

RESEARCH ARTICLE

Advancement of microcontroller-based fire suppression system for enhanced safety in sugar cane plantations

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ABSTRACT

The occurrence of accidental fires in sugarcane plantations is a significant cause of pre-harvest loss in the sugar industry, particularly during arid seasons. This paper introduces the conceptualization and implementation of a microcontroller-based prototype system for mitigating accidental fires in sugar cane plantations. The proposed system encompasses two distinct subsystems: the field monitoring unit and the fire control unit. The field monitoring system, deployed within the sugarcane field, assumes responsibility for fire detection via smoke detectors, infrared detectors, as well as carbon dioxide and carbon monoxide detectors, which are accompanied by a fire extinguishing mechanism. Conversely, the fire control unit, installed at the fire brigade office, establishes wireless communication with the field monitoring system through the global system for mobile communication (GSM) network. Upon detecting a fire, the microcontroller promptly dispatches a fire alert to the fire brigade while simultaneously activating water pumps to suppress the fire until the brigade arrives to fully extinguish it. Furthermore, the fire control unit triggers the fire alarm and exhibits the global positioning system (GPS) coordinates of the burning field to facilitate precise localization. The proposed system uses the Arduino-Mega and Arduino-Leonardo microcontroller platforms and is programmed using the C++ programming language in Visual-Studio-Code software and the Arduino integrated development environment. The designed prototype can detect fires and alert the fire brigade in less than twenty seconds and activate water pumps in less than one second after fire detection.

Keywords: *Arduino, Fire detection, GSM, Microcontroller, Sugarcane*

INTRODUCTION

The Sri Lankan sugar industry needs drastic changes ranging from micro to macro level to bring it to a correct path for better contribution to national and regional development (Keerthipala, 2007). Sugarcane (*Saccharum officinarum* L.) belongs to the family of the Poaceae. It originated in South Asia and Southeast Asia for the production of sugar and other by-products (De Silva *et al.*, n.d.). Sugarcane, being the primary economic crop in the Monaragala district, plays a

crucial role in the local economy by serving as the main source of income for the region (Mohotti, 2009). Sugarcane stalks are the feedstock to produce both sugar and ethanol (França *et al.*, 2014). When using sugar cane in the sugar industry, sugar is not the only product few by-products can be produced. Power can be cogenerated using bagasse, while ethanol and animal foods can be created using molasses and the rest of the waste (filter cake) can be used as a fertilizer for sugar cane (Arachchige *et al.*, 2020). However, the Lanka Sugar Company (Pvt) Limited faces a significant challenge due to accidental fires occurring in sugarcane fields. The problem with sugarcane fires is that sugarcane plantations are usually full of dry canes and burning leaves that act as a fuel source (Perera, 2021). The company's fire unit is responsible for controlling these fires, when a fire occurs in the sugar cane field, the personnel on duty in the fields are responsible for notifying the fire unit. However, the existing fire control system exhibits notable inefficiencies. Issues such as delayed fire identification, breakdowns in communication with the fire unit, and extended response times have resulted in substantial damage by the time the fire unit reaches the affected fields (Perera, 2021).

The identified issues within the fire control system of the Lanka Sugar Company (Pvt) Limited stem from various factors, and understanding these root causes is essential for devising effective solutions. The first issue lies in the process of fire identification, which appears to be slow and ineffective. The current methods used for fire detection may not be efficient enough, leading to delays in recognizing and reporting fires to the fire unit. Additionally, there seems to be a breakdown in communication between the field personnel and the fire unit, which hampers the timely notification of fire incidents. Inadequate means of communication contribute to these delays or even failures in alerting the fire unit promptly.

Moreover, the response time of the fire unit in controlling the fires is noticeably high, potentially due to limited resources, inadequate staffing, or the absence of proper protocols for quick mobilization (Perera, 2021). This delay in response further exacerbates the damage caused by the fires. Furthermore, insufficient fire prevention measures may contribute to the problem, as the lack of proactive measures to prevent fires or mitigate their spread increases the risk of substantial damage in the sugarcane fields.

