# FiMoDeAL: pilot study on shortest path heuristics in wireless sensor network for fire detection and alert ensemble

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**ABSTRACT**

With the incessant outbreak of fire, the heavy loss to both lives and properties in the society fire has since become a critical issue and challenge that needs our daily attention to be resolved. Loss of lives and properties to fire outbreak in 2021 alone as occurring in major Nigerian markets and residential homes was estimated at over 3 trillion Naira. Our study proposes a wireless sensor network internet of things (IoT) based ensemble to aid the effective monitoring, detection and alerting of residents and fire service departments. With cost as a major issue and the requisite installation of fire and smoke detectors in many houses our ensemble can efficiently integrate into the existing system using the ESP8285-controller to create a comprehensive access control system. The system provides real time monitor and control capabilities that will allow administrators to track and manage fire monitor and detection within a facility. Thus, enhances system's efficiency and performance.



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## 1. INTRODUCTION

Fire as an entity, has birthed significant industrial and technological growth with advances in the field of informatics and, remains a threat that must be addressed [1], [2]. Unfortunately, the rise in trend of fire outbreaks has since become a societal menace today leaving the loss to lives and property on it is wake [3]. Smoke, as associated with fire sucks all air and quickly render unconscious persons in it is immediate environ, leaving them with little or no time to escape [4]. With plenty synthetic materials rippled across our homes today [5]–[7], these elements yield hazardous compounds that increases the danger of fires and as the fire spreads it consumes available oxygen and releases toxic fumes from the incomplete combustion [8]–[11].

The havoc wr eaked by it has become major concern as inhaled smoke has been a major cause of fire-related deaths [12]. Thus, birthing fire detection system, which automatically detect fire yielding an early alert protocol for occupants therein a building or otherwise of the existence and imminent threat/dangers of fire. There are a variety of communication mode for wireless sensor devices known as internet of things (IoT) based devices and these includes: i) device-to-device allows the device to interact directly with networks so that the devices fundtions as intended using protocols such as Bluetooth, Z-Wave, and ZigBee enable direct communication between them. Many home automation systems uses this architecture [13], [14]; ii) device-to-cloud uses a cloud service provider to directly connect an IoT device and allow data echange using pre-existing communication channels such as WiFi or wired Ethernet [15]–[17]; iii) device-to-gateway links an IoT device to a cloud service using an ALG service as a conduit, which implies the application software running on a local gateway device that serves as a bridge between the device and the cloud service and offers security and other features like data or protocol translation [18], [19]; and iv) backend data-sharing mode enables users to export and combine data from external sources with smart object data from a cloud service for analysis. It supports a user's view to grant other parties access to retrieved records in it is evolution of the single device-to-cloud comms paradigm, which may lead to data silos if an IoT device uploads data only to a single app service provider. Data collected from a single IoT device stream may be aggregated and analyzed [20]–[22].

The audible or visual alarm provided by a fire detection system, signals occupants to evacuate a premise. It is very important in large, multi-storey buildings where occupants may be unaware of fire in another part the building, and thus, is unlikely or impractical for warning to be provided. The capacity to identify the presence of fire is an essential component of a comprehensive fire detection strategy. We cannot inform inhabitants, trigger numerous other fire safety devices, or summon the fire department without a means of detection. If a flammable object comes in contact with oxygen and heat, fire can ignite quickly spreading to nearby goods [23]. As it grows, it become more intense in open space [24], [25]. In a close environ, fire can grow it is intensity until everything in it is path is consumed. It can also burn at a steady rate depending on the amount of oxygen [26]–[29]. Kizilkaya *et al.* [30] extended Kong *et al.* [31] to conclude that fire poses a grave threat with a record high of over 64,000 deaths reported annually between 2000 and 2019. It is financial impact resulted from losses estimated at over 1-trillion dollars worldwide, regardless of whether lives are lost [32], [33]. This damage can be extensive, with the severity of the fire determining the extent of the destruction. Direct losses may include property damage, sprinkler activation, firefighting expenses, falling debris, and structural damage and the indirect costs may result from repair time and temporary or permanent relocation [34]–[36].

