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Research Article

Multisensor Fuzzy Logic Approach for Enhanced Fire Detection in Smart Cities

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As smart cities expand rapidly, the demand for strong fire protection has become even more essential. A significant challenge lies in ensuring that fire detection systems integrate seamlessly into our modern infrastructures. Leveraging multisensor systems can yield reliable data on potential fires. Particularly in smart buildings, the effectiveness of multisensor fire detection algorithms becomes paramount. This research introduces a fuzzy logic-driven method that harnesses the power of smoke, flame, and temperature sensors. While smoke, flames, and elevated temperatures are primary fire indicators, they can manifest concurrently or sequentially. We have amalgamated various fuzzy logic rules (IF-THEN structures) to gauge the intensity of fires. When a fire ignites, the sensors spring into action, identifying its source and promptly notifying users via the Internet and GSM modems. Moreover, they relay the fire's precise geographic coordinates to fire departments. The fire's status will be consistently updated on a dedicated online portal. It was observed from our results that the system proficiently sends fire alerts to residents, and the fire status undergoes regular updates at 45-second intervals. This refreshing is initiated by the identification of a designated percentage of smoke and flame. These outcomes validate the system's effectiveness in enhancing the precision and responsiveness of fire detection capabilities.

1. Introduction

Fire is a physical process that produces smoke, heat, and flame. Fire is used for many household activities such as cooking, lighting candles, and many more. On the other hand, fire can seriously harm people and damage their property. Systems for detecting fires are necessary to reduce the loss of personal property due to both induced and artificial fires [1, 2]. The International Association of Fire and Rescue Services reported that from 1993 to 2020, there were 1123.6 thousand fire-related fatalities [3]. However, the number of deaths from 1993 to 2020 is gradually decreasing. Thankfully, more intelligent fire warning devices have steadily reduced the number of fire injuries. Due to this, numerous novel fire detection and prevention sensors have the capacity to use the fire detection module to identify the fire source in the case of a fire outbreak. They may then convey the identified message to the user over the Internet and a GSM modem, as well as communicate the precise latitude and longitude coordinates of the fire's location to the fire station, thanks to advancements in recent years. As a result, the construction of smart buildings and structures is given more attention globally [4, 5].

Fire can create havoc during outbreaks. The things that require fire to exist are oxygen, fuel, and temperature. It can cause a loss of lives and property damage. The three components' availability decides the number of fire outbreaks (hearth) to develop. A combination of oxygen, fuel, and heat can cause hearth. So, the fuel and oxygen required to create the fire are abundant in households and industries. During a fire outbreak, the wood, ceiling, papers, or combusted fuel is potential fuel. The accidental fire outbreak starts slowly, can last long hours, cause huge property damage, and make survival impossible. During fire outbreaks, a large amount of smoke is generated, which causes invisibility. The ceiling helps to raise the temperature and helps the small fire to develop into a big one. Hence, fire detectors are invented to detect fire in the early stages. However, the fire detectors have some problems that cannot be resolved. There are three types of fire detectors which are as follows: smoke, flame, and thermal. Thermal detectors are further classified as spot detectors, fixed temperature line-type detectors, and fixed temp detectors. Spot detectors detect the abnormal rise in temperature over a short period. Fixed temperature line-type detectors are composed of two cables enclosed in an insulated sheathing designed to rupture when exposed to high temperatures. One of the advantages of these detectors is their relatively lower installation cost. On the other hand, smoke detectors emerged in the late 1990s, and their functioning is based on the principles of photosensitivity and ionization.

The advantage of smoke detectors compared to thermal detectors is that they can detect the fire during the starting stage and help reduce the damage being done. Flame detectors are the line-of-sight devices that are operated on the principle of infrared and ultraviolet rays. These are primarily used in vehicles. Fire alarm systems are enabled with the help of these detectors. In the 1980s, the smoke detectors were invented, and with the help of these, a fire alarm system is discovered. The fire alarm system consists of a single smoke sensor and a buzzer. Many false alarms are triggered due to the lack of novelty in the mechanism used to design the fire alarm system. To overcome this issue, multiple sensors are used. The fuzzy logic mechanism (IF-THEN rules) can be used to minimize the issue. Hence, the multiple sensors (temperature, flame, and smoke) and fuzzy logic are combined. Most of the alarm systems consist of sirens or any other mode of caution. The far-off notification system uses the GSM communication system because of its cozy and dependable nature. Utilizing a web portal facilitates updating the fire intensity information, which is transmitted through an IoT module. This paper presents an enhanced version of a fire detection system based on fuzzy logic. The application of fuzzy logic is advantageous as it allows for the separation and analysis of information from multiple sensors, simplifying sensor data processing.

The multisensor fuzzy logic approach for enhanced fire detection holds significant utility for smart cities due to its ability to address the unique challenges and requirements posed by the dynamic and complex urban environments. The following provides key justifications for the usefulness of this approach in smart cities.

1.1. Comprehensive Detection. Smart cities are characterized by diverse infrastructures, including residential, commercial, and industrial areas. The integration of multiple sensors (smoke, flame, and temperature) in the fuzzy logic approach enables a comprehensive detection mechanism that considers various fire indicators simultaneously. Comprehensive detection improves the system's ability to identify and respond to fires of different origins and characteristics, ensuring a more effective and versatile fire detection system for the diverse settings within a smart city.

1.2. Adaptability to Dynamic Environments. Smart cities are dynamic, with changing environmental conditions, fluctuating population densities, and evolving infrastructures. Fuzzy logic is inherently adaptable and capable of dynamically adjusting to varying conditions and uncertainties in the urban landscape. The adaptive nature of the fuzzy logic approach ensures that the fire detection system can respond effectively to real-time changes, reducing false alarms and enhancing the system's reliability in dynamic smart city environments.

