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Web GIS Technologies in Advanced Cloud Computing Based Wildfire Monitoring System

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Abstract

Wildfires are natural phenomena that cause significant economic damage. Apart from preventive measures, early fire detection on one side and quick and appropriate intervention on the other, are measures of vital importance for wildfire damage minimization. Therefore the wildfire monitoring and surveillance is quite important wildfire prevention measure. It is traditionally based on human wildfire surveillance, but modern ICT technologies today offer more advanced, video camera based wildfire-monitoring capabilities. The last generation of video based wildfire monitoring systems have two important features, first they are integrated with Geographic Information Systems (GIS), because the complete information about wildfire is not only its existence but also its position, and second, today's wildfire monitoring "goes in cloud", which means that it belongs to cloud computing or Web Information Systems (WIS) applications. This paper describes an example of such advanced cloud computing based wildfire monitoring system, where GIS, or more precisely Web GIS system is used, not only for fire location determination, but also to improve camera's manual control and to enhance distant virtual video presence on wildfire field. The described system named iForestFire® is not just another laboratory prototype; it is a real time working system, widely used in Croatian National and Nature Parks and Adriatic Regions.

Keywords: wildfire detection, wildfire monitoring, video based systems, GIS, Web GIS

1. Introduction

Apart from preventive measures, **wildfire detection in incipient stage** on one side and **quick and appropriate intervention** on the other, are measures of vital importance for wildfire damage minimization. Therefore in almost all countries with high wildfire risk great efforts are made to organize reliable wildfire surveillance service. Traditionally it is based on **human wildfire observation**. The human observers are located on selected monitoring spots and their main job is to find wildfires in its incipient stage using natural senses, primarily sight. In most cases they are equipped only with binoculars, communication equipment and appropriate maps, but sometimes alidade like devices are used for wildfire location determination. In fire season human observers work 24 hours and although they are sometimes located in lookup towers they are exposed to isolation, extreme weather conditions, especially high temperatures and need for continuous concentration.

A rather new, technically more advanced approach to human wildfire surveillance is **video cameras based human wildfire surveillance and monitoring**. Remotely controlled video cameras are installed on monitoring spots and the human observer is located in the observation center where working conditions are greatly improved as well as operator's working efficiency. The disadvantage of those systems is primarily that wildfire detection still entirely depends on human observation and human concentration. Therefore, especially in the last decades, a great effort has been done to replace human based wildfire detection with automatic wildfire detection. Although those systems are usually called **automatic video camera based wildfire detection systems**, they are in fact semi-automatic, because the final decision of wildfire existence is still by human operators. Automatic wildfire detection systems are used for routine image inspection and wildfire smoke and/or flame recognition, but when the possible fire is spotted the operator is alerted. Operator inspects the generated alarm and decides is it a real fire or a false alarm.

To facilitate the inspection of suspicious regions in today's modern automatic wildfire detection systems usually a powerful camera's manual control mode is also implemented and for such systems the name **automatic wildfire surveillance and monitoring system** is used. The last step in development of wildfire monitoring systems is their integration with meteorological monitoring, meteorological simulations, fire risk index calculation, fire-spread simulation and geographic information system (GIS). To emphasize the difference between such integrated systems and simple automatic wildfire monitoring systems, the name **advanced automatic wildfire surveillance and monitoring system** was proposed (Stipaničev et al, 2010).

The group of few monitoring systems working together in cooperation forms a **network**, and such network could have a lot of new additional features. It could be even more efficient than simple collection of separated stand-alone units. This paper describes a certain features of such advanced automatic wildfire surveillance and monitoring network iForestFire Net® composed of advanced and intelligent wildfire monitoring systems named iForestFire®. Both of them were developed at University of Split, Croatia. This wildfire-monitoring network is not just another one prototype system developed at University for research purposes, it is also a working system implemented in Istria County in Croatia. The system features and theoretical background based on the formal theory of perception and observer network theory has been described in other papers (Stipaničev et al, 2007b, Stipaničev et al, 2007c, Stipaničev et al, 2010, Šerić et al, 2009) and in this paper we will be particularly focus on two iForestFire Net features: cloud computing based architecture and integration with GIS.