To reduce fire hazards, Li *et al.* [37] must consider the time spent between fire detection and alert of all requisite authorities. Early detection is critical to ensure fire remains controllable. Fire detection at it is infancy is an effective instrument for saving lives and minimizing property damage. It is imperative to incorporate a scheme to detect a fire incident at it is incipient stage. When emergencies occur, lives can be saved and properties damage reduced by promptly providing information on quick and safe evacuation routes [38], [39]. Fire can be mitigated via IoT. IoT integration in resolving fire challenge will help yield accurate detection systems with real-time monitor and crisis management [40]. Smart homes direct their attention today, to IoT as means to streamline monitoring, tracing, communication, and management activities. It leverages on IoT's heterogeneity, real-time analytics, interoperability, distributed computing and linked tags to enable automated supply monitoring, and to achieve optimal results in data processing activities [41], [42]. We thus, presents a fire detection and alert ensemble that leverages IoT to identify fire in real-time and at it is earliest stages using a network of connected devices, sensors, software, and other technologies that enable seamless communication via the internet.

## 2. MATERIALS AND METHODS

### 2.1. Fire monitor and detection

A fire detection system yields an automatic mode to detect fire and alert [43], [44] residents of fire threat using either an audible or visual alarm that signals the evacuation of the occupants. This is critical in large or multi-storey buildings where occupants may be unaware of fire outbreak within the structure, and it is likely point of origin. It is ability to identify fire and it is source, is very essential as a fire detection strategy. The scheme should also trigger other fire safety measures and devices as well as inform inhabitants, and/or summon the fire department [45], [46]. While, humans can excellently detect fire since we can feel it is heat, perceive it is flames and smoke it is often not a dependable mode as we may not be available and at a variety of point within a building. Thus, we leverage on technology as means to monitor the radiation spectrum that our eyes cannot observe effectively. Thus, we explore the IoT's capacity to detect a range of spectrum via devices with photovoltaic, solid-state, or ionized gas tube components that respond to such spectrum(s). Electromagnetic signals at infrared, visible, or ultraviolet wavelengths can be recognized using flame detection systems [47].

Fire protection is the application of science and engineering principles aimed at protecting people, properties and the environment from a devastating fire. From ancient times, people have realized that early detection of fire has a positive effect in fire control. Development of fire detection technology was introduced due to a series of loss of lives and property damage [48], [49]. However, growth in fire detection scheme has been substantial over the last decade because of advances in sensors, data technologies, a greater understanding of fire physics, and new fire detection technologies and concepts developed over the last 2 decades [50].

### 2.2. Existing IoT-based detection ensemble

The proposed system extends [51] with priority to monitor indoor spaces with early detection that seeks to prevent potential danger. Existing model consists of 5-components: a gateway, an action point, an end device, a server and a user as in Figure 1. Careful analysis of the experimental framework is [52]–[55] and these includes; i) the end device with detection algorithm is equipped with sensors to measure gas, smoke, temperature, and humidity (indoors) monitoring the various levels of temperature, humidity, carbon monoxide, and smoke. Data collected via sensors are used to compute the probability of fire occurrence via a fuzzy system. With initialized room condition data, the fuzzy values are transmitted to the gateway via XBee comms. The detection algorithm then considers the temperature, humidity, smoke, and carbon monoxide inputs to generate probability output representing the likelihood of a fire. The rule-system assigns member-functions of low, medium, and high to each input; and, normal, fire, and alert to each output [56].

