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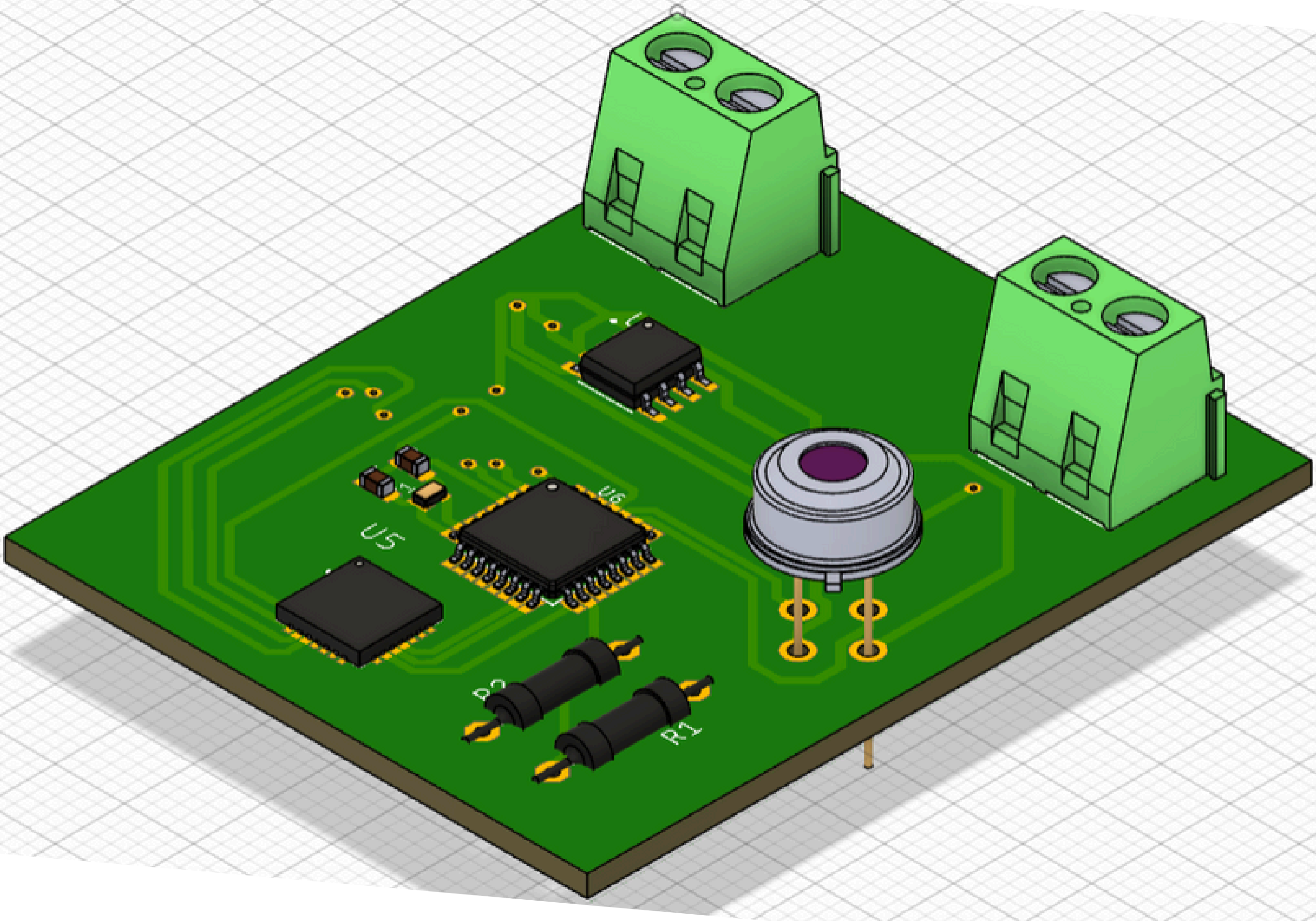
IC Innovation

# ICS FOR SUSTAINABILITY AGAINST CLIMATE CHANGE

*Design and Simulation Report of an IC-Based System for Natural Resource Preservation Through Wildfires Detection*




*Created by ENIG Guardians team*

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# Acknowledgments

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Chapter 1

# Introduction

## 1.1 Problem Statement

Forest fires are the most pernicious natural disasters due to their high impact on ecosystems, biodiversity, and human lives.

It is for reasons like these that it is imperative to identify fires as soon as possible in order to limit destruction and enable an immediate, focused response.

Traditional methods of fire detection and suppression are often inadequate, especially in remote or large forested regions where people do not go.

## 1.2 Project Context

In this paper, we propose a new application of our project to an automated forest fire detection system which offers solutions such as integration of IoT technologies, LoRa (Long Range) communication and autonomous drones for the vital purpose over real-time detection and action against forest fires.

Our vision is to use these technologies to break the barrier of existing systems and provide fire detection and extinguishment as a scalable, sustainable solution.

Justification of this project is in its capabilities to monitor remote and large areas of forest, use low-power communication protocols and provide quick response with a fire-fighting drone.