Addressing these root causes is crucial for enhancing the effectiveness and efficiency of the fire control system in sugarcane fields. By implementing more efficient fire detection methods, improving communication channels, reducing response times, and enhancing fire prevention measures, the Lanka Sugar Company (Pvt) Limited can minimize the damage caused by accidental fires and ensure the timely and effective control of such incidents. This study proposed a system for fire detection and control in sugarcane fields that holds immense importance in terms of public safety, national interests, and economic benefits. Leveraging sensor technology, efficient communication systems, and quick response mechanisms, this system potentially aids in the early detection and

effective suppression of fires, thereby minimizing damage, protecting public safety, preserving national resources, and supporting the economic stability of the sugar industry.

MATERIALS AND METHODS

This study utilizes Arduino Mega 2560 and Arduino Leonardo as the primary controllers, which interact with SIM800L and SIM900A GSM modules to facilitate communication. The system is composed of two separate entities, the field monitoring system and the fire control unit.

Overview of Field Monitoring System

Figure 1 depicts the block diagram of the field monitoring system. This system fulfils two primary roles. The initial role pertains to fire detection, wherein the sensing array perceives the surroundings and transmits sensor signals to the connected input card module. The input card performs signal conversion and transmits the processed signal to the microcontroller. Upon receiving a (High) signal, the microcontroller triggers a notification to the fire control unit systems through the GSM module. Furthermore, it activates water pumps to initiate fire suppression until the fire brigade arrives at the field.

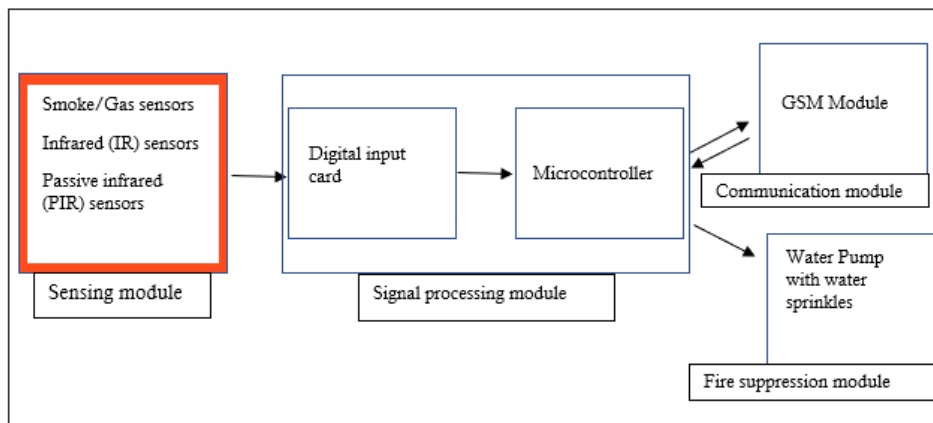


Figure 1: Field monitoring system’s block diagram.

The system consists of a main module called “Sensing module” for detecting fire. Signal processing module for receiving, processing sensors signal and control fire suppression module and communicate with GSM module. The GSM module communicates with the fire control unit and fire suppression module to control the fire until the fire brigade reaches the burning field. Incorporates a primary power supply to energize the field sensor arrays, while a secondary power supply is dedicated to the microcontroller, GSM module, and input card. Furthermore, a relay mechanism is implemented to control the activation of the water pump.

Hardware Design of Field Monitoring System

Sensing Module

The primary purpose of the sensing module is to ascertain the presence of fire. To accomplish this, Passive InfraRed Sensors (PIR), Infrared (IR) sensors, MQ02, and MQ135 gas sensors are employed. The digital outputs of all these sensors serve as input signals for the digital input card, while the analogue data from the MQ gas sensors is utilized to calibrate the threshold values. Figure 2 visually represents the temporal variations in sensor values upon the detection of fire.

