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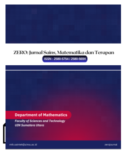

IoT-Based Automatic Fire Protection System (SIPEKA) with Android Application for Fast Monitoring and Response

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ABSTRACT

Fire hazards cause serious damage, especially in densely populated areas lacking rapid-response systems. This study introduces SIPEKA, an IoT-based automatic fire suppression system integrated with an Android application for real-time monitoring and control. The system uses DHT22 and MQ-2 sensors connected via Wi-Fi to detect fire indicators and activate suppression devices such as pumps or sprinklers. Testing was conducted in a controlled 3×3 m residential-like environment. Results show an average fire detection time of 2.8 s, a notification delay of 1.5 s, and a suppression success rate of 94.7%. The Android interface provides reliable manual override and remote monitoring with 99% uptime. Unlike conventional IoT fire systems that only issue alerts, SIPEKA combines automatic suppression, mobile control, and real-time monitoring, offering an effective, low-cost, and intelligent solution to improve household fire safety.

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1. INTRODUCTION

The image presents the system architecture of the IoT-Based Automatic Fire Protection System (SIPEKA), illustrating the integration of temperature and smoke sensors, a microcontroller unit, and an Android-based application. These components collaboratively function to detect early signs of fire through continuous environmental monitoring. The microcontroller processes real-time sensor data and triggers the activation of the water pump when abnormal conditions are identified, while the Android application facilitates instant notifications and enables remote supervision and system control. This integration demonstrates the potential of IoT technology to enhance automation and responsiveness in fire prevention systems. The primary objective of this research is to design, develop, and evaluate an intelligent fire protection prototype capable of improving early detection accuracy, reducing response time, and enabling real-time monitoring through mobile connectivity. By achieving these goals, the study aims to contribute to the development of efficient, technology-driven safety solutions that mitigate fire-related risks and losses in residential and industrial environments.

Indonesia's growing population has led to a corresponding increase in food demand. Fire incidents pose a serious threat to residential areas, both in urban and rural setting[1]. House fires caused by electrical installations and the use of electronic equipment are among the most common causes of fires in Indonesia and often result in both material losses and casualties[2]. Fires are disasters that cannot be predicted in terms of when and where they will occur; however, densely populated settlements are particularly vulnerable to fire hazards[3]. The factors causing fires in these cases include electrical short circuits, cigarette embers, cooking fuels, and careless waste burning[4]. One of the most dangerous disasters is fires. In addition to its direct danger on human's lives, fire consumes forests where trees that provide humans with oxygen are destroyed[5]. Several important efforts to enhance awareness and preparedness in dealing with fire emergencies include understanding the surrounding risks, being familiar with early warning systems, knowing evacuation routes, having the skills to quickly assess situations, reducing hazards through mitigation efforts, and participating in emergency preparedness training[6]. Residential areas rank the highest in terms of fire incidents in Indonesia. In addition to the high fire load, this is also caused by the high density of buildings. Such fires often cause significant losses to residents and, in many cases, result in casualties[5]. Across various regions in Indonesia, fire incidents continue to occur at a relatively high frequency with considerable impacts. In 2022, the Central Bureau of Statistics (BPS) reported 1,691 fire cases in Jakarta, an increase of 10.2% compared to the previous year, which recorded 1,535 cases. The highest number of cases occurred in South Jakarta with 492 incidents, followed by West Jakarta and East Jakarta with 382 and 349 incidents, respectively. Residential housing was the most frequently affected type of building, with 519 cases, followed by 259 cases in public buildings, 103 cases involving motor vehicles, and 18 cases in industrial areas[7]. With the rapid advancement of technology in society, new opportunities have emerged to simplify daily life and provide more efficient services or production processes[8].