## 1.3 Challenge Framework

### 1.3.1 Resource Monitoring Alignment

**Air Quality Monitoring :**

Forest fires produce large amounts of pollutants that are released into the atmosphere, such as carbon dioxide ($CO_2$), carbon monoxide (CO), and particulate matter (PM). The system offers a real-time detection of fire incidents by employing MLX90614 temperature sensors in each node, indirectly contributing towards air quality monitoring.

- **Justification :** Detecting fires earlier will help to minimize the impact of atmospheric pollution because there will be a faster response time.
- **Scalability :** This system could be combined with air-pollution sensors ($NO_2$ or PM2.5) so as to track air pollution following wildfires and analyze effects on the environment.

### 1.3.2 Commitment Towards Optimal Utilization of Resources

- **Modules with Solar Energy Source :**

  Both nodes use solar panels with a battery management system (TP4055) so all the circuits work using renewable energy and for longer periods, reducing energy consumption.

  - **Justification :** Solar power matches the goals of this challenge by reducing depletion and emissions.
  - **Contrast :** Unlike traditional systems relying on grid power or disposable batteries, it is sustainable and cost-effective as it reduces both waste and energy costs.
- **Communication — LoRa (SX1278) :**

  The long-range and ultra-low-power design of LoRa optimizes communication between nodes and the central monitoring hub.

  - **Explanation :** LoRa avoids high-energy protocols like GSM or Wi-Fi by primarily (i) supporting the economical use of resources and (ii) having low power requirements from a system perspective. GSM/4G, while offering high data rates, would require too many energy resources and incur higher costs, making LoRa a superior choice in terms of sustainability.

### 1.3.3 Acting Early for Environmental Sustainability

**Instant notification of firefighters :**

By leveraging LoRa communication, the system transmits real-time alerts with precise fire location data, enabling teams to act swiftly significantly reducing the spread of wildfires and their environmental impact.

**Integration of a Drone System :**

If a fire is detected, the central hub releases an autonomous drone armed with hydrogen bombs to neutralize it on the spot.

— **Justification :** This system reduces the spread of flames, protecting natural habitats, maintaining biodiversity, and minimizing carbon emissions from prolonged wildfires.

— **Possible Extensions :** The drone could be used to monitor reforestation efforts after a fire or analyze atmospheric pollutants.

## 1.4 Proposed Solution

Our approach consists of setting up a grid of sensor nodes interconnected through LoRa modules to an admin tracking station. These sensors identify spikes in temperature, which subsequently activate alarms at a central hub. The system includes three circuits : sensor nodes equipped with temperature sensors, intermediary hubs handling data aggregation and communication between nodes, and a final central unit responsible for sending alarm messages to firefighters and transmitting data to the drone that will distribute Hydrogen extinguishing bombs. This method reduces human intervention and presents an efficient fully autonomous solution to forest fire management.

Chapter

# 2 Objectives

## 2.1 Primary Objective

An integrated real-time forest fire detection and automatic fire suppression system.

This aligns with the increasing demand for sustainable and automated solutions in addressing globally increasing instances of wildfires.

## 2.2 Specific Objectives

### 2.2.1 Detect Environmental Parameters

By monitoring temperature, humidity, and smoke, we can be alerted to fires earlier.

This approach addresses the challenge faced by existing systems, which is delayed detection resulting in widespread devastation.

### 2.2.2 Deploy LoRa for Robust Long-Distance Communication

With its long-range, low-power features, LoRa is perfectly suited to these remote forested areas in which wireless networks such as Wi-Fi or GSM are unfeasible.

### 2.2.3 Sensor Data Visualization Dashboard

A single interface for decision-makers to view where fires are being detected so they can be proactively stopped before causing major damage.

### 2.2.4 Autonomous Firefighting

We address the question of human safety by sending a drone carrying hydrogen extinguishing bombs to suppress the fire.

Chapter
# 3 Literature Review

## 3.1 Existing Systems

Most wildfire detection systems are based on traditional sensors (smoke detectors or temperature sensors).

However, these solutions face range, power savings, and communication reliability problems, particularly in remote locations.

Additionally, firefighting is human-driven, making it a slow or potentially life-threatening process.

## 3.2 Gaps in Current Solutions

Existing systems do not incorporate precise long-range communication protocols, effective real-time data aggregation, and autonomous firefighting capabilities.

These constraints hinder their ability to deliver rapid response for vast or hard-to-reach areas.

## 3.3 Proposed Innovation

The presented solution addresses these gaps by integrating long-range, low-power communication through LoRa technology with autonomous drones for targeted fire suppression.

It facilitates not merely accurate detection at an early stage but also swift automated action, showcasing the role modern IoT technologies can play in tackling forest fire management.

Chapter
4

# Methodology

## 4.1 System Architecture

### 4.1.1 Overview Diagram

An abstract overview of the relationships between :

— **Sensor Node Circuit :** Responsible for detecting fire and transmitting data via the LoRa module.

— **Principal Central Circuit :** Acts as the main hub, gathering sensor data, ensuring its integrity, and relaying alarm messages to firefighters and drones.

— **Fire department-Based Circuit :** Displays the sensor data on a mapped interface using LED indicators to identify the location of detected fires.

