International Journal of Engineering and Information Systems (IJEAIS)
ISSN: 2643-640X
Vol. 10 Issue 1 January - 2026, Pages: 62-67

Deployment of an intelligent decision support system for fire management in the Democratic Republic of Congo

Pamphile Kazadi Mulumba [1] and Pactole Cipa Cipa [2]

Faculty of Computer Science, Notre-Dame du Kasayi University, Kananga, Kasai-Central, Democratic Republic of Congo [1]
Faculty of Computer Science, Notre-Dame du Kasayi University, Kananga, Kasai-Central, Democratic Republic of Congo [2]
plkazadi@gmail.com [1] , pactolecipa793@gmail.com [2]

Abstract: *The article presents an intelligent fire management system combining IoT sensors, microcontrollers, network infrastructure, a central server, and a mobile application with a GIS module. The system is based on several layers:Local détection, Transmission and processing, GIS module and mobile application. The combination of multi-sensor detection, local decision logic, and GIS tools reduces false positives, improves emergency response times, and facilitates decision-making in emergency situations. The system is also designed to accommodate local connectivity and infrastructure constraints, ensuring its suitability for the Congolese context.*

Keywords: *Fire Detection System, Internet of Things (IoT), Geographic Information Systems (GIS), Decision Support System, Emergency Management*

1. Introduction

The Democratic Republic of Congo, due to its rapid and often unplanned urbanization, faces a significant increase in fire risks, both in urban areas and in industrial or peri-urban spaces. Fires there cause not only loss of life but also considerable material damage, exacerbated by precarious electrical infrastructure and a lack of effective monitoring and response systems. In this context, the development of an intelligent decision support system capable of detecting fires early and effectively guiding emergency response teams is an urgent necessity. The integration of Internet of Things (IoT) and Geographic Information Systems (GIS) technologies makes it possible to implement a system capable of monitoring at-risk areas in real time, issuing reliable alerts, and automatically calculating optimal routes for firefighters' interventions.

1. Theoretical framework and literature review

1.1. Fire-related theories

A scientific understanding of fires is an essential prerequisite for implementing any fire detection and risk management system. In a context like that of the Democratic Republic of Congo, characterized by rapid urbanization, often unregulated construction, and precarious electrical installations, the theoretical analysis of fire not only allows for a better understanding of fire ignition mechanisms but also guides the selection of sensors, detection thresholds, and intervention strategies. This section presents the main theories related to fire and combustion that underpin the design of modern automatic fire detection systems.

1.1.1. Theory of fire and combustion

a. Fire Triangle

The fire triangle theory is one of the oldest and most widely accepted foundations in the study of fires. It is based on the idea that a fire can only start and be sustained if three essential elements are present simultaneously: a fuel, an oxidizer, and an energy source. The fuel represents any material capable of burning, whether it be wood, fuels, plastics, or textiles. The oxidizer is usually the oxygen present in the air, while the energy source corresponds to a heat source sufficient to initiate the combustion reaction. [1]

b. Combustion process

Combustion is an exothermic chemical reaction in which a fuel reacts with an oxidizer, releasing energy in the form of heat and, often, light. This process does not occur instantaneously but follows several successive phases, including heating of the material, pyrolysis, ignition, and combustion itself. Pyrolysis is the thermal decomposition of the fuel, which releases flammable gases even before the visible appearance of flames. [1]

c. Fire spread

Fire spread refers to how a fire develops and spreads within a given area. It depends on several factors, including the layout of the site, the nature of the materials, ventilation conditions, and topography. In urban areas, fire spread is often rapid due to the high density of buildings and the lack of firebreaks. In rural or peri-urban areas, particularly in the DRC, bushfires and domestic fires can spread over long distances due to wind and drought. [3]

1.1.2. Classification and typology of fires

Fire classification is essential for understanding combustion mechanisms and for selecting appropriate detection and response methods. It allows us to distinguish fire types based on the nature of the fuels involved and the environments in which they develop. In the context of fire risk management in the Democratic Republic of Congo, this classification is particularly useful for adapting prevention measures and guiding the operational decisions of emergency services.

