Case studies of forest fire detection systems

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Abstract—**The global warming and the frequent forest fires are the greatest evils, that is happening to the world today. They are key motivation factor in development of systems for an early prevention and detection of forest fires. In this paper, we review the general architecture of a forest fire system, present several existing systems and pilot-projects, describe their specific architectures and emphasize the main mutual similarities and differences. At the and we address the open issues and improvement opportunities, that appear with the mobile technologies and smart phones.**

I. Introduction

One third of Europe is now covered by forests, corresponding to 185 million hectares (ha) [1]. The total forest area has increased over the recent decades. The forest fires are one of the greatest evils that are happening in the world today. They are usually accompanied by loss of human lives, loss of homes, loss on forest, biodiversity change and climate change. Most of the damage occur during the summer. Every year forest fires in Europe burn on average about 500 000 ha (twice the area of Luxembourg). Nearly 95 % of the total burned area lies in the Mediterranean region [2]. Therefore, the early prevention and timely dealing with forest fires becomes essential.

The fires are mainly caused by humans, then lightning and other reasons, that contribute to easy start of fires, as the global warming. The prevention of fires is very complex, it requires a lot of work, that includes the long-term process of changing the consciousness of the population and a short-term protection of the forests with a regular maintenance. The short-term aspect is for example, minimizing the side effects including a fire control, increasing the resistance of the assets of a fire, in the case of forests, relocation of resources away from the path of the fire as well as reducing the possibility of a fire occurrence. Although the number of fires in the last decade has increased in Europe, the burned area has not expanded significantly due to the improved firefighting methods.

Several methods and technics are known and used in the world, such as satellites [3], spy planes, surveillance pillars, heat sensors and the combination of these methods. The Satellites are very expensive, only limited areas are monitored and cannot detect small fires. The clouds are also a problem, but in a lack of other solutions for the large inaccessible areas, they are the only way to detect forest fires. The spy planes are used in USA, Canada, Russia, Finland, as well as in other countries with large forest areas, as early warning systems. They are embedded in planes that patrol with regular cameras and use IR-cameras for night vision. The surveillance pillars were used a long time ago as the only possible method that oversees the forest fires.

Lately, these pillars have been complemented with modern and sophisticated cameras or an appropriate types of sensors, that collect information and transmit data to the control centers. Due to their geographical infrastructure, some countries have to use combined methods because they are not able to oversee the whole territory by using only one method.

In the world, there are several systems and pilot-projects, which have been created for an early prevention and detection of forest fires. There are many scientific studies that have covered this issue from different aspects [4] [5]. The starting point in the almost all researches is the great number of forest fires in recent years and the need to act preventive and to deal faster, easier and simpler without major consequences for the population and the forests.

II. Fire System General Architecture

Motivation for analyzing the forest fires early detection and prevention systems are the positive aspects of one such system present in a country. The existence of such a system requires certain conditions to be fulfilled. First, there have to be a good coverage of automated measuring stations, suitable for obtaining meteorological data on the territory that is aimed at protection. Then an access to the data from the satellites is required to calculate the designated parameters. Additionally a detection system in the area is needed, consisted of a combined set of cameras [6], sensors and extended with a crowd-sourcing modules, such as citizens' smart phones. All of these real time data should be merged with the static data (vegetation map, demographic maps, orthophoto maps, etc.) into one integrated system. The system should give all necessary items required for early warning and prevention of forest fires. Fig. 1 shows a general architecture of a Forest Fire System, with a server-side computational unit [7] [8], data providers and users.

III. Example systems

A. *Canadian Wildland Fire Information System (CWFIS)*

One of the most advanced systems in the world is the Canadian Wildland Fire Information System[1], shown in Fig. 2, that is based on a GIS system. This system creates products on a daily basis, which are maps of the daily fire danger,