### 4.1.2 System Description

The system consists of three main circuits :

#### 4.1.2.1 Sensor Node Circuit

**Function :** The Sensor Unit detects fire within a 1-meter radius using sensors (DHT11 and MQ-7). Upon detection, it sends its unique ID and fire alert data to the Central Unit via the LoRa SX1276 module. Powered by a rechargeable battery with efficient power management, the unit also provides real-time status feedback using RGB LEDs. This ensures reliable and long-range monitoring in forest environments.

**Components :**

- **Microcontroller :** (ATmega328P) : Acts as the control unit to manage the sensors, LoRa communication, and logic operations.

  - **Advantages :**

  The ATmega328P is energy-efficient and compact, making it ideal for IoT-based systems. It features sleep modes, consuming as little as 0.3 µA in power-down mode, which helps extend battery life. Additionally, it is compatible with the Arduino ecosystem, making it easy to program and integrate into projects. The ATmega328P is often chosen for simple, low-power, and small-scale applications like yours.

  - **Alternatives :**

  Alternatives to the ATmega328P include the ESP8266, which offers built-in Wi-Fi but consumes more power, around 70 mA in active mode. The STM32F103C8T6 offers higher processing power but requires more complex programming and might be overkill for simple IoT applications. Another alternative is the PIC16F877A, which is versatile but consumes more power and lacks the strong community support that ATmega328P enjoys.

- **Battery (3.7V 18650 Li-Ion) :** Supplies power to the entire sensor unit.

  - **Advantages :**

  The 18650 Li-Ion battery is widely chosen for its high energy density, offering capacities between 2600 and 3500 mAh per cell, which ensures long operational periods. It is rechargeable, supporting multiple cycles, and is compact, making it ideal for portable IoT devices. This battery type is commonly used in low-power systems where long-term sustainability and reliability are key.

  - **Alternatives :**

  Alternatives include NiMH batteries, which have a lower energy density and are prone to self-discharge, making them less suitable for long-term use. LiPo (Lithium Polymer) batteries are another option, offering lightweight and compact designs but with stricter charging and discharging requirements, making them less forgiving. Non-rechargeable alkaline batteries could be used, but they are not environmentally friendly and have a lower capacity, which reduces the overall operational time.

— **LoRa SX1278 :** LoRa long-range communication module.

  — **Advantages :**

  The SX1276 LoRa module is ideal for long-range, low-power wireless communication, offering ranges up to 10 km in open areas, which is perfect for forest monitoring. It is also energy-efficient, consuming as little as 10 mA during receiving and less than 1 µA in sleep mode, which makes it well-suited for battery-powered IoT devices. LoRa's spread spectrum modulation provides robustness in noisy environments, ensuring reliable communication in challenging conditions.

  — **Alternatives :**

  Other alternatives include the ESP8266 Wi-Fi module, which offers higher data transmission rates but has a much shorter range, typically under 100 meters indoors, and higher power consumption. The Zigbee (XBee S2C) is another option, providing low-power consumption and mesh networking capabilities, though its range is limited to approximately 1.5 km outdoors. NB-IoT Modules (SIM7000) provide cellular connectivity, but they depend on network availability and incur subscription costs, making them less ideal for remote forest monitoring.

— **Charge Controller (TP4056)** Safeguards the battery by managing safe charging and protecting against overcharging.

  — **Advantages :**

  The TP4056 charge controller is a widely used and cost-effective solution for managing safe charging of Li-Ion batteries. It prevents overcharging and short circuits, ensuring the battery's health during field use. Its small size and simplicity make it easy to integrate into compact IoT designs. This controller is an essential component for maintaining battery life and safety in field applications

  — **Alternatives :**

Alternatives to the TP4056 include the MCP73831, which offers higher efficiency but requires additional external components. The BQ24074 is another option, offering more advanced features such as thermal regulation, but at a higher cost and complexity. Another choice is the CN3065, which is similar in functionality to the TP4056 but has less availability and documentation in the maker community.

— **Boost Converter (MT3608)** Steps up the 3.7V battery voltage to 5V for components like the LoRa module and sensors.

  — **Advantages :**

  The MT3608 boost converter is chosen for its efficiency and versatility, stepping up a 3.7V input to a stable 5V output, which is crucial for powering components like the LoRa module and sensors. With up to 93 percent efficiency, it minimizes heat loss and ensures reliable operation. Its small size and cost-effectiveness make it a popular choice for small-scale projects.

  — **Alternatives :**

  Alternatives include the XL6009, which can handle higher currents (up to 5A), but it is bulkier and less efficient in low-current applications. The LM2623 is another option, offering ultra-low power consumption but at a higher cost. The LM2577 is known for its reliability but is less efficient and larger, which may not be ideal for compact applications.

— **DHT11 (Temperature and Humidity)**

  — **Advantages :**

  The DHT11 is a cost-effective sensor for measuring temperature and humidity, suitable for environmental monitoring. It offers basic accuracy with a temperature range of 0°C to 50°C and humidity range of 20-90 percent. Its simplicity and affordability make it ideal for low-cost IoT systems.