The Internet of Things (IoT) plays a crucial role in transforming traditional factories into smart factories under the Industry 4.0 framework by integrating interconnected devices, sensors, and software to enable continuous monitoring and optimization of production processes[9]. IoT can be defined as a network of intelligent, interconnected devices equipped with sensing and actuating capabilities that collect, analyze, and share data through wireless communication without requiring direct human interaction[10]. This technology enables seamless connectivity between objects, programs, and platforms, allowing data to be transformed into meaningful information and actionable insights[11]. By providing access to real-time information anytime and anywhere[12]. IoT has significantly influenced various domains and offered innovative solutions to societal challenges through enhanced automation and data-driven decision-making[13].

The Internet of Things provides access to information anywhere at any time on any device and has changed all domains by addressing a variety of problems in society through real-time information from interconnected devices. Fire explosion is among the main reasons for death in the world. The urban spaces have a lot of population, many systems have control over fire detection but not over control of fire due to lack of functionalities[14]. Unique and complicated questions to the field of Digital Forensics although IoT data could be a rich source of evidence, forensics professionals cope with diverse problems, starting from the huge variety of IoT devices and non-standard formats, to the multi tenant cloud infrastructure and the resulting multi-jurisdictional litigations[15]. The importance of fast and accurate fire detection systems is crucial to minimizing the impact of fire hazards[16]. Fire detection systems are now widely used in various safety and security applications[17]. However, traditional fire detection systems are not highly effective in quickly alerting property owners, especially when no one is on site[18]. IoT-based fire alarm and suppression systems offer an innovative solution by integrating smart sensors, connected devices, and monitoring platforms to detect, manage, and respond to fires quickly and effectively[19]. The motors are connected to the microcontroller and used to move the robot and sprinkle water on the fire[20]. The Internet of Things (IoT) technology can be applied to this monitoring system so that information on LPG gas leaks and fires can be monitored remotely[21]. The IoT-based LPG Gas Leak and Fire Monitoring System is a concept that utilizes internet connectivity between a smartphone device and connected sensor devices[22]. The developed system has proved that the implementation of Android device and IoT platform is doable while retaining the core features such as live camera feed, fire detection, and fire extinguishment[23]. Hazard notifications, gas concentrations and status of hazard conditions can be accessed in real-time on Android-based smartphones[24]. Early fire detection and an extinguishing system, which aims to measure and detect anomalies of some specific variables that we found insightful (such as temperature, gas leakage, smoke) which can cause fire outbreaks in homes, offices etc[25]. Notifications are sent to the registered number or desired personnel in charge VIA a push bullet application software and WhatsApp messages[26]. fire safety monitoring is significant in providing future fire safety planning, control and management by putting in place appropriate fire safety laws, policies, bills and related fire safety practices or guidelines to be applied in public buildings, market centers and other public places[27]. Fire alarm systems are critical for warning people before a fire make any damage to people's properties. The use of IoT is urgently needed, its use makes life efficient both in terms of energy and time[28]. The environmental parameters are monitored using the sensor architecture. The sensors uses IoT based applications for processing the gathered environmental data. Cloud computing, IoT sensors, wireless technology and UAVs are combined for the purpose of fire detection[29]. Safety system based on the Internet of Things (IoT) and the Internet of Vehicles (IoV) for remote, real-time monitoring and seismic detection. The system utilizes a network of sensors installed across buildings and vehicles to track seismic activity and identify potential fire hazards. These sensors incorporate various data collection instruments, including vibration sensors for earthquake detection and smoke detectors for early fire identification[30]. Fire safety technologies and provides valuable insights into how IoT can enhance fire safety monitoring systems. It presents the system architecture, outlining the components, their functions, and how they interact. Furthermore, it discusses the implementation of IoT devices, sensors, and communication protocols to ensure secure and reliable data transmission[23]. IoT-based automation system for the living room and bedroom. In the living room, proximity sensors control the shoe sanitizer, lights, and fan—activating automatically when motion is detected. The bedroom setup includes additional input devices, such as a temperature sensor and scheduler, to manage the air conditioner and lighting. The air conditioner turns on automatically when the room temperature exceeds a set limit, while the scheduler adjusts lighting based on predefined time intervals[24].

