A Decision-support Service for Firefighting in Environments of Dry Tropical Forest

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Abstract. *Forest fires significantly threaten the environment, society, and economy by harming biodiversity, causing economic losses, displacing communities, and impacting air and water quality. This article presents an innovative real-time monitoring application for forest fires, enhancing early detection, rapid response, and efficient coordination for Brazilian fire brigades. The app offers features such as fire location tracking, weather updates, image and video storage, and fire outbreak management. It aggregates data from various sources to provide valuable information for strategic planning and operational support.*

1. Introduction

According to data from the Fire Program (*Programa de Queimadas*[1]) of the National Institute of Space Research (*Instituto Nacional de Pesquisas Espaciais*, INPE), the number of fires in Brazil nearly doubled in January and February 2024 compared to the same period in 2023. The Caatinga biome, the largest continuous expanse of Seasonally Dry Tropical Forest and Woodland (SDTFW) in the Neotropics, covers over 800,000 km^2 in northeastern Brazil [Silva Junior and Pacheco 2021]. Its semiarid climate, combined with socioeconomic factors, leads to the overuse of natural resources, threatening species diversity [Maia et al. 2017]. Fires in the region are mainly due to warmer and drier climates from climate change and deforestation, as well as criminal burning for land conversion to agriculture and livestock [Silva Junior and Pacheco 2021].

Firefighting in vegetation areas is complex and challenging, requiring expertise, strategic planning, and extensive resources. Tasks include recognizing affected areas, planning, and deploying staff and equipment [Komalapati et al. 2021]. This complexity highlights the need for technological tools to support decision-making [Çolak and Sunar 2020]. For this reason, the present work proposes a decision-support service that aggregates data from various sources, presenting it clearly to fire brigades to aid in strategic planning and operational tasks.

[1]https://terrabrasilis.dpi.inpe.br/queimadas/portal/

2. Background

The increasing frequency and severity of global forest fires necessitate innovative firefighting and prevention methods. This work examines how technology, particularly Software as a Service (SaaS), can enhance firefighting capabilities and reduce fire risks. SaaS significantly enhances firefighting efficiency, decision-making, and resource management by leveraging cloud-based solutions, freeing brigades from managing software operations [Castro-Basurto et al. 2021]. The adoption of SaaS offers numerous advantages [Seifert et al. 2023], including: i) Real-time data access: firefighters can access critical information and updates in real-time from any location; ii) Scalability and flexibility: the service can adjust to changing operational needs, ensuring effective response times during peak usage; iii) IoT and sensor integration: aggregating data from sensors, drones, and satellite imagery provides proactive fire detection and monitoring; iv) Collaboration and communication: SaaS facilitates continuous collaboration and communication among firefighting teams, monitoring centers, and support staff; v) Reliability: consistent system availability supported by monitoring and diagnostic tools.

Research areas like Remote Sensing, Geographic Information Systems (GIS), IoT, and Business Intelligence (BI) intersect significantly with the current application. Remote sensing platforms (satellites, drones, aerial systems) aim to detect and monitor disasters early, providing real-time data on fire spread, flooding, and hotspots to prioritize intervention areas [Arab et al. 2022]. GIS applications integrate spatial data to create detailed maps and models, aiding visualization and decision-making for firefighters by mapping fire perimeters, evacuation routes, and critical infrastructure [Subburaj et al. 2024]. IoT devices and sensor networks play a crucial role in gathering real-time environmental data, including temperature, humidity, and wind speed. Teamed with remote sensing platforms and GIS, these sensors facilitate timely decision-making and response efforts [Shah et al. 2019]. The principles of BI enhance decision-support services by utilizing data-driven technologies and analytical tools to process, analyze, and visualize critical information.

3. A Decision-support Service for Firefighting in Dry Tropical Forest

Caatinga is the most important biome for livestock in the Brazilian semi-arid region [Maia et al. 2017]. To support its preservation, this work proposes a decision-support service that consolidates useful information into a single application, such as location, weather conditions, video/image storage, fire outbreaks management, and tracks to fire outbreaks. The service architecture comprises three main components, as illustrated in Figure 1: data sources, back-end, and front-end. Data sources include various external data streams from the web. The back-end collects, processes, and stores information, then sends it to the front-end, which consists of a mobile application and a web interface for managers and firefighters to access. The chosen architecture and technologies ensure the service's efficiency, security, and availability.

