ICEF 2023

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International Conference on Electrical Facilities and informational technologies 2023

August 22(TUE) - 25(FRI), 2023
Almaty University of Power Engineering and Telecommunications, Kazakhstan

Organized by : KIEE Electrical Facilities Society, Energo University

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- AC-DC Hybrid Grid Operation, Control and Protection
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- Electric Machinery and Drives
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- Heat Power Engineering

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- Smart Grids, Micro-grid, and Utility Applications
- Smart Energy Management for Home, Building and Factory
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MATHEMATICAL MODELING AND DEVELOPMENT OF AUTOMATED FIRE MONITORING SYSTEM

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Abstract. *Mathematical modeling and the development of automated fire monitoring systems involve the use of mathematical equations and computer algorithms to analyze data and predict the occurrence of fires. In this process, we create a mathematical model to simulate the behavior of fire and use it to develop an automated fire monitoring system. The first step in the process is to develop a mathematical model that describes the behavior of fire. The model should take into account various factors such as fuel type, temperature, humidity, wind speed, and direction. We can use different modeling techniques, such as computational fluid dynamics (CFD) or finite element analysis (FEA), to develop a detailed and accurate model of fire behavior. Once we have developed a mathematical model, we can use it to develop an automated fire monitoring system. The system should be able to detect and analyze fire behavior in real-time and provide early warning to authorities and individuals in the affected area. The system should also be able to predict the behavior of the fire and provide recommendations for firefighting operations.*

There are several types of sensors that can be used in an automated fire monitoring system, such as thermal imaging cameras, smoke detectors, and infrared cameras. These sensors can detect changes in temperature, smoke density, and radiation levels, which can indicate the presence of a fire. The data collected by the sensors is then processed by a computer system, which uses the mathematical model to analyze the behavior of the fire. The system can also use machine learning algorithms to learn from past fire incidents and improve its predictions. In conclusion, mathematical modeling and the development of automated fire monitoring systems can help prevent and mitigate the damage caused by fires. By developing accurate models of fire behavior and using advanced sensors and machine learning algorithms, we can provide early warning and improve firefighting operations, ultimately saving lives and reducing property damage.

Keywords: *fire, automated system, mathematical modeling, fire monitoring systems.*

I. INTRODUCTION

Fires can cause significant material damage and pose a serious threat to people's lives. As a result, it is very important to have effective fire control measures in order to detect possible fires in a timely manner and react quickly. Fire control systems play an important role in fire prevention and suppression. They must be carefully designed, installed and maintained to ensure their effectiveness in detecting and responding to fires. The development of a fire management system can provide a number of advantages, such as increasing safety, reducing damage and loss, and increasing property value. A well-thought-out fire management system helps reduce damage, protect human lives, and comply with safety regulations.

The article discusses the problems of monitoring and forecasting forest and steppe fires, determining the mathematical model used to prevent forest and steppe fires, and developing an automated system. We all know about the harm and consequences of a silent enemy. For this reason, forest fires are currently recognized as one of the most important factors in changing landscapes. Each resulting fire is thrown into the atmosphere about a million combustion products, which are released many toxic substances and chemical elements. Depending on the spread of fire and its dynamics, the description of mathematical models varies. Among the mathematical models of Fire Prevention, the most important and complex are those that characterize the dynamics of forest and natural fires. Therefore, since fire prevention is a huge problem all over the world, we examined mathematical models used for the prevention and control of emergency situations and analyzed fire control, forecasting systems, their features in the article.

The purpose of the work is to develop technology and software for automated control and forecasting of forest and steppe fires using mathematical modeling.

II. RESEARCH MATERIAL AND METHODS. DESCRIPTION OF THE ALGORITHM AND MODULES

Controlling and forecasting forest and steppe fires requires a multidisciplinary approach that combines various research materials and methods. Here are some common research materials and methods used for the control and forecasting of forest and steppe fires: Remote sensing involves the use of satellites, aircraft, and other remote sensing platforms to collect data on fires, weather conditions, and fuel moisture. This data is used to detect and monitor fires, as well as to forecast their behavior. Geographic Information Systems (GIS) - GIS is a computer-based tool that allows researchers to analyze and visualize data related to fires, weather, topography, and vegetation [1]. This tool can be used to identify high-risk areas and to develop fire management plans. Fire behavior models are computer simulations that predict the behavior of fires based on environmental conditions, such as fuel moisture, topography, and weather. These models can be used to forecast the spread of fires and to develop effective firefighting strategies. Meteorological data, such as temperature, humidity, wind speed, and direction, can be used to forecast fire behavior and to develop fire management plans. This data can be collected from weather stations, satellites, and other remote sensing platforms. Fuel moisture sampling involves collecting samples of vegetation to measure their moisture content. This data can be used to predict the potential for fires and to develop fire management plans. Fire detection systems, such as cameras, smoke and heat detectors, and automated weather stations, can be used to detect fires early and to provide accurate information to emergency services. Fire management plans are developed based on research data and involve the implementation of measures to prevent and control fires. These plans may include fuel reduction, prescribed burns, and the development of fire breaks.