a. Classes A, B, C, D, F

The most commonly used international classification distinguishes fires into several classes, designated A, B, C, D, and F. Class A fires involve combustible solid materials such as wood, paper, or textiles. They are very common in homes and markets in the DRC, where buildings make extensive use of flammable materials. Class B fires involve flammable liquids such as fuels, oils, or solvents, often found in garages, gas stations, or certain artisanal activities. Class C fires are electrical in origin, linked to live equipment, a type of fire particularly common in Congolese urban areas due to the often precarious state of electrical installations. Class D fires involve combustible metals, less frequent in domestic settings but possible in certain industries. Finally, Class F fires are associated with cooking oil and grease fires, frequently observed in both domestic and professional kitchens. [3]

b. Urban and industrial fires

Urban and industrial fires are distinguished by their frequency, speed of spread, and the extent of the damage they can cause. In urban areas, fires generally develop in densely built-up spaces, with close proximity between structures and a significant presence of combustible materials. In the DRC, rapid and often unplanned urbanization promotes the rapid spread of fire, particularly in densely populated neighborhoods. Industrial fires, on the other hand, often involve technical installations, machinery, chemicals, or fuels, which increases their complexity and danger. [4]

The literature highlights that urban and industrial fires require rapid detection and effective coordination of emergency services to limit human and economic losses. In this context, automatic detection systems coupled with geolocation applications and GIS tools represent a relevant solution, as they allow for the precise location of the fire and guide response teams to the most critical areas. [5]

1.1.3. Detection Automatic Fire Protection

Automatic fire detection is the technological core of modern fire prevention and response systems. Its aim is to identify the early warning signs of a fire as quickly as possible, triggering an alert before the fire reaches a critical stage. In contexts like that of the Democratic Republic of Congo, where response times can be prolonged by logistical and infrastructural constraints, early detection plays a crucial role in reducing human and material losses. Detection approaches can be broadly classified into single-sensor and multi-sensor systems, each with its own advantages and limitations.

a. Single- sensor detection

Single-sensor detection relies on using only one type of sensor to identify a fire. The most commonly used sensors are smoke detectors, temperature sensors, and flame detectors. This approach has historically been the most widespread due to its ease of implementation and low cost. In many domestic and commercial environments, particularly in the DRC, smoke detectors are often preferred because they can detect a fire at a relatively early stage, during the smoldering or pyrolysis phase. [7]

b. Multi- sensor detection

Multi-sensor detection involves combining several types of sensors to improve the reliability and accuracy of fire detection. This approach is based on the idea that a real fire manifests itself simultaneously through several physical phenomena, such as a temperature rise, smoke emission, and, in some cases, the presence of flames. By integrating these different signals, the system is able to more effectively distinguish a real fire from a simple environmental event. [8]

c. Reduction of false positives

Reducing false positives is a major challenge in automatic fire detection systems. False positives are alerts triggered when there is no actual fire, which can lead to unnecessary mobilization of emergency services and a loss of system credibility. In constrained operational contexts such as that of the DRC, where firefighters' resources are limited, the proliferation of false alarms can undermine the overall effectiveness of fire response. [9]

1.2. Internet of Things (IoT) Theories

The Internet of Things (IoT) refers to a technological paradigm in which physical objects are equipped with communication, computing, and perception capabilities, enabling them to interact with each other and their environment. In the field of fire and emergency management, the IoT represents a major evolution, as it allows for continuous, automated, and distributed risk monitoring, while facilitating real-time decision-making.

1.2.1. Fundamental concepts of the IoT

The fundamental concepts of the IoT are based on the integration of several complementary technological elements, including connected objects, machine-to-machine communication, and the use of sensors and actuators. [11]

- Objects connected

Connected objects are physical devices capable of collecting, processing, and transmitting data via a communication network. They form the basic building block of any IoT system. In the context of fire detection, these objects can be nodes equipped with temperature, smoke, or gas sensors, integrated with microcontrollers such as Arduino or microcomputers like Raspberry Pi. The literature emphasizes that the added value of connected objects lies in their ability to operate autonomously while remaining integrated into a global ecosystem. [12]

- Machine-to-machine communication

Machine-to-machine (M2M) communication refers to the automatic exchange of information between devices without direct human intervention. It allows connected objects to cooperate, share data, and coordinate their actions. In an IoT-based fire detection system, for example, M2M communication allows multiple sensors to confirm an event before transmitting an alert to a central platform. This communication is essential to ensure the speed and consistency of decisions in critical systems. [13]

- Sensors and actuators

Sensors and actuators form the interface between the physical and digital worlds. Sensors measure physical quantities such as temperature, smoke, or gas concentration, while actuators act on the environment, for example, by triggering an alarm or activating a fire suppression system. In IoT systems dedicated to fire management, sensors play a central role in collecting reliable data, while actuators ensure a rapid response to critical situations. [14]

1.2.2. IoT Architectures

IoT architectures define how the different components of the system are organized and interact. They allow for the structuring of the data flow from sensors to end applications.