[1]Canadian Wildland Fire Information System, http://cwfis.cfs.nrcan.gc.ca

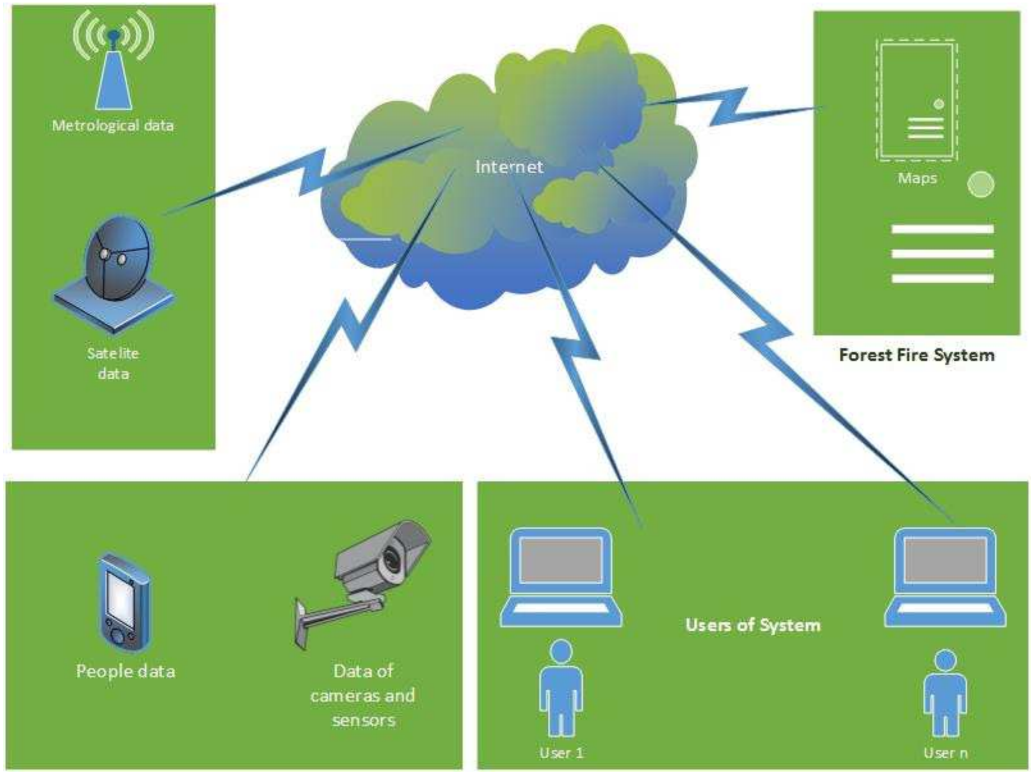

Fig. 1. Forest Fire System General Architecture.

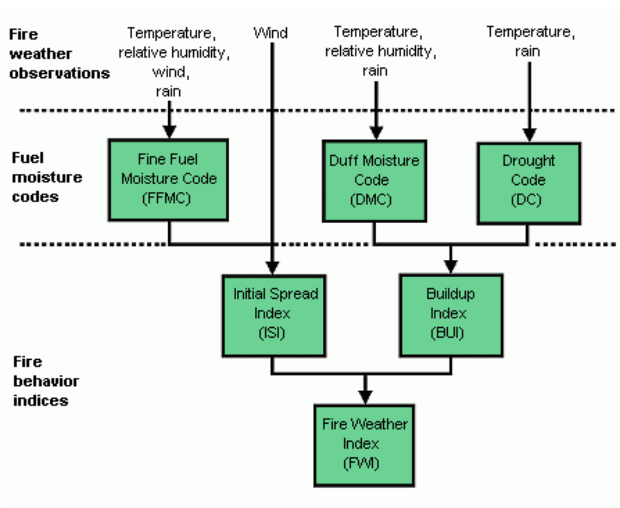

Fig. 2. Diagram of Canadian Forest Fire Weather Index (FWI).

the annual fire behavior and the fire points (popularly called "Hot spots") during the fire season, generally from May to September. These maps are used by the agencies, that deal with fires, for their research and it is open to the public. Forecasts are made six days earlier. This is a computer-based system, that follows the daily danger and conditions for the occurrence of a fire in Canada.

All weather data from Canada is gathered on a daily basis and it is used so that the maps of danger and fire behavior are created. Satellites are additionally used to detect fires. The main benefits of this system are maps, national situational reports for the entire territory and historical analysis. This system consists of several modules, such as:

1) Fire weather data acquisition: The system uses weather data and weather forecasts from the Atmospheric Environment Service (AES) and the Canadian Hydro meteorological Service. The data is gathered automatically and manually from the meteorological stations and the ANIK-D satellite from the North part of Canada. This project integrates 250 meteorological stations on the entire territory of Canada.