2. Cloud computing based advanced wildfire monitoring and surveillance system and network

Croatia is a Mediterranean country with high wildfire risk. In summer season, seven coastal counties in Croatia, including in particular the Adriatic islands, are permanently exposed from high to very high fire risks. This is due to meteorological conditions, densely spaced conifer forests and incoming tourists. According to Croatian Forests data (Žaja, 2008) from 1992 to 2007 there were 4.851 wildfires in Croatia and the burning area was 251.910 ha. Fire seasons 2000 and 2003 were particularly severe with 706 and 532 wildfires and the total damage caused by wildfires was huge. For example in 2003 only in Split and Dalmatia County there were 130 wildfires, the total burned area was

9.700 ha, the direct damage caused by wildfires (firefighters interventions and post-fire terrain recovery) was 16 mil.€, but the indirect damage, taking into account energetic equivalent of lost woody biomass, was assessed to 66 mil.€ (Stipaničev et al., 2004, Stipaničev et al. 2007).

The catastrophic 2003 fire season has motivated researchers from *Department for Modeling and Intelligent Systems and Center for Scientific Computing at Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture University of Split* to initiate research connected with early detection of wildfires based on images captured by video cameras in visible and near infra-red spectra. After two years of research, advance and innovative wildfire video monitoring and surveillance early warning system was developed and experimentally tested during 2004 and 2005 fire seasons. The system was named iForestFire® - **Intelligent Forest Fire Monitoring System** and until today it was successfully applied in various Croatian regions, National and Nature Parks. The most sophisticated implementation was in Istria County where iForestFire Net® composed of 29 video monitoring stations, 17 meteorological monitoring stations and 7 distributed processing and operational centers is implemented. Figure 1 shows system layout and few screen prints.

Figure 1 — iForestFire Net implemented in Istria County Croatia

The main system feature is that it belongs to **cloud computing** based systems or **Web information system (WIS)**, which means that the operator could be located on any location with broadband Internet connection and that the only user interface is standard Web browser. No special program has to be installed and no local storage is required. All system features and stored data could be accessed through standard Web browser and IP based protocols. The system is based on field units and operation center units interconnected in **virtual private network** (VPN).

Processing tasks are distributed between various embedded servers and central processing servers. Communication between all of them is based entirely on IP protocols. The field unit is typically composed of pan/tilt/zoom controlled IP based video camera connected to IP based embedded video processing server, mini meteorological station connected to IP based embedded data processing server and IP based embedded watchdog device. Monitoring unit is connected via wired or wireless LAN to the closest operation center and operation center is connected by broadband ADSL connection to Internet through dedicated external firewall device. The firewall is used for encrypted VPN connection between operation centers, so the whole system, including all embedded and central servers, belongs to the same virtual private network. It is important is to emphasize that on all embedded and the central server the operational system is Unix based.

The user could be located on any location where wired or wireless broadband connection to Internet exist, and that is today in countries like Croatia, more or less anywhere. The user computer could have any operating system (Windows, Mac, Linux) and the only requirements are OpenVPN client and standard browser according to W3.org specifications (Firefox and Chrome are preferred). After connection through OpenVPN client to any operation center firewall, the user becomes a part of the systems virtual private network and he (or she) could access any embedded or central server in the whole network through dynamic and interactive Web pages.

The whole wildfire-monitoring network of Istria County is divided in operational regions having its own operational center and up to 5 monitoring field units, so one operator is responsible for 5 monitoring locations. The main operator screen is shown in Figure 1 (bottom left) where real time video streams from all monitoring locations, together with selected meteorological data are presented. On the right side there are control buttons that could activate any of system features. Figure 2 shows the iForestFire software organizational structure of one operational region.

The video and meteorological data are stored in local SQL databases and data warehouses, but GIS database is also important. The system has five working modes:

- *Manual Mode* – user-friendly multiple cameras manual control by pan, tilt and zoom.
- *Automatic Mode* – automatic fire detection based on images captured by video cameras in the visible and near infrared spectra.
- *Archive Mode* – video and meteorological data archive retrieval using various user-friendly procedures.
- *Simulation Mode* – fire behavior modeling and fire-spread simulation.
- *Fire Risk Calculation Mode* - micro location fire risk index calculation based not only on real time and simulation meteorological data but also on other risk factors like sociological and historical risk factors.

