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Proactive Forest Fire Prediction and Intelligent Causal Analysis using Ensemble Machine Learning

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Abstract:

Forest fires are a serious environmental issue that result in loss of a large area of natural resources, damaging wildlife habitat, and destruction of homes. In order to prevent forest fires, we need to be able to identify predisposed high-risk conditions that can lead to outbreaks before an actual fire happens. The authors propose a proactive approach to forest fire prediction using meteorological variables such as temperature, wind speed, and relative humidity, as well as calculated Fire Weather Index (FWI) numbers, to assess possible fire hazard conditions. Their focus is on developing a predictive framework based on the use of the XGBoost machine learning algorithm to evaluate weather-related variables in order to provide users with forest fire risk predictions. In addition, using an Intelligent Causal Analysis (ICA) feature within the system, users will obtain a better understanding of what environmental factors have contributed to elevated fire risk levels when evaluating their situation. An Internet-enabled user interface called Forest Guardian Command Center will also be created to provide users with real time monitoring, geospatial observation of threats, and role-dependent access control to the command center for authorized personnel. Additionally, automated SMS and Email notification services will be incorporated into the system to ensure immediate communication with emergency responders when dangerous fire risk conditions are identified. Ultimately, the authors propose that by integrating predictive analytics, explainable insights, and automated emergency notifications into one platform, they will assist users in managing forest fire proactively, and reduce the risk of forest fires starting.

Keywords — **Forest Fire Prediction, XGBoost, Fire Weather Index (FWI), Intelligent Causal Analysis, Emergency Alert System, Role-Based Access Control (RBAC), Web Command Center.**

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I. INTRODUCTION

Forest fires represent one of the most significant threats to the environment as they destroy not only forests but also wildlife, homes, and businesses. The common methods of monitoring for forest fire activity are both manual patrols and satellite-based observations. These traditional methods are reactive and cannot provide timely information to assist in Fire detection. As the detection timing is typically after a response has been initiated, it often results in a rapid fire spread and greater damage than if the fire had been detected early.

The recent advances in Machine Learning have led to the creation of predictive systems that provide an early warning of the potential for the occurrence of forest fires based on predictive modeling of weather patterns and Fire Weather Index (FWI) parameters.

Currently, we propose to develop a forest fire prediction system using the XGBoost algorithm with real-time weather data and FWI metrics to predict the potential for fire, to carry out intelligent causal analysis of any fires that occur and generate automated SMS and Email alerts. The system has been developed to provide real-time information through a web-based Forest Guardian Command Center that uses role-based access control and geospatial threat visualization to enable authorities to effectively monitor and respond to potential forest fire threats.

II. LITERATURE SURVEY

1. ***P. Cortez and A. Morais (2007) – Forest Fire Prediction Using Meteorological Data :***
   In their research P. Cortez and A. Morais introduced a method for using meteorological information in order to predict the occurrence of forest fires through data mining techniques. They showed that various aspects of weather could be used, in the context of a fire prediction algorithm, along with machine learning techniques, to estimate the probability of a fire. However, this work provided only predictive analytics and not real-time monitoring of active fires, alerts for emergencies, or explainable analytics related to the prediction of the fires. In addition, there was no web-based decision support solution for forest authorities to assist them with their operational activities.

2. ***B. Safi and A. Bouroumi (2021) – Forest Fire Prediction Based on Machine Learning Technique :***
   B. Safi and A. Bouroumi used machine learning algorithms to predict the potential for forest fires, using both environmental and meteorological data sets. This work used only data-driven models to enhance the predictive accuracy of the models created. Their analysis illustrated the potential of machine learning methods for use in firefighters managing wildfires; however, their research did not provide capabilities for intelligent causal analyses or automated SMS or email alerts for fire-related events. The system was also unable to provide role-based access to information or centralized monitoring of the system through a web dashboard.

