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Deploying an IoT-Enabled Realtime Fire Detection and Alert Model for Residential Homes

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ABSTRACT

While fire has facilitated significant technological and industrial advances, it is also a major threat that demands attention. The impact of fires, including the loss of human life and property, is a significant concern. This study proposes a novel fire detection and alert model that employs Internet of Things (IoT) technology to detect fires in real time. The specific objectives of this study are to model Internet of Things (IoT)-enabled fire detection system, assess its effectiveness, and compare it to existing methods to identify any gaps therein. The system comprises four sensors, each designed to detect fire-related factors. Sensors were connected to a NodeMCU microcontroller. The microcontroller analyzes sensor inputs in real time, providing precise information and alarm signals to building occupants and fire-fighting equipment. This study stands out in its exploration of this crucial area, including the application of Dijkstra's Algorithm to locate the fire service department. An experimental result shows that the model effectively detects fires and that the reaction time varies with the distance from the fire's source. The comparative data analysis between the existing system and proposed model demonstrates that the proposed model is more efficient, reliable, and better equipped to handle dynamic events than the existing system.

1. INTRODUCTION

Fire outbreaks unfortunately, occur quite too frequently; causing extensive damage and wreckage to both lives and property yearly (Altowaijri et al., 2021; Ariati et al., 2019). The entity fire, has continued to both enable significant great industrial and technological advances births and industrial advancements, and it is also a threat that must be addressed. The havoc wreaked by fire has become major concern (Benzekri et al., 2020; Boutsika & Papathanassiou, 2008). The smoke inhaled has been the most cause of fire-related death rather than the fire-burn experienced. Smoke quickly render a person unconscious, leaving them with little or no time to escape. Modern homes contain a lot of synthetic materials and elements (Bouabdellah et al., 2013; Ehsan et al., 2022) found to produce hazardous compounds when burned, further increasing the danger of fires. As fire spreads – it consumes available oxygen and slows down burning processes by releasing toxic fumes from the incomplete combustion (Al-Bashiri et al., 2017; Alqourabah et al., 2021; Carlson, 2005; Mukherjee et al., 2022).

If and when a flammable object comes in contact with both oxygen and heat, a fire can ignite. At first, the flames may only affect one object, but they can quickly spread to nearby items (Chin et al., 2019). As the fire grows, it becomes more intense and reaches its peak in open space. However, flames

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eventually slow as the available fuel is consumed. In a closed environment, the fire can continue to grow in size and intensity until everything inside is consumed. This occurs during the burning period, during which the fire reaches its maximum intensity and continues to burn at a steady rate, influenced by the amount of oxygen that can enter through any available ventilation (Durani et al., 2018).

Brushlinsky (2017) cited in Kodur et al., (2020) concluded fire poses a grave threat to both lives and property with a record high of about 64,000 death cases reported annually between 2000 and 2019. The financial impact resultant from the losses was estimated at over 1-trillion dollars, worldwide, regardless of whether lives are lost. The damage caused by fires can be extensive, with the severity of the fire determining the extent of destruction (Paredes-Valverde et al., 2016; Perilla et al., 2018). Direct losses may include property damage, sprinkler activation, firefighting expenses, falling debris, and structural damage. In addition, indirect costs may result from repair time and temporary or permanent relocation (Kizilkaya et al., 2022; Kong et al., 2016).

Hossain et al., (2020) opine that a critical aspect that can reduce fire hazards is the time spent between fire detection and alerting the appropriate authorities. As a result, early detection is critical to ensure the fire remains controllable. Detection of a fire outbreak at its early stage is an effective instrument for saving lives and minimizing property damage. It is thus, imperative to incorporate a scheme to detect a fire incident at its incipient stage. When emergencies occur, lives can be saved and properties damage reduced by promptly providing information on quick and safe evacuation routes (Hossain et al., 2020; Kodali & Yerroju, 2017). As a major prevalent issue, fire can be mitigated via Internet of Things (IoT) based solutions and technology. Integrating IoT into resolving such challenge will yield a precise and accurate fire detection systems with real-time monitoring and crisis management. Recently, smart homes, precision farming, manufacturing, robotics, healthcare, entertainment, and transportation etc – have directed their attention towards IoT . This innovation seeks to streamline monitoring, tracing, communication, and management of smart embedded devices. Thus, IoT leverages on the heterogeneity, interoperability, real-time analytics, distributed computing and tags from linked RFID in supply chains to enable automated supply monitoring, and to achieve optimal results in data processing activities (Li et al., 2019; Liu et al., 2021; Marwedel, 2021).

Thus, our study presents an innovative fire detection and alert model that leverages on IoT to identify fires in real-time, even at their earliest stages. IoT refers to a complex network of connected digital and mechanical devices, equipped with sensors, software, and other cutting-edge technologies that enable seamless communication with other systems and devices via the Internet.