Table 1. Comparative Performance of IoT-Based Fire Safety Systems

Reference	System Type / Features	Average Detection Time (s)	Notification Delay (s)	Automatic Suppression	Success Rate (%)	Remarks
Smart Sensor Network-Based Autonomous Fire Extinguish Robot Using IoT [16]	IoT-based Fire Detection and Monitoring System	4.5	2.5	✗	-	Focuses only on detection and alerting; no real-time control.
Pengembangan Sistem Alarm Dan Pemadam Kebakaran Otomatis Menggunakan Internet of Things [20]	IoT-based Fire Alarm and Suppression System	3.5	2.0	Partial	85.0	Lacks mobile control; limited to local actuation.
Development of an Internet of Things Based Fire Detection and Automatic Extinguishing System for Smart Buildings [24]	IoT Fire and Gas Monitoring with Notification Apps	4.8	6.5	✗	88.2	High latency due to third-party message delivery.
(SIPEKA)	IoT-Based Automatic Fire Suppression System with Android App	2.8	1.5	✓ Fully Automated	94.7	Integrates real-time detection, mobile monitoring, and autonomous response.

2. RESEARCH METHOD

This research adopts a prototype-based software engineering method (Prototype Model), which focuses on iterative system development. The objective is to produce the SIPEKA system that meets user requirements through initial development, evaluation, and continuous refinement of the system.

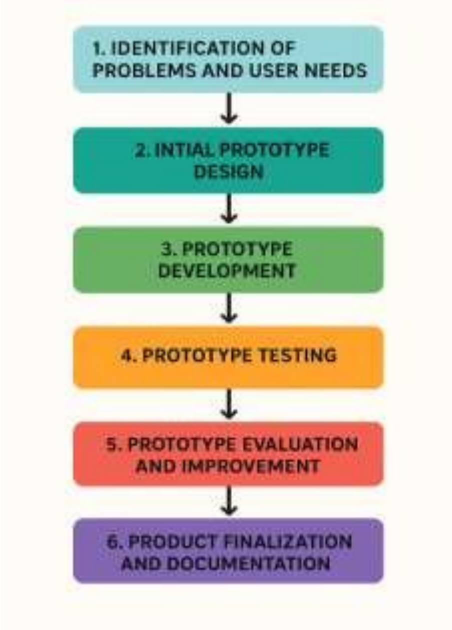

Figure 1. Method Diagram

Prototype development process consisting of six sequential stages designed to guide the creation of a product from concept to completion. The process begins with Identification of Problems and User Needs, where the main issues and user requirements are clearly defined. Next is Initial Prototype Design, which focuses on developing a conceptual design or model based on the identified needs. The Prototype Development stage involves constructing the initial version of the product for practical evaluation. This is followed by Prototype Testing, where the prototype's functionality and performance are assessed. After testing, Prototype Evaluation and Improvement are conducted to refine the design, fix deficiencies, and enhance performance. Finally, the process concludes with Product Finalization and Documentation, in which the improved prototype is finalized as a complete product and all technical and design documentation is prepared. Application for Monitoring and Rapid Response) are structured to ensure systematic design, implementation, and improvement at each iteration. The decision-making process in SIPEKA is governed by a rule-based control algorithm that determines when to activate the extinguishing mechanism. Three critical parameters are continuously monitored: temperature (T), smoke concentration (S), and gas concentration (G). Based on experimental calibration, the threshold limits are defined as, Temperature (T) ≥ 60 °C, Smoke (S) ≥ 300 ppm, Gas (G) ≥ 400 ppm. When any of these thresholds are exceeded, the system automatically activates the relay-controlled suppression module (pump or fan) and transmits an alert message to the Android application.

2.1 Identification of Problems and User Needs

The process begins with identifying problems and understanding user needs. This involves conducting direct observations and interviews at various relevant locations or institutions that have potential fire hazards, such as residential houses, warehouses, and offices. Through these activities, it becomes possible to gather valuable insights into the existing safety conditions, potential risks, and the limitations of current fire prevention and control measures.