1.3. Reduced False Alarms. False alarms in smart cities can lead to unnecessary panic, resource wastage, and disruptions. The multisensor fuzzy logic approach, by considering multiple parameters and employing nuanced decision-making, minimizes false alarms by differentiating between normal variations and actual fire events. Reduction in false alarms enhances the efficiency of emergency response teams, prevents unnecessary evacuations, and fosters public trust in the reliability of the fire detection system.

1.4. Localization and Rapid Response. Smart cities often have densely populated areas and critical infrastructures. The multisensor approach facilitates the localization of fire sources, allowing for targeted responses to mitigate the impact of the fire. Rapid response is critical for minimizing damage and ensuring public safety. By accurately determining the intensity of fires, the system can trigger timely alerts, coordinate emergency services, and streamline response efforts.

1.5. Integration with IoT and Smart Infrastructure. Smart cities leverage the Internet of Things (IoT) and interconnected devices. The multisensor fuzzy logic approach aligns well with the principles of IoT, enabling seamless integration with other smart infrastructure components. Integration with IoT facilitates real-time data exchange, enables remote monitoring, and contributes to the overall synergy of smart city systems. Thus, the fire detection system is an integral part of the interconnected urban ecosystem.

The multisensor fuzzy logic approach for enhanced fire detection is particularly advantageous for smart cities as it addresses the multifaceted challenges posed by dynamic environments, diverse infrastructures, and the need for reliable, adaptive, and accurate fire detection systems in urban settings.

The following is a summary of this paper's structure. An overview of the literature survey and the significant contributions of this study are given in Section 1.6 and in

Section 1.7 respectively. The materials and techniques used for the suggested fire detection approach are described in Section 2. Section 3 presents the implementation of the proposed model for intelligent fire detection. Section 4 presents and evaluates the simulation's outcomes. The paper is concluded by summarizing the major discoveries and contributions in Section 5.

1.6. Literature Review. Soft computing techniques have recently emerged as powerful tools because they are crucial in addressing real-world problems involving uncertainty, imprecision, and complexity. Unlike traditional computing approaches that rely on precise logic and mathematical models, soft computing techniques provide approximate solutions that can effectively handle uncertain and incomplete data. Due to their merits, soft computing techniques are effectively applied to numerous engineering problems [6–10]. Fire detection systems have grabbed significant attention from researchers during the past few decades. Several fire detection approaches exist, such as image processing, computer vision, and machine and deep learning approaches. A detailed review of various sensors used for fire detection can be found in [11]. In order to reliably identify and detect fire occurrences, several fire detection methods have been proposed in the literature. These methods make use of different techniques and algorithms. Some of these methods examine flame geometry, including its position, rate of spread, length, and surface. For instance, a study by the authors in [12] classified nonrefractory pixels using average intensity, while fire pixels were categorized using color and the presence of smoke. A real-time fire detector was created using a different method [13], incorporating color data with registered foreground and background frames. A novel fire color model based on image processing was proposed in [14] to detect fire using statistical measurements efficiently. In addition, advanced object detection convolutional neural network (CNN) models were employed for image-based fire detection in [15], offering robustness and real-time performance. In [16], vision-based indoor fire and smoke detection systems were created using tiny training datasets and photos with different pixel densities. Unmanned aerial vehicle (UAV) of computer vision-based fire detection was investigated in [17], with a focus on early identification and prevention of fire threats. CNNs and smoke motion properties-based algorithms for recognizing flames were proposed in [18]. The use of static ELASTIC-YOLOv3 as a fire detection system for urban settings was also presented in [19]. The temporal and spatial dynamic fire textures were analyzed in [20] using 2D and 3D wavelet fragmentation. In addition, the authors in [21–26] discussed machine learning and deep learning methods for detecting forest fires. These studies highlight the diverse range of techniques and algorithms employed in fire detection research, showcasing advancements in accuracy, efficiency, and real-time performance. Recent advancements in Internet of Things (IoT) technology have revolutionized fire alarm systems, enabling accurate fire point detection and real-time monitoring. These techniques have a number of advantages, such as real-time tracking, online upgrades, and simple maintenance. Many nations have intensively explored research on wireless communication technology applications for preventing indoor fires. For instance, an interior fire monitoring system was described in a study [27] that used a ZigBee wireless network to track the temperature, humidity, and smoke concentration at the fire location in real time.

In [28], wireless sensor networks (WSNs) were used to gather precise environmental data, such as temperature, relative humidity, and different gas concentrations, and send it to base stations connected to the ground. The study in [29] employs radial sector scanning using the UV sensor to enhance detection optimization up to 360°, demonstrated through an embedded system. The experiment reveals a 53% improvement in detection results, varying with sensor azimuth width and device height. Due to their minimal complexity, low power consumption, and low-cost advantages, LPWAN-based IoT surveillance systems were another suggested alternative [30]. The advantages of integrating IoT into fire detection systems have been emphasized in numerous research studies. For instance, the authors in [31] provided an evaluation of an IoT-based fire alarm navigation system and its uses. The work in [32] describes the development of an early fire detection system that uses UAV and sensor network technology to stop fire occurrences. Opportunistic networks, spurred by the IoT, face storage congestion from handheld devices [33]. This research develops an AI rule-based fire engine model, tested with advanced classification algorithms and implemented via the ONE simulator tool with the MaxProp protocol. By achieving a 98% accuracy through k-fold validation across six algorithms, significant improvements over MaxProp are observed. The node-level delivery ratio rises by 20%, the buffer level by 5%, and the throughput increases by 500 kbps at the network level and by 150 kbps at the buffer level. These findings highlight the efficacy of AI in addressing congestion challenges and enhancing performance in opportunistic networks. Delay tolerant networks (DTNs) are an evolving facet of wireless multihop networking within sensor networks research [34]. These networks contend with intermittent connectivity and prolonged delays due to mobility. This study prioritizes custodian node selection based on storage capacity to reduce packet drops amid limited device storage. By introducing an intelligent history and a buffer-based approach, the study surpasses the MaxProp protocol in simulations, excelling across node, network, and buffer levels. In [35], a cloud-based fire detection method was proposed, utilizing features extracted from the IoT-captured video footage sent to the cloud instead of transmitting the entire video. Binary video descriptors and CNN were employed to develop the fire detection algorithm. In addition, a unique approach to wildfire detection using IoT networks with UAV support was presented in [36]. The study's main objective was to assess the effectiveness and dependability of UAV-IoT networks for wildfire detection and to provide recommendations for improving fire detection probability while keeping costs to a minimum. These research works highlight the significant contributions of IoT technologies in advancing fire detection systems, enabling enhanced monitoring, timely alerts, and improved efficiency.