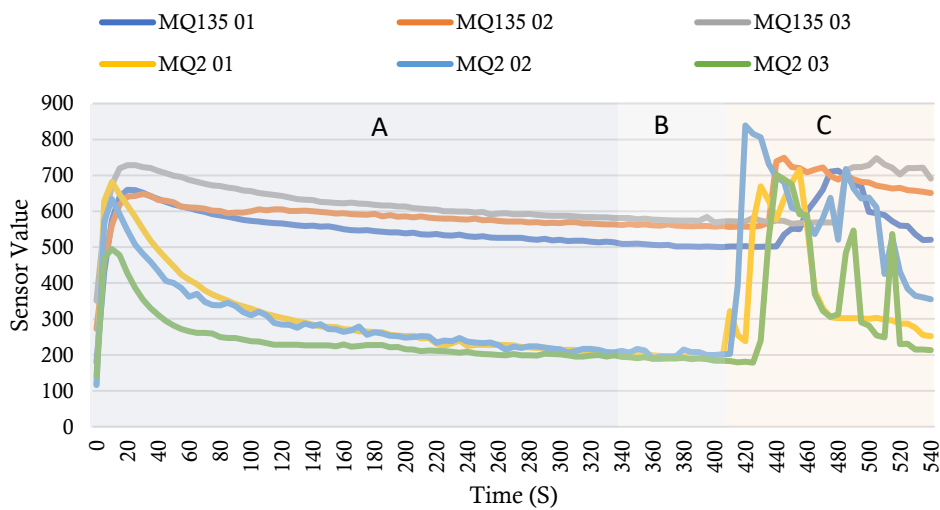


Figure 2: Sensor values of MQ series gas sensor vs time.

Area A represents the heating stage of the MQ series gas detectors, where the sensors were heated and stabilized from 330s to 360s. This heating time was critical for pausing data reading to prevent high-value reading errors from the microcontroller during heating. Area B shows the sensor values in clean air, while Area C indicates the sensor values during smoke detection. Based on the graph, a threshold value of 250 was set for MQ2 sensors and 600 for MQ135 sensors. When the digital output of each sensor is activated, it triggers the relay module, which functions as a 12V signal switch to the 12V digital input card.

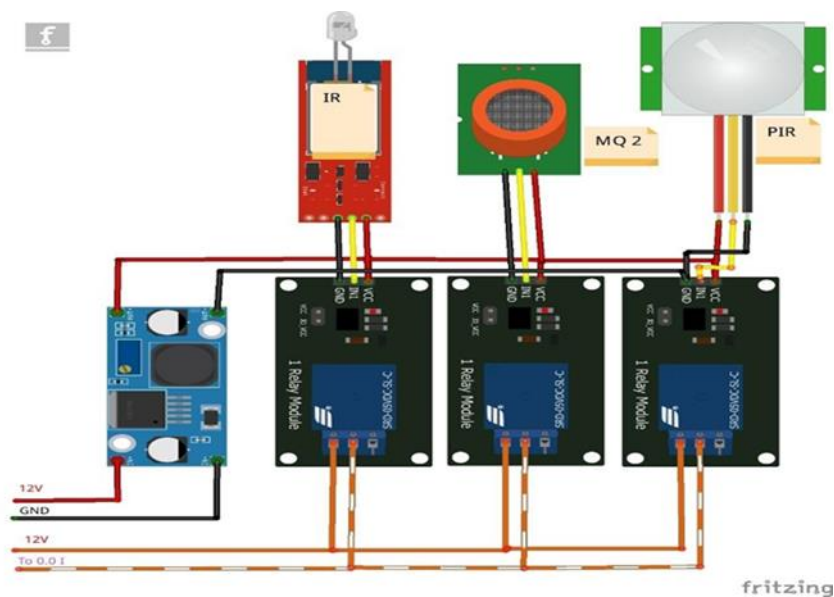


Figure 3: The sensor array is implemented in a breadboard configuration.