There is a certain level of interconnection between various working modes, particularly automatic mode and fire risk calculation mode and manual mode and simulation mode.

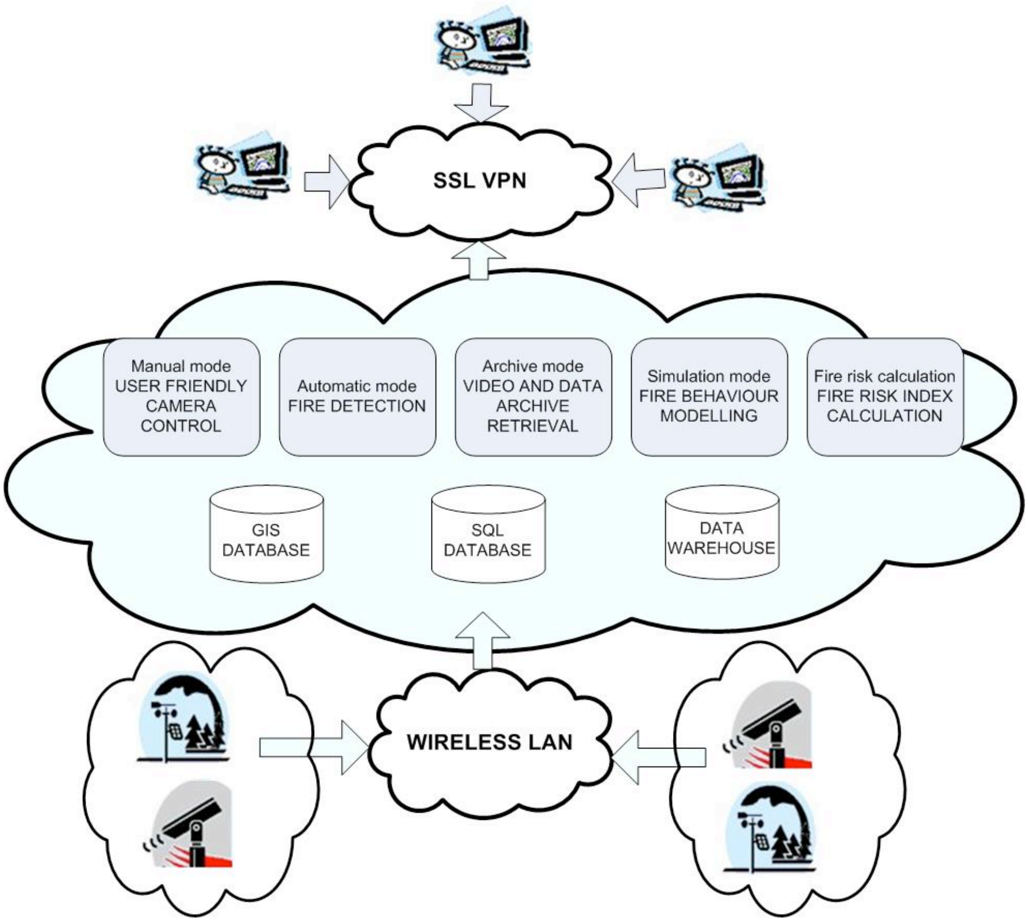


Figure 2 — iForestFire software organizational structure in one operational region

Also, an important system characteristic is information and data fusion, particularly real time video data, real time meteorological data and GIS data discussed in more details in next sections. Last but not least, let us here mention that iForestFire has a lot features derived from artificial intelligence (AI), computational intelligence (CI) and distributed intelligence (DI) like multi-agent architecture, advanced image processing and analyses algorithms, advanced intelligent procedures for false alarms reduction and augmented reality features described in more details in other papers (Šerić et al., 2009, Krstinić et al., 2009, Krstinić et al., 2011, Jakovčević et al., 2009, Jakovčević et al., 2010, Stipaničev et al., 2007c). In this paper the main topic is system integration with GIS.