Furthermore, Table 1 provides a critical analysis to systematically outline some of the limitations identified in the existing literature.

1.7. Contributions. Fire detection systems play a vital role in safeguarding lives and properties by providing early warning of fire incidents. Traditional fire detection methods often rely on simple threshold-based approaches, which may not be effective in complex environments or situations involving uncertainties. In recent years, the integration of soft computing techniques in fire detection systems has emerged as a promising solution to enhance their performance and reliability.

(i) Particle swarm optimization, fuzzy logic, neural networks, evolutionary algorithms, and other soft computing methods provide effective tools for dealing with uncertainty, imprecision, and missing information. These techniques excel in dealing with complex systems and can adapt to dynamic environments. By incorporating soft computing techniques into fire detection systems, it becomes possible to improve these systems' accuracy, responsiveness, and robustness.

(ii) This research aims to develop an intelligent fire detection system that utilizes soft computing techniques to detect and respond to fire incidents effectively. The suggested system integrates several sensors, including smoke, flame, and temperature, to capture various elements of fire behavior and characteristics. These sensor inputs are then processed using advanced soft computing algorithms to accurately identify and distinguish fire occurrences from false alarms or other environmental factors.

(iii) Soft computing techniques enable the system to handle uncertainties associated with fire detection, such as varying environmental conditions, sensor noise, and partial occlusions. The system can dynamically adapt its decision-making process based on real-time sensor data and historical patterns, thereby enhancing its performance and reducing false alarms.

(iv) Furthermore, the intelligent fire detection system incorporates connectivity features, allowing it to communicate with external entities such as consumers and emergency services. In a fire, the system can promptly send alert messages, including the precise location coordinates, to designated recipients through internet-based communication or GSM modems. This enables quick response and facilitates timely evacuation, minimizing potential risks and damages.

(v) The research presented in this paper focuses on developing and evaluating an intelligent fire detection system using soft computing techniques. Through experimental analysis and validation, the effectiveness and efficiency of the proposed system will be assessed, highlighting its potential contributions to fire safety in various applications, including smart buildings, industrial facilities, and public spaces.

Overall, integrating soft computing techniques in fire detection systems represents a significant advancement in enhancing these systems' accuracy, adaptability, and responsiveness. The intelligent fire detection system proposed in this research aims to leverage the benefits of soft computing techniques to provide robust and efficient fire detection capabilities, thereby contributing to improved fire safety standards in diverse settings.

2. Materials and Methods

The efficiency of the fire detection system is based on the values of the sensors obtained. The usage of the multiple-sensor system has its advantages when compared to the single-sensor-based fire alarm system. The fuzzy logic system shown in Figure 1 is used because it disentangles the combination of the information from various sensors, making it less demanding to break down the sensor information. We can classify the temperature range into cool, mild, and hot during the fuzzification [37]. In the fuzzy interface engine, the IF-THEN rule is used to make a decision. The fuzzy values are then defuzzified into an output. The fuzzy sets of each sensor are created using triangular functions [37].

The density of the smoke is divided into three membership sets: low, high, and medium, as shown in Figure 2. The smoke sensor MQ2 collects the data in analog voltage forms. The Arduino board consists of an analog to digital converter, and the values are in the range from 0 to 1023. The temperature sensor (LM35) readings have been divided into three membership sets: low, medium, and high, as shown in Figure 3. The range that the sensor can measure is from 16 to 110c. Figure 4 shows that the membership sets of the readings of the flame sensor are also divided into three sets: 1: low, 2: medium, and 3: high. The flame sensor collects the data in the analog form. Since the Arduino board consists of the analog to digital converter, the range of values is from 0 to 1023.

The output variables of fuzzy sets are divided into three sets. They are as follows: (1) no fire, (2) fire detected, and (3) potential fire. To determine the fire status, these fuzzy sets are used. These inputs are fuzzified using a rule base (IF-THEN). The system architecture of the device and its subsystems are shown in Figure 5. The device consists of three sensors, smoke, flame, and temperature, to detect the fire. The Arduino board, GSM modem, and IoT module are attached. The fire alert will be sent through an SMS, and it will be updated in the web portal. The primary goal of this fire detection system is to provide real-time notifications to individuals when a fire is detected. The capacity of the fire detection system to give quick input on the fire's status is a noteworthy feature. Once a fire is discovered, this quick

Table 1: Critical analysis table: limitations in existing studies.