2) Data storage and analysis: CWFIS operates in the Workstation County on top of a UNIX platform. The descriptive data model is implemented in the Oracle relational database. The spatial data is stored in ARC/info, in the raster and vector format.

3) Fire Weather Modeling: This system is used by the Canadian Forest Fire Weather Index (FWI) System (Van Wagner 1987), as a basis for modeling and displaying of the possibility of fire occurrence in the forests. The calculation of the components is based on consecutive daily monitoring of the temperature, the relative humidity, the wind speed, and the 24-hour rainfall.

4) Fine Fuel Moisture Code (in this case, the wood, Duff Moisture Code, Duff Moisture Code, Drought Code, Initial Spread Index and Buildup Index): It is the ratings of the total amount of the available combustion fuel, which are numerical

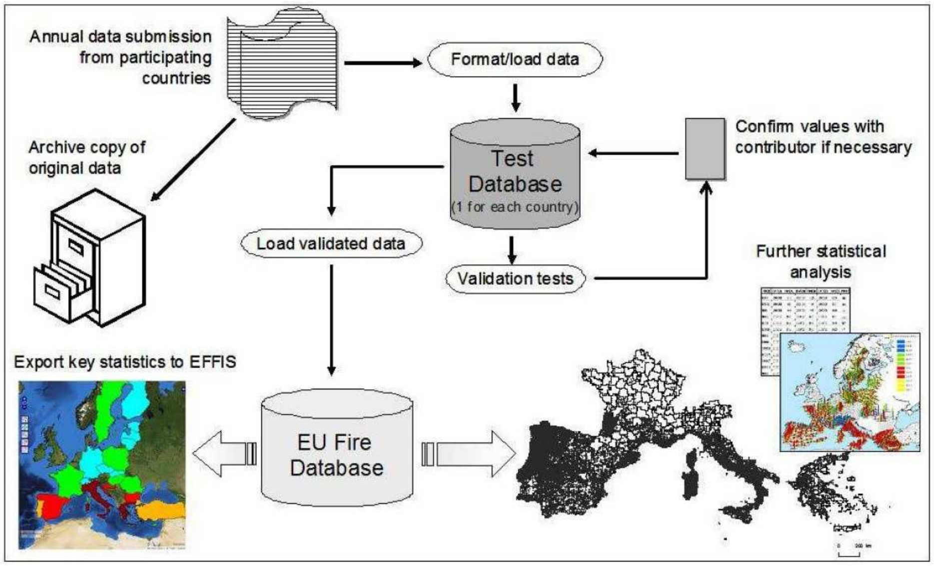

Fig. 3. EFFIS system.

values and are calculated by mathematical means.

5) Fire Weather Index: It is the numerical value of the potential fire intensity, that is the combination of the initial spread index and the ratings of the fuel.

B. European Forest Fire Information System (EFFIS)

EFFIS[2] has been implemented by the Joint Research Centre (JRC) and the General Environmental Directory (ENV) as the main information provider for forests fires in Europe in 1998. The system does evaluation during the two phases, before and after the fire. It takes into consideration the prevention, preparedness, dealing with the fires and the consequences of the fire [1] [9]. Maps of daily meteorological fire danger and a six-day forecast are produced. The satellite images are updated from the last seven days and the latest hotspots maps and possible fires are updated daily.

The whole system, shown in Fig. 3, is divided into two parts: The Current Situation with Fires and Fire Updates.

1) The Current Fire Situation: In this part, EFFIS has presented several products on the map, such as the annual fire forecast, the Hot spot map or the possible potential fires and burned territories. The fire hazard forecast is done with the same methodology that is applied in the Canadian system using the same parameters and calculations. The territory constants are tested and adjusted for Europe because there are parameter differences between Europe and Canada. The data is obtained from two satellites, MODIS [10] and SEVIRI. The information for the burned areas is obtained from all European states including Macedonia, that have an obligation to submit annual reports for the fires.

Technically, the system has been designed as a modular geographic informational system. It consists of web-based modules, a data processing part and a spatial database that collects and shows information for the forest fires on the pan-European scale. The main purpose of EFFIS is to forecast the daily danger of fire and to obtain data for the burned areas, by the use of software tools, meteorological and optical satellite data gathered on a daily basis.