3. ***S. Jain et al. (2020) – Machine Learning Applications in Wildfire Science and Management :***
   Under a recent report from Jain and Co., researchers provided a comprehensive overview of how machine learning can be applied to fire science and management. The authors identified multiple predictive models used for the prediction of fire behaviour, as well as their corresponding results. While the authors recognised the importance of predictive analytics, they also identified challenges such as limited interpretability of predictive algorithms, no real-time implementation, and no automated emergency response systems to help 1st responders. Overall, the authors mostly focused on predictive analytics without adequately providing integrated operational support for 1st responders.

III. EXISTING SYSTEM

Current systems for predicting forest fires have relied heavily on the Random Forest algorithm in their attempts to analyze weather and climate datasets. While Random Forest does have the ability to model very complicated datasets and reduce the severity of the problem of overfitting, the Random Forest algorithm will analyze each decision tree in isolation and will not incorporate errors made within the decision trees back into the training dataset for subsequent decisions. As such, the Random Forest algorithm will be unable to model an environment where the weather is

constantly changing, resulting in a prediction accuracy of only approximately 80%.

To compound the problems created by limitations of the Random Forest algorithm, traditional methods of managing wildfires utilise manual patrols and satellite imagery for detection of fires. As such, these are primarily reactive systems that can only detect the presence of fires after they have begun to burn. Therefore, authorities will have limited options for putting into place measures to prevent the fire from spreading.

Another key issue with both existing fire prediction systems and traditional methods of managing wildfires is the total lack of automated emergency communication /decision support features. Most systems do not provide instant email or SMS notifications to emergency responders upon detection of a threat; thus delaying the response time of emergency responders. Also, they do not provide much in the form of insight into environmental elements contributing to a fire's potential development, making it challenging for forest officers to make informed decisions related to fire prevention.

IV. PROPOSED SYSTEM

This project outlines a proactive approach to predicting forest fires through the application of XGBoost to meteorological and Fire Weather Index (FWI) data. The method of incorporating new information (incremental learning) into the prediction process allows for continuous development of an estimation model as new weather patterns become available. XGBoost has a prediction accuracy of approximately 93%, providing reliable predictions of fire risk during the early stages of development.

The system predicts prospective fire dangers prior to their ignitability and helps agencies take preventative action An Intelligent Causal Analysis (ICA) module will be added to further aid in the decision-making processes. The ICA module will outline the vital environmental variables correlated with fire risk. Finally, a web-based Forest Guardian Command Center will be developed to provide geospatial visualization of threat loading, as well as granting role-based access to those needing to use the information real-time.
Moreover, the system integrates automated SMS and email alert services to immediately notify about potential dangerous situations when identified.

Advantages

- 93% prediction accuracy through XGBoost
- Predict the danger of fires occurring prior to happen
- Use of the intelligent causal analysis
- Automate alerts via text message (SMS)
- Automate alerts via email
- Role-based access controlled (RBAC)
- Monitor real-time through web-based dashboards
- Enhance emergency response and decision-making processes

V. SYSTEM ARCHITECTURE

The system architecture of the proposed forest fire prediction system is shown in figure 1.

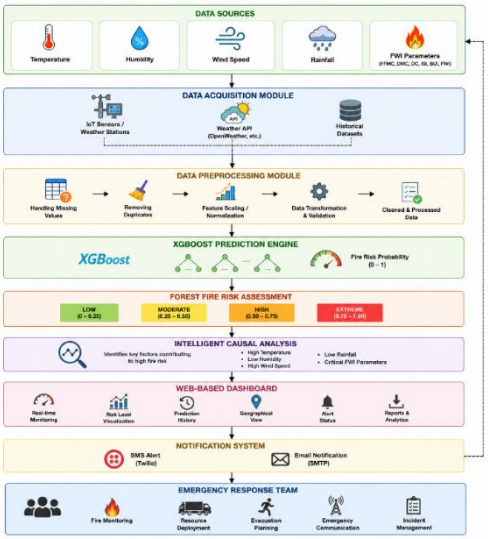

Figure 1 : System Architecture

The proposed system will forecast the potential for forest fires based upon meteorological information and various parameters based upon the Fire Weather Index (FWI) referenced above. The environmental factors considered will include temperature, relative humidity, wind speed, precipitation (rainfall), and fuel-related indices. These environmental factors will be collected and processed in order to provide data for the proposed system.