- Three-layer architecture [15]

The three-layer architecture is one of the most widespread conceptual models for describing IoT systems. It consists of the perception, network, and application layers.

- Perception : The perception layer is responsible for collecting data from the physical environment. It includes sensors and onboard devices that measure relevant parameters. In the context of fire detection, this layer includes smoke, temperature, and gas sensors, which constitute the first line of surveillance.
- Network: The network layer ensures the transmission of collected data to processing and storage systems. It relies on communication technologies such as Wi-Fi, GSM, LoRa, or Zigbee . In developing countries, the choice of this layer is heavily influenced by infrastructure availability and energy constraints.
- Application: The application layer provides end-user services, such as visualizing alerts, mapping incidents via a GIS, or sending notifications to emergency services. It transforms raw data into actionable information for decision-making.

- Edge computing

The edge Edge computing involves performing some data processing as close as possible to the sources, that is, at the level of connected devices or local gateways. This approach reduces latency, limits bandwidth consumption, and improves system responsiveness. In a fire detection system, the edge computing makes it possible, for example, to filter false positives before sending an alert, which is particularly relevant in environments with limited connectivity.

1.2.3. IoT for emergency management

The use of IoT in emergency management improves the speed, coordination, and efficiency of interventions, particularly in the event of a fire. For example, we have:

- real-time IoT
- Reliability and latency
- Constraints in developing countries

1.3. Geographic Information Systems (GIS) Theories

1.3.1. Fundamental concepts of GIS [18]

Geographic Information Systems (GIS) are a set of computer tools that enable the collection, storage, analysis, and representation of geographically referenced data. They are based on the fundamental principle that any information related to a real-world phenomenon can be located in space. In the context of fire management, this ability to spatialize events is essential for understanding their distribution, evolution, and territorial impact, particularly in the densely populated urban areas of the Democratic Republic of Congo.

Spatial data is the central element of a GIS. It describes the location of objects or phenomena on the Earth's surface, in the form of points, lines, or polygons. This data can come from various sources such as GPS sensors, satellite imagery, or administrative databases. In a fire detection system, spatial data makes it possible to precisely locate the source of the fire and link it to its immediate surroundings.

1.3.2. Route calculation and network analysis

Route calculation in a GIS relies on network analysis, an approach derived from graph theory. In this framework, the road network is modeled as nodes (intersections) and arcs (roads), to which costs such as distance, travel time, or road condition are associated. This modeling is particularly relevant for emergency response, where the choice of route can have a direct impact on the severity of damage. [20]

Dijkstra's and A* algorithms are among the most widely used for calculating the shortest path. Dijkstra's algorithm guarantees the determination of the optimal path in a weighted graph, while the A* algorithm improves performance by incorporating a heuristic. In an emergency context such as firefighting in the DRC, these algorithms make it possible to optimize the movements of firefighters by taking into account terrain constraints and urban dynamics. [21]