Study	Limitation	Implication
Hong et al. [23]	Limited sensor integration	Reduced capacity to capture diverse fire indicators simultaneously
Kang et al. [26]	Lack of dynamic adaptability	Inability to adjust to changing environmental conditions and fire scenarios
Wu et al. [27]	Reliance on fixed thresholds	Susceptibility to false alarms and suboptimal adaptability to varying contexts
Roque and Padilla [30]	Single-sensor approach	Restricted coverage and potential for inaccurate fire detection in complex environments
Sharma et al. [32]	Inadequate consideration of environmental factors	Limited effectiveness in diverse smart city settings

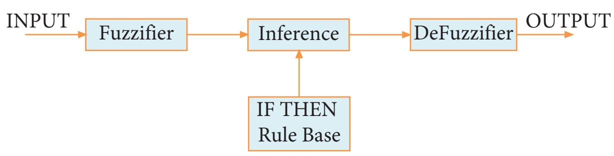

Figure 1: Block diagram of a fuzzy logic system.

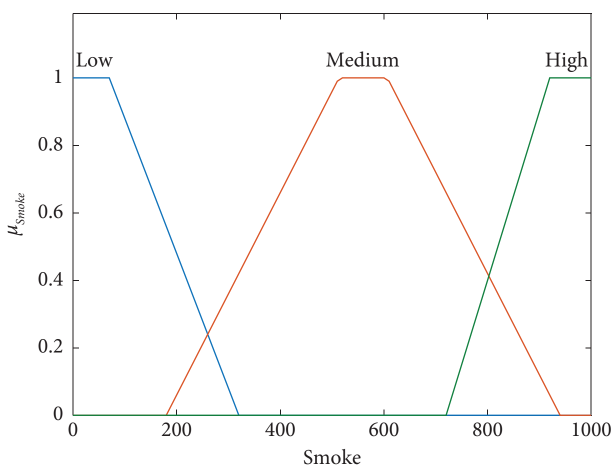

Figure 2: Subsets of the smoke values.

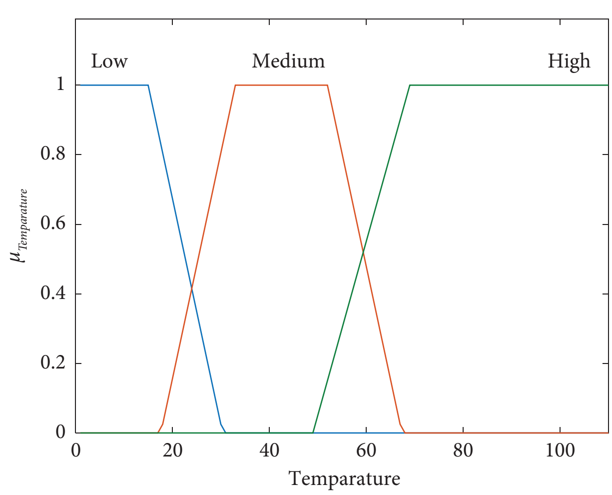

Figure 3: The membership sets of the temperature values.

response is essential. The device's alarm makes sure that fire events are acknowledged acoustically and that pertinent parties are notified remotely. A simple fire

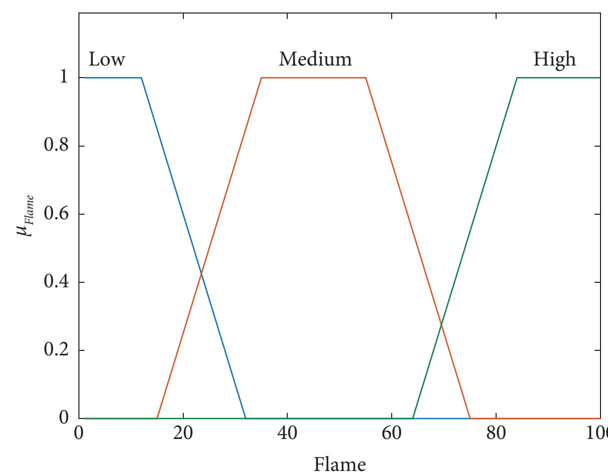

Figure 4: The membership sets of the flame values.

outbreak signal would have been sufficient, but using the device to visualize the fire's location and provide useful information about the afflicted structure adds more context.

Smoke density, ambient temperature, and flame intensity are crucial parameters in fire detection systems, as they provide diverse and complementary information that helps in accurately identifying and responding to potential fire incidents [32]. Smoke is a byproduct of combustion, and an increase in smoke density often indicates the presence of a fire. Monitoring smoke levels is fundamental to early fire detection. Monitoring ambient temperature helps identify abnormal increases in heat associated with fire. Rapid temperature rises are indicative of fire initiation or progression. Flames are a direct and visible confirmation of a fire event. Monitoring flame intensity provides an immediate indication of the severity of the fire. By combining information from smoke density, ambient temperature, and flame intensity, a multisensor system, especially one driven by fuzzy logic, can make informed decisions, reduce false alarms, and enhance the overall effectiveness of fire detection. This comprehensive approach is particularly valuable in smart city environments where diverse conditions and potential sources of fires need to be considered.

The pseudocode and algorithm for the multisensor fuzzy logic approach for enhanced fire detection in smart cities are discussed as follows (see, Algorithm 1).