Sensor Installation in the Field

To enable easy removal from fields during agricultural activities like harvesting and land preparation, the sensors were affixed to 3 m portable metal poles (Figure 4). At the pinnacle of each pole, one MQ2 sensor and one MQ135 sensor were mounted. To mitigate false triggers caused by the body temperature of field workers, the PIR sensors were positioned at a 3-meter elevation. These PIR sensors possess a horizontal detection angle of approximately 110 degrees (Ladyada, 2022), enabling four sensors to cover a complete 360-degree area. In order to ensure effective coverage, the IR sensors were positioned at a height of 1 meter, considering the typical height of dry leaves, which ranges from 1 to 1.5 meters. With a detection angle of approximately 60 degrees (Microcontrollerslab, 2022), a minimum of six sensors are necessary to cover a full 360-degree area.

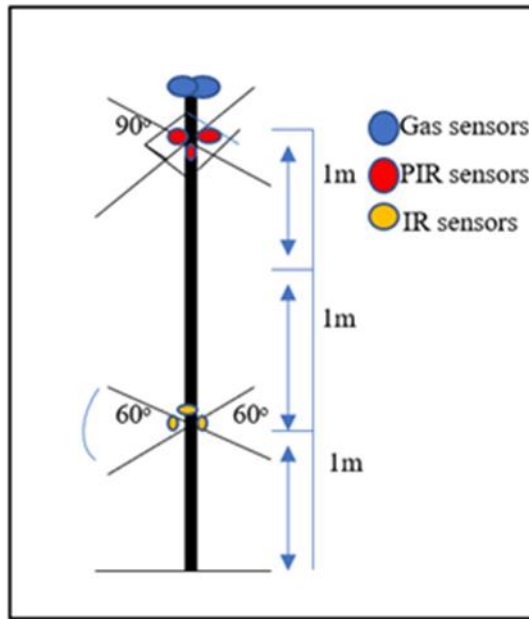


Figure 4: Sensor installation on the metal pole.

As the PIR sensors have a maximum detection range of 7 meters, it is recommended to maintain a spacing (d) of 14 meters between two sensor poles for optimal coverage (Figure 5).

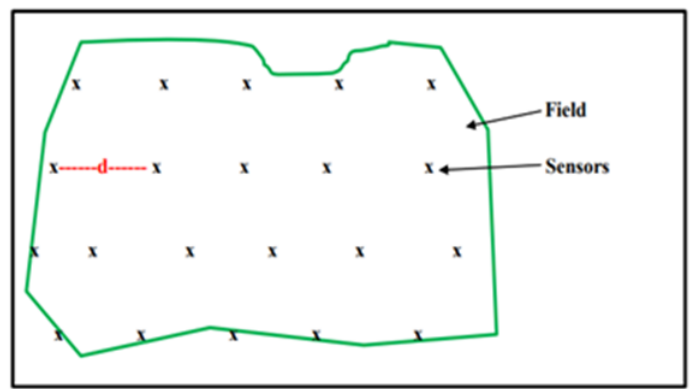


Figure 5: Sensor arrangement in the field.

Detail of the Used Components in Field Monitoring System

Arduino Mega 2560 development board was used as Microcontroller. The Arduino system offers a set of analog and digital pins that can be integrated to many other boards and circuits which absolutely have different functions in a design. Atmega 2560, commonly found in the Arduino Mega 2560 as its main microcontroller. It's an AVR RISC-based microcontroller that executes powerful instructions in a single clock cycle. This allows it to strike a fine balance between power consumption and processing speed (Mahzan *et al.*, 2018).

For communication SIM800L GPRS GSM breakout module was used. SIM800L GSM/GPRS module is a miniature GSM modem, the module supports quad-band GSM/GPRS network, meaning it works pretty much anywhere in the world (Engineers, 2020b).

The MQ 02 and MQ 135 used as smoke detectors. The MQ2 and MQ135 sensors were also employed to detect smoke with detection ranges of 200-10000 ppm and 10-1000 ppm, respectively. As a gas-sensitive material for such sensors, wide-gap semiconductor oxides (SnO_2 , ZnO , Fe_2O_3 , etc.) or oxide compositions the electrical resistances of which are dependent on the ambient atmosphere are used (Malchenko *et al.*, 1993).

For Flame/Infrared Sensors PIR motion sensor (HC-SR501) were used. The PIR sensor is a passive sensor. It detects infrared radiation from a passing heat source. It can be used for motion detection of the flame. When the moving IR source intercepts the other half of the sensor (leaves the sensing region), the opposite happens, and the sensor produces a negative differential change. By reading this change in voltage, motion is detected (Engineers, 2020).