  — **Alternatives :**

  Alternatives include the DHT22, which offers better accuracy and a wider range (-40°C to 80°C and 0-100 percent humidity) but at a higher cost. The BME280 adds pressure sensing but comes at a premium price, while the SHT31 offers higher precision and faster response times, but also at a higher cost.

- **MQ-7 (Carbon Monoxide Sensor)**
  - **Advantages :**

  The MQ-7 is highly sensitive to carbon monoxide (CO), making it ideal for fire detection systems. It is cost-effective and sensitive to combustion gases, which are critical for environmental safety applications.

  - **Alternatives :**

  Alternatives include the MQ-2, which detects multiple gases, including CO, but is less specific to CO. The MiCS-5524 is more compact and offers low power consumption but is less available. The TGS2442 provides greater accuracy but is significantly more expensive.

- **Solar Panel** : Solar-powered operation ensures long-term deployment in remote areas.
- **DHT11 Relay Module (RT314012)**
  - **Advantages :**

  The RT314012 relay module is reliable and flexible, capable of switching loads up to 10A, making it suitable for activating alarms or devices when a fire is detected. Its compact size allows for versatile applications.

  - **Alternatives :**

  Alternatives include Solid State Relays (SSR), which are quieter and more durable but more expensive, especially for DC loads. The HK4100F-DC5V-SHG relay is cheaper but rated for 5A, and the G5Q-1A4 DC12 relay is compact but also limited to 5A or lower currents.

- **RGB LED (WS2812B)**
  - **Advantages :**

  The WS2812B RGB LED is ideal for providing visual feedback of a sensor unit's status, offering addressability with a single data line. Its compact, bright, and vibrant display is perfect for IoT projects requiring visual alerts.

  - **Alternatives :**

    Alternatives include APA102 LEDs, which offer faster refresh rates but are more expensive. The SK6812 provides higher brightness at a premium cost, while traditional RGB LEDs are cheaper but require more GPIO pins and are not addressable.

- **Transistor (2N2222)**

  - **Advantages :**

    The 2N2222 is a general-purpose NPN transistor suitable for switching or amplifying signals in low-power applications. It is inexpensive, reliable, and commonly used in small-scale IoT systems.

  - **Alternatives :**

    Alternatives include the BC547, which has a lower current capacity (100 mA), the 2N3904 with similar capabilities but a lower power rating, and the TIP31C for higher current needs, though it is bulkier and may be unnecessary for simple switching.

#### 4.1.2.2 Central Circuit

**Function :** This unit receives data from the sensor units, identifies the source (via the ID), processes the information, and sends an alert to the safeguard station. If no data was received from one of the sensor node circuits within 4 hours, then the specified sensor is not working as programmed and should be diagnosed.

**Components :**

- **Microcontroller (ATmega2560)** : The "brain" of the system that processes incoming data.
- **LoRa Module (SX1276)** :Enables long-range communication between sensors and the central unit.
- **Battery (LiFePO4 3.2V, 12Ah)** :Provides sustainable and reliable power.

  - **Advantages :**

LiFePO4 batteries offer high energy density, long cycle life (up to 2000 cycles), and thermal stability, making them ideal for remote sensor systems that need to operate over extended periods. They also have a safer chemistry compared to lithium-ion batteries.

— **Alternatives :**

Lithium-ion (Li-ion) batteries are an alternative with higher energy density but shorter lifespan and more safety concerns. Nickel-metal hydride (NiMH) batteries are cheaper but have lower energy density and shorter lifespans.

— **Additional Storage (EEPROM/SD)** : Logs detection data for analysis and monitoring.

— **Advantages :**

EEPROM and SD cards are reliable storage options for logging data. EEPROM is non-volatile, providing a backup of critical information, while SD cards offer large capacity for continuous data storage. Both allow easy data retrieval for further analysis.

— **Alternatives :**

Flash memory offers higher speed and more storage capacity but is more expensive than EEPROM. Cloud storage via LoRa or other communication modules can also be used but may require more infrastructure and increase data transmission costs.

— **Solar Panel** : Solar-powered operation ensures long-term deployment in remote areas.

— **Indicator LEDs (Red, Green, Yellow)** :Provide visual status indications.

— **Voltage Regulators (AMS1117, LM2596)** :Provide stable power for the microcontroller and LoRa module.

— **Advantages :**

The AMS1117 is a low-dropout regulator that provides stable output voltage, suitable for applications with limited power supply variations. The LM2596, a buck converter, is efficient for stepping down voltage from higher sources while maintaining power stability.

— **Alternatives :**

LM7805 is another linear regulator but less efficient than the AMS1117. DC-DC converters like the XL4015 provide greater efficiency and flexibility in voltage regulation at higher current levels but are bulkier and more expensive.

#### 4.1.2.3 Safeguard Station based Circuit

**Function :** This station receives information from the central unit and visually indicates affected zones by lighting up corresponding LEDs. It also triggers an alarm in case of fire detection.

• Normal State : The LED glows green, showing that everything is okay and the sensors are not detecting any fire.