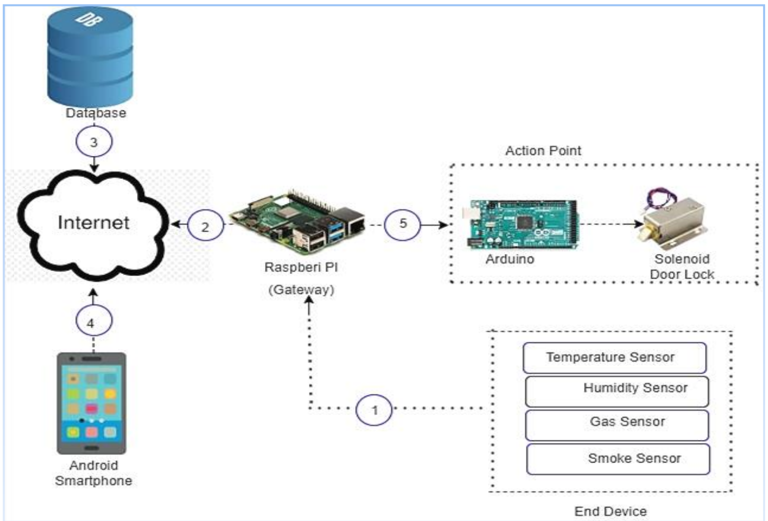


Figure 1. Block diagram of the existing system [51]

This approach enhances it is accuracy and reliability while, reducing number of false alarms a user receives. The output via the transmission algorithm, determines if (or not) the probability of fire as output and sends to it is gateway via XBee communication. This decision is based on the classification of the fuzzy output of normal, fire, and alert; ii) the gateway is composed of a Raspberry Pi, XBee comm, and buzzer alarm. Sensor data from the end device is sent to a server via the XBee. If fire probability value from obtained data is categorized as alert, the gateway switches on the alarm to alert residents. If the probability value is categorized as fire, the gateway continuously rings and transm it is a command broadcast to the action point to unlock the door as well as trigger other alarms. However, the buzzer does nothing if the condition is normal. The server helps store the data both in the cloud and on the user access media [57].

To ease user access, system uses the Android app as a primary medium to help users connect via gateway using either the server, or directly to the gateway (if user is on the same local network). When the fire probability rises to the level of alert or fire, the server sends an alert to the application through cloud messaging to inform the user; and iii) the action point consists an Arduino board, XBee module, and solenoid door lock (whose initial state is locked). There are 3 modes to unlock an action point by changing it is status. First, is to unlock the door via a user command on app. All action points are opened for 5 seconds, and returns to a locked state. Secondly, when a user touches the action point unlock button, this hybrid mode unlocks the doors; and lastly, when the fire probability enters a FIRE class, this unlocks the action point until the level of fire decreases.

Our design prioritizes early intervention by monitoring the environment and employing safety measures to avert potential harm. It combines sensor, fuzzy logic, transmission algorithms, and cloud databases to ensure accuracy and reduce false alarms. It is interface eases users' access to data and alerts with action point to unlock the doors on a need-basis.

### 2.3. Experimental procedure for fire monitor, detection and alert (FiMoDeAL) scheme

It involves both hardware and software parts as in Figure 2. To efficiently and effectively detect any fire outbreaks, alert her occupants, and call the fire department emergency contact via twilio the ensemble consists of the sensors (flame, MQ-2, temperature, and gas). Each of which is designed to detect the various elements of change in the instance of fire as well as a variety of gas concentration (for LPG, propane, methane, and smoke). It then uses the WiFi, which acts like a transmitter to send the received data for analysis by the Node MCU. It also fuses a Node MCU (ESP8285) controller with a buzzer, and LCD for seamless operation [58]–[60]. With the data acquired therein as input and sent to the ESP8285 the ensemble retrieves it is threshold values and analyse them via comparison against the input values received from the sensors in real-time. It provides accurate data and alerts to residents and fire-fighting facilities. Divided into 2 segments based on it is function to both provide a real time data cum alert residents, and a cloud-app that interacts directly with the fire department emergency contact [61]–[63].

