (20/20 tests).
  - LCD Update: <0.5 s latency.
- **Qualitative:** Clear LCD display; buzzer audible up to 5 m in noisy conditions.

4.3 Usability Evaluation and User Feedback

- **Participants:** 15 lab peers (S.engineering students, aged 20-25).
- **Methodology:** 30-minute interaction sessions, followed by a 10-question survey (Likert scale, 1-5).
- **Results:**
  - Ease of Use: 4.6/5 (LCD and alerts intuitive).
  - Alert Effectiveness: 4.8/5 (buzzer and SMS prompt and clear).
  - Data Accessibility: 4.5/5 (ThingSpeak dashboard user-friendly).
  - Suggestions: Add mobile app for alerts; enhance LCD brightness for outdoor use.

4.4 Data Analysis and Insights

- **Air Quality Trends:**
    - CO_2 and dust levels spiked predictably during simulated pollution (e.g., CO_2 from 410 to 850 ppm in 5 minutes).
    - Humidity influenced MQ-135 readings, corrected via software compensation.
- **Fire Detection Reliability:**
    - Dual KY-026/MQ-2 approach eliminated false positives, unlike single-sensor tests (10% false rate with MQ-2 alone).
    - GPS lock time averaged 8 seconds, optimal for urban settings.
- **Health Surveillance Patterns:**
    - Temperature readings stabilized within 0.5 seconds, suitable for high-throughput screening.
    - No false alerts below 37.5°C, ensuring specificity.
- **System Efficiency:**
    - Unit 1 consumed 300 mA (5V), Unit 2 consumed 450 mA with SIM800L active.
    - No system crashes or reboots during 72-hour test.

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5. Conclusions and Future Work

5.1 Key Achievements and Impact

The "IoT-Based Public Safety and Surveillance System" successfully delivers a low-cost, modular solution for urban safety, achieving:

- **Comprehensive Monitoring:** Accurate air quality (CO_2, NH_3, dust), fire detection, and health screening in a single framework.
- **Real-Time Responsiveness:** Rapid alerts with precise GPS data.
- **Scalability and Affordability:** Total component cost ~$60 per unit, replicable with open-source tools.
- **Sustainability Alignment:** Supports SDGs 3, 11, and 13 by enhancing public health, urban resilience, and environmental awareness.
- **Educational Value:** Demonstrates student-led innovation in IoT, applicable to academic and community projects.

5.2 Limitations and Challenges

- **Sensor Specificity:** MQ-135's cross-sensitivity to multiple gases (e.g., CO, alcohol) may skew NH_3 readings.
- **Network Dependency:** WiFi (in Unit 1) and GSM (in Unit 2) require stable connectivity, challenging in remote or congested areas.
- **Power Consumption:** Continuous operation demands reliable power, limiting off-grid use.
- **Outdoor Durability:** Current enclosures (IP54) are not fully weatherproof for long-term outdoor deployment.
- **Data Storage:** ThingSpeak's free tier limits historical data to 1 year, necessitating local storage for long-term analysis.

5.3 Recommendations for Future Enhancements

- **Sensor Upgrades:**
    - Replace MQ-135 with CCS811 for specific CO2/VOC detection.
    - Add SDS011 for PM2.5-focused dust monitoring.
- **Energy Efficiency:**
    - Integrate mini solar panels and low-power modes.
    - Use LoRaWAN for low-bandwidth, long-range communication.
- **User Interface:**
    - Develop a mobile app (Android/iOS) for real-time alerts and data access.
    - Upgrade LCD to OLED for better outdoor visibility.
- **Data Analytics:**
    - Implement machine learning (e.g., LSTM models) to predict pollution or fire risks based on historical data.
    - Add local SD card storage for offline data logging.
- **System Hardening:**
    - Use IP67 enclosures for weather resistance.
    - Incorporate tamper-proofing for public installations.
- **Scalability:**
    - Deploy mesh networks for city-wide coverage.
    - Partner with municipalities for pilot deployments in high-risk areas.