• Fire Detected : The LED turns red to warn of danger, a buzzer is activated to alert the safeguard station professionals and a notifications will be sent to them through gmail while connected to internet.

**Components :**

— **Microcontroller (ATmega328P) :** :Controls the LEDs based on signals received from the central unit.

— **Advantages :**

The ATmega328P is a low-power, cost-effective microcontroller with sufficient I/O capabilities for handling LED control and receiving signals. Its small form factor and ease of use make it ideal for basic control tasks in small systems.

— **Alternatives :**

The ATmega2560 is a more powerful alternative with more I/O pins and greater memory, but it's overkill for simple tasks and comes at a higher cost. The ESP8266 can also be considered for wireless communication, but it's more complex and consumes more power.

— **Solar Panel** : Solar-powered operation ensures long-term deployment in remote areas.

— **LED Display (SUNLEDSMD1)** :Clearly indicates the status of monitored zones.

— **Advantages :**

The SUNLEDSMD1 is a bright and clear display, making it suitable for outdoor or high-visibility environments. Its simplicity and reliability ensure that zone status can be read easily even in low-light conditions.

— **Alternatives :**

OLED displays provide higher resolution and more flexibility for text and graphic displays but consume more power and are more expensive. 7-segment displays are another alternative, offering simplicity and low power consumption, but they can display less information than a full LED array.

- **Buzzer (5V Active Buzzer)** :Provide stable power for the microcontroller and LoRa module.
- **Reset Buttons** :Allow manual resetting of LEDs after an alert.

  - When a fire is detected, the LED corresponding to the sensor's location is activated, enabling a rapid visual alert.

## 4.2 Communication Network

**Network Topology :**

- A star topology where the sensor nodes communicate directly with the central hub via SX1278 LoRa modules.

**Data Transmission :**

- Periodic transmission of sensor data (e.g., temperature readings).
- Threshold breaches trigger immediate alerts to prioritize fire detection and response.

**Comparison with Other Communication Protocols :**

| Protocol | Range | Power Consumption | Cost | Data Rate | Suitability for Wildfire Monitoring |
|---|---|---|---|---|---|
| Wi-Fi | Short (50-100m) | High | Moderate | High (up to 600 Mbps) | Not suitable for remote areas or long distances. |
| Zigbee | (10-300m) | Low | Moderate | Moderate (250 kbps) | Limited range makes it less ideal for forests. |
| LoRa | Long (up to 10km) | Very Low | Low | Low (0.3–37.5 kbps) | Ideal for long-range, low-power sensor communication. |
| GSM/4G/5G | Very Long | High | High | High (up to 1 Gbps) | Effective but expensive and power-intensive. |