In conclusion, the control and forecasting of forest and steppe fires require the integration of various research materials and methods. These tools can help to detect and monitor fires, forecast their behavior, and develop effective firefighting strategies. The use of these tools is critical in protecting human lives, property, and the environment from the devastating effects of fires [2].

Using the materials and methods necessary to develop the above monitoring system, it is possible to effectively develop a system for monitoring and forecasting forest and wildfires based on the following algorithm. Developing an algorithm for monitoring and predicting forest and steppe fires requires a comprehensive approach that takes into account multiple factors that can influence fire behavior. Here is a general algorithm for monitoring and predicting forest and steppe fires:

- Data Collection: Collect data on weather conditions, fuel moisture, vegetation, topography, and other relevant factors. This data can be collected through remote sensing, meteorological stations, fuel moisture sampling, and other means.
- Fire Detection: Detect fires through various fire detection systems such as cameras, smoke and heat detectors, and automated weather stations. These systems can detect fires in real-time and provide accurate information to emergency services.
- Fire Behavior Prediction: Use fire behavior models to predict the spread of fires based on environmental conditions such as fuel moisture, topography, and weather. These models can be used to forecast fire behavior and to develop effective firefighting strategies.
- Fire Danger Rating: Use fire danger rating systems to assess the potential for fires based on weather conditions, fuel moisture, and other factors. These systems can help to predict the likelihood of fires occurring and provide warnings to people living in high-risk areas.
- Fire Management: Develop fire management plans based on the data collected in steps 1-4. These plans may include fuel reduction, prescribed burns, and the development of fire breaks. The plans should also include a strategy for responding to fires when they occur.
- Continuous Monitoring: Continuously monitor weather conditions, fuel moisture, and other factors that can influence fire behavior. This monitoring should be done in real-time to allow for immediate action if conditions change.
- Response Planning: Develop a response plan that outlines the steps to be taken in the event of a fire. This plan should include procedures for alerting emergency services, evacuating people and animals, and providing support to firefighters [3-4].

Developing an algorithm for monitoring and predicting forest and steppe fires requires a comprehensive approach that involves data collection, fire detection, fire behavior prediction, fire danger rating, fire management, continuous monitoring, and response planning. This algorithm can help to prevent fires and minimize their impact on human lives, property, and the environment. At the same time, the analysis of the currently operating systems was carried out in the article. Although each system has its own advantages and disadvantages, each system has its own users. The analysis of some automated systems used in the control and forecasting of forest and steppe fires is shown in the table 1.

TABLE I. SOME AUTOMATED SYSTEMS USED IN THE CONTROL AND FORECASTING OF FOREST AND WILDFIRES

Systems	Description
FireWatch	FireWatch is a satellite-based fire detection system that uses a combination of infrared and visible light sensors to detect fires in real-time. The system can detect fires as small as 30 meters in diameter and can provide accurate location data to emergency services within minutes.
Farsite	Farsite is a fire behavior and growth model that uses terrain, weather, and fuel data to simulate the spread of fires. The model can be used to forecast the potential size and direction of fires, allowing emergency services to plan their response.
MODIS (Moderate Resolution Imaging Spectroradiometer)	MODIS is a NASA satellite-based system that can detect fires in near real-time. The system can detect fires as small as 1000 square meters and can provide data on fire location, size, and temperature.
Fire Danger Rating Systems	Fire Danger Rating Systems (FDRS) are used to assess the potential for fires based on weather conditions, fuel moisture, and other factors. These systems can help to predict the likelihood of fires occurring and provide warnings to people living in high-risk areas.
Alertwildfire	Alertwildfire is a camera-based system that provides real-time video of wildfires to emergency services. The system uses cameras mounted on towers or other high points to provide a panoramic view of the area. This can help emergency services to assess the situation and make decisions about how to respond.

These are just a few examples of the automated systems for monitoring and forecasting forest and steppe fires that exist. Each system has its own strengths and weaknesses, and some may be better suited to certain types of fires or environments than others. It is important to choose the right system for the specific needs of the area being monitored [5].