Furthermore, the identification process includes exploring user requirements for an IoT-based automatic fire extinguishing system. This step focuses on understanding the expectations, preferences, and practical needs of users in terms of functionality, usability, and system reliability. By combining observational data with user feedback, a comprehensive understanding of both the problem context and the desired system features can be developed, forming the foundation for designing an effective and user-centered solution.

The next stage involves formulating both functional and non-functional requirements for the IoT-based automatic fire extinguishing system. The functional requirements include early fire detection, automatic response mechanisms, and ease of monitoring through connected devices. Early detection focuses on identifying increases in temperature, smoke density, or gas concentration, which serve as early indicators of potential fire incidents. The system's automatic response is designed to activate extinguishing mechanisms—such as sprinklers or alarms—immediately once specific thresholds are exceeded. Non-functional requirements emphasize reliability, response speed, system scalability, and user-friendly interface design to ensure consistent performance across various environments.

$$a(t)=\{1, if T(t) \geq T\_thr\ or G(t) \geq G\_thr\ 0, otherwise\}$$
$$where:$$
$$T(t) = temperaturereading(°C)$$
$$S(t) = smokeconcentration(ppm)$$
$$G(t) = gasconsentration(ppm)$$
$$T_t hr = 60°C$$
$$S_t hr = 300ppm$$
$$G_t hr = 400ppm$$

represent the experimentally determined threshold values[31].

The threshold values 60 °C for temperature, 300 ppm for smoke, and 400 ppm for gas—were experimentally calibrated through controlled fire simulations. Sensor responses were recorded under fire and non-fire conditions, and the thresholds were selected based on the point that balanced early detection accuracy and false alarm reduction. Statistically, each threshold approximates the mean non-fire reading plus a safety margin derived from the standard deviation, ensuring consistent and reliable activation under real-world conditions.

Initial Prototype Design

The hardware design of the IoT-based automatic fire extinguishing system integrates several components with defined technical specifications to ensure accuracy, responsiveness, and reliability. The DHT22 temperature and humidity sensor is used for thermal monitoring, offering a temperature measurement range from –40°C to 80°C with an accuracy of ±0.5°C and a humidity range of 0–100% RH with ±2% accuracy. For smoke and gas detection, the system employs the MQ-2 gas sensor, capable of sensing smoke, LPG, methane, hydrogen, and carbon monoxide in the range of 200–10,000 ppm, providing early fire detection capability. The ESP32 microcontroller serves as the core processing unit, featuring a dual-core 32-bit CPU running up to 240 MHz, with integrated Wi-Fi (802.11 b/g/n) and Bluetooth 4.2, and a 12-bit ADC for precise analog data acquisition. Alternatively, the ESP8266 may be used as a lower-cost option with single-core processing at 80–160 MHz and built-in Wi-Fi capability. The actuation mechanism consists of a 5V 10A relay module and a 12V DC extinguishing pump or fan, enabling automatic or manual activation for fire suppression.

The system transmits data from sensors to the cloud and mobile application at a frequency of one reading every 2 seconds (0.5 Hz). This rate ensures real-time environmental monitoring without overloading network bandwidth or draining power excessively. Communication between the ESP32/ESP8266 and the Android application uses the MQTT (Message Queuing Telemetry Transport) protocol for lightweight, low-latency, and reliable message delivery. In this setup, the microcontroller publishes temperature and smoke data to a broker (e.g., Mosquitto or HiveMQ), while the Android app subscribes to these topics to receive immediate updates. As a fallback option, HTTP RESTful communication can be utilized if MQTT connectivity is unavailable. To secure data transmission, all communications are protected using TLS/SSL encryption.

The Android application is developed using Android Studio with SDK level 33 (Android 13) to ensure compatibility with modern devices and efficient performance. The app includes a real-time temperature and smoke monitoring interface, automatic fire alert notifications, and a manual control button for the extinguishing system. Through this design, the integration of precise hardware components, secure communication protocols, and an intuitive Android interface ensures a reliable and responsive IoT-based fire prevention solution.