EFFIS works as two inter-dependent systems on on two 64-bit Red Hat Linux servers. These processing (back-end) modules download and process spatial data and generate reports on forest fires. The components ('front-end') consist of web-based mapping tools, through which the EFFIS layers are published and allow the users to search and analyze the information in a web browser.

2) Processing: The spatial and related attribute data are stored in the ORACLE spatial and relational data management system. The MODIS satellite images are saved as ordinary files. Several Payton and Bash Shell scripts, based on GDAL/ORG geospatial libraries, have been developed for processing and management of the raster and vector spatial data, updated on a daily basis or longer. Linux Bash scripts have been developed to download at moderate resolution imaging from the MODIS, TERRA & AQUA satellite data as the images of the German AeroSpace Centre (DLR). The satellite data is merged and a mosaic of 250 meter resolution is created. This data is also used as a mapping base of the rapid assessment of damages, which are used by the experts in forest fires during the fire season.

3) Web-based tools: The EFFIS web-site has been developed in Joomla Content Management System. The web-mapping is the main tool of EFFIS and the most important part is the map search. The browser provides a direct access to FWI as the Web Map Service (WMS), the locations of the hotspots and the burned areas as well as the daily MODIS mosaic. The EFFIS web portal provides access to the news about the fires gathered on the principle of GeoRSS, the data

[2]European Forest Fire Information System, http://effis.jrc.ec.europa.eu/

that has been detected daily by the subscribers of the news "plethora of news feed on the web".

GeoServer and UNM Mapserver are both used for management and presentation of the fire danger forecast and other layers associated with the fires in a wide range of formats, including INSPIRE and Open Geospatial Consortium (OGC) standards, such as Web Map Service (WMS), that generates maps in an image format online, Web Feature Service (WFS), which generates vector data using Geographic Mark-Up Language (GML) and Web Coverage Service (WCS) that offers raster or grid data.

The future research plans of EFFIS are focused towards the integration of Volunteered Geographic Information VGI and Web 2.0 services. The aim is to include the new resources from the spatial geo-referenced information in the shape of images from the services, such as Flicker and Panoramio, tweets from Twitter and videos from YouTube. These services can provide information and alerts during the fire season because some of these services are relatively new and potential sources of information, in terms of crowd sourcing or crowd sensing. Other researches are aimed towards including meteorological data from sensors using the technology of OCG, Sensor Observation Service (SOS).

C. iForestFire - Croatian intelligent forest fire monitoring system

iForestFire[3], shown in Fig. 4, is an integral and intelligent system for remote monitoring and protection of fire on an open space. An automatic early fire detection is implemented by analysis of camera images in the visible part of the spectrum during the day and of the infrared part of the spectrum during the night.

This kind of a system with 29 cameras has been installed in Istra (Croatia) covering the whole area. As an observer, it has many advantages over the standard observers on the ground. The only disadvantage is that an operator has to watch the screen all the time in order to spot a fire. Therefore, there is a need to automate the fire prediction from the images. Then, the system will automatically recognize the fire and will give a report, i.e. an alarm. The operator will just check and will make a final decision on whether the alarm is true or false. This system uses data from a satellite to make a hotspot map of potential fires just like the Canadian system. iforestFire is a typical web-based information system and the user interface is a web browser. The system consists of terrain unit and a central unit to accept, display, process and store the data from the regional units. The central server unit accepts the data from at most 5 cameras, then processes and displays the results.

It is an integral system and uses three types of data.

1) Video information: The digital video signal is used in the manual and automatic mode of the system. In the automatic mode, the video signal is the source of images for an automatic fire detection. Whereas in the manual mode, the signal is used for a remote video observation and a remote video inspection.

2) Meteorological data: Meteorological data is used in the post-process systems to eliminate false alarms [11]. It also, can be used to calculate the index of forest fire danger during the prevention or in the control phase to follow the spreading of the fire during the fire phases.

3) The Geographic Information System: It contains information that is not only geographical but also other data relevant for the forest fires, such as the fire history, vegetation maps, etc. This part has two working modes, a manual and an automatic mode. In the manual mode, there are control interfaces over the cameras using joysticks, a keyboard, a mouse, virtual controls, geo-referenced maps and panoramic images. In the automatic mode, the system detects smoke in height of 10 meters at a distance of 10 km and automatically activates the alarm.

