Agent Based Intelligent Forest Fire Monitoring System

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Abstract - Forest fires represent a constant threat to ecological systems, infrastructure and human lives. The only effective way to minimize damage caused by forest fires is their early detection and fast reaction, apart from preventive measures. Great efforts are therefore made to achieve early forest fire detection, which is traditionally based on human surveillance. Traditional human surveillance is direct human observation by observers located on monitoring spots. Technologically more advanced system is the use of video monitoring systems, and the most advanced approach is automatic surveillance based on automatic early forest fire detection. Today there are several different approaches but the most feasible one is system based on video cameras sensible in visible spectra. In almost every country which encounters high risk of forest fires at least one such system was developed. In Croatia there is also such system called Intelligent Forest Fire Monitoring System (iForestFire®). The system was successfully implemented in various Croatian regions, National and Nature Parks. This paper describes the main concept and the main idea of iForestFire system and particularly explains its "intelligent" parts – design based on the observer network theory, system multi-agent architecture and detection algorithm based on advanced image processing and analysis procedures.

I. INTRODUCTION

Forest fires represent a constant threat to ecological systems, infrastructure and human lives and cause significant economic damage and hazard to environment all over the world. According to prognoses, forest fires, including fire clearing in tropical rain forest, will halve the world forest stand by the year 2030. In Europe, up to 10,000 km^2 of vegetation are destroyed by fire every year, and up to 100,000 km^2 in North America and Russia. Approximately 20% of CO_2 emission into the atmosphere is caused by forest fires [1] .

Croatia belongs to countries with high forest fire risk. In summer seasons seven coastal counties in Croatia and in particular the Adriatic islands are permanently exposed from high to very high fire risks, due to densely-spaced conifer forests. Only in Split and Dalmatian County in the year of 2003, wildfire occurred as many as 130 times. The total burned area in the year 2003 was 9.700ha. The direct and indirect damage of the lost woody biomass in 2003. in Split and Dalmatian County was assessed at the level of 16 and 60 mil.€, respectively [2].

The only effective way to minimize damage caused by forest fires is their early detection and fast reaction, apart from preventive measures. Great efforts are therefore made to achieve early forest fire detection, which is traditionally based on human surveillance. Usually the human forest fires surveillance is realized by 24 hours observation by human observers located on appropriate monitoring spots. In Croatia the human forest fires surveillance is mainly organized by Croatian Forests (Hrvatske šume) – the governmental organization responsible for protection and exploitation of forests in state ownership. Human surveillance is usually organized only during summer months. For example in Split and Dalmatia County there are 16 forest fire surveillance stations of Croatian Forests in operation from June 1st to September 15th and there are also few other observation stations organized by other authorities and organizations. Human observers are usually equipped only with standard binoculars and communication equipment and their observation area is only the area covered by their sight of view. The Croatian regulations concerning forest fire observation defined the maximal distance between two monitoring stations. In regions where there is a high risk of forest fires the distance between two monitoring stations has to be less than 15 km.

Technically more advanced approach to human forest fire surveillance is installation of remotely controlled video cameras on monitoring spots. Instead of human observers, video cameras are located on monitoring spots and human observer working place is the monitoring centre equipped with appropriate video presentation and video storing devices. Video cameras and the monitoring center are connected by wired or wireless communication infrastructure.

This video cameras based human forest fires surveillance has many advantages in comparison to direct human observation on monitoring spots. Let us mention the most important of them. Using video cameras the human observer is capable of monitoring a wider area covered by few video monitoring field units (one man up to 5 monitoring locations). Cameras are usually equipped with power zoom (optical zoom with at least 22 x magnification) so the observer could easily inspect suspected areas. System usually has video storing capabilities, at least for the last couple of days, and that is quite useful for post-fire analysis.

In Croatia only one area is completely covered by such a system. That is the Istria region where the video surveillance system consists of 29 video monitoring units.

The next more advanced step in forest fire monitoring is automatic surveillance and automatic early forest fire detection system. There are two main types of automatic forest fire surveillance:

a) terrestrial systems based on ground monitoring stations, and
b) satellite systems based on monitoring from satellites.