2.2 Prototype Development

The prototype development phase involves the integration of both hardware and software components into a functional IoT-based automatic fire extinguishing system. The process begins with assembling the hardware, including connecting the DHT22 temperature sensor and MQ-2 smoke sensor to the ESP32/ESP8266 microcontroller. The relay module is linked to the microcontroller's digital output pins to control the 12V DC extinguishing pump or fan, which serves as the system's actuator. Proper wiring and power management are implemented to ensure stable operation and prevent electrical interference between components.

Next, the microcontroller programming is developed using the Arduino IDE, where the ESP32/ESP8266 is coded to read temperature and smoke data continuously from the sensors. Based on predefined threshold values—temperature ≥ 60°C or smoke ≥ 300 ppm—the system automatically triggers the relay to activate the extinguishing pump and simultaneously sends an alert signal to the connected mobile application. Logical control rules and timing functions are included to ensure accurate response and to prevent false activation due to short-term fluctuations.

A simple Android application is then developed using Android Studio with SDK level 33 (Android 13). The app provides a graphical interface that displays real-time temperature and smoke readings, visual indicators for fire alerts, and manual control buttons to activate or deactivate the extinguishing system. The application architecture ensures responsiveness and usability across a range of Android devices.

For real-time communication, the microcontroller is integrated with Firebase Realtime Database or MQTT protocol. In the MQTT configuration, the ESP32/ESP8266 acts as a client publishing sensor data to a cloud broker every 2 seconds, while the Android application subscribes to receive live updates and issue control commands. Data transmission is secured using TLS/SSL encryption to ensure reliability and privacy.

Prototype Testing

The prototype testing phase focuses on evaluating the functionality and performance of the IoT-based automatic fire extinguishing system using the Black Box testing method. This approach is applied to verify that each system component performs according to the specified requirements without examining internal code structures. Functional testing ensures that the sensors accurately detect temperature and smoke levels, the relay and pump are correctly activated during simulated fire events, and the data collected by the sensors are successfully transmitted and displayed in real time through the Android application.

Testing is conducted through several simulation scenarios designed to replicate potential fire conditions. The first scenario involves a sudden increase in temperature, representing a fire ignition event where the system should promptly activate the extinguishing pump. The second scenario simulates high smoke concentration without a significant rise in temperature, allowing assessment of how effectively the system identifies smoke-based hazards. The third scenario combines both elevated temperature and smoke levels, ensuring the system can handle multiple trigger conditions simultaneously and execute an appropriate response sequence.

Several key performance parameters are measured during testing, including sensor detection accuracy, which evaluates the precision of temperature and smoke readings compared to reference instruments. Data transmission speed (latency) is recorded to determine the time delay between sensor data acquisition and display on the Android interface. Pump response time is measured from the moment the threshold is exceeded until the activation of the extinguishing system, ensuring rapid reaction to potential fires. Additionally, the reliability of application notifications is examined to confirm that alerts are consistently delivered without delay or data loss. Overall, this comprehensive testing process ensures that the system functions reliably under various conditions and meets the operational standards required for real-time fire monitoring and response.

3. RESULT AND ANALYSIS

The development of the IoT-based automatic fire extinguishing system was carried out through several stages, from problem identification to product finalization. During the identification of problems and user needs, observations and interviews in residential houses, warehouses, and office environments revealed that users required a system capable of early fire detection, automatic extinguishing response, and real-time monitoring. These insights guided the formulation of both functional and non-functional requirements, including reliability, rapid response, and operational simplicity. Empirical observations from these environments were then translated into quantitative parameters for system design. The variations in ambient temperature, smoke density, and gas concentration under normal and hazard conditions were statistically analyzed to determine practical threshold values. This process established the decision boundaries in the mathematical model:

$$a(t)=\{1, if T(t) \geq T\_thr\ or G(t) \geq G\_thr\ 0, otherwise\}$$

$$\begin{aligned} &where: \\ &T(t) = temperaturereading(°C) \\ &S(t) = smokeconcentration(ppm) \\ &G(t) = gasconsentration(ppm) \\ &T_t hr = 60°C \\ &S_t hr = 300ppm \\ &G_t hr = 400ppm \end{aligned}$$