The proposed tool consumes data from different sources: online weather information[2], fire information from FIRMS[3], and geospatial data from OpenStreetMaps[4]. The

[2]https://www.weatherapi.com/

[3]https://firms.modaps.eosdis.nasa.gov/

[4]https://www.openstreetmap.org/

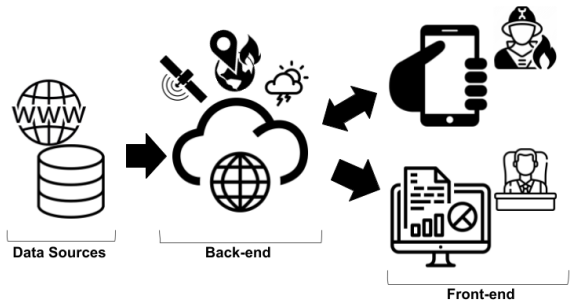

Figure 1. The project architecture of the proposed application.

Weather API provides weather conditions for specific locations at given timestamps, such as wind speed, temperature, humidity, and precipitation forecasts. The weather information is collected for the current user location and each identified fire outbreak from FIRMS, an open-data project by NASA that uses satellites to capture global fire data. Additionally, OpenStreetMap offers free geographic data and maps for public use. The back-end component receives streaming data from these sources, which is then standardized, cleaned, and stored by a developed algorithm. This processing ensures the quality, reliability, and accuracy of the information provided to users.

The front-end component presents data collected by the back-end in a user-friendly interface, divided into two perspectives: a mobile application and a web interface. The mobile application, used by firefighters for planning and fighting fires, provides information on fire locations, weather conditions, and related details, supporting decision-making. Firefighters can also add and share information, such as new fire outbreaks, images, videos, fire tracks, and fire status updates. The web interface, designed for managers and stakeholders of government agencies, offers dashboards with historical and analytical information. It uses BI principles to generate intuitive reports, ensuring that collected data is transformed into useful information for guiding firefighting efforts and improving firefighter tasks.

4. Results and Application

A decision-support tool was developed to assist fire brigades through a mobile application and a BI interface. The mobile app, created with React Native[5], provides firefighters with information on weather, fire geolocation, terrain, and regional features such as roads, water sources, and natural parks. React Native combines the benefits of React with native development, enhancing the app's user interface. The BI interface, built with Next.js, offers an analytical view of fire outbreak data. Next.js enables the creation of high-quality web applications using React components. BI reports facilitate prevention and firefighting planning, such as identifying patterns of recurrent fires that may indicate criminal activity or poor farming practices.

The back-end, developed in Python using Flask[6], runs algorithms to collect real-time information about fires and weather conditions. Flask, a lightweight WSGI[7] application framework in Python, is designed for simplicity and flexibility, allowing for easy

[5]https://reactnative.dev/

[6]https://flask.palletsprojects.com/en/3.0.x/

[7]https://wsgi.readthedocs.io/en/latest/what.html

scaling to complex applications. The service consumes data from the FIRMS API, collecting and storing specific information such as the geolocation of fires (latitude and longitude), the timestamp of fire detection, and fire brightness (intensity of fire outbreaks). Both the Weather and FIRMS APIs provide real-time data, offering valuable insights into fire locations and current weather conditions. This data aids firefighters during active firefighting and serves as historical data for year-round planning and management.

The collected data, including geolocation of fires, date/time of detection, fire brightness, and real-time weather information, are stored in the NoSQL database Cloud Firestore[8]. Developed by Firebase and Google Cloud, Cloud Firestore is a flexible and scalable database designed for mobile, web, and server applications. This database is ideal for managing large volumes of varied, real-time data, providing flexibility and scalability in storing and querying critical information, therefore, facilitating quick and efficient access by firefighters and managers during emergencies and strategic planning.