3. GIS based advanced wildfire monitoring and surveillance systems and networks

Wildfire is a spatial phenomenon having three temporal phases: ignition, spread and extinguishing, and all of them are connected with geographic coordinates and geographic locations. Wildfire monitoring and surveillance systems are used for early detection of wildfire, but also for fire spread and propagation monitoring and in both cases location information is of the vital importance. The complete information about wildfire ignition is the ignition location and the time of ignition. Therefore, even in the case of the most simple human based wildfire monitoring services sometimes alidade like devices have been used to determine the wildfire ignition location more preciously, like Osborne Fire Finder (Flaming and Robertson, 2003) or modern DragonPlot (DragonPlot, 2011).

In more advanced computer based wildfire monitoring and management system location information is obtained by system integration with Geographic Information System (GIS) programs and GIS databases. In almost all systems, both research and commercial ones, a certain level of GIS integration exists (Trevis et al., 2004; Hough, 2007). The same situation is in advanced wildfire monitoring and surveillance systems and networks based on iForestFire units discussed in this paper. In iForestFire, GIS databases and GIS based algorithms and programs are important in all working modes. In manual mode, GIS is used for user friendly camera control and advanced augmented reality based video presentation, in automatic mode GIS is used for wildfire location determination, in simulation mode the wildfire spread simulation is entirely based on GIS data as well as in the fire risk calculation mode, but fire risk calculation data is used in automatic mode for detection algorithm sensitivity parameters adaptation, so again certain automatic mode features are based on calculations derived from GIS.

Most wildfire monitoring and surveillance systems on the market are desktop applications so GIS integrated with them is also desktop application. As opposite to that, iForestFire is cloud computing based application so its GIS features were realized by GIS server applications and Web GIS presentation based on various Internet based GIS technologies. Seamless integration with various public GIS services as well as GIS information exchange with dedicated data servers were realized, and such data exchange is totally invisible to the operator. Figure 3 shows examples of such integration where wind meteorological data are shown on Google Maps but also on Corine Land Cover Land Use vector GIS layer.