2. IOT TECHNOLOGY COMMUNICATION

A variety of IoT communication model and means includes (Ray et al., 2017; Roque & Padilla, 2020):

1. **Device-to-Device Comms:** Interacting with networks directly is a component of device-to-device communication. In order for devices to function as intended, protocols like Bluetooth, Z-Wave, and ZigBee enable direct communication between them. Many home automation systems uses this architecture.

2. **Device-to-Cloud Comms:** An Internet cloud service, such as an application service provider, is connected directly to an IoT device via a device-to-cloud

communication architecture in order to exchange data and control message flow. This technique often uses pre-existing communication channels, including Wi-Fi or wired Ethernet (Kim et al., 2021; Saponara et al., 2021; Suleiman & Reza, 2019); passed via the modem, where it is modulated and sent to the control via communication medium. (Stouffer et al., 2015). At remote site 2, both the WAN card and the intelligent electronic device (IED) are connected directly to the modem. There is enough intelligence built in to process some of the data, so no PLC is required. Field site 3 is similar to the field site except that the RTU is replaced by a PLC. Protocols are required for communication between sensors, other field devices, and RTU/PLC.

3. Communication Link: There is usually a long distance between the Field Sites and the Control Center ranging from a few kilometers to hundreds of kilometers or at times thousands of kilometers. Effective communication is necessary for effective flow of data to/fro the MTU and other devices (Oliveira et al., 2016) as in Figure 1. The link can be one of the following: We replaced the rental phone line. Power line-based communication. Wireless; Microwaves; Cellphones; Satellite and Wide Area Networks (WAN).
4. Control Center: The main part of SCADA Server (or MTU), the HMI, Workstations, Data Historian, and Communication routers – all of which are linked to a LAN. Data collected by the field is via a control center, where it is recorded and displayed on the HMI to enable the operator to take appropriate actions needed based on detected events.

Trend analysis, alarms and central reporting are also the responsibility of the control center (Stouffer et al., 2015).

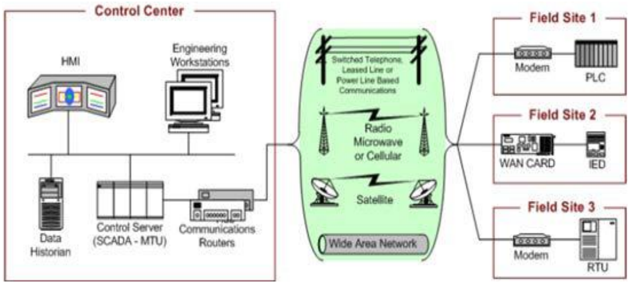

Figure 1: The schematic diagram of the SCADA Architecture

3. MATERIALS AND METHODS

3.1. Existing IoT-Fire Detection Ensemble

The proposed system extends Saptura et al (2020) with priority to monitor and track indoor spaces with early intervention that seeks to prevent any potential danger. The system is composed of 5-components namely: a gateway, an action point, an end device, a server and a user as in Figure 3.

End-Device (with Detection Algorithm) is equipped with an array of sensors that measures temperature, humidity, gas, and smoke. It monitors levels of temperature, humidity, carbon monoxide, and smoke in indoor areas. The data collected via sensors are used to compute probability of a fire occurring via a rule-based fuzzy system. Having intialized room condition data, the fuzzy values are transmitted to the gateway via the Zig-XBee comms. Our detection algorithm also considers temperature, humidity, smoke, and carbon monoxide inputs to generate a probability output representing likelihood of a fire. The rule-based system assigns membership functions of low, medium, and high to each input;

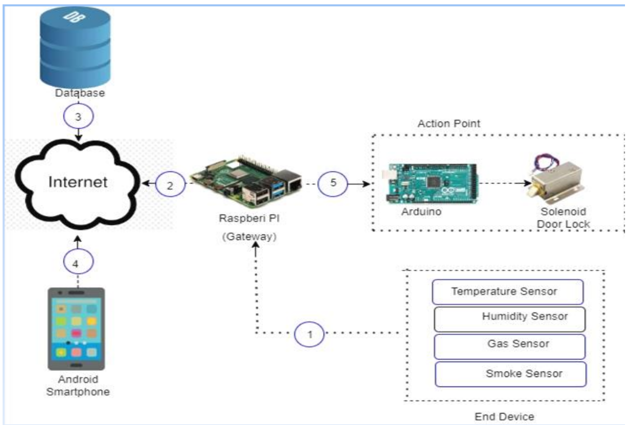

Figure 2: Schematic diagram of the existing system (Source: (Saputra et al., 2017))