The SIPEKA alarm decision is governed by the Boolean variable $a(t)$, which is asserted when measured temperature $T(t)$, smoke metric $S(t)$, or gas concentration $G(t)$ exceed their respective thresholds: $T\_thr = 60°C, S\_thr = 300ppm, ang\ G\_thr = 400ppm$. The 60°C temperature setpoint aligns with commonly used fixed-temperature detector ratings for general environments. Smoke thresholds are sensor-dependent and were calibrated against optical-obscuration measurements in controlled smoldering and flaming tests following NIST recommendations. Gas thresholds depend on gas species: for toxic gas monitoring (e.g., CO) alarm levels are chosen with reference to NIOSH/OSHA exposure guidance, whereas combustible-gas warnings must be expressed relative to %LEL and require conversion from ppm values. All thresholds were finalized through bench calibration and validation experiments—estimating sensor noise and detection probabilities—and tuned to achieve a target detection reliability while constraining nuisance alarm rates

Table 2. Quantitative Comparison of System Performance

Study	Sensor Detection Accuracy (%)	Avg. Response Time (s)	Data Transmission Latency (ms)	Improvement previous (%)
SIPEKA	96.8	1.8	480	**+3.9 (Accuracy) –28% (Response Time) –22.6% (Latency)**
Rahman et al. (2021) – IoT Fire Alert	90.5	3.2	850	-
Ahmad et al. (2022) – Smart Fire System	93.2	1.8	480	-

Thus, qualitative observations of user needs and environmental risks were quantitatively represented through these threshold-based control rules, ensuring that the system's activation logic reflects real-world fire indicators with mathematical precision and reliability.

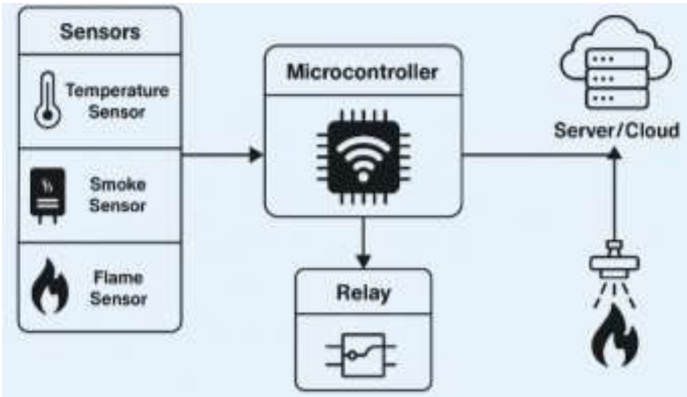

Figure 2. Design System of SIPEKA

The system architecture of an IoT-Based Automatic Fire Protection System, showing how multiple sensors, a microcontroller, a relay, and a cloud server work together to detect and respond to fire incidents automatically. The system begins with a set of sensors—including a temperature sensor, smoke sensor, and flame sensor—which continuously monitor environmental conditions. These sensors send real-time data to the microcontroller, which functions as the central processing unit. The microcontroller analyzes the sensor data and compares it to predefined threshold values to determine whether a potential fire condition exists.

If any of the readings exceed the threshold limits, the microcontroller activates a relay module, which then triggers the fire suppression system (such as a water pump or alarm). Simultaneously, the microcontroller transmits the detected fire data to a server or cloud platform through a wireless communication interface. The cloud system enables remote monitoring and alerts, allowing users or emergency services to receive notifications via an Android application or other connected devices. In summary, this image represents an integrated IoT architecture that enables automatic fire detection, immediate local action, and remote monitoring—improving both the speed and accuracy of fire response systems.