Satellite systems are suitable for monitoring wide forest areas like Canada or Siberia. Sometimes airplane-based systems are used to monitor such areas, but today wide area monitoring is usually only satellite-based. As an example, let us mention Canadian Fire Monitoring, Mapping, and Modelling (Fire M3) System [3], or European FUEGO program [4]. Links to satellite systems which cover our region could be find on Web portal for forest fire protection in Split and Dalmatia County http://vatra.fesb.hr. Satellite systems are very good for post fire season analysis, but for real time monitoring and monitoring areas like Adriatic coast and islands, their spatial and temporal resolution is not adequate, so terrestrial or ground-based systems are more suitable.

In terrestrial or ground-based systems different kinds of fire detection sensors and detection procedures could be used:

a) video cameras sensitive in visible spectra based on smoke recognition during the day and fire flame recognition during the night,
b) infrared (IR) thermal imaging cameras based on detection of heat flux from the fire,
c) IR spectrometers which identify the spectral characteristics of smoke gases, and
d) light detection and ranging (LIDAR) systems which measure laser light backscattered by the smoke particles.

Infrared and laser-based systems are quite sensitive, but their price is still quite high in comparison to solid state video (CCD or CMOS) cameras sensitive in visible spectra. Also infrared based systems have high rate of false alarms. To reduce them quite often the detection system is conceived of both detection in infrared spectra and detection in visible spectra [5, 6]. Detection in visible spectra is used to check detection results obtained in infrared spectra, so the logical question is: *If you need additional checking of infrared detection with detection in visible spectra why to use infrared detection at all?* Additional reason against fire detection based on infrared cameras is their price and sensor life time. Infrared cameras are still quite expensive and sensor life time is much lower then in cameras sensitive in visible spectra. Additional beneficial feature of today's video cameras sensitive in visible spectra is their dual sensitivity. They are color cameras sensitive in visible spectra during the day, and black and white cameras sensitive in near IR spectra during the night.

The terrestrial systems based on video cameras sensitive in visible and near IR spectra are today the best and the most effective solution used for realizing automatic surveillance and automatic forest fire detection systems. In almost every country which encounters high risk of forest fires at least one such systems was developed and proposed. Some of them are on the market under various commercial names like FireWatch (Germany), FireHawk (South Africa), ForestWatch (Canada), FireVu (England), UraFire (France), etc. In all those systems automatic forest fire detection is based on smoke recognition during the day and flame recognition during the night.

The main disadvantage of visible spectra based systems is relatively high rate of false alarms due to atmospheric conditions (clouds, shadows, dust particles), light reflections and human activities. Because of that, systems are usually supervised by a human operator and his decision is the final one. After the fire alarm is generated and suspicious part of the image is marked, the human operator confirms or discards the alarm. The task of a human operator is not to monitor camera displays all the time, like in direct human surveillance based on video monitoring mentioned previously, but only to confirm or discard possible fire alarms. If the human operator is not sure about a fire alarm he could switch the system to manual operation and make additional inspections using camera pan, tilt and zoom features. Although the system is semi-automatic, the human operator efficiency is highly improved. One operator can control more cameras and his work fatigue is greatly reduced. For well tuned systems the false alarm rate could be less then 10 %.

Croatia belongs to countries with enhanced summer forest fire risk. The catastrophic fire season in the year of 2003. motivated researchers at the Department for Modelling and Control and Center for Scientific Computing at Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture University of Split to initiate research connected to early detection of forest fires based on images captured by video cameras in the visible and near infrared spectra. After two years of research, advance and innovative forest fire video detection and early warning system was developed and experimentally tested during 2005 and 2006 fire seasons. The system was named **iForestFire® - Intelligent Forest Fire Monitoring System** (in Croatian **IPNAS** – **I**nteligentni **P**rotupožarni **NA**dzorni **S**ustav) and developed by partial financial support of Ministry of Science, Education and Sport of Republic Croatia through technological project [7] and Split and Dalmatia County authorities through forest fire protection program [8]. Today (2009) the system was successfully implemented in various Croatian regions, National and Nature Parks. In 2007 **iForestFire** system received the first price, on Croatian E-novation contest organized by magazine Vidi and Institute R.Boskovic It was chosen as technologically most advanced Croatian product in the year 2007.

This paper describes the main concept and the main idea behind **iForestFire** system and particularly explains its "intelligent" parts – theoretical background based on the observer theory, system agent architecture and detection algorithm based on advanced image processing and analysis procedures. Since 2003, **iForestFire** system went through various design phases and versions. Now is in its stable version 2.7, but development of such system is "never ending story".