Signal Processing Module

Design Circuit of 12 V Input Card

The aim of designing a 12 V digital input card was to mitigate voltage drop in the signal wires resulting from their length. All sensors utilized in the project operated at 5 V, generating a corresponding 5 V output voltage. In order to optimize costs, sensor installation in the field employed 16/0.20 twisted twin (TT) wires. Kelani Cables, 2016 reported a maximum DC resistance of 39.0 Ω /km for these wires at a temperature of 20 °C. The suggested maximum installation distance for the sensors was 300 m. According to Calcutor.net, 2022, the calculated voltage drop was 3.51 V, corresponding to a voltage drop percentage of 70.20%, resulting in a voltage reading of 1.49 V at the end of the wires. However, given that the temperature within sugarcane fields often exceeds 20 °C, the voltage drop could

surpass 3 V. The Arduino (ATmega) reports a (Low) signal for voltages below 1.5 V and (High) for voltages above 3.0 V (5 V boards) when pins are configured as inputs using `pinMode ()` and read using `digitalRead ()` (Arduino cc, 2021). As a result, a 5 V output cannot reliably recognize [HIGH] signals for the Arduino. By employing a 12 V output with the input card, the voltage drop was reduced to 1.17 V, resulting in a voltage drop percentage of 9.75%, and a voltage reading of 10.83 V at the end of the wires (Calcutor.net, 2022). The purpose of the 12 V input card module was to convert these end voltages to 5 V, thereby providing input signals compatible with the Arduino.

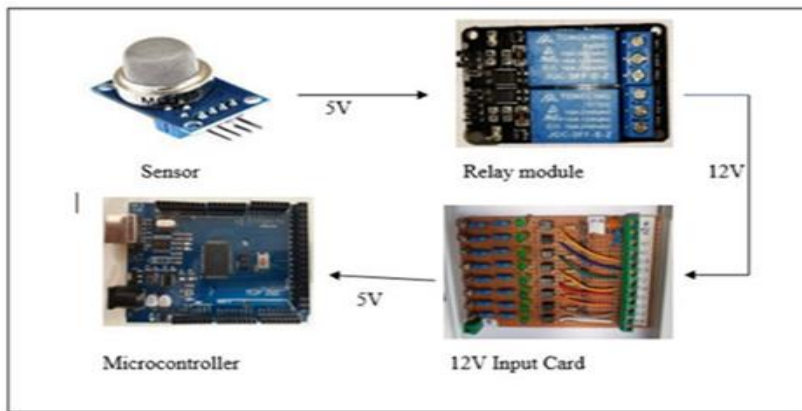


Figure 6: Voltage conversion process. 5v sensors triggers the relay module, which functions as a 12v signal switch to the 12V digital input card. 12v input card converts 12v signal to 5v for providing input signals compatible with the Arduino

Overview of Fire Control Unit

Figure 7 illustrates the block diagram of the fire control unit. This system serves two primary functions: receiving fire alerts from the field monitoring system and notifying the fire alert through audio and visual means. The fire control unit consists of a microcontroller, field indicators, a fire alarm, an LCD display, and a GSM module.

The microcontroller stores the GPS coordinates of the sugarcane fields along with their corresponding field numbers. Each field unit is assigned a unique number. When a fire is detected by the field unit, it sends the field number to the fire control unit via SMS. The fire control unit's GSM module receives the SMS, and the microcontroller responds by activating the relevant indicator bulb for the corresponding field. Additionally, the fire alarm is triggered, and the LCD display shows the GPS coordinates of the relevant field, which are stored in the microcontroller. This procedure enables the fire unit to swiftly respond to any

accidental fire occurring in the sugar cane field and accurately locate its exact position.