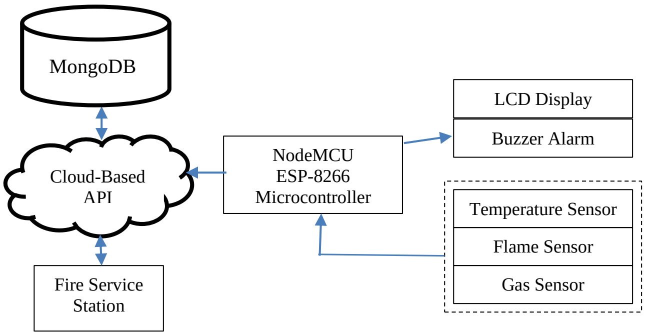


Figure 2. Block diagram of the experimental ensemble (FiMoDeAL)

Ensemble effectively detects fire outbreaks instantaneously via the ESP8285 and it is sensors to ensure residents are alerted in real-time, and fire department notified of the emergency. This system is a testament to the power of technology in ensuring public safety [64], [65]. To ensure fast-response of the system, all sensors and other components are connected via the Node MCU to detect fire or flame within 760–1,100 nanometres wavelength. This ensures that indoor data generated via the wireless sensors, are sent within the fastest time possible [66]. Furthermore, the Node MCU analyses all data, and compares it is output with set threshold to determine the fire outbreak probability. With set parameters exceeding those of the predetermined threshold value(s), it indicates the existence of fire. The ensemble then further alert residents and via the cloud-app (API), it computes the nearest fire service department using the Algorithm 1 to alert the fire department in real-time to yield a reliable, efficient mode to detect indoor fire outbreak. It is use of the sensors and controller, will promptly alert residents in the event of a fire outbreak [67].

Algorithm 1. For FiMoDeAL
INPUT: Number of nodes, N; OUTPUT: Print distance, previous

```
Create vertex set D
For each vertex v in G Do
    distance[v] ← infinity
    previous[v] ← undefined
    add v to D; distance[source] ← 0
where D is not empty Do
     u ← in D with min_distance[v]
     remove u from D
For each neighbour v of u Do
    sum ← distance[u] + length(u, v)
    if sum < distance[v] then
       distance[v] ← sum;
       previous[v] ← u;
end For
return distance[ ], previous[ ]
```

## 3. FINDINGS AND DISCUSSION

### 3.1. Performance evaluation and discussion

The shortest path algorithms include a single-path is between a single sources or supply node and all other vertices and all-pair path which evaluates the shortest path between all vertices in a graph. This study determines the chosen algorithm based on the features and needs of the program. While, the single-source yields fastest responses we compared the Dijkstra and Bellman's Ford to identify the shortest, most efficient path between any 2 nodes, and this agreed with [68]. Dijkstra was found to outperformed Bellman Ford in both (un) directed nodes with positive weights, with simulations and comparative analysis as in Table 1.

Table 1. Application response time with scalability results

| Number of nodes | Bellman-Ford in (ms) | Dijkstra in (ms) |
|---|---|---|
| 5 | 1,351 | 513 |
| 10 | 3,724 | 756 |
| 15 | 9,577 | 2,072 |

Dijkstra's algorithm takes time on a graph with edges |E| and vertices |V| in finding it is time complexity to yield O(|E|+|V| Log|), which agrees with [69]–[71]. Also, for the Bellman-Ford, the time required is O (|V|×|E|). We infer that the Bellman-Ford algorithm takes more time than the Dijkstra algorithm. Hence, the comparison shows that the Dijkstra algorithm is faster than the Bellman-ford algorithm. For the longest amount of nodes [72]–[74], the Djikstra's algorithm yielded a 2,072 seconds response time; while the Bellman-Ford algorithm yielded a 9,577seconds response time for the same ensemble.