2. System architecture and operation

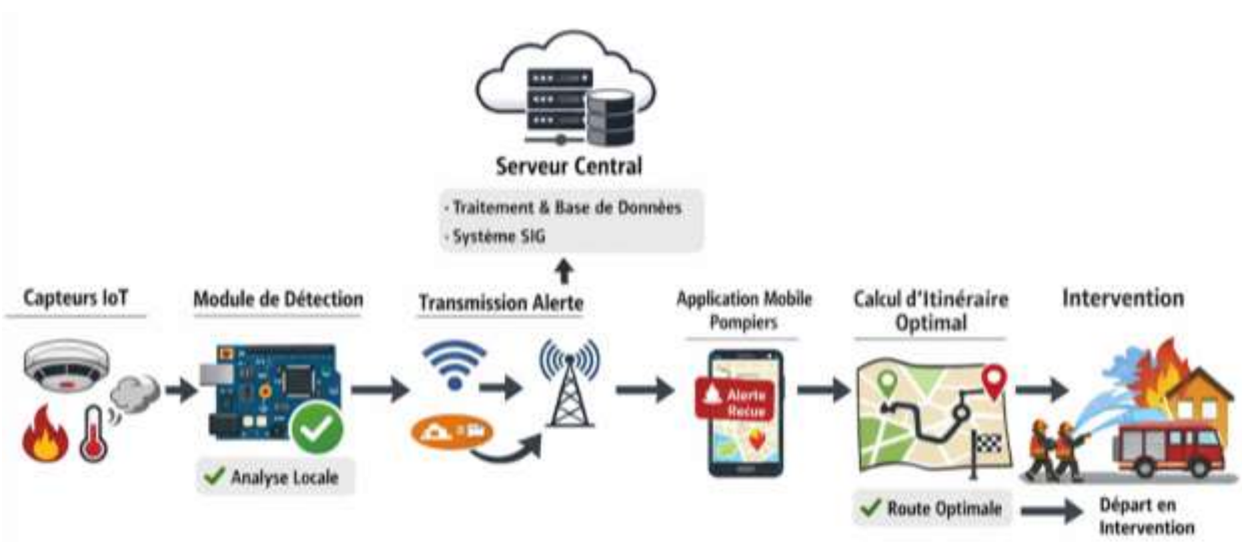

Figure 1System Architecture

The overall system architecture is based on a coherent integration between an IoT detection module, a processing backend, and a mobile application with a GIS module. This architecture aims to ensure a smooth flow of information, from early fire detection to decision support for firefighters.

2.1. Components

- IoT detection module

The detection module relies on the use of sensors (smoke, temperature, flame) connected to a hardware platform such as an Arduino or Raspberry Pi. Local decision logic enables initial data filtering to reduce false positives before the alert is transmitted. This approach is essential in areas where network connectivity may be unstable. [22]

- Transmission and backend

Data transmission occurs via lightweight protocols adapted for IoT, to a central server responsible for storing and processing information. The backend plays a key role in data aggregation, alert management, and interfacing with the mobile application.

- Firefighters' mobile application

The mobile application serves as the primary interface between the system and the firefighters. It enables the receipt of real-time notifications, the display of essential information, and access to navigation functions.

- GIS Module

The GIS module maps detected fires and displays them in real time. It enables a rapid understanding of the spatial situation and facilitates operational decision-making. The calculation of the optimal path is based on criteria such as distance, estimated time, and road accessibility. The algorithmic implementation relies on proven shortest path algorithms, adapted for emergency situations.

2.2. Principles of overall operation

The decision support system for fire management relies on a continuous functional chain, from early detection to operational decision-making by firefighters. It is a distributed system, combining IoT technologies, a communication infrastructure, a processing backend, and a mobile application integrating a GIS module.

- Local fire detection

The system begins with the IoT detection module, installed in a building, industrial area, or hazardous space. This module consists of several sensors (smoke, temperature, and possibly flame) connected to an Arduino board or a Raspberry Pi.

The sensors continuously monitor the environment. When an abnormal change is detected (rapid temperature increase, persistent smoke), the data is immediately transmitted to the microcontroller. The microcontroller then applies local decision logic based on predefined thresholds or a combination of conditions. This step prevents a simple environmental phenomenon from triggering an unjustified alarm. When the conditions correspond to a likely fire scenario, the system validates the event as a fire alarm.

- Generation and transmission of the alert

Once the fire is confirmed locally, the IoT module generates an alert message containing essential information:

- The sensor identifier ,
- Geographic location (GPS coordinates or recorded fixed position),
- The timestamp ,
- The values measured by the sensors.

This message is transmitted to the central server via a suitable communication network (Wi-Fi, mobile network, or other locally available technology). The transmission is designed to be lightweight and fast, ensuring near-instantaneous alerts, even in areas with limited connectivity, such as some urban neighborhoods in the DRC.

- Server-side processing and GIS integration

The central server receives the alert and records it in a database. It verifies the consistency of the received data and associates it with the corresponding geographic information. This step allows the event to be integrated into the system's GIS module.