III. THEORETICAL BACKGROUND OF **iForesFire** SYSTEM

The theoretical background of the **iForestFire** system is the observer network theory [9,10] derived from the sensor network architecture, formal theory of perception and a notation of the observer .

In 1987 Bennet, Hoffman and Prakash [11] introduced an approach to a study of perception that attempted to be both rigorous and general. They proposed a new formal foundation – the observer. The ***observer*** is defined as a six-tuple

$$O = (X, Y, E, S, \pi, \eta) \qquad (1)$$

where X and Y are measurable spaces, E and S are subsets of X and Y respectively , π measurable surjective function and η conclusion kernel. Space X is a ***configuration space*** of the observer and E is a ***configuration event*** of the observer. Space X is a formal representation of those possible states of affair over which the configuration event E of the observer is defined. Y is an ***observation space*** of the observer. Space Y is a formal representation of the premises available to the observer for making inferences about occurrences of E. S is the ***observation event***. All and only points in S are premises of observer inferences which conclude that an instance of the configuration event E has occurred. π is a ***perspective map***, the measurable surjective function from X to Y ($\pi : X \rightarrow Y$) with π(E) = S. η is a ***conclusion kernel*** of the observer. For each point in the observation event $s \in S$, η(s,·) is a probability measure on E supported on ($\pi^{-1}(s) \cap E$). This means that kernel η is a convenient way of assigning to every point of S a probability measure on E.

We have applied the observer idea to modified three layer sensor network architecture (sensor and networking layer, services layer and application layer) originally proposed by EU Eyes project [12]. The final result was three layer observer network architecture shown in Fig. 1 for our case study – the forest fire detection system.

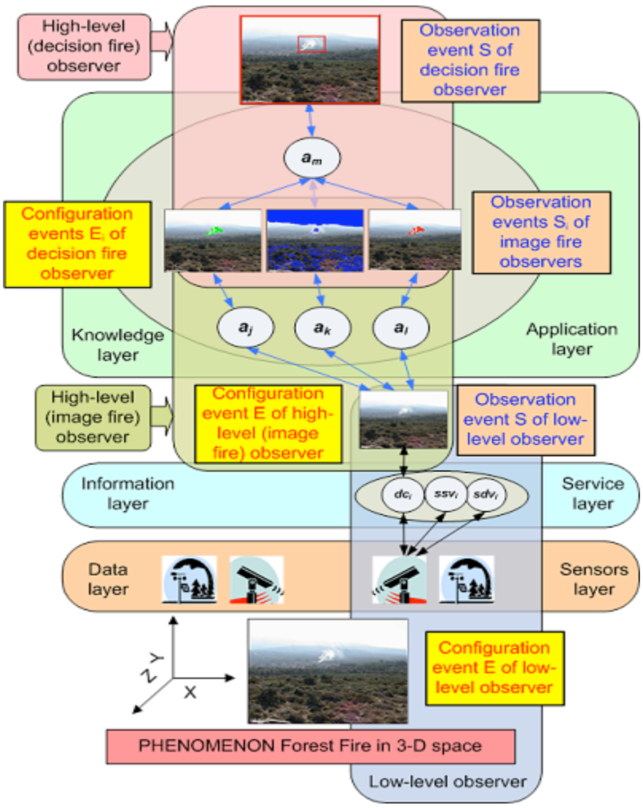

Fig. 1. Forest fire detection system seen as an observer network.

Two types of observers has been designed – the low level observer and high level observer. The ***low level observer*** or ***data observer (DO)*** is responsible for image acquisition and image preparation for high level observers. Its configuration space is the real world, configuration event the real phenomenon – forest fire in 3-D space, observation space the 2-D space of images and the observation event the set of appropriate digital images showing the phenomenon of interest.

Task of the ***high-level observer*** is not only the forest fire detection, but also the determination of forest fire position in 3-D space. Because of that its internal structure is not so simple and it includes several types of observers arranged in groups. Each group of internal observers is connected with one low – level observer, in reality with one monitoring camera. High level observer has two internal layers ***image fire observers (IFO)*** and ***decision fire observer (DFO)***. There are several types of image fire observers, but all of them correspond to one low-level observer. This means that all of them have the same configuration event E and that is the digital image created by the low level observer corresponding to one camera. Image fire observers represents various forest fire detection algorithms and procedures, so they have different observation events representing results of various detection algorithms and procedures. Outputs of the image fire observers are inputs to decision fire observer, so decision fire observer configuration events are these detection algorithms results. The observation event of the decision fire observer is the final decision about forest fire detection. More details about observer network theory could be found in [9,10].

iForestFire system was practical implementation of the observer network system. Before choosing the best environment and architecture for observer network system implementation, we have stated a number of requests, primarily the system has to be modular, suitable to run on distributed environments and controlled through a number of user parameters. Last but not least request was that the knowledge base has to be easily accessed and changeable.