Chapter

5

# Results and Analysis

## 5.1 Shematic Design

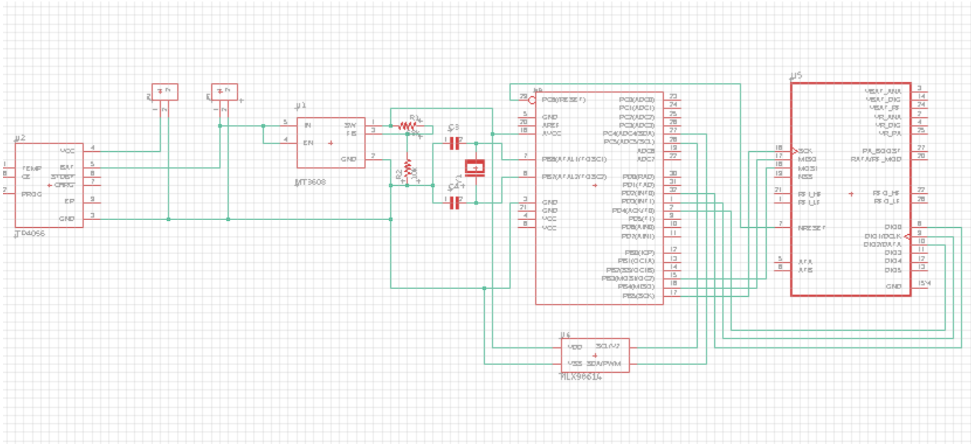

FIGURE 5.1 – Sensor Schematic

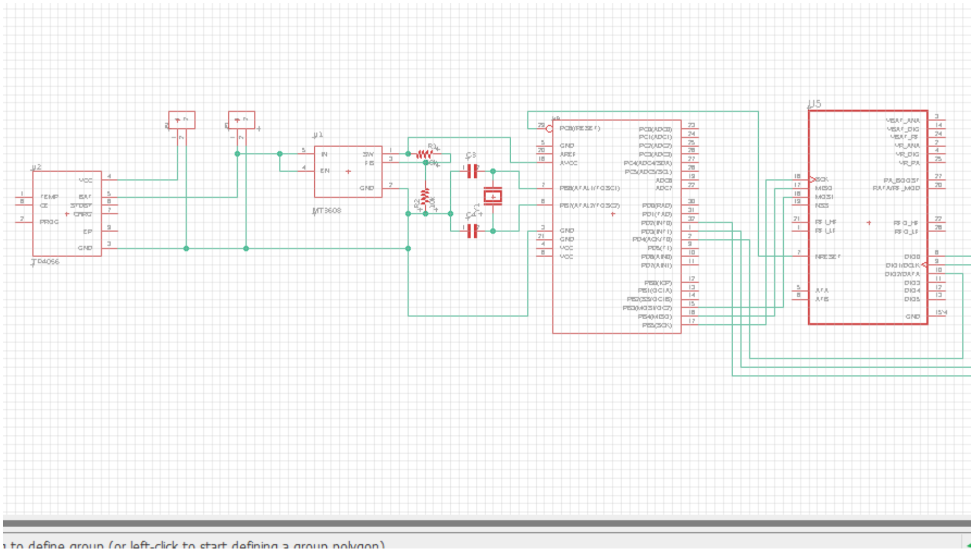

FIGURE 5.2 – Central Schematic

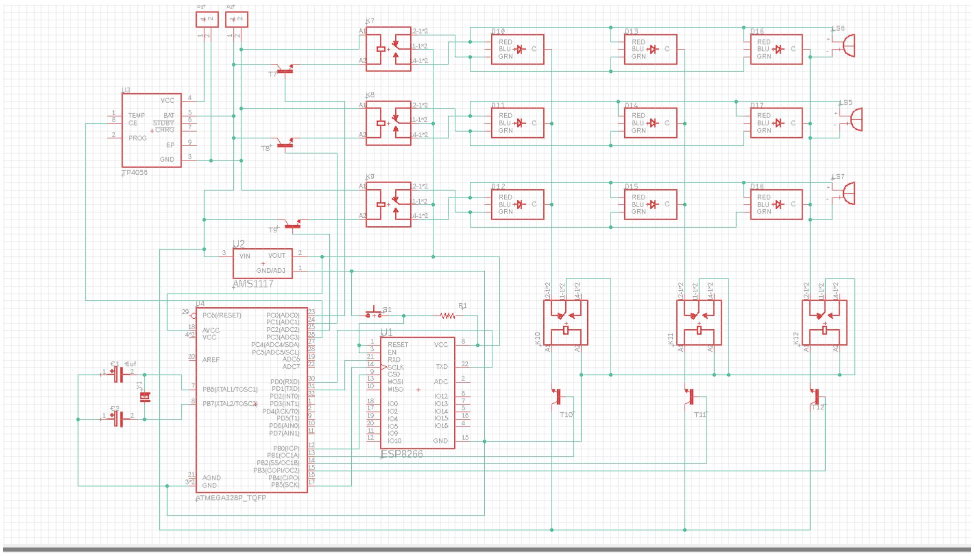

**FIGURE 5.3 – Dashbord Schematic**

## 5.2 PCB Design

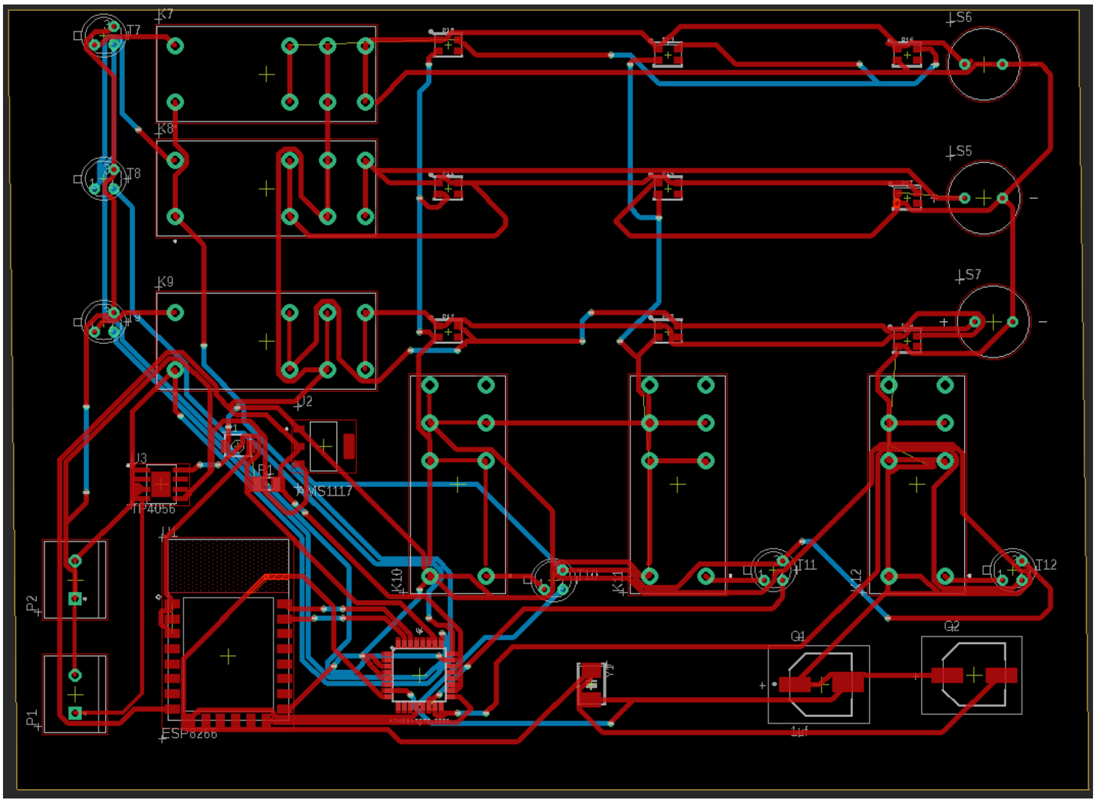

**FIGURE 5.4 – Dashbord Rotage**

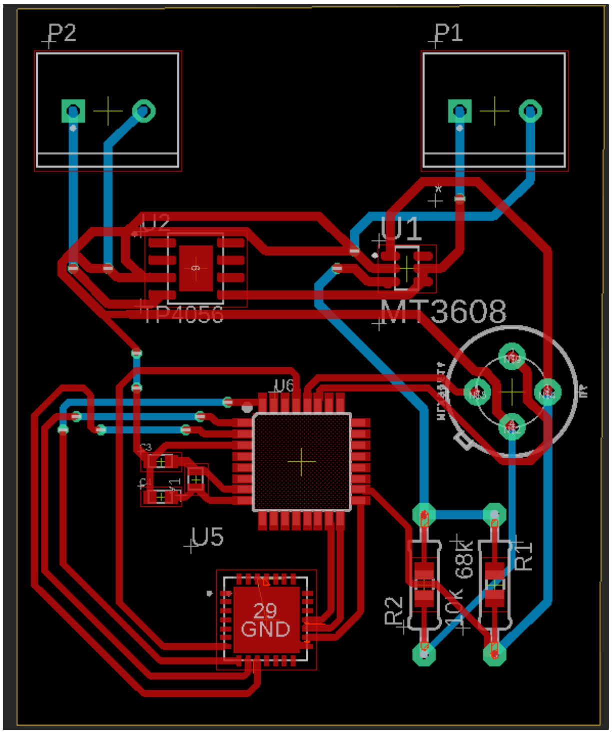


**FIGURE 5.5 – Sensor Rotage**

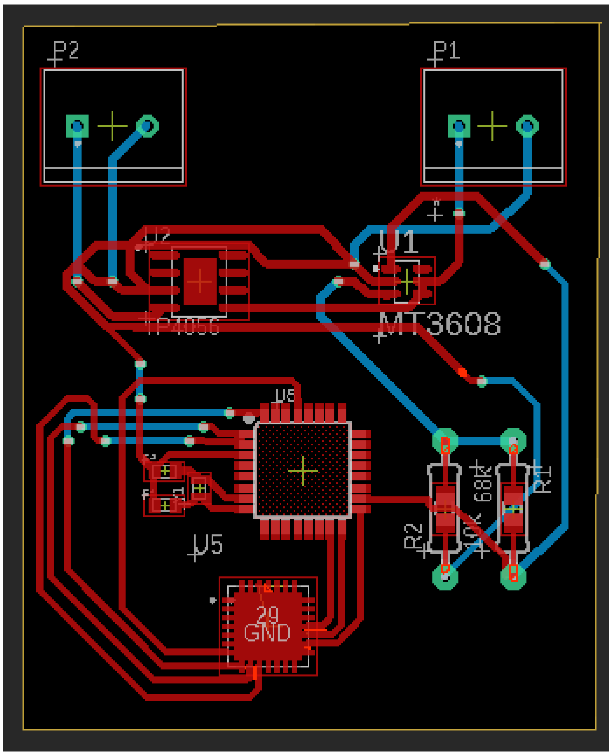


**FIGURE 5.6 – Cebtral Rotage**

## 5.3 3D Design

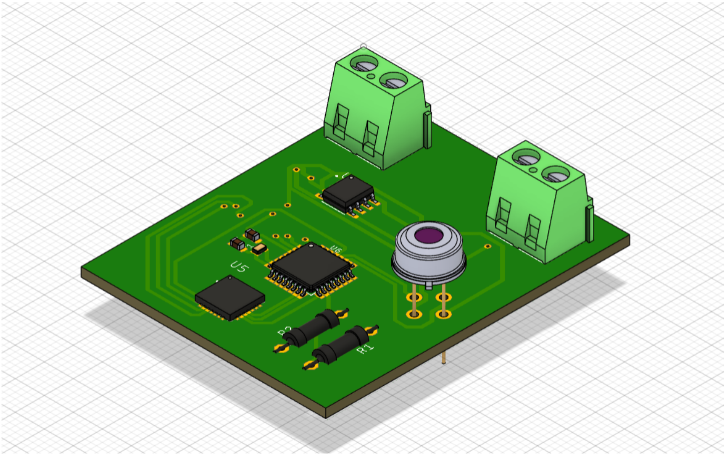

**FIGURE 5.7 – Sensor 3d**

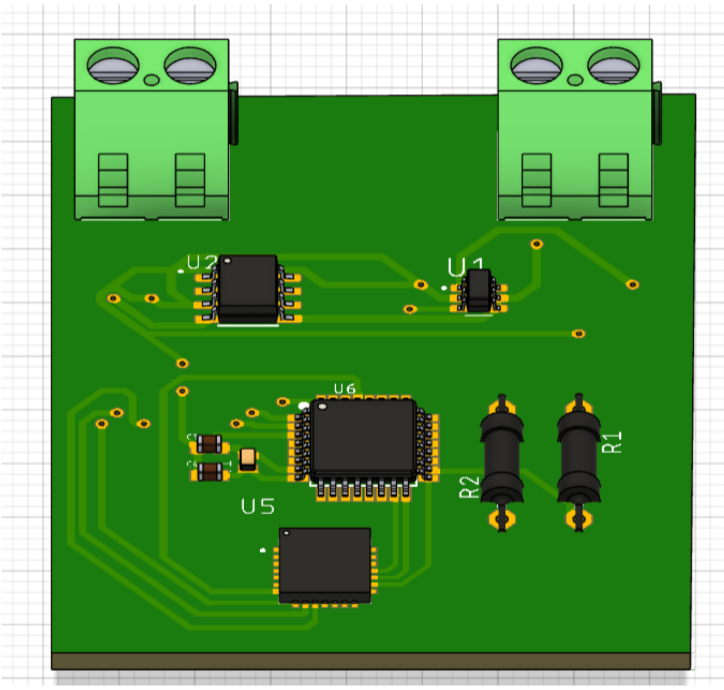


**FIGURE 5.8 – Central 3d**

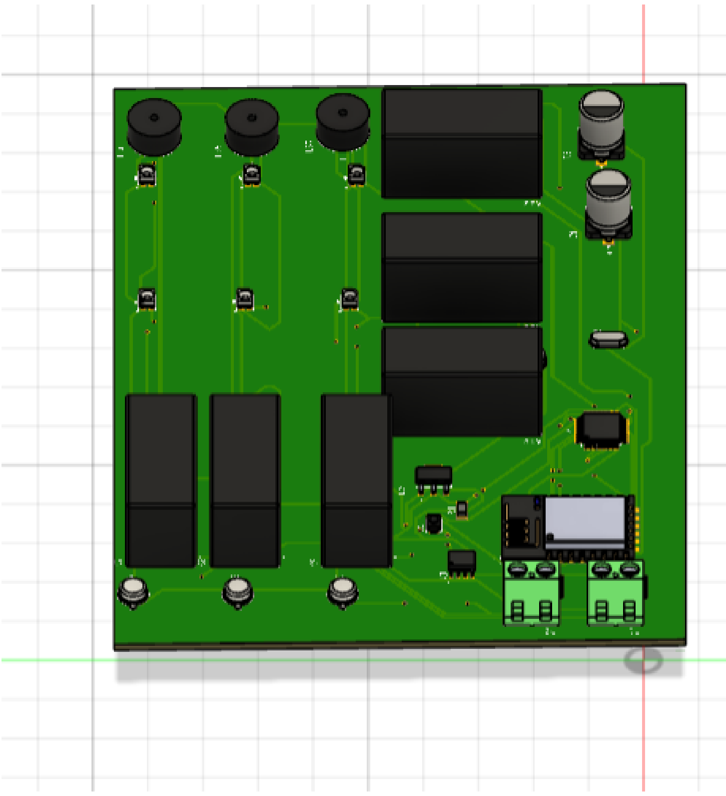

**FIGURE 5.9 – Dashbord 3d**

Chapter 6

# Conclusion and Future Work

## 6.1 Conclusion

The proposed fire detection system combines the efficiency of sensor units, a centralized processing unit, and a safeguard