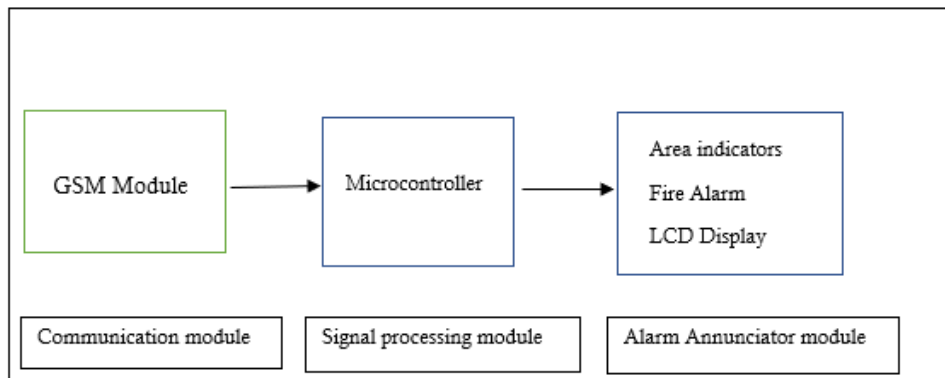


Figure 7: Fire Control Unit's block diagram.

The system consists of a main module named “Communication module” for receiving fire alerts from the field units. Signal processing module for process received signal and control alarm annunciator system. Alarm annunciator module for indicating fire alerts through audio and visual means.

Microcontroller Programming

Visual Studio code with PlatformIO and Arduino IDE Version 8.1.13 used for programming Microcontroller (Figure 8).

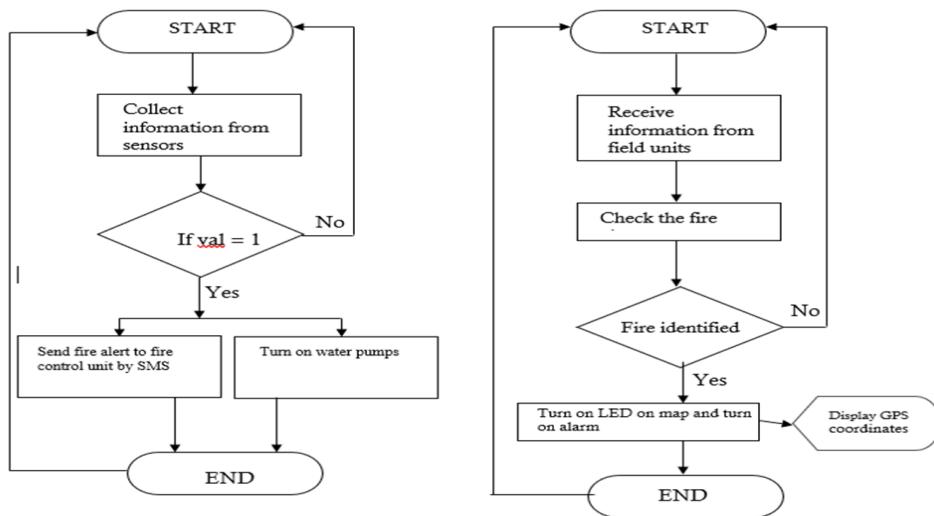


Figure 8: Flow chart of the Field monitoring system (left) and flow chart of the fire control unit (right).

Testing the Prototype Using Simulated Fire and Smoke

In this study, the obtained results were validated through simulated controlled fire experiments. The cigarette lighter flame was utilized as a source of flame, while dried cane leaves served as the material for generating smoke. It was determined that the infrared (IR) sensors employed in the investigation featured an embedded potentiometer, facilitating sensitivity adjustments. Precisely, by manipulating the potentiometer, the sensors' trigger point was calibrated to 200 lux flame intensity at a distance of 1m. Additionally, the passive infrared (PIR) sensors utilized in the research were also fine-tuned to activate when encountering a flame intensity of 200 lux at a range of 7 m. These meticulous adjustments played a pivotal role in ensuring the sensors' consistent and accurate detection of flame within the prescribed range and intensity. IR sensors exhibit a high sensitivity towards sunlight, making it imperative to install them in a manner that avoids direct exposure to sunlight, thus preventing false alarms from being triggered.