Our final choice was the multi-agent architecture, so forest fire observer was realized as a multi-agent system configurable using database, knowledge base and properties files.

II. **iForestFire** DESCRIPTION AND ARCHITECTUREE

iForestFire is integrated and intelligent video based monitoring system for early detection of forest fires. Forest fires are detected in incipient stage using advanced image processing and image analyses methods. Intelligent fire recognition algorithms analyze images automatically, trying to find visual signs of forest fires, particularly forest fire smoke during the day and forest fire flames during the night. If something suspicious is found, pre-alarm is generated and appropriate image parts are visibly marked. The operator inspects suspicious image parts and decides is it really the forest fire or not.

iForestFire is a **Web Information System** (WIS) and the only user interface is standard Web browser. The system is based on field units and a central processing unit. The field unit includes the day & night, pan/tilt/zoom controlled IP based video camera and an IP based mini meteorological station connected by wired or wireless LAN to a central processing unit, where all analysis, calculation, presentation, image and data archiving is done.

iForestFire is both integral and intelligent user friendly system. Its organizational structure is shown in Fig.2.

iForestFire has three data bases: data warehouse with input images and alarm images, SQL database with meteorological data and temporal information of alarm images and GIS database with all relevant GIS data.

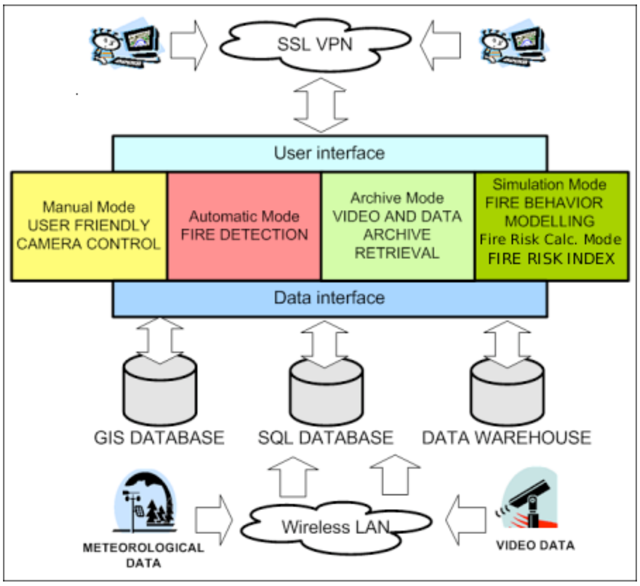

Fig. 2. Organizational structure of iForestFire system.

iForestFire has five working modes:

a) ***Manual Mode*** – user friendly camera manual control by pan, tilt and zoom.

b) ***Automatic Mode*** – automatic fire detection based on images captured by video cameras in the visible and near infrared spectra.

c) ***Archive Mode*** – video and meteorological data archive retrieval using various user friendly procedures.

d) ***Simulation Mode*** – fire behavior modeling and fire spread simulation using meteorological data and various GIS layers.

e) ***Fire Risk Calculation Mode*** - micro location fire risk index calculation using, not only meteorological data, but sociological parameters connected with forest fires too.

iForestFire is **integral** because it is based on three different types of data:

a) ***Real time video data.*** Digital video stream is used in both system modes, the automatic one and manual one. In automatic mode the video stream is a source of images for automatic forest fire detection. In manual mode the video stream is used for distant video presence and distant video inspection.

b) ***Real time meteorological data.*** The meteorological data are used by the post-processing unit for false alarm reduction, but also for forest fire risk calculation during the monitoring phase and fire spread estimation during the fire fighting phase. Main meteorological parameters are measured using high tech ultra sound mini meteorological station.

c) ***GIS (Geographical Information System) database***. GIS system stores not only information on pure geographical data (elevations, road locations, water resources etc.), but also all other relevant forest fire information related to a geographic position, like fire history, land cover – land use, local forest corridor map, tourist routes and similar. This data are used for user friendly camera pan/tilt control but also they are quite useful for fire fighting management activities. GIS data are important for Simulation and Fire Risk Calculation Modes. These modes are used for forest fire behavior modeling, forest fire spread simulation and calculation of micro location fire risk index.