Once the collection and processing of environmental data occurs, the XGBoost prediction model will be used as the basis for analyzing the relationship between the input data and the occurrence of wildfires. The prediction model will provide information about potential wildfire risk based upon historical relationships between all of the input factors and the occurrence of wildfires in the past.

An additional component included within the proposed system to enhance the model's interpretability is the inclusion Intelligent Causal Analysis (ICA). The ICA uses the same data used for the prediction model and will identify the environmental factors that contribute to an increase in the likelihood of a wildfire occurring. This information will also provide additional insight to emergency responders for their determination of future actions and

The results of the predictions will be provided to the user/agency via the Forest Guardian Command Center, a web-based application that supports real-time monitoring and role-based access to users. The Command Center will allow users to monitor the data in real-time and receive automated SMS or email notifications when environmental factors lead to a significant likelihood of a wildfire.

VI. METHODOLOGY

The overall Methodology of the proposed forest fire prediction system is shown in figure 2.

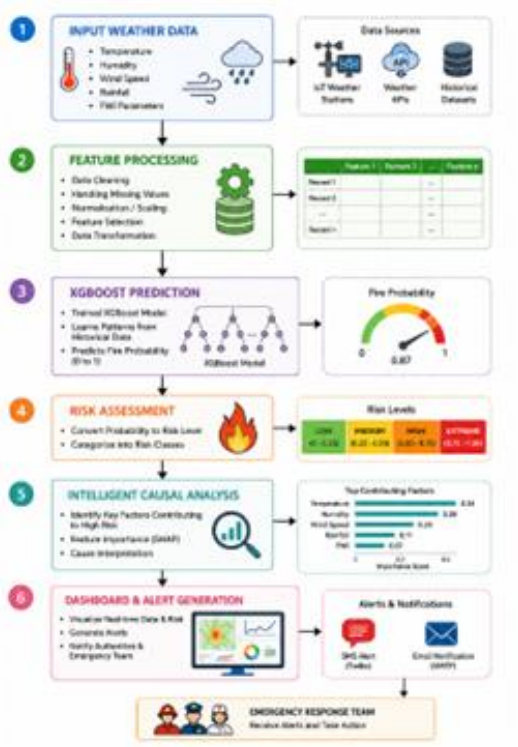

Figure 2 : Methodology

A. Dataset Description

The Forest FireWeather and Meteorological dataset consist of meteorological data and fire weather indexes for 1998 through 2006: temperature (C),

relative humidity (%), wind speed (m/s), and amount of precipitation (mm) at the fire location, as well as FFMC, DMC, DC, ISI, BUI, and FWI corresponding to those dates. All features of this dataset will be utilized to assess the likelihood of forest fires

B. Data Preprocessing

The dataset underwent many forms of data cleaning/processing prior to analysis. Specifically, we have properly handled missing values in the dataset, as well as selected the most influential features in order to improve the performance of the prediction models.

C. XGBoost Model

We will utilize XGBoost as our approach to model prediction of the risk of starting a forest fire based on weather/FWI measurements. XGBoost is an implementation of gradient boosted decision tree methodology, which iteratively refines the prediction error from one prediction to produce improved accuracy on the next prediction. Thus, the predicted risk of an individual fire will yield greater accuracy than other models.

D. Prediction Work Flow

Weather/FWI data is received as input into the system and is processed prior to the application of the XGBoost model for predicting the risk of fire. The predictions generated by the model will be used to assess the risk associated with a fire, to evaluate potential causes of fire, and to generate warnings for the public about the risk of fire at a given location and time.

VII. INTELLIGENT CAUSAL ANALYSIS

Developed to provide better insight into forest fire prediction (rather than just giving a risk), the Intelligent Causal Analysis (ICA) Framework will also offer an understanding of why we believe a certain environmental condition will lead to a fire event occurring.

Within this framework we will use historical data to analyze multiple parameters including the following: temperature, relative humidity, wind speed, rainfall, Fire Weather Index (FWI). All of these variables will be cross-evaluated against the prediction for future fire risk in order to assess their level of contribution to future fire risk.

