Wireless Communication-Based Automatic Fire Alarm System: A Review

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ABSTRACT

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In recent years, the development of Internet of Things (IoT) technology, big data, cloud computing, and other digital technologies has increased interest in wireless communication-based automatic fire alarm systems. Fire or smoke detection systems can be monitored locally on-site or remotely from distant locations according to user requirements. Remote alarm systems allow building owners or users to monitor conditions from a distance and take immediate action after receiving an emergency notification. Remote monitoring systems can be developed using various technologies, including Wireless Sensor Networks (WSNs), Ethernet, image processing, and other digital communication techniques. Although these systems generally offer reliable monitoring and communication, several concerns remain regarding system complexity, large configurations, high implementation costs, and excessive supporting components. Therefore, there is a need for fire alarm systems that are reliable, responsive, simple, easy to implement, and cost-effective. This review discusses the development of wireless communication-based automatic fire alarm systems, particularly the application of fire detection sensors, WSN communication, and remote notification systems. The reviewed studies indicate that wireless communication can support flexible fire monitoring, reduce dependence on conventional wiring, and enable automatic remote warning. However, further development is still required to improve system simplicity, communication performance, reliability, and implementation efficiency.

Keywords: automatic fire alarm system, wireless communication, Wireless Sensor Network, GSM, remote monitoring

INTRODUCTION

The use of Wireless Sensor Networks (WSNs) has expanded widely in various fields, including science, medicine, industry, and military applications [1]. Wireless sensor networks can also be applied for environmental monitoring, smart home applications, and smart transportation systems [2]. In fire safety applications, fire alarm systems can be integrated with air-conditioning systems, access control systems, fire extinguishing systems, and Building Management Systems (BMS). Fire alarm panels are generally used to indicate the location where a fire or fire-related condition is detected. Traditionally, cables have been used to integrate the devices in fire alarm systems and to provide both power and communication between the devices [3].

A fire or smoke alarm system can be monitored locally within a building or remotely from another location according to the monitoring requirements. A remote alarm system provides building owners or users with the ability to monitor conditions from a distance and take immediate action when an emergency notification is received. Remote monitoring systems can be developed using Wireless Sensor Networks, Ethernet, image processing, and other digital communication technologies [4]. Although these systems provide several advantages, they may also be associated with complexity, large system configurations, high implementation costs, and redundant components. Therefore, there is a need for fire alarm systems that are reliable, fast in response, simple to implement, and cost-effective [5].

A Wireless Sensor Network consists of a number of small and self-regulating wireless sensor nodes that integrate sensing, processing, and wireless communication technologies. Through these technologies, WSNs can detect, collect, process, and transmit information from their monitoring areas to a central unit or user. WSN technology provides several advantages, including wide monitoring coverage, remote monitoring capability, rapid network establishment, and relatively affordable implementation. In addition, GSM networks provide advantages such as mature communication technology, wide coverage, long communication distance, and reliable communication capability [6].

The integration of WSN and GSM technologies has therefore been considered a promising approach for remote monitoring and automatic warning systems. Huang et al. [6] described a remote home security system that combines the advantages of WSN and GSM communication. When an abnormal or dangerous condition, such as a gas leak or intrusion, is detected, the system can transmit an alarm short message to the user through the GSM network. The use of wireless sensor nodes also offers advantages in terms of easier installation, reduced dependence on wiring, and relatively low power consumption [6].

Fire can cause considerable economic, social, and safety losses, making rapid and accurate detection important for reducing potential damage [7]. Conventional fire detection and alarm systems commonly use wired connections between smoke or temperature detectors and a central control panel. Such systems generally provide good reliability and resistance to interference and have been widely used in residential and industrial buildings [7]. However, wired systems may involve relatively high installation costs as well as complex design, construction, and maintenance requirements [8]. These limitations have encouraged the development of wireless fire detection and alarm systems. The increasing availability of wireless networks and mobile devices has also supported the development of remote monitoring and notification systems in various application areas [7].

Previous studies have proposed various wireless fire alarm systems using different sensors, Wireless Sensor Network architectures, microcontrollers, and remote communication technologies. These systems generally aim to provide reliable fire detection while reducing wiring requirements and enabling remote alarm notification. Nevertheless, differences in sensor selection, communication mechanisms, system architecture, and notification methods make it necessary to review and compare the approaches that have been developed. In addition, several systems still face limitations related to complexity, cost, communication performance, and implementation requirements [5].