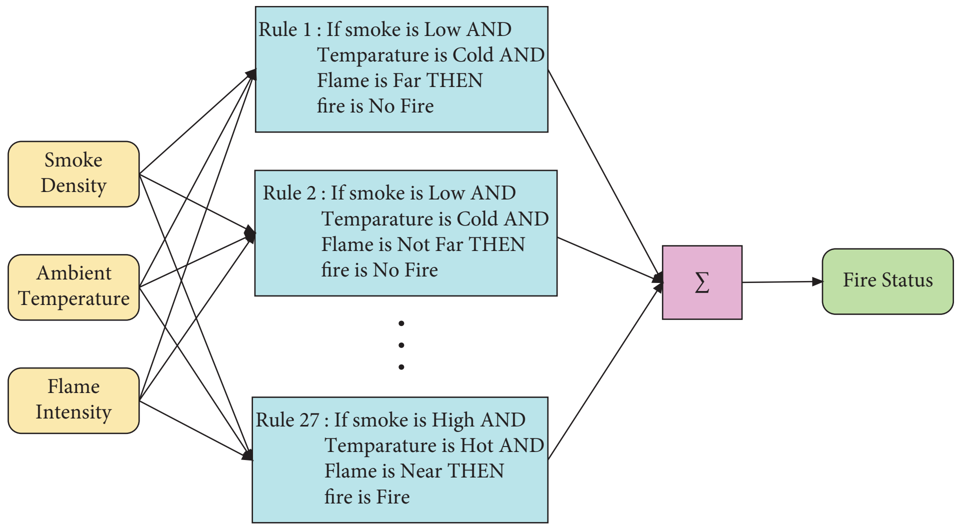

Figure 5: Fire detection fuzzy logic system.

2.1. Pseudocode for Multisensor Fuzzy Logic Approach. 2.2. Algorithm for Multisensor Fuzzy Logic Approach

(i) Initializing sensors: the values from smoke, flame, and temperature sensors are read
(ii) Fuzzification: fuzzification functions are applied to convert sensor values into fuzzy sets
(iii) Rule evaluation: fuzzy logic rules (IF-THEN statements) are used to evaluate the degree of activation for each rule based on fuzzy sets
(iv) Aggregation: the rule activations are combined to determine the overall degree of activation
(v) Defuzzification: the aggregated fuzzy output is then converted back to a crisp value, representing the fire intensity
(vi) Decision-making: if the fire intensity is classified as high, the alarm is triggered, the authorities are notified, and the online portal is updated

3. Implementation

An overview of the fire detection system is shown in Figure 6. The figure shows that all the sensors are interfaced with the Arduino board and the GSM, GPS, and IoT modules. The fuzzy logic system is present in MATLAB. MATLAB consists of the fuzzy tool kit where we can implement the rules and design the system. The embedded Fuzzy Logic Library (eFLL) files are used for implementing the fuzzy logic system in the Arduino board. The flow depicts the operation of the fire detection system. There are the following three cases for the output: (1) no fire, (2) potential fire, and (3) fire detected. No fire alerts will be sent to the resident during the first two cases, and during the third case, alerts through SMS and the fire status will be updated in the web portal. During the potential fire output, the buzzer will be activated to notify the people in that area during a fire outbreak. The flowchart of the fire detection system is illustrated in Figure 6, depicting the sequential steps involved in the detection process. Furthermore, Figure 7 showcases the hardware implementation of the fire detection system, providing a visual representation of the physical components utilized.

In this work, the embedded Fuzzy Logic Library (eFLL) embedded in Arduino is likely utilized to implement a fuzzy logic system for fire detection using multiple sensors. The following gives a detailed description of how the eFLL file embedded in Arduino can be used in this context.

3.1. Library Inclusion. The first step is to include the eFLL library in the Arduino sketch. This is typically performed by adding an "#include" directive at the beginning of the sketch to import the necessary header files from the eFLL library.

```
#include <eFLL.h>
```

3.2. Initialization. After including the library, the fuzzy logic system needs to be initialized. This involves setting up fuzzy variables, linguistic terms, fuzzy sets, and fuzzy rules that define the behavior of the system. This initialization is typically performed in the "setup()" function of the Arduino sketch.

```
void setup() {
  //Initialize fuzzy logic system
  //Define input/output variables, linguistic terms, fuzzy sets, and rules
  //Initialize sensors
}
```

3.3. Sensor Readings. In the "loop()" function of the Arduino sketch, the sensors are read to collect data about the environment, such as temperature, smoke density, or other relevant parameters. These sensor readings will serve as inputs to the fuzzy logic system.

```
void loop() {
```

```
# Initialize sensor variables
smoke_sensor_value = read_smoke_sensor()
flame_sensor_value = read_flame_sensor()
temperature_sensor_value = read_temperature_sensor()
# Fuzzification
fuzzy_smoke = fuzzify_smoke(smoke_sensor_value)
fuzzy_flame = fuzzify_flame(flame_sensor_value)
fuzzy_temperature = fuzzify_temperature(temperature_sensor_value)
# Rule Evaluation
rule_activation = evaluate_rules(fuzzy_smoke, fuzzy_flame, fuzzy_temperature)
# Aggregation
aggregated_activation = aggregate_rules(rule_activation)
#Defuzzification
fire_intensity = defuzzify(aggregated_activation)
# Decision-making
if fire_intensity is high:
    activate_alarm()
    notify_authorities()
    update_online_portal()
# End of algorithm
```

Algorithm 1: Pseudocode for the multisensor fuzzy logic approach.