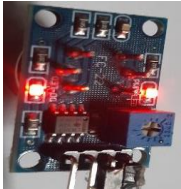
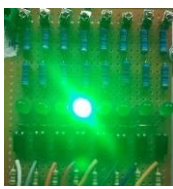
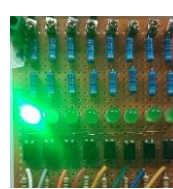
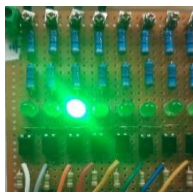
RESULTS AND DISCUSSION

IR and PIR Sensors for Flame Detection

Passive infrared (PIR) sensors use a pair of pyroelectric sensors to detect heat energy in the surrounding environment. These two sensors sit beside each other, and when the signal differential between the two sensors changes the sensor will engage (Arrow, 2018).

IR sensors successfully detected a flame intensity of 200 lux at a range of 1 m and PIR sensors successfully detected a flame intensity of 200 lux at a range of 7 m. (Table 1)

Table 1: Testing of different sensors and their results.

Test case	What to expect	Testing Sensor	Testing Input Card	Result/ Remarks
Power up the MQ2 Sensor to detect smoke and capture the Digital signal by input card	Sensor DO (Digital Out) indicator LED turn ON and Input Card's indicator LED turn on			Valid
Power up the MQ135 Sensor to detect smoke and capture the Digital signal by input card	Sensor DO (Digital Out) indicator LED turn ON and Input Card's indicator LED turn on			Valid
Power up IR detector to detect and capture the Digital signal by input card	Sensor DO (Digital Out) indicator LED turn ON and Input Card's indicator LED turn on			Valid *Maximum detecting distance 2-5m. *Depend on intensity of fire
Power up PIR Sensor to detect flame and capture the Digital signal by input card	Turn on relay and indicator of relay, Input Card's indicator LED turn on			Valid Maximum detecting distance 7-8m. Very sensitive to human body temperature

Testing GSM Modules to Send and Receive Fire Alert

Following the successful transmission of a fire alert by the SIM800L module and reception of the alert by the SIM900A module, the LCD display promptly shows

the GPS coordinates of the burning area and illuminates the relevant field's area indicator (Figure 9). The LCD display is integrated with the system to provide a visual representation of the alert for quick identification and response to the burning area.