Therefore, this review aims to examine and synthesize previous studies on wireless communication-based automatic fire alarm systems, particularly focusing on multi-sensor fire detection, Wireless Sensor Network communication, GSM-based remote notification, and the advantages and limitations of the developed systems. This review is expected to provide an overview of the current application of wireless communication technologies in automatic fire alarm systems and identify areas that require further development.

MATERIALS AND METHODS

This study employed a qualitative approach using a traditional literature review to examine the development and application of wireless communication-based automatic fire alarm systems. Relevant scientific articles were collected from Google Scholar and Scopus without limitation on publication year. The literature search focused on studies related to wireless fire alarm systems, Wireless Sensor Networks (WSN), fire detection sensors, GSM-based communication, and remote fire monitoring systems.

Literature Selection

Articles were selected based on their relevance to the topic of wireless communication-based automatic fire alarm systems. Studies were included when they discussed at least one relevant aspect, such as fire detection sensors, WSN architecture, microcontroller-based fire alarm systems, GSM communication, wireless data transmission, or remote alarm notification. Articles that were not directly related to fire detection or wireless alarm communication were excluded from the review.

Literature Review and Data Collection

The selected articles were reviewed qualitatively by identifying and collecting information concerning the components, architecture, and operating principles of wireless fire alarm systems. Particular attention was given to the types of sensors used for fire detection, including temperature, smoke, gas, infrared, ultraviolet, and other sensors capable of detecting physical or chemical characteristics of fire.

Information concerning the structure of WSN systems was also collected, including sensor nodes, data processing units, wireless communication modules, central control units, and power management units. In addition, studies

describing GSM modules and remote notification mechanisms were reviewed to identify how warning information could be transmitted from a fire detection system to users at distant locations.

Data Analysis

The collected literature was analyzed descriptively and comparatively. Information from the selected studies was grouped into four main themes: (1) multi-sensor fire detection, (2) Wireless Sensor Network communication, (3) GSM-based remote notification, and (4) advantages and limitations of wireless fire alarm systems.

The findings from different studies were then compared and synthesized to identify common system characteristics, communication mechanisms, advantages, and limitations. The analysis focused on explaining how sensors, WSN technology, microcontrollers, and GSM communication are integrated to support automatic and remote fire detection.

Review Framework

Based on the literature analysis, the review focused on the general operating sequence of wireless communication-based fire alarm systems, consisting of fire-related parameter detection, sensor data acquisition, wireless data transmission, processing by the central control unit, alarm decision-making, and remote notification. The synthesized findings were subsequently presented and discussed to describe the current application and potential development of wireless communication-based automatic fire alarm systems.

RESULTS AND DISCUSSION

Multi-Sensor Fire Detection

The reviewed studies show that wireless communication-based automatic fire alarm systems commonly use several types of sensors to detect different characteristics of fire. These sensors include temperature sensors, smoke detectors, gas sensors, infrared sensors, ultraviolet sensors, and image sensors. Each sensor detects a specific physical or chemical change that may occur during the combustion process.

Fire produces several detectable characteristics, such as heat, flame radiation, smoke, carbon monoxide (CO), carbon dioxide (CO_2), and burning sound. Jing and Jingqi [4] explained that these characteristics can be used as fire detection parameters because they represent changes produced during combustion. Therefore, selecting appropriate sensors is an important part of designing an effective automatic fire alarm system.

The use of several sensors can provide broader information than a system that relies on only one parameter. For example, temperature sensors detect increasing heat, gas sensors detect CO or CO_2, while smoke sensors identify combustion particles. Infrared and ultraviolet sensors may also be used to identify flame radiation. This multi-sensor approach enables the system to observe different indicators of fire development. Overall, the reviewed literature indicates that multi-sensor detection is an important feature of modern fire alarm systems. Combining several sensing parameters can support more comprehensive monitoring of fire-related conditions. For example, Vijayalakshmi and Muruganand developed a wireless fire detection node for real-time monitoring using sensor data transmitted through a wireless sensor network [9]. However, the reviewed studies provide limited quantitative comparison regarding the accuracy and response time of each sensor type.

Wireless Sensor Network Communication

The reviewed studies indicate that Wireless Sensor Networks (WSNs) are commonly used to connect distributed sensing devices with a central control unit. A typical WSN consists of several data collection nodes and one central node. Each data collection node collects environmental information from connected sensors before transmitting the data wirelessly to the central node. Dong et al. developed a dedicated wireless communication protocol for an automatic fire alarm system to support rapid fire detection, alarm transmission, and low-power operation [10].