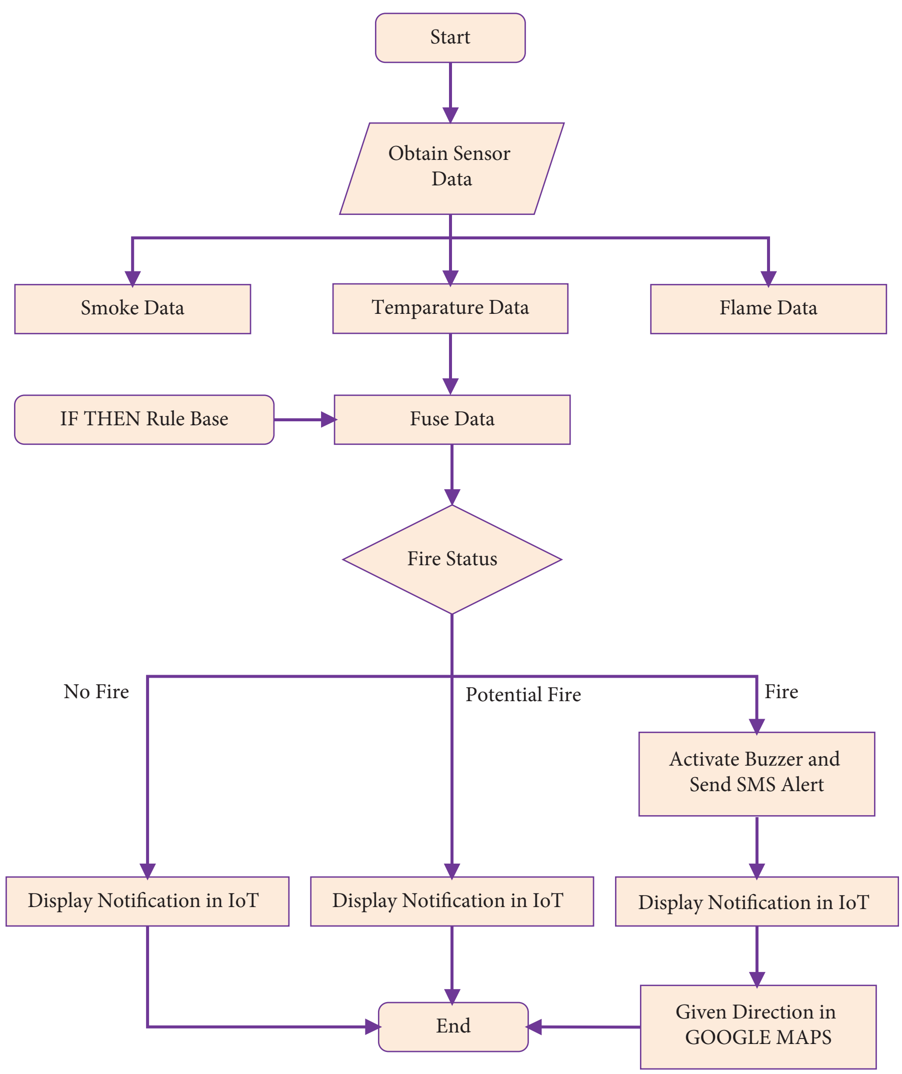

Figure 6: Flowchart of the fire detection system.

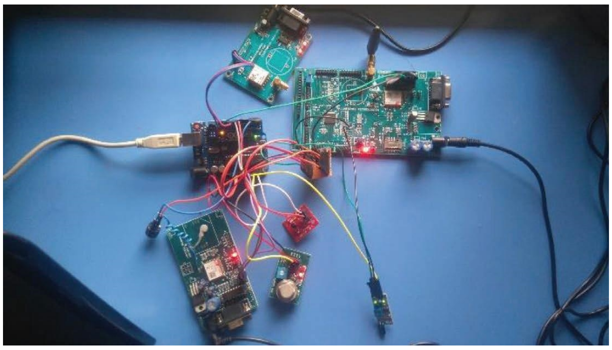

Figure 7: Hardware implementation of the system.

```
    //Read sensor data
    float temperature = readTemperatureSensor();
    float smokeDensity = readSmokeDensitySensor();
    //Pass sensor data to fuzzy logic system
    //Perform fuzzy inference
    //Take appropriate action based on fuzzy logic output
}
```

3.4. Fuzzy Inference. Within the "loop()" function, the sensor data are passed to the fuzzy logic system for inference. The fuzzy logic system evaluates the inputs based on the predefined linguistic terms, fuzzy sets, and rules to determine the degree of fire risk or the likelihood of a fire event.

```
void loop() {
    //Read sensor data
    //Pass sensor data to fuzzy logic system
    float fireRisk = fuzzyLogicInference(temperature, smokeDensity);
    //Take appropriate action based on fuzzy logic output
}
```

3.5. Output Processing. Depending on the output of the fuzzy logic system (e.g., the degree of fire risk), appropriate actions are taken. This could include activating alarms, notifying authorities, or triggering fire suppression systems.

```
void loop() {
    //Read sensor data
    //Pass sensor data to fuzzy logic system
    //Perform fuzzy inference
    //Take appropriate action based on fuzzy logic output
    if (fireRisk > threshold) {
        activateAlarm();
    }
}
```

3.6. Further Customization. The eFLL library provides various functions and methods for customizing the fuzzy logic system, including adjusting linguistic terms, fuzzy sets, rules, and membership functions. This allows the system to be tailored to specific application requirements and environmental conditions.

By following these steps and leveraging the functionalities provided by the eFLL library, the Arduino board can effectively implement a fuzzy logic-based fire detection system using multiple sensors.

Table 2 presents details about general-purpose input/output (GPIO), which is a set of pins on a microcontroller or microprocessor that can be configured to serve as either input or output. These pins are versatile and can be used for a variety of purposes in electronic circuits and embedded systems. As inputs, GPIO pins can be used to read digital signals from sensors, switches, or other devices. As outputs, they can be used to send digital signals to control actuators, LEDs, relays, or other output devices. The configuration of a GPIO pin is typically programmable, allowing developers to dynamically set its behavior based on the requirements of the application. In the context of embedded systems and microcontrollers, GPIO plays a crucial role in interfacing with the external world, enabling communication between the microcontroller and various sensors, actuators, and other peripheral devices. The flexibility of GPIO pins makes them fundamental building blocks in designing and prototyping electronic systems.