The fire is then represented as a point or area on the digital map. The system automatically updates the situation and triggers a notification to the fire department's mobile application.

- Notification and decision support for firefighters

Firefighters receive a real-time notification on their mobile app. This contains essential information about the detected fire, including its location and estimated severity level.

Thanks to its integrated GIS module, the application displays the location of the fire on a dynamic map, as well as the location of the fire station or emergency vehicle. The system automatically calculates the optimal route, taking into account the available road network. This information allows emergency response teams to reach the scene quickly by following the shortest or fastest route.

CONCLUSION

The deployment of an intelligent IoT and GIS system for fire management represents a significant advancement in prevention and response in the DRC. By integrating early fire detection, real-time processing, and decision-making mapping, this system not only reduces human and material losses but also optimizes the use of limited firefighting resources.

Beyond simple detection, the system offers a powerful decision-support tool, capable of guiding interventions through optimized routes and instant notifications. Future prospects include integrating artificial intelligence for predicting risk zones, improving route calculation algorithms based on traffic and terrain conditions, and expanding the system nationwide to cover all urban and industrial areas.

References

[1] "An Introduction to Fire Dynamics, 3rd Edition | Wiley," Wiley.com. Accessed: January 23, 2026. [Online]. Available from: https://www.wiley.com/en-us/An+Introduction+to+Fire+Dynamics%2C+3rd+Edition-p-9780470319031

[7] "NFPA 72 Code Development." Accessed: January 23, 2026. [Online]. Available from: https://www.nfpa.org/codes-and-standards/nfpa-72-standard-development/72

[8] JA Milke, D. Stacy, and J. Poole, "Design Fire and Material Performance Database Report."

[9] M. Yu, H. Yuan, K. Li, and J. Wang, "Research on multi-detector real-time fire alarm technology based on signal similarity," *Fire Saf. J.* , vol. 136, p. 103724, Apr. 2023, doi: 10.1016/j.firesaf.2022.103724.

[10] "Home | Fire Technology | Link Springer Nature." Accessed: January 23, 2026. [Online]. Available at: https://link.springer.com/journal/10694

[11] K. Ashton, "That 'internet of things' thing," *RFID J.* , vol. 22, no · 7, p. 97-114, 2009.

[12] L. Atzori, A. Iera, and G. Morabito, "The Internet of Things: A survey," *Comput. Netw.* , flight. 54, no · 15, p. 2787-2805, Oct. 2010, doi: 10.1016/j.comnet.2010.05.010.

[13] Y. Fischer, A. Bauer, and J. Beyerer, *A conceptual framework for automatic situation assessment* . 2011, p. 239. doi: 10.1109/COGSIMA.2011.5753451.

[14] J. Gubbi, R. Buyya, S. Marusic, and M. Palaniswami, "Internet of Things (IoT): A vision, architectural elements, and future directions," *Future Gener. Comput. Syst.* , flight. 29, no · 7, p. 1645-1660, Sept. 2013, doi: 10.1016/j.future.2013.01.010.

[15] "Internet of Things: An Overview of Underlying Technologies, Protocols and Applications | IEEE Journals and Magazines | IEEE Xplore." Accessed: 23 January 2026. [Online]. Available from: https://ieeexplore.ieee.org/document/7123563

[16] PP Ray, "A survey on Internet of Things architectures", *J. King Saud Univ. - Computing. Inf. Sci.* , flight. 30, no · 3, p. 291-319, July. 2018, doi: 10.1016/j.jksuci.2016.10.003.

[17] E. Serban, M. Ordonez, and C. Pondiche, "DC-Bus Voltage Range Extension in 1500 V Photovoltaic Inverters," *IEEE J. Emerg. Salt. Great. Power Electron.* , flight. 3, no · 4, p. 901-917, Dec. 2015, doi: 10.1109/JESTPE.2015.2445735.

[21] EW Dijkstra, L. Beauguitte, and M. Maisonobe, "EW Dijkstra, 1959, A Note on Two Problems in Connection with Graphs. Numerische Mathematik 1, p. 269271 Bilingual and commented version".

[22] "Internet of Things: Principles and Paradigms | Guide books | ACM Digital Library," Guide books. Accessed: 23 January 2026. [Online]. Available at: https://dl.acm.org/doi/book/10.5555/3050877