D. Monitoring forest fires system in the surrounding of Brandenburg, Germany

The Forest Research Institute in the surrounding of Brandenburg (Forest Research Institute, Baden-Wrttemberg) developed a modern system for an early warning and detection of forest fires by the use of Optical Sensor System (OSS). It is also called an automatic monitoring system for the forest fires.

The idea of this type of monitoring came from the German Air Center, where the original software was developed and some parts of the sensors, during the preparation for a space mission. This system was brought into production by IQ Wireless Ltd. and was further tested and developed in cooperation with the German State Brandenburg in 1999. Today, there are 109 cameras for monitoring of the forest areas in Brandenburg. The equipment has been installed on the former control towers, pillars of the mobile transmitters or tall buildings. It can catch the smoke clouds in radius of 15 km with minimum resolution of 10x10 m. The optic sensors can rotate around their own axis and it provides a continuous panorama of 360°. Three scans (images) are created on every 10°.

The images are compared and analyzed and the system can show the slightest changes in the atmosphere due to the very fine grey scale that uses over 16,000 nuances. It is a starting point for the origin of the cloud on the electronic map. In this manner, the forest fire can be detected in its early stage (when it starts to smolder). Each system monitors a forest area of about 70,000 ha by the rotation of 4-8 minutes (the setting can be specified if necessary). Currently, there are 11 fire centers where the data is monitored and analyzed. It is planned to be improved and to be merged into 6 modern state fire centers.

About 60% of all the fires have been detected by this system of sensors, whereas the others happen during the late night hours, when the optical sensor system is powerless (blind). Therefore, the system should be extended with a night vision option for detection and analysis.

E. Integrated system for forest fires detection using wireless sensor networks, Waspmote

The company DIMAP-FactorLink, under the name "SISVIA Vigilancia y Seguimiento Ambiental" within the common

[3]Intelegent Forest Fire monitoring system, http://ipnas.fesb.hr/index.php

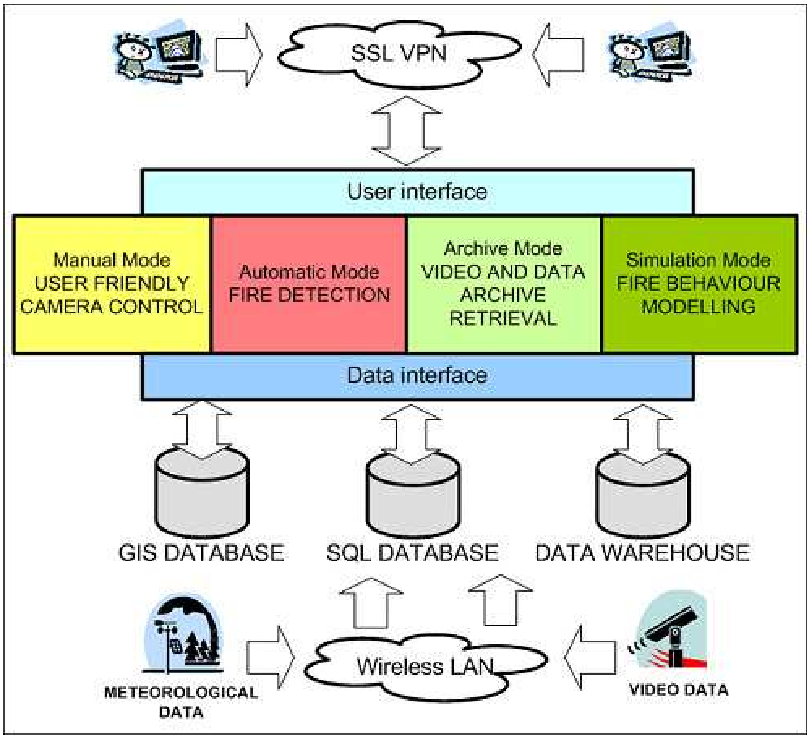

Fig. 4. Croatian iForestFire system.

commercial projects in the protection of the environment, have developed and integrated a system for a forest fires detection that uses the products of Libelium. An area of 210 ha in the region of Northern Spain was covered. The aim was to provide information to different organizations, to monitor the environmental infrastructure and to provide alarms for an early warning of different dangers, such as the forest fires. The system consists of a wireless sensor network [12], a communications network and a reception center [8] [13].