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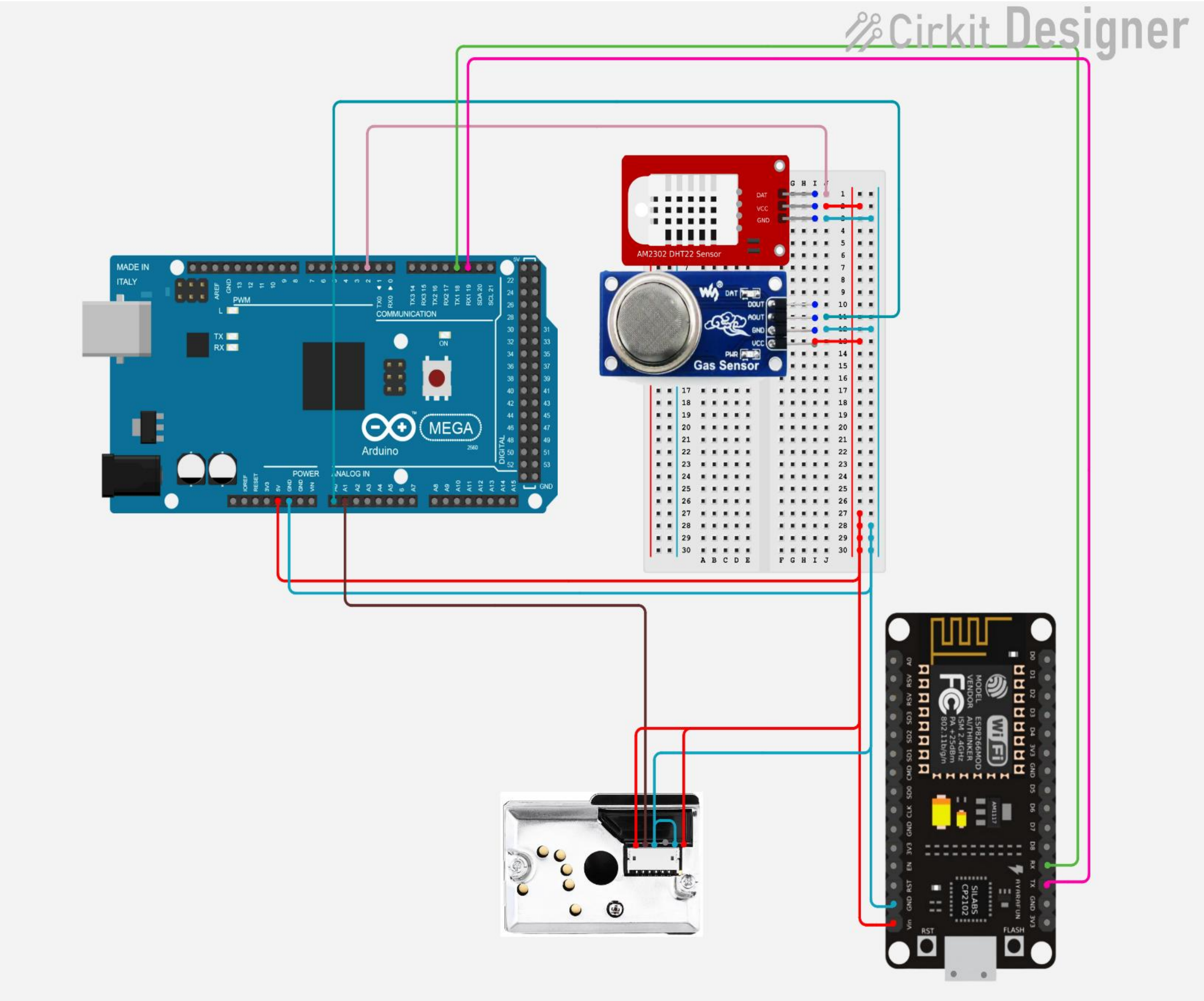