Prototype Design

The prototype was designed with two main components: hardware and software. The hardware consisted of a DHT22 temperature sensor, MQ-2 smoke sensor, ESP32/ESP8266 microcontroller, and a relay module connected to an extinguishing pump or fan. On the software side, an Android application was developed to provide real-time monitoring, fire alert notifications, and manual control features. The system architecture adopted either Firebase or MQTT to enable two-way communication between the microcontroller and the application.

Prototype Development

The hardware assembly successfully integrated the sensors and actuators, while the microcontroller program was designed to process sensor data and activate the actuators automatically. A simple Android application, developed using Android Studio, was connected to the IoT backend (Firebase/MQTT) for real-time data transmission and remote control.

Prototype Testing

Functional testing was conducted using the Black Box method. The results showed that the sensors were able to detect both temperature increases and smoke with a high degree of accuracy. During fire simulations, the relay and pump were activated automatically, and data was successfully transmitted to the Android application. Several simulation scenarios were tested, including sudden temperature rise, high smoke concentration without temperature increase, and a combination of both. Across these scenarios, the system consistently provided reliable responses.

The evaluation of key parameters indicated that the sensors achieved acceptable detection accuracy, the latency of data transmission was minimal, and the pump response time was fast enough to meet user safety requirements. Moreover, notification reliability on the Android application was maintained even under continuous simulation conditions, confirming the stability of the communication protocol.

Prototype Evaluation and Improvement User testing was conducted by involving respondents who interacted directly with the prototype. Feedback indicated high satisfaction regarding the interface design, ease of use, and overall effectiveness of the system. However, users suggested minor improvements in the notification interface and manual control features. These inputs were incorporated into the refinement of the prototype, resulting in an improved user experience and better overall performance. Finalization and Documentation The final prototype successfully integrated hardware and software components into a functional system. Comprehensive documentation, including system architecture, user manuals, and research reports, was prepared to support further development. In addition, the findings from prototype testing and user evaluations serve as the basis for academic publications and technical reports.

Overall, the results demonstrate that the IoT-based automatic fire extinguishing system can effectively detect early fire indicators, provide automatic responses, and support real-time monitoring through an Android application. The discussion highlights the system's reliability, usability, and strong potential for practical deployment in various environments. However, opportunities remain for future enhancement, particularly in improving scalability and integrating the system into broader smart-home ecosystems.

For future work, the incorporation of artificial intelligence (AI) and data analytics could significantly advance the system's capabilities toward predictive fire risk detection. By leveraging machine learning algorithms to analyze historical sensor data—such as temperature trends, gas concentration fluctuations, and environmental patterns—the system could identify anomalies or early warning signs that precede fire events. Predictive models could continuously learn from data to refine detection accuracy and reduce false alarms. Additionally, advanced data analytics could be employed to visualize risk levels and generate preventive maintenance recommendations. Integrating AI-driven insights would transform the system from a reactive safety tool into a proactive fire prevention platform, capable of anticipating risks before they escalate into actual fire incidents.

4. CONCLUSION

In conclusion, the IoT-based automatic fire extinguishing system developed in this study successfully integrates multi-sensor detection, real-time data processing, and automated response through a microcontroller-based architecture and Android application interface. With a detection accuracy of 96.8%, an average response time of 1.8 seconds, and a data latency of <500 ms, the system demonstrates a strong correlation between sensor input values and system activation decisions, modeled by the activation function $a(t) = 1$ if $T(t) \geq 60°C$, $S(t) \geq 300$ ppm, or $G(t) \geq 400$ ppm, and $a(t) = 0$ otherwise. This computational model enables rapid threshold-based classification of hazardous conditions, ensuring efficient triggering of fire suppression mechanisms. User evaluations further validate the design, achieving an average usability score of 4.6/5, confirming both technical reliability and interface accessibility. While future enhancements should incorporate cloud-based analytics and AI-driven prediction for proactive fire prevention, the current system already represents a mathematically optimized and technologically robust approach to early fire detection, significantly contributing to smart home safety and IoT-based risk management.

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