4. Simulation Results

The system is tested in a closed room. Through the introduction of controlled experiments involving a flame (using a candle), smoke (burning paper), and heat (using a hair dryer), the obtained results demonstrate that the system significantly improves the reliability of fire detection as shown in Figure 8. The system successfully sends fire alerts to the residents, and the fire status is updated at regular intervals of 45 seconds, triggered by the presence of a specific percentage of smoke and flame as depicted in Figure 9. These findings affirm the system's effectiveness in enhancing the accuracy and responsiveness of fire detection capabilities. If the probability of the fire is less than 0.5, then the status shown is potential fire; if it is more than 0.5, the status shown is fire detected. An SMS will be sent to the mobile number and the fire department with the coordinates of latitude and longitude as shown in Figure 10. The web portal can be accessed from anywhere to know the fire status. There are a series of screenshots sent by the device during the fire alert situations.

Table 3 presents user-size information for data collection and disseminating alerts. This table categorizes user size into three categories: small, medium, and large, each with a brief description of the corresponding user base. It outlines different methods for data collection and alert dissemination tailored to each category. For instance, small user sizes may utilize surveys and manual monitoring, while large user bases could benefit from real-time sensor networks and continuous monitoring. The table aims to guide the selection

Table 2: GPIO vs devices/components design in the proposed prototype.

Sr. no.	GPIO	Device/component	Description
1	GPIO 1	Smoke sensor	Detects the presence of smoke particles
2	GPIO 2	Flame sensor	Identifies the presence of flames
3	GPIO 3	Temperature sensor	Measures the ambient temperature
4	GPIO 4	Internet module	Facilitates communication over the Internet for real-time alerts
5	GPIO 5	GSM modem	Enables SMS alerts to be sent to residents
6	GPIO 6	Microcontroller	Controls the overall functionality and integration of sensors
7	GPIO 7	GPS module	Determines the precise geographic coordinates of the fire
8	GPIO 8	LED indicator	Provides visual feedback on the system's status
9	GPIO 9	Buzzer	Audible alert to supplement visual notifications
10	GPIO 10	Power supply unit	Provides the necessary power to all components

151	FIRED_ETCTED	04/29/2017	11:01:53
152	FIRED_ETCTED	04/29/2017	11:02:35
153	POTENTIALFIRE	04/29/2017	11:03:17
154	FIRED_ETCTED	04/29/2017	11:04:00
155	FIRED_ETCTED	04/29/2017	11:04:42
156	POTENTIALFIRE	04/29/2017	11:05:24
157	POTENTIALFIRE	04/29/2017	11:06:07
158	POTENTIALFIRE	04/29/2017	11:06:49
159	POTENTIALFIRE	04/29/2017	11:07:31
160	POTENTIALFIRE	04/29/2017	11:08:14
161	FIRED_ETCTED	04/29/2017	11:08:56
162		04/30/2017	12:03:27
163		04/30/2017	12:03:30
164	POTENTIALFIRE	04/30/2017	12:03:47
165	POTENTIALFIRE	04/30/2017	12:04:29
166	POTENTIALFIRE	04/30/2017	12:05:11
167	POTENTIALFIRE	04/30/2017	12:05:53
168	POTENTIALFIRE	04/30/2017	12:06:36
169	POTENTIALFIRE	04/30/2017	12:07:17
170	POTENTIALFIRE	04/30/2017	12:07:59
171	FIRED_ETCTED	04/30/2017	12:08:42

Figure 8: Screenshot for the fire status on the web page.

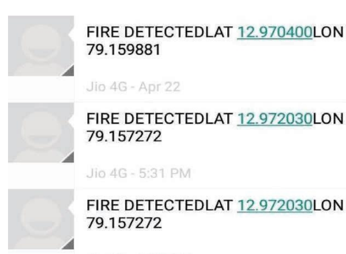

Figure 9: Location of the fire detected place.

of appropriate strategies based on the scale of the user population, providing flexibility and adaptability in data collection and alerting mechanisms.

The multisensor fuzzy logic approach for enhanced fire detection in smart cities holds several advantages over classical approaches. Fuzzy logic excels in handling uncertainty and imprecision, which are common in dynamic smart city environments. It allows for a more nuanced interpretation of sensor data, accommodating variations in fire characteristics that may not be well-defined by rigid rules. Integrating multiple sensors, such as those measuring smoke, flame, and temperature, allows for a more comprehensive analysis of fire indicators. Fuzzy logic can effectively combine information from different sensors, providing a holistic view that enhances detection accuracy. Fuzzy logic employs rule-based decision-making, allowing for dynamic adjustments based on changing environmental conditions. The system can adapt its responses to evolving fire scenarios, leading to improved responsiveness. Fuzzy logic's ability to model complex relationships and incorporate multiple parameters reduces the likelihood of false alarms. It provides a more nuanced evaluation of sensor inputs, distinguishing between actual fire events and benign fluctuations. In summary, the fuzzy logic approach, especially when applied to a multisensor system, has the potential to outperform classical techniques by providing a more adaptive and nuanced approach to fire detection, potentially leading to higher detection rates (DRs), lower false alarm