Wherever and whenever a high-risk environmental condition occurs, the ICA Framework will establish key parameters contributing to that high-risk prediction. This provides forest officers with the ability to see, not only that a given area has high-risk potential for fire occurrence, but also to identify the specific reasons why this is so.

The resulting data will be available through the command centre of the forest guardian system, which will facilitate sound decision making and aid in preventing fires before they occur.

VIII. FOREST GUARDIAN COMMAND CENTRE

The Forest Guardian Command Centre is the main site of data and information for the proposed system. The Forest Guardian Command Centre is a web-based interface to allow authorized users to monitor forest fire risk and view prediction results in real-time.

The Command Centre displays all necessary information (including weather, fire risk status and maps of geospatial fire risk) on a single dashboard and allows users to easily identify high-risk areas and track the effects of environmental changes on fire hazard potential.

In order to provide secure access, the Command Centre provides Role-Based Access Control (RBAC) to allow different users to have access to certain features of the system depending on their jobs. This ensures an efficient operational

environment with the ability to keep the system secure.

The Command Centre also provides features like Intelligent Causal Analysis reporting and automated alert management. By providing all of the features needed for prediction, visualization and communication in a centralised location, the platform helps to provide timely decision-making for authorities to make decisions regarding the prevention and response to forest fires.

IX. AUTOMATED EMERGENCY ALERT SYSTEM

sends a notification to the fire department when the predicted fire threat surpasses a specified level so that they can take appropriate precautions before the expected arrival of a fire. The Automated AEAS will also automatically send SMS alerts to relevant forest officers and emergency responders using the Twilio API with automatic texts that provide information about the predicted fire threat and its location.

In addition to sending SMS alerts, the system will also send warning emails as part of the SMTP-based email services to provide multiple points of contact for coordinating during an emergency.

Automating the notification process means that less time is generally needed to notify about an event or for an agency to respond to an event, thus improving the efficiency of solving a fire management problem and assisting with disaster preparedness.

X. RESULTS AND DISCUSSION

The meteorological data and Fire Weather Index (FWI) were used to assess the performance of the system developed for fire prediction. The XGBoost model created for comparing the effectiveness of Random Forest with regards to predicting the occurrence of forest fires.

In experimental runs, the prediction of Random Forest result was about 80%, while the prediction of the XGBoost model was approximately 93%. This indicates the improved capability of XGBoost for working with complex datasets such as environmental measurements in comparison to Random Forest.

The system did not only predict, but also provided Intelligent Causal Analysis, provided a real-time dashboard with monitoring capabilities, and provided automatic text and email alerts. These added features will help to enhance decision-making capabilities and to support proactive forest fire management practices.

TABLE 1 : PERFORMANCE COMPARISON

MODEL	ACCURACY
Random forest	80%
XGBOOST	93%

XI. CONCLUSION

This document described a fire prediction system for forests that uses prediction algorithms along with fire weather index (FWI) parameters to determine potential forest fire threats prior to their occurrence. The overall framework consists of three main components: (1) An Intelligent Causal Analysis, (2) A web-based Forest Guardian Command Center, and (3) Automated SMS & Email Alert Services. By combining these three elements, the resulting system is capable of providing a safe and reliable way of supporting effective monitoring of forest fire disasters; while enhancing the ability to provide a rapid response to farm fires, provide a proactive solution and improve/prevent forest fire management and disaster preparedness.

XII. FUTURE WORK

The proposed system can be further improved by using satellite imagery and drone-based tools for monitoring for increased accuracy and coverage of forest fire detection compared to the current method of using ground-based observation only. By combining real-time video imagery with meteorological and Fire Weather Index (FWI) data, it is possible to create a more comprehensive overview of areas susceptible to fire and thus allow for the quicker identification of possible threats.
The system could be enhanced through an application that can be used by fieldworkers and emergency response personnel. The eventual plans for the system may depend upon the incorporation of deep learning techniques, an increase in the number of geographic regions being supported, and the inclusion of additional environmental factors so that the accuracy and ability to operate at optimal levels can be achieved.

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