iForestFire is **intelligent** because it has:

a) ***Agent based architecture.*** iForestFire software organization is based on agent architecture. Intelligent software agents are responsible for image collecting, image and data storing, sensors integrity testing, image pre-processing, image processing, image post-processing, pre-alarms and alarms generation.

b) ***Advanced image analyses algorithms.*** In its automatic mode, the forest fire detection is based on various advanced image processing, image analyzes and image understanding algorithms.

c) ***Advanced procedures for false alarms reduction.*** In post-processing analysis various methods derived from AI field are used to reduce the number of false alarms, as for example the rule-based expert system, data fusion algorithms and integration of fire risk calculation with automatic adjustment of detection algorithms parameters.

In system design phase particular attention was given to create a user friendly system. All iForestFire modules and components could be reached and administrated through dynamic and interactive Web pages, where real time video and meteorological data are shown together with GIS data and user friendly interface for camera pan/tilt/zoom camera control. From the beginning, the final system users firefighters were involved in experiments with iForestFire system prototype. The final user interface was designed taking into account their advices. Fig. 3. shows a typical camera control screen, and Fig.4. shows a typical fire alarm screen.

For appropriate decision about firefighting intervention, both the early fire detection and appropriate judgement about the potential fire danger are important. That is the reason why from the firefighters point of view, both automatic detection of forest fires and manual camera control modes are of equal importance. That was the reason why we have in iForestFire implemented various user friendly procedures for camera manual control. Let us mention few of them:

a) ***Geo-referenced camera map control.*** The user can control camera pan movement by simple clicking on geo referenced map. The camera control system is integrated with GIS, so it automatically detects and informs the user is the chosen point visible from the camera location or not.

b) ***Camera control using panorama image.*** In left upper corner of Fig.3. the 360^{o} panorama image is shown. By simply clicking on panoramic image camera moves to chosen position by both pan and tilt.

c) ***Camera control using preset positions.*** Camera could by simple click on preset thumbs, moved to preset positions, pre-defined by pan, tilt and zoom.

d) ***Virtual pan-tilt-zoom commands and joystick emulation.*** Virtual commands are shown in upper right part of Fig.3. Simple, self explaining virtual commands for pan, tilt and zoom camera control were implemented, together with joystick emulation.

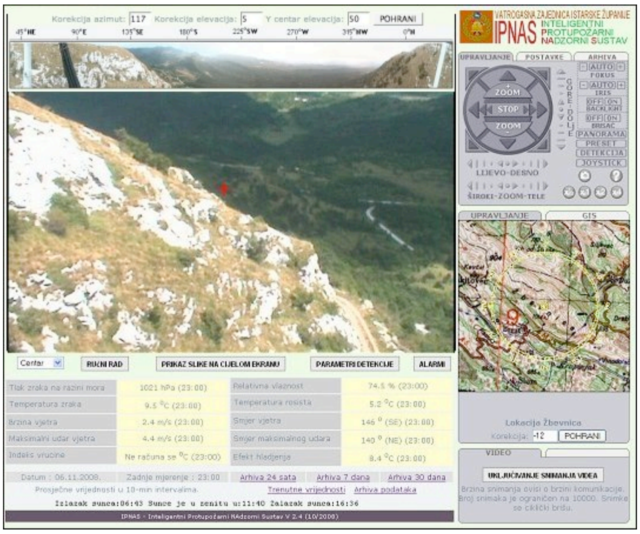

Fig. 3. Typical iForestFire camera control screen with various manual control modes.