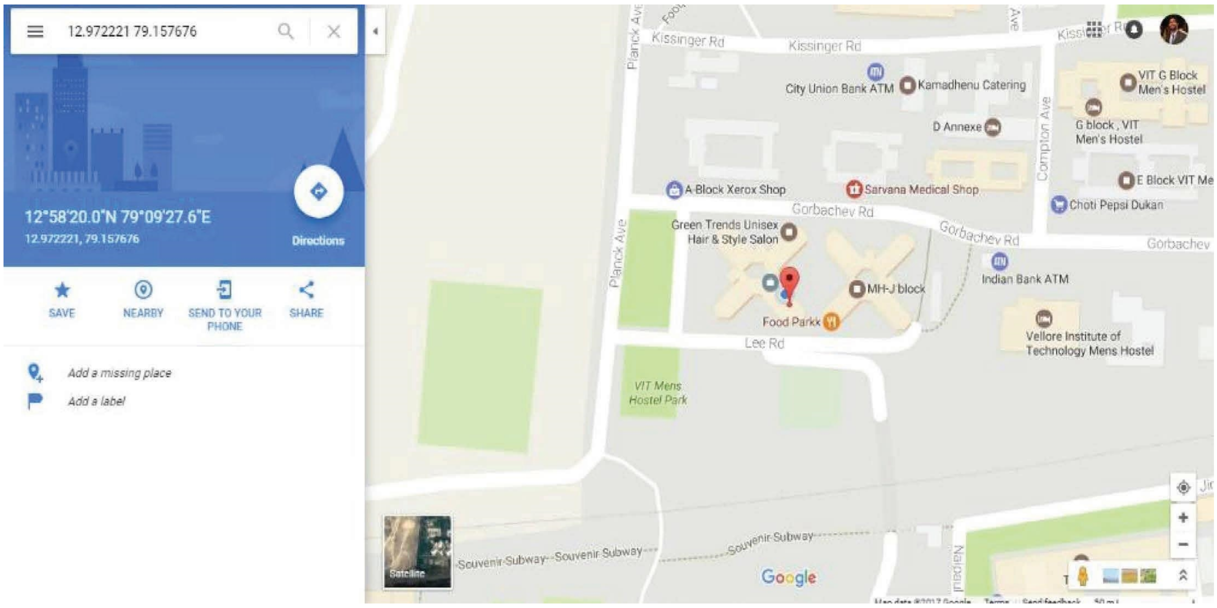

Figure 10: Screenshot of SMS sent by the GSM modem.

Table 3: User size for data collection and disseminating alerts.

User size	Description	Data collection method	Alert dissemination method
Small	Limited user base, e.g., <100 users	Surveys/questionnaires and manual monitoring	E-mail notifications and SMS alerts
Medium	Moderate user base, e.g., 100–500 users	Automated data logging and periodic sampling	Mobile applications and push notifications
Large	Large user base, e.g., >500 users	Real-time sensor networks and continuous monitoring	Web portals and social media notifications

Table 4: Comparison of different methods.

Method	Detection rate (%)	False alarm rate (%)	Accuracy (%)
[27]	96.34	17.23	90.32
[30]	95.97	8.58	91.79
[32]	97.11	7.34	93.63
Proposed method	98.78	5.01	96.26

rates (FARs), and improved overall accuracy rate (AR) in smart city environments as presented in Table 4. In the table, the efficacy of the proposed approach is compared with that of the random forest algorithm [27], gradient boosting algorithm [30], and image processing approach [32]. The parameters DR, FAR, and AR are evaluated according to the following expressions:

$$\mathrm{DR} = \frac{\mathrm{TP}}{\mathrm{TP} + \mathrm{FN}}, \tag{1}$$

where TP and FN indicate true positives (the number of correctly detected fire instances) and false negatives (the number of missed fire instances), respectively.

$$\mathrm{FAR} = \frac{\mathrm{FP}}{\mathrm{FP} + \mathrm{TN}}, \tag{2}$$

where FP and TN indicate false positives (the number of nonfire instances incorrectly identified as fires) and true negatives (the number of correctly identified nonfire instances), respectively.

$$\mathrm{AR} = \frac{\mathrm{TP} + \mathrm{TN}}{\mathrm{TP} + \mathrm{TN} + \mathrm{FP} + \mathrm{FN}}. \tag{3}$$

5. Conclusion

An intelligent fire detection system using a soft computing technique is successfully designed and tested. Intelligent systems are at the forefront of fire detection and alarm technology, representing the latest advancements in this field. These intelligent systems, as opposed to conventional alarm systems, use microprocessors and system software to monitor and regulate the operations of each alarm and signaling device. Each intelligent fire alarm device essentially performs the same responsibilities as a small computer, supervising and controlling a variety of input and output devices to ensure effective functioning and improved fire protection measures. Three smoke, flame, and temperature sensors are included in the fire detection system to help in fire detection and to help deliver accurate information to prevent false alarms. By introducing flame (a matchstick), smoke (a paper coil burning), and temperature (a flashlight), an experimental study is obtained. Information about the situation is relayed to remote areas using GSM connectivity. The SMS is sent using the GPS and GSM modem. When a fire is discovered, an SMS containing the latitude and longitude coordinates is sent to the resident and the fire rescue service. The status concerning the fire is updated every 45 seconds on the online portal with the assistance of IoT. The information regarding the fire will be updated on the web page from where we can find the data regarding the intensity of the fire. The latitude and longitude coordinates would be helpful for the fire department to reach that exact place within less time.

Data Availability

The data used to support the findings of this study are available from the first author upon request (vegenaveen@vit.ac.in).

Conflicts of Interest

The authors declare that they have no conflicts of interest to report regarding the present study.

Authors' Contributions

Naveen Kumar Vaegae visualized the study, investigated the study, collected the resources, and performed formal analysis. Visalakshi Annepu conceptualized the study, visualized the study, performed data curation and formal analysis, proposed the methodology, provided the software, and wrote the original draft. Kalapraveen Bagadi supervised the study, administered the project, and reviewed and edited the manuscript. Fadl Dahan curated the data and investigated the study.

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