First, users must log in to the application using their credentials to enhance security and prevent unauthorized access. Once logged in, users can view a map displaying fire outbreaks from the past 48 hours, with the period configurable by the user. As shown in Figure 2 (a) and (b), users can switch between different map styles, including terrain, satellite, road map, and hybrid. The Mapbox SDK[9] for React Native was used to render maps, providing a dynamic and real-time user experience. The mobile application shows precise locations of all detected fire outbreaks, helping firefighters understand the surrounding environment, including roads, mountains, buildings, and water sources, which can impact firefighting efforts. If FIRMS delays or fails to report a fire, users can manually add fire outbreaks to the map. A black bar at the top of the screen displays four key climate metrics: wind speed, temperature, humidity, and precipitation chances. This mobile application delivers valuable, real-time information to firefighters via their smartphones, even during challenging operations.

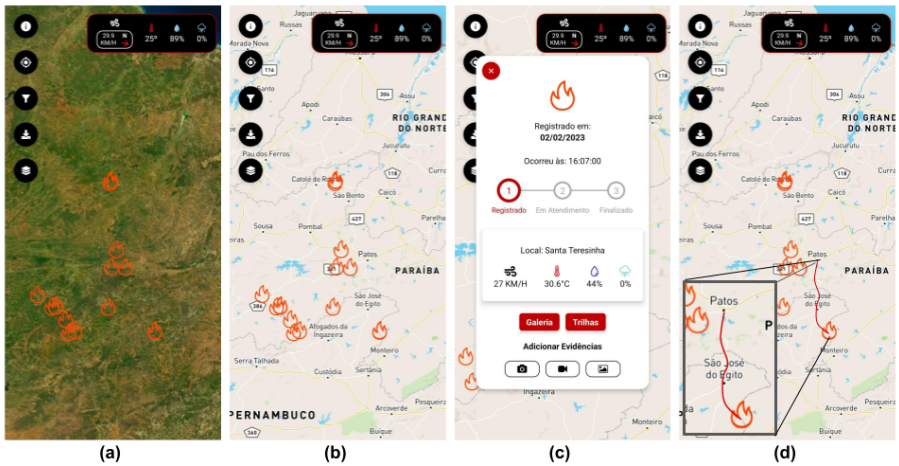

Figure 2. Screens of the proposed application: (a) fire outbreaks in satellite image view; (b) fire outbreaks in road view; (c) details of a specific fire outbreak; (d) a possible track to the fire outbreak.

By clicking on the fire outbreak icon, users can access additional information

[8]https://firebase.google.com/docs/firestore
[9]https://www.mapbox.com/

about the specific fire, including the city name, weather conditions, and timestamp of the fire registration, as shown in Figure 2 (c). When a user adds a fire outbreak, their user profile also appears as additional information. To manage the fire outbreak, firefighters can change its status to one of the following: i) registered (fire is recorded in the system); ii) in attendance (firefighters are dispatched to the scene); and iii) concluded (fire is extinguished). The fire status helps firefighter units manage their operations and provides valuable analytical data on the ratio of attended fires to all registered fires.

An essential functionality of the app is the ability for users to upload videos and photos specific to a fire outbreak, as shown in Figure 2 (c). This allows firefighters to assess the size and scope of the fire in real-time, aiding in planning and coordination. Firefighters can also record and share routes to access fires, which is crucial since they often need to traverse several kilometers through dense forests and hard-to-reach areas, as depicted in Figure 2 (d).

Another component is the BI interface, shown in Figure 3, which features a heat map that offers a two-dimensional representation of data, with colors indicating different values. In this scenario, the colors indicate the concentration of fire outbreaks in the region: green signifies a low incidence of fires, while red signifies a high incidence. This information is highly useful for analyzing regions that frequently experience forest fires, which can be due to natural conditions or criminal activity. For instance, a high concentration of fire outbreaks in the same area over a year may indicate criminal fires set to clear land for livestock farming.