One example of a mathematical model that can be applied to an automated system for monitoring and predicting forest and wildfires is the Rothermel model, which is a widely used fire spread model. The Rothermel model is based on the physical processes involved in the spread of surface fires, and it takes into account factors such as fuel characteristics, topography, and weather conditions.

The Rothermel model uses a set of equations to estimate the rate of fire spread, fireline intensity, and other fire behavior parameters. These equations take into account the following factors:

Fuel Characteristics - The Rothermel model accounts for the fuel characteristics of the vegetation being burned, including fuel load, fuel moisture content, and fuel particle size.

Topography - The Rothermel model accounts for the effect of topography on fire behavior, including slope, aspect, and the presence of ridges and valleys.

Weather Conditions - The Rothermel model accounts for weather conditions, including wind speed and direction, temperature, humidity, and atmospheric stability.

The Rothermel model is typically implemented in a computer program that allows fire managers to input data on fuel characteristics, topography, and weather conditions, and then generates predictions of fire behavior, including fire spread rate, direction, and intensity [6-8]. The model can be used to develop fire management plans, to identify high-risk areas, and to support decision-making during firefighting operations. The following is the general formula for the Rothermel model:

$$ERR= \rho*H**w**S**(1+\beta) \quad (1)$$

where:

ERR is the energy release rate (kJ/m^2/s);

ρ is the density of the fuel (kg/m^3);

H is the fuel bed depth (m);

w is the fuel moisture content (fraction);

S is the wind speed (m/s);

β is a correction factor that accounts for the slope of the terrain.

The Rothermel model also includes equations to estimate the rate of spread (ROS) and fireline intensity (FLI), which are given by:

$$ROS=k*(ERR/\rho)^{n}, \quad (2)$$

$$FLI=(\rho*H**w**c**(T-273))^{1.5}*(ROS/60) \quad (3)$$

where:

k and n are empirical constants that depend on the fuel type and moisture content;

c is the specific heat of the fuel (kJ/kg/°C);

T is the ambient temperature (K).

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III. Result and Discussion

Linking the Rothermel model to an automated forest and wildfire monitoring and forecasting system involves integrating the Rothermel model into the overall system architecture. Here are the steps involved in linking the Rothermel model to an automated forest and wildfire monitoring and forecasting system.

System design: The overall system architecture should be designed to accommodate the Rothermel model. This may involve selecting appropriate hardware and software platforms and designing the user interface.

Data acquisition: The system should be able to acquire data on fuel characteristics, topography, and weather conditions. This can be done through various means, such as remote sensing, ground-based sensors, and weather stations.

Data processing: The data acquired by the system needs to be preprocessed and organized for use in the Rothermel model. This may involve converting data to appropriate units, filtering out erroneous data, and calculating additional parameters.

Rothermel model implementation: The Rothermel model needs to be integrated into the overall system architecture. This may involve developing custom software or integrating existing software tools into the system.

Calibration and validation: The Rothermel model needs to be calibrated and validated for the specific area being monitored. This involves adjusting the model parameters to match local fuel types and moisture conditions and comparing the predicted fire behavior to actual fire behavior observed in the field.

Visualization and reporting: The results of the Rothermel model should be presented in a way that is easy for fire managers to interpret. This can include maps, graphs, and other visualizations. The system should also provide reports on fire behavior predictions, risk assessments, and other relevant information.

Integration with other systems: The automated system should be integrated with other fire management systems such as fire detection and suppression systems. This will allow for a comprehensive approach to fire management.

Overall, linking the Rothermel model to an automated forest and wildfire monitoring and forecasting system requires careful planning and design to ensure that the system is reliable, accurate, and easy to use. The system should also be regularly updated and maintained to ensure that it remains effective over time.

IV. Conclusion

We all know the harm and consequences of a mute enemy. One of the most pressing and difficult issues in the world is the Prevention of fires in forest areas, forest countries, its prevention, protection from deforestation and deforestation. Forest fires damage the economy of the area where the fire occurred, affected. Fire extinguishing costs can be a heavy burden for locally allocated funds. To eliminate fires, expensive equipment such as aircraft, helicopters, fire trucks and tankers carrying cy is required. At the same time, it is clear that biological restoration of the habitat will not be an easy task either. To prevent the same damage, a system is being developed that monitors, predicts forest and wildfires in real time. The system provides information about the time of occurrence of a fire, the level, the area of possible fire coverage using space data. With the help of new software for monitoring forests based on space data, it is possible to significantly reduce the time of fire response and, as a result, avoid large losses due to forest fires.

The work was carried out at the Research Institute of Mathematics and Mechanics of the Kazakh National University named after al-Farabi.

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