### 3.2. Temperature response

We installed the proposed experimental ensemble/device in a kitchen at an initial distance of 0.25-meters from the fire source, to investigate it is rate/speed of fire monitoring and detection. Table 1 shows the experiment conducted, placing the ensemble as varied distances from the fire-source so as to measure it is response time and fire detection capability. The response time is the time required to detect fire and notify the fire service department. If we varied the device at a variety of distances ranging at 0.25 m, 0.5 m, 0.75 m, 1.25 m, 1.5 m, 1.75 m, 2.0 m, 2.25 m, 2.5 m, 2.75 m, 3.0 m, and 3.25 m respective we retrieved a corresponding time response of 0.312 s, 1.014 s, 1.716 s, 2.418 s, 3.120 s, 3.822 s, 4.524, 5.226 s, 5.928 s, 6.630 s, 7.032 s, and 7.734 s respectively as in Table 1 – with its result in agreement with [75]. The ensemble detects fire accurately with response time that varies appropriately, according to it is distance from the source of fire as illustrated in Figure 3 [76], [77]. This wireless sensor network ensemble yielded several insights on functionality and performance. First, it yielded an accurate measure of environ. Second, ensemble effectively compared collected values with high level of accuracy in determining the fire source. Lastly, it efficiently alert residents and fire department to instill confidence and reliability as it is core functionality [78].

### 3.3. Flame response

Any flame sensor by design is instructed to detect light within a specific range of wavelengths allowing the sensor to observe and capture as input, light within the spectrum and threshold set. Studies identified 33 nm as the acceptable, allowable range to aid fast detection capability [79], [80] as a change in distance will cause a consequent change in the observed wavelength values, so that the greater the distance and increase in nm increase the less accurate the it is prediction/detection. And with a lesser accuracy yield is observed with an increased distanced between the sensor and the flame incident. As in Figure 3, for 2.5 cm the reading was detected and observed in a response time of 0.312 s. In 32.5 cm the reading was detected and observed in 7.734 s as in Figure 3.


Figure 3. Test result from fire detection testing

## 4. CONCLUSION

Study models a fuzzy system that fuses sensors and ESP8285 controller to determine fire probability output. It sends an alert to users via a send algorithm having monitored environment conditions as they quickly change. Previous systems used were often found to have provided false alarms owing to their configuration logic. The experimental design that yielded the proposed ensemble however notifies both the residents and the nearest fire department of fire outbreak, source and location using a shortest distance algorithm. The proposed ensemble is efficient, reliable and can handle dynamic changes as in the send algorithm. Our goal was to integrate this ensemble onto existing components within residential facilities so as to effectively reduce the loss of life and properties. The increased use and adoption of machine learning approaches and a variety of other automated processes with industrial IoT technologies both on the home (residential) frontiers and industrial applications has continued to drive up the demand for adaptation of advanced flame detection solutions.

These detectors can be integrated into complex automation systems, enabling real-time monitoring, remote alerts, and automated response actions. These, we hope will be modified to help effectively manage the risks associated with fire as well as address other critical issues of needs therein. With IoT-based fire detection and sensing systems, sensors are placed as detection nodes with built-in interaction units. A key problem to be addressed for the future also is the issues of low-power, and fault tolerance. Many flame sensors have been found to yield high rate in false alarm due to it is infrared, visible, and ultraviolet radiation. Such interferences often caused by non-fire sources, should be compensated. Also, the EMI-and-RFI noises can also affect the performance of the sensor, so it needs to be studied. Fire detection and control is a complicated operation. Because of it is various phases, diverse appearance, colors, emission spectra, combustion fuel, and position, complexities arise. In these circumstances, using fuzzy logic and deep learning-based algorithms to improve the current fire detection system's performance could be beneficial. Optimization techniques need to be improved to minimize false alarms. After simultaneous interpreting, all data from various sensors must be processed and analyzed according to sensor fusion technology.

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