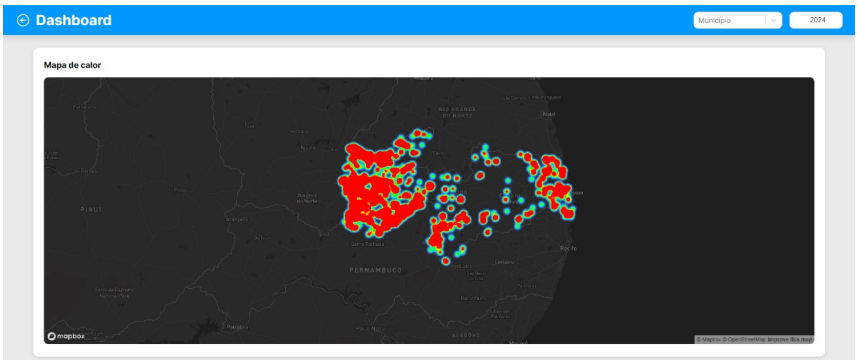

Figure 3. Example of graphs in the BI interface, which show information regarding fire spots throughout the year.

The BI interface also provides different information such as the number of detected fires, number of attended fires, fire growth rate, a line graph with the number of detected fires during the year, and a heat map with the concentration of fire outbreaks in the region. From these reports (composed of different kinds of graphs), managers can evaluate and compare the growth rates during the years and provide enough information to the governments in terms of planning investments and resources.

During 2022 and 2023, we conducted software and user tests in controlled environments to evaluate the proposed tool, resulting in a significant reduction in errors when deployed in real-world contexts. Based on error reports, improvements were implemented across all interfaces of the tool. Currently, the app has been deployed at the Fire Brigade of the Paraíba, supporting the firefighting in the Caatinga region. Regarding the BI mod-

ule, historical data is being collected. With the use of the app by firefighters, an increasing number of data will be stored. From them, the reports have already been made available so that firefighters and managers can apply them as a decision-support tool.

5. Related Work

Considering the rising number of fires across Brazil and the limitations in resources and equipment within fire brigades, it is crucial to adopt strategies that support decision-making and action planning for combating forest fires. Following, we present technological solutions used around the world to combat forest fires: i) FireScope[10] - A tool that supports firefighters planning during firefighting operations in real-time. The app provides detailed information about topography, vegetation, and weather conditions, allowing firefighters to receive information regarding how to fight the fire. ii) Firefighter Log[11] - An application that allows firefighters to record information about the fire, including the type of fire, the dimension of damage, and the location. The app also assists in coordinating firefighting operations between different fire units. iii) FireReady[12] - Platform developed by the Australian government to provide real-time fire alerts, similar to the data provided by FIRMS. Also, the platform provides educative information on fire risk levels and guidance on what to do in case of fire. iv) Wildfire[13] - Software that allows firefighters to receive real-time information regarding the location, dimension, and intensity of forest fires across the USA country, with a focus on the state of Idaho. The software aims to support the coordination of firefighting efforts, similar to FIRMS, but with the scope only for the USA.

Although technological tools such as satellite images [da Silva et al. 2018] and support software [Çolak and Sunar 2020, Cazzolato et al. 2017] have been used to combat and prevent forest fires, there is a lack of approaches that centralize extensive information on portable devices like cellphones and tablets [Komalapati et al. 2021]. Based on our market research, no fire brigades in Brazil currently use software similar to the one proposed in this work. This decision-support service was specifically developed for the needs of the Caatinga region and optimized for the requirements of the local firefighting teams, including features and functionalities that address the unique demands of firefighting in this environment.

6. Conclusion and Future Works

This paper details the development and deployment of a service designed to address the challenges of firefighting, such as limited resources and equipment. The service collects and integrates data from various sources, presenting useful information through a user-friendly interface to aid strategic planning and support firefighting efforts. Currently in use by the Fire Brigade of Paraíba in the Caatinga region, the service has received positive feedback for its effectiveness in facilitating planning and firefighting actions. Future goals include expanding the tool to additional fire brigades across Brazil and integrating artificial intelligence, specifically machine learning algorithms, to predict fire occurrences using the collected data.

[10]https://firescope.caloes.ca.gov/
[11]http://www.firefighterlog.com/
[12]https://fireready.org.au/
[13]https://www.nifc.gov

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