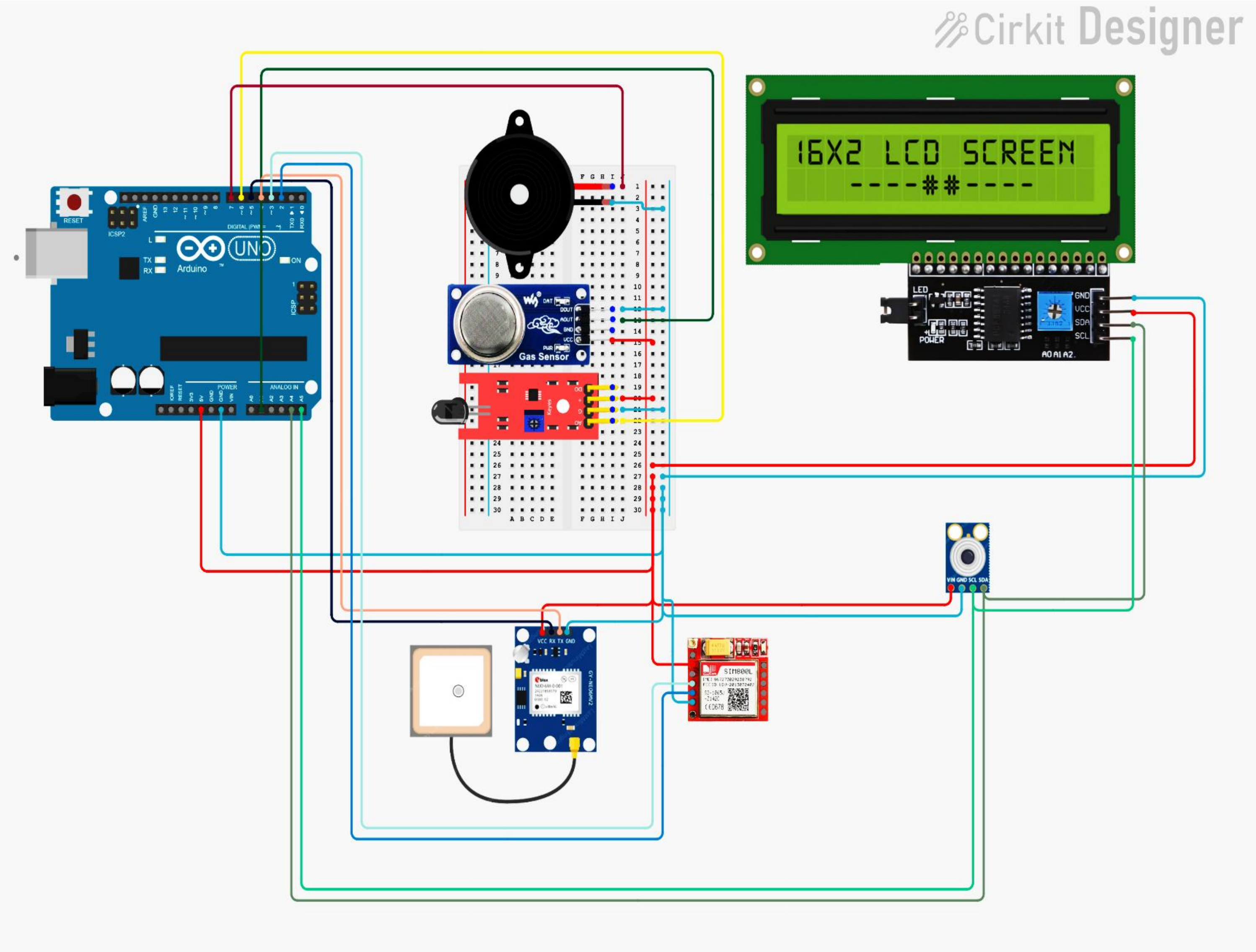
6. Appendices