3.2. Technical Experimental Procedure

It involves both hardware and software parts(Chevalier et al., 2003; Tarafdar & Zhang, 2005):

1. **Input Design** We designed the model to respond efficiently to fire accidents by detecting outbreaks, alerting building occupants, and calling the fire service department emergency phone number through Twilio. The model comprises four sensors, each of which is specifically designed to detect the various elements that change during a fire. These sensors include a flame sensor that detects and reacts to the occurrence of fire or flame, a temperature sensor for measuring temperature of its environment, and an MQ-2 sensor for sensing the concentration various gases such as LPG, propane, methane and smoke. In addition to these sensors, a Node MCU (ESP8285) controller, buzzer, and LCD are fused into the system to ensure seamless operation(Sarwar et al., 2019; Sendra et al., 2020; Sungheetha & Sharma R, 2020).
2. **The Processing Node MCU ESP8285** microcontroller plays a crucial role in the system. It receives threshold values and analyzes analogue and digital inputs from the sensors in real time to provide accurate information and alert messages to building inhabitants and fire-fighting facilities. The system is divided into two segments based on its function.

   The first part is a real-time embedded system that provides real-time data and alerts to building occupants. The second segment is the cloud-app used to interact with fire service department emergency phone number(Sathyakala et al., 2018; Shahraki et al., 2018; Sharma et al., 2020).The model effectively detect and respondto fire outbreaks using microcontroller and sensors to ensure residents are alerted in real-time, and fire service department is immediately notified in case of an emergency. This system is a testament to the power of technology in ensuring public safety(Singh & Sharma, 2017).
3. **Real-time embedded systems:** This segment is designed to focus on the generation of data from the indoor environment through the use of sensing devices. The MQ-2 gas sensor detects the concentration of various gases such as LPG, Smoke, Propane, Methane, Carbon Monoxide, and fuel vapour. Additionally, a DHT-11 temperature sensor measures and provides temperature values while a flame sensor detects a fire or flame within 760 – 1100 nanometers wavelength. The NodeMCU analyses indoor features such as temperature, gas concentration, pressure and compares its output with set threshold.

Figure 3 shows the conceptual diagram of the proposed model.

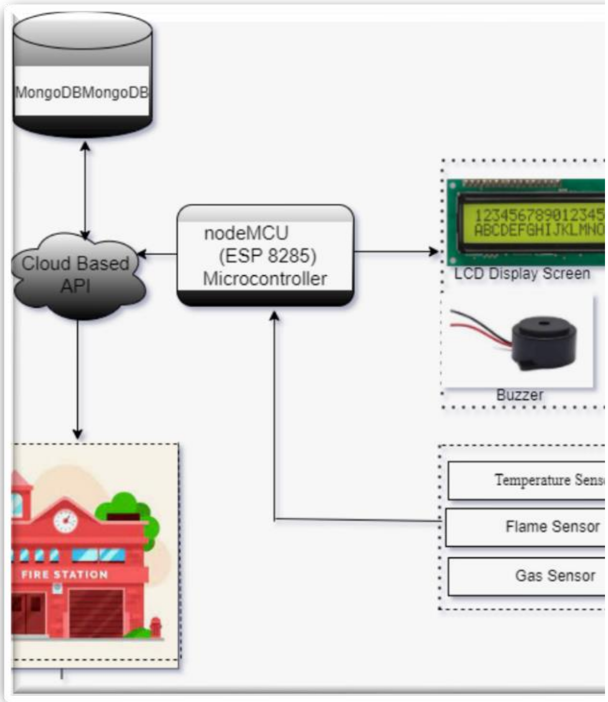

Figure 3: Conceptual Diagram of the Proposed Model

3.3 Adopted Algorithm for the Study

Our study utilized Dijkstra's algorithm due to its superior efficiency in finding the shortest route between a starting node and all other nodes in a graph. We compared two shortest path algorithms, Dijkstra and Bellman-Ford, by analyzing the time and space complexity. Our analysis revealed that Dijkstra's algorithm outperformed the Bellman-Ford algorithm in both small and large graphs. The purpose of the algorithm was to locate the nearest fire station from the site of a fire occurrence, and we concluded that Dijkstra's algorithm was the most suitable for this task. Edsger Dijkstra, a renowned Dutch computer scientist, developed the algorithm in 1956 and published it in 1959 (Singal & Chhillar, 2014).