Figure 9: Turns on relevant area indicator and LCD display shows GPS coordinate

Prototype of the Field Monitoring System

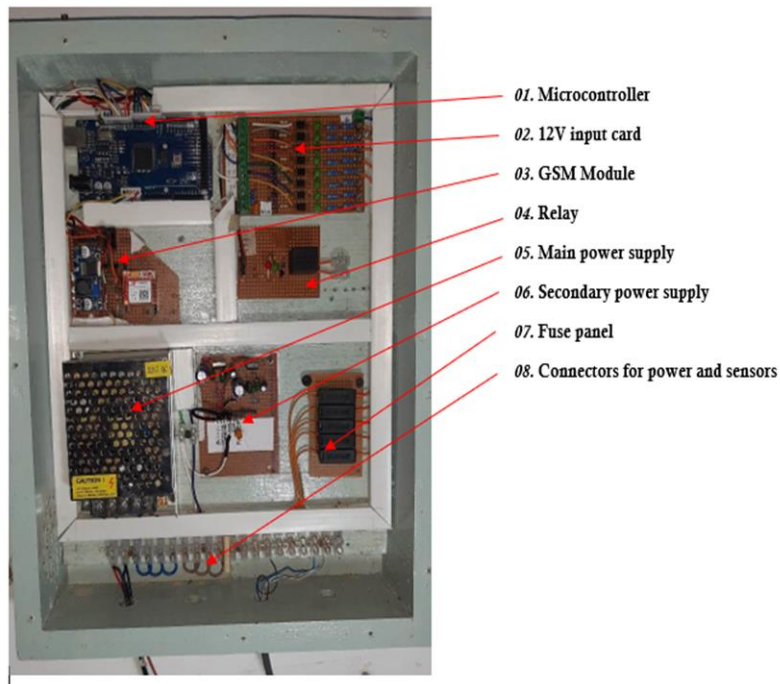


Figure 10: The prototype of the Field monitoring system

Prototype of the Fire Control Unit

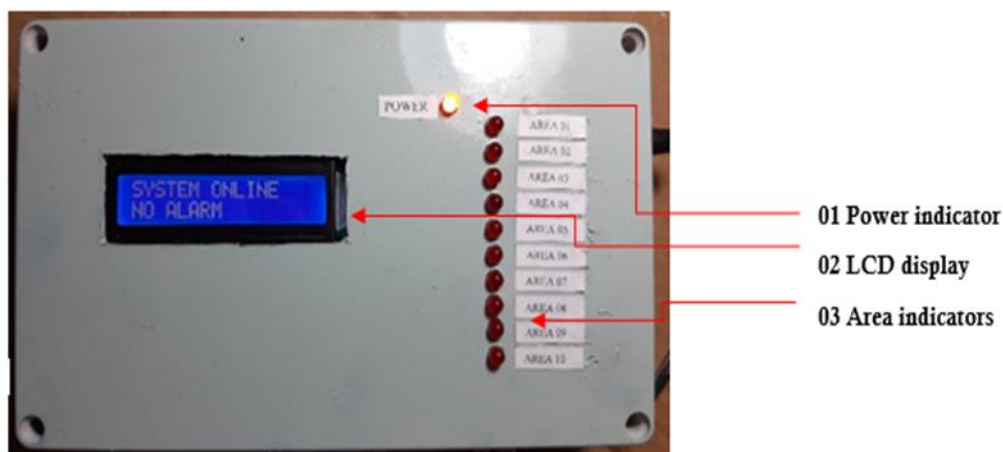


Figure 11: Fire Control Unit

Testing Digital Output of Sensors and Test Input Card

Based on the specified functions of the field monitoring system, tests of sensors can be carried out by demonstrating that each function has fully operated as expected.

MQ-Series Gas Sensors for Smoke Detection

Metal oxide semiconductor (MOS) type gas sensor also known as chemiresistors as the detection is based upon a change of resistance of the sensing material when the gas comes in contact with the material. Using a simple voltage divider network, concentrations of gas can be detected (Robu, 2021). In this study, it was observed that MQ2 sensors exhibit a higher sensitivity to smoke compared to MQ135 sensors.

Suggestions for Future Developers

This system has the potential to be expanded into a comprehensive weather station for monitoring various environmental parameters such as temperature, soil moisture, relative humidity, wind speed and direction, and rainfall intensity in the field. Additionally, it can be configured to control water pumps by sending SMS to irrigate the field. Optical smoke detectors can also be integrated for detecting smoke and triggering appropriate actions. Moreover, the system can be designed to automatically shut down during rainfall. Furthermore, wireless

sensors can be developed with radio transmitting capability and self-powered by solar energy for easy installation in the field. Such enhancements could further improve the system's overall functionality and versatility.

CONCLUSIONS

The principal aim of this investigation was to formulate an effective system with the capability to accurately identify smoke and flames in sugarcane fields and promptly alert the fire brigade. The system integrates infrared (IR) sensors for the detection of flames with a minimum intensity of 200 lux within a 1-meter sensing range. Simultaneously, PIR sensors are deployed to detect the same flame intensity within a maximum sensing range of 7 meters. Furthermore, MQ2 and MQ135 sensors are employed for smoke detection. The experimental outcomes unequivocally establish the efficacy of the system. The Arduino Mega 2560 microcontroller exhibited exemplary performance, swiftly initiating a fire alert to the fire control unit system through the SIM800L module within a remarkable timeframe of 20 seconds upon detecting a fire. Moreover, the water pumps were expeditiously activated within a mere one-second interval following the identification of a fire incident. These results substantiate the efficiency of the system and its capacity to augment early fire detection and subsequent fire suppression measures.

Nevertheless, challenges persist in safeguarding the sensors against environmental elements such as rain, dust, and sunlight. Additionally, the incurred installation costs associated with wired sensors present significant hurdles in this endeavor.

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