station to create a reliable and scalable forest monitoring solution. Using LoRa communication ensures long-range, low-power data transmission, making the system suitable for vast and remote forest areas. The integration of temperature, humidity, and gas sensors with real-time alert mechanisms enhances early fire detection, reducing the risk of widespread damage. The safeguard station's intuitive visual feedback (LED indicators) ensures that fire alerts are immediately noticed and acted upon. This system demonstrates a cost-effective, energy-efficient, and practical approach to addressing forest fire challenges.

## 6.2 Future Work

1. **Enhanced Sensor Accuracy :** Incorporate advanced sensors for smoke, flame, and heat detection to improve fire detection precision and reduce false alarms.
2. **Energy Harvesting :** Introduce solar panels for all units to enable sustainable, self-powered operation in remote environments.
3. **Mesh Networking :** Upgrade the communication system to a LoRa mesh network, enabling dynamic routing for improved reliability and scalability.
4. **Integration with AI :** Implement AI-based algorithms in the Central Unit for predictive fire analysis and smarter resource allocation.

5. **Drone-Assisted Monitoring :** Integrate drones to work alongside sensor units for real-time aerial monitoring and rapid fire confirmation.
6. **Weather Influence :** Include weather data (e.g., wind direction and speed) to predict fire spread and optimize alert accuracy.
7. **Mobile App Integration :** Develop a mobile application for real-time updates and remote management of alerts.
8. **Testing and Deployment :** Conduct extensive field trials in diverse forest environments to refine system performance and reliability.

These advancements will further enhance the system's effectiveness, scalability, and utility in combating forest fires.