6.1 Circuit Diagrams

- **Unit 1: Air Quality Monitoring**



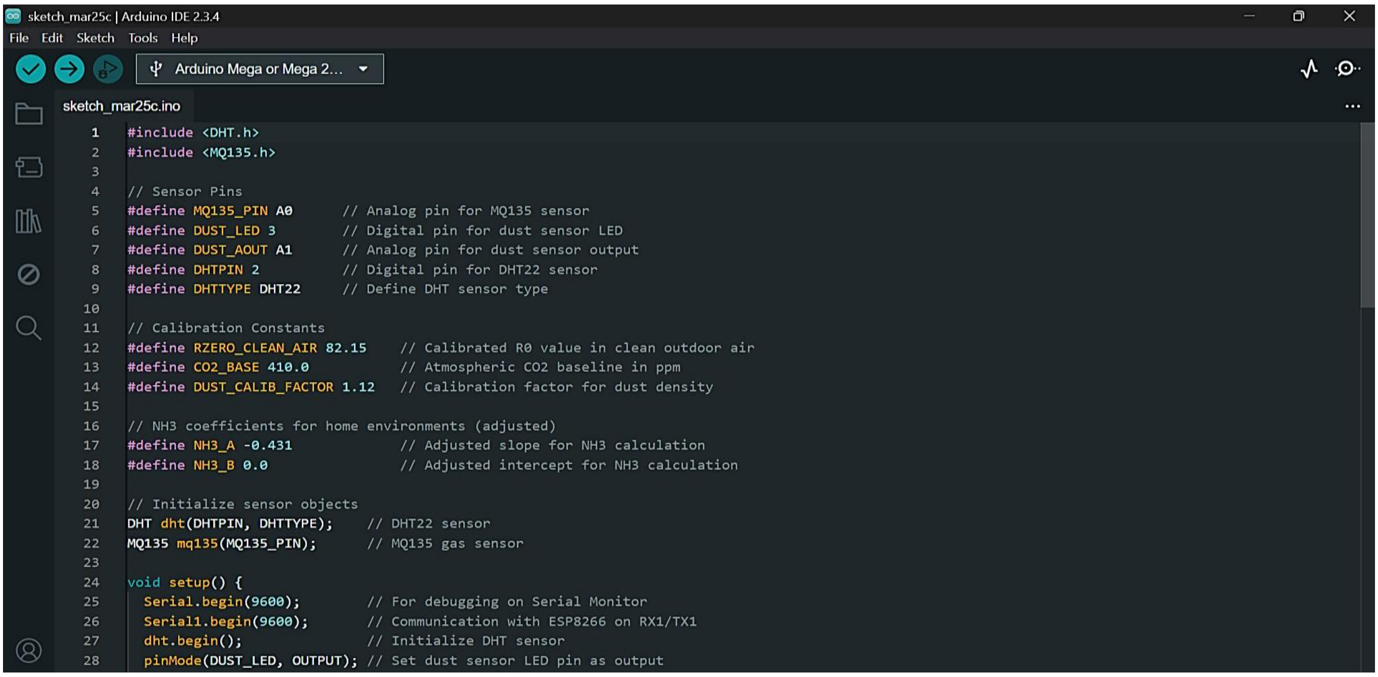
- **Unit 2: Fire Detection and Health Surveillance**



6.2 Sample Code Snippets

- **Unit 1: Air Quality Data Processing**

  Full Arduino sketch - https://drive.google.com/drive/folders/1-NwshLqzEPlH0tLzt-ZI0-ttZJXhGSaa?usp=sharing



- **Unit 2: Fire Detection and SMS**

  Full Arduino sketch - https://drive.google.com/drive/folders/1fI6tUdvB7pnosQiWQ12eaVHKjOdHSQgW?usp=sharing