The WSN node generally consists of four main components: a data collection unit, a data processing unit, a wireless communication unit, and a power management unit. In the reviewed system, the C8051F310 microcontroller was selected as the processing unit, while the CC1100 wireless chip was used to provide short-range wireless

communication between the nodes. Communication between the C8051F310 and CC1100 is performed through the Serial Peripheral Interface (SPI). The microcontroller controls the communication process, including data transmission and reception. The reviewed studies also describe the use of threshold-based communication, such as TEEN, in which sensor data are transmitted when significant changes in the monitored parameter are detected [6].

The application of WSN technology provides flexibility because multiple sensor nodes can be installed at different monitoring points without extensive wiring. This makes wireless fire alarm systems suitable for residential or building environments. Bhattacharjee et al. demonstrated that WSN-based fire detection can support early fire alarming, location identification, and monitoring, although network delay can increase as the number of communication hops increases [11]. However, the reviewed studies provide limited information regarding wireless transmission distance, packet loss, communication delay, and long-term network reliability.

GSM-Based Remote Notification

Another important finding from the reviewed studies is the use of GSM communication to provide remote fire alarm notifications. While the WSN transfers sensor information within the monitored area, GSM communication enables alarm information to be transmitted from the central control unit to a user's mobile phone.

The TC35 GSM module is one of the communication modules described in the reviewed system. This module supports GSM900 and GSM1800 frequencies and provides communication through standard AT commands. When abnormal sensor information is received by the WSN central node, the microcontroller can activate the GSM module to send an alarm short message.

The reviewed system uses GSM communication as the final stage of the warning process. The information flow can generally be described as sensor detection, wireless data transmission, central processing, alarm decision, GSM activation, and notification to the user's mobile phone. Huang et al. [6] reported that when the monitored temperature exceeded the predetermined threshold, the system activated the GSM module and transmitted an alarm message. The use of GSM technology therefore extends the function of a conventional local fire alarm system. Users can receive fire-related warnings even when they are not present in the monitored area. Nevertheless, the reviewed studies do not provide detailed quantitative information regarding SMS transmission delay, message delivery success rate, or the effect of GSM network conditions on system performance.

Advantages and Limitations of Wireless Fire Alarm Systems

The reviewed literature shows several advantages of wireless communication-based automatic fire alarm systems. One of the main advantages is the reduction of physical wiring because sensor nodes can communicate wirelessly with the central control unit. This can simplify system installation and allow sensors to be distributed more flexibly throughout the monitored environment.

Another advantage is the integration of automatic sensing and remote communication. The sensor nodes continuously monitor environmental conditions, while the central controller processes the collected information and determines whether an alarm condition exists. GSM communication can then be used to transmit warning information directly to the user's mobile phone. The combination of multiple sensors, WSN communication, microcontroller processing, and GSM notification demonstrates the potential of wireless technology for developing more flexible fire monitoring systems. The reviewed systems also show that threshold-based communication can be used to activate alarms only when abnormal conditions are detected, thereby reducing unnecessary communication between sensor nodes.

Despite these advantages, several limitations remain in the reviewed studies. Quantitative information regarding detection accuracy, false alarm rate, sensor response time, communication distance, packet loss, power consumption, and GSM notification delay is still limited. Therefore, future studies should provide more comprehensive performance evaluation to determine the reliability and effectiveness of wireless communication-based automatic fire alarm systems under different fire and environmental conditions.

CONCLUSION

This review shows that wireless communication-based automatic fire alarm systems can provide an effective approach for remote safety monitoring by integrating Wireless Sensor Networks (WSNs) and GSM communication. The reviewed systems are capable of detecting abnormal conditions such as fire, gas leakage, and unauthorized intrusion, and can transmit alarm messages to users through remote communication networks. Several reviewed systems employ hardware components such as the C8051F310 microcontroller, CC1100 wireless transceiver, and Siemens TC35 GSM module. These components support sensor data acquisition, wireless data transmission, processing, and remote alarm notification. The software used in these systems enables the collection and transmission of sensor information and allows alarm messages to be sent automatically when hazardous conditions are detected. Overall, the integration of WSN and GSM technologies offers several advantages, including wireless communication, relatively low power consumption, flexible installation, remote monitoring capability, and ease of use. These characteristics indicate that wireless fire alarm systems have strong potential for residential and building safety applications. However, further studies are needed to improve system reliability, communication performance, detection accuracy, and cost efficiency for wider practical implementation.

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