Dijkstra's Algorithm

1. function Dijkstra (Graph, Source)
2. create vertex set D
3. for each vertex v in Graph:
4. distance[v] ← INFINITY
5. previous[v] ← UNDEFINED
6. add v to D
7. distance[source] ← 0
8. While D is not empty do:
9. u ← in D with min distance[v]
10. remove u from D
11. for each neighbour v of u:
12. Σ ← distance[u] + length (u, v)
13. if Σ < distance[v]
14. distance[v] ←Σ
15. previous[v] ← u
16. end while
17. return distance[], previous[]
18. end function

4. RESULTS AND DISCUSSION

4.1. Result Findings and Discussion

We installed proposed model embedded system device in a kitchen at a distance of 0.25 meters from the fire source to detect fire. We conducted the experiments by varying device distances from the fire-occurring place to measure the response time and fire detection capability. . Response time is time required to detect fire and notify the fire service department. If we varied the device at a distance of 0.25m, 0.5m, 0.75m, 1.25m, 1.5m, 1.75m, 2.0m, 2.25m, 2.5m, 2.75m, 3.0m and 3.25m, response times are 0.312s, 1.014s, 1.716s, 2.418s, 3.120s, 3.822s, 4.524, 5.226s, 5.928s, 6.630s, 7.032s and 7.734s respectively as in Figure 4. This agrees with (Akpoyibo et al., 2022).

An experimental result indicates that the model detects fire accurately and response time varies according to distance from the source of a fire place. Figure 4 shows result analysis of variations in devices from the location of the fire.

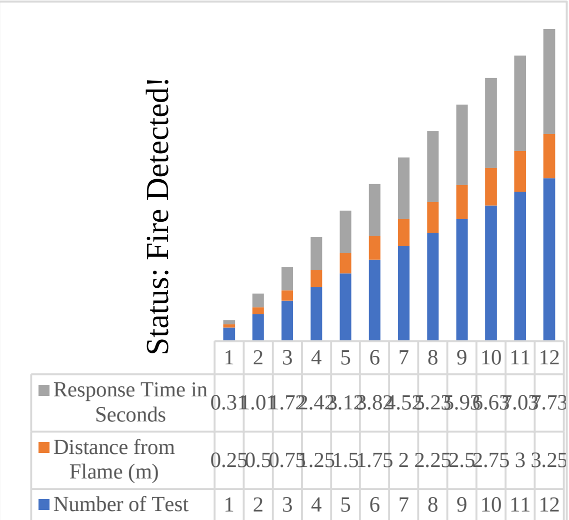

Figure 4: Test results from the resultant fire detection ensemble

4.2 Comparative Analysis between Dijkstra and Bellman-Ford Algorithms in Shortest Path Optimization

Shortest path algorithms are classified into two categories: single source shortest path (SSSP) and all pair shortest path (APSP). SSSP finds the shortest path between a single supply vertex and all other vertices, whereas APSP finds the shortest path between all vertices in the graph. The algorithm chosen is determined by the program's characteristics and needs. SSSP tries to deliver fast responses. The Dijkstra and Bellman's Ford methods are used to identify the shortest and most efficient path between two vertices. The Dijkstra method performs effectively in directed or undirected networks with positive weights, whereas the Bellman-Ford algorithm discovers negative edge cycles in a graph. The Bellman-Ford method performs best when there are few nodes, but Dijkstra's algorithm performs best when there are many nodes. AbuSalim et al., (2020).

Dijkstra's algorithm takes time on a graph with edges E and vertices V, which may be written as a function of |E| and |V| using the Big-O notation. Dijkstra's algorithm runs in 0 time (|E|+|V| Log|). Moreover, the time required by the Bellman-Ford algorithm is O (| V |. | E |). We can infer from the time complexity 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. Table 1 shows running time of the two algorithms, while Table 2 shows comparison of the two algorithms based on simulation result analysis.

Table 1: Running Time of the two algorithms

No of nodes Dijkstra	Dijkstra (in ms)	Bellman-Ford (in ms)
5	1351	513
10	3724	756
50	2072	9577

Table 2: Comparison of the Two Algorithms

The Algorithm	Complexity For Time	Complexity For Space	Number of Nodes
Dijkstra	0(|E|+|V|Log|V|)	O (V2)	Large
Bellman-Ford	O (| V | ·| E |)	O (V2)	Small

5. CONCLUSION

This study extensively examined the realm of technological advancements, specifically exploring the latest innovations that have the potential to significantly decrease the occurrence of fire-related disasters. We developed a comprehensive model and subjected it to rigorous evaluations for scalability and effectiveness. The system has demonstrated a practical, cost-effective and cheap solution for managing access to areas within a facility. We have successfully also integrated IoT and ESP32-controller to create a comprehensive fire monitor, alerting and detection system. Its many benefits are improved monitoring and observation of system conditions, better security, system efficiency, and user convenience. The system also provides real-time monitor and control capabilities that will allow building alert occupants of fire incidence, which in turn yields system efficiency. With the ongoing advancements in sensor technology, the value of our model is bound to increase even further.

Conflict of Interest

The authors declare that there is no conflict of interest.

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