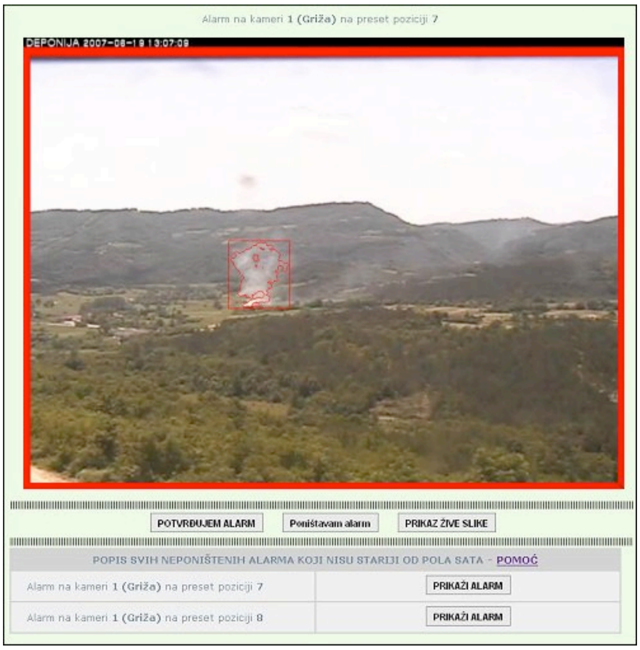

Fig. 4. Typical fire alarm screen (location Buzet 2007). The user can accept or discharged the generated alarm.

iForestFire automatic mode is based on various image processing and analysis algorithms. Initial research was started in 2003. by collecting images of fires in typical Adriatic landscapes. Controlled fires were burned and lot of video material was collected and used in first phase of detection algorithms development. The same procedure is used today, but now we have a database with more than 2.500 selected images segmented by human observer. One such image is shown in Fig.5. together with the result of region segmentation derived by human observer.

This database is essential for forest fire detection algorithms development. Detection procedure are based on various algorithms working in parallel, using advanced algorithms for motion detection of amorphous objects with changing boundaries, advanced and adaptive region segmentation algorithms and advanced recognition methods.

Fig. 5. Selected image from our forest fire database and result of region segmentation by human.

Important part of detection procedure is post-processing used for reduction of false alarms. In post-processing phase the data fusion is used based not only on image analysis and recognition results but also on micro location meteorological data. Few of them are discussed in [13]. Detection algorithms have different tuning parameters used for local algorithm adaptation to various landscapes and meteorological conditions. To facilitate the algorithm tuning a special procedure was developed based on the results of micro location fire risk index calculation [14].

iForestFire has a powerful archive retrieval methods for both, input images and alarm images. Three months input images and one year alarm images are stored and all of them could be easily analysis using various image retrieval procedures.

Each monitoring station is equipped with mini meteorological station used for measuring the most important meteorological parameters: air temperature, relative humidity, air pressure, wind speed and wind direction. Additionally it is possible to measure other meteorological parameters as for example isolation, precipitation, moisture, ground temperature, lighting activity, etc.

Meteorological data are used in Automatic Mode for false alarms reductions in post-processing procedures, Fire Risk Calculation Mode for micro location fire risk index calculation and Simulation Mode for simulation of potential forest fire spread. All meteorological data are stored in database, so they could be easily find, retrieved and analyzed.

IV. IMPLEMENTATION OF iForestFire SYSTEM

Fire seasons 2005 and 2006 were iForestFire experimental and testing period. Three experimental monitoring stations were installed (Marjan Hill – Split, Vidova gora - Brac and FESB faculty building Split), and two operation centers were organized, one in our laboratory and the other in Fire Brigade Control Center for the Adriatic coast and islands in Divulje. Fig.6. shows Marjan hill monitoring station.

After the testing period a lot of improvements in both, hardware and software design were implemented and since 2006 the system was successfully applied in various Croatian regions, National and Nature Parks. The most advanced application is in Buzet County where five camera system is in everyday use since July 2008.

Fig. 6. Monitoring unit and user interface of experimental intelligent forest fire monitoring system iForestFire on Marjan hill in Split. The system was used for iForestFire development.

V. CONCLUSION

The only effective way to minimize damages caused by forest fires is their early detection and fast reaction, apart from preventive measures. Great efforts are therefore made to achieve early forest fire detection, which is traditionally based on human surveillance. This paper shows how modern technologies could be used for automatic forest fire detection and monitoring. It describes the advanced forest fire monitoring system named iForestFire.

iForestFire is a practical realization of the observer network theory. Observer network was defined as a more advanced sensor network described using formal theory of perception and a notation of the observer. iForestFire is both integral and intelligent. Integral because it is based on various data types (images, meteorological data, GIS data) and intelligent because it has few features derived from the field of intelligent technologies (multi-agent architecture, advanced image analysis and image recognition algorithms, advanced procedures for false alarm reduction). The system was developed as a scientific research project, but today it is widely used as an advanced forest fire monitoring system successfully applied in various Croatian regions, National and Nature Parks.

VI. ACKNOWLEGEMENT

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