Waspmot devices are deployed in strategic locations as shown in Fig. 5. The four measured parameters are Temperature, Relative humidity, Carbon Monoxide (CO) and Carbon Dioxide (CO_2). They are measured every 5 minutes. If the value of a measured parameter goes beyond the configured threshold, then the system reacts by sending an alarm to the fire-fighting services. They will immediately know where exactly the fire is, with a reliable accuracy, because within every Waspmote device can be integrated a GPS device that determines the exact position and time of the received information.

One of the main features of the Waspmote is its low power consumption. Waspmote hibernates most of the time in order to save the battery energy. Waspmote awakes on a defined interval (programed by the user), reads from the sensors, establishes a wireless communication and sends data. Every device is powered by batteries and solar panels, that make the system to be completely independent.

Two Meshlium devices are installed to aid the data transmission, to collect information and to send it via WiFi. Meshlium and the Multiprotocol router are capable for an interconnection with WSN (802.15.4 / ZigBee), WiFi (2.4GHz or 5GHz in high or low power), GPRS (quadband, Bluetooth communication with mobile phones or the PDA devices), GPS and Ethernet. The Meshlium device is a parser that divides all the data in small packages or variables that are kept in the server in a MySQL database. The data can be processed after it has been stored in the database. SISVIA has made a control panel to show the information with a graphic interface. The solution has been integrated with GIS, to show the information in 2D or 3D maps.

IV. Conclusions

In this paper were shown five forest fire detection systems and pilot projects, which have been created in different countries and different regions in the world. At the beginning has been analyzed the Canadian Wildland Fire Information System, whose concept is the basis for many other systems, such as the European Forest Fire Information System, shown as a second such system in this paper. In addition we analyzed the Intelligent Forest Fire monitoring system in Croatia, which is a bit different from the previous two, due to its integrated and intelligent video based module for an early detection of forest fires. The system in Brandenburg, Germany, is similar to the Croatian. This is a modern automatic monitoring system for an early warning and detection of forest fires with the use of optical sensors. A different approach for a fire forest detection is the integrated system for a forest fire detection in Spain, that uses wireless sensor networks and Waspmote devices.

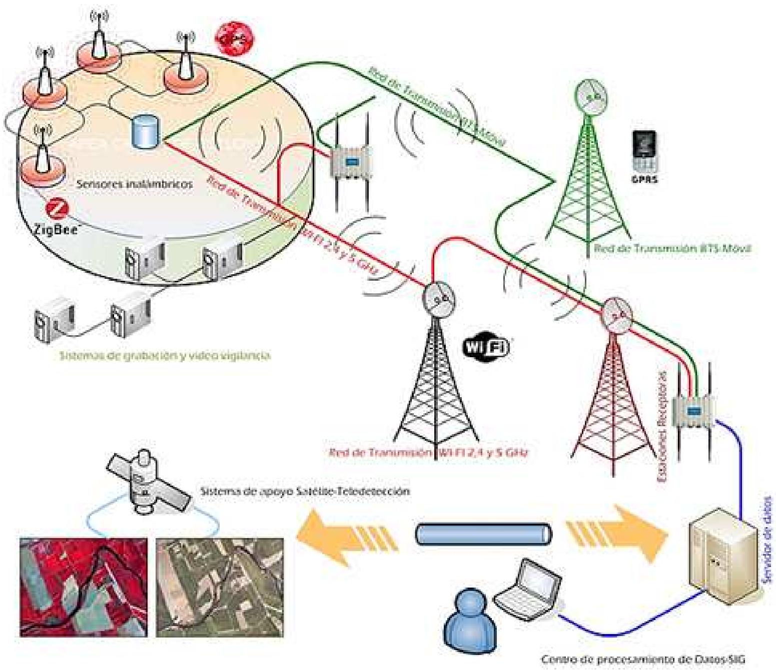

Fig. 5. Waspmote system.

The most effective way to minimize the damages caused by the forest fires is the early detection of forest fires and a fast appropriate reaction. In that direction, in the future, more effective forest fire detection systems need to be developed, that will also utilize the new technologies as smart phones. The appearance of smart phones is a good way to use them as a mobile measuring stations and video detection devices. The biggest challenge in the future is to integrate these modern technologies in order to make the forest fire detection and prevention systems more efficient and useful.

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