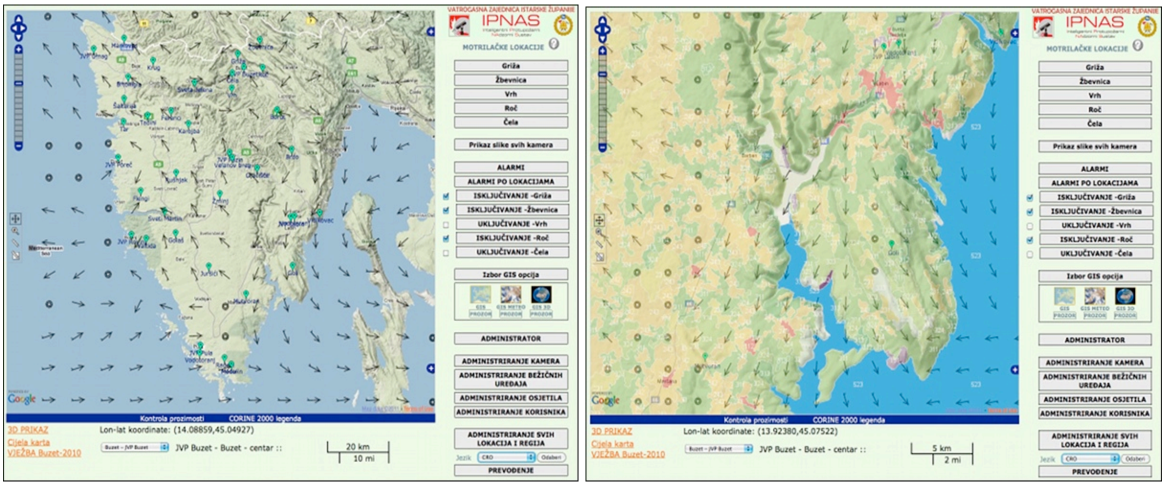


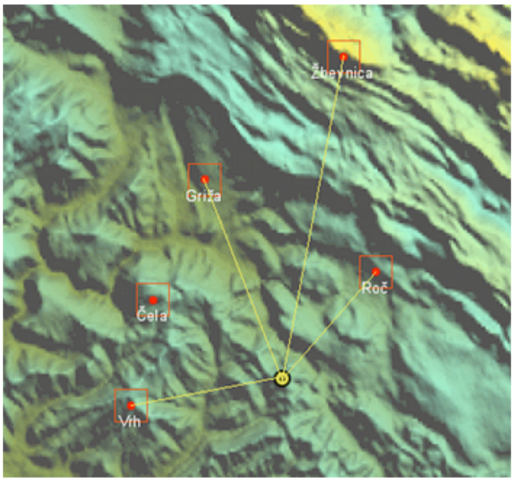
Figure 3 — GIS data presentation in iForestFire monitoring system. On the left side wind data are superposed on standard Google Map layer for the whole region and on the right side they are superposed on CORINE Land Cover land Use layer for limited area in Istria

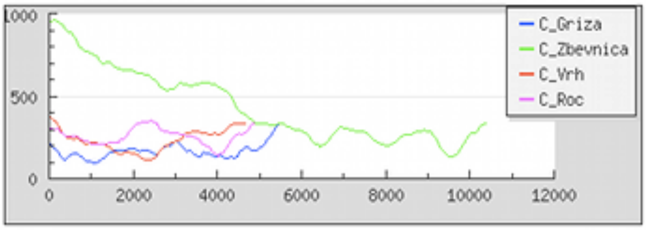
Information about wind speed and direction superposed on maps are results of meteorological weather prediction simulation model ALADIN HR of Croatian Meteorological and Hydrological Service (ALADIN, 2011). ALADIN weather predictions are calculated twice a day and after that ALADIN server and iForestFire server exchange predicted meteorological data for the next 12 hours in predefined CSV format. Data are stored on iForestFire server in appropriate database, but also dedicated GIS application is used for wind data raster GIS layer creation. Finally WMS Server presents GIS data to the user in main wildfire monitoring and surveillance screen as Figure 3 shows.

4. Utilization and integration of data extracting from GIS in video monitoring systems (GIS – video integration)

Three types of GIS data utilization and integration in iForestFire video monitoring system have been implemented or are currently in implementation phase: a) GIS based user friendly one-click multiple cameras control, b) Augmented Reality based video stream presentation and c) Augmented Reality based automatic adjustment of detection parameters.

Operators working with wildfire monitoring system are usually responsible for several cameras, so one of system's important features in manual mode is user-friendly multiple cameras pan and tilt control. To facilitate this we have developed one-click multiple camera control based on geo referenced maps. For the user the system is quite simple. Operator simply clicks on the position he (or she) wants to inspect (target location marking). The system automatically calculates the appropriate target geographic coordinates, the visibility and terrain profile in target directions from all cameras in target visibility zone, target azimuth and elevation angles and appropriate cameras pan and tilt movements for all cameras that can see the target location. Finally video images from all these cameras are presented to the operator in separate window (Stipaničev et al, 2009). An example is shown in Figure 4.





Camera	C_Griza	C_Zbevnica	C_Vrh	C_Roc
Visible	Yes	No	Yes	Yes
Azimuth	169.5°	189.3°	79.7°	236.9°
Elev. angle	1.1°	-12.3°	-0.6°	0.4°
Distance	5547 m	10460 m	4665 m	4877 m

Figure 4 — Multiple cameras one-click control. Clickable map is on the left side and visibility calculations, profiles and calculated cameras control parameters are on the right side.

Augmented Reality (AR) is another iForestFire advanced feature. The system is geo-referenced, so for every image pixel the corresponding geo-coordinate is known and vice versa. The augmented reality features, now in experimental phase, based on fusion and integration of GIS information and real time video images are used in both, manual and automatic mode. In manual mode important GIS information like toponyms, coordinates, altitudes and similar, could be presented on real-time video stream or on alarm image as Figure 5 (left) shows. In automatic mode Augmented Reality is used for automatic adjustment of detection algorithm sensitivity. The false alarm rate could be greatly diminished by appropriate adjustment of detection parameters according to local meteorological conditions, but also according to wildfire risk degree for a particular location. Our experience was that operators rarely use parameter adjustment features so we have started to experiment with automatic parameters adjustment using quasi real-time fire risk maps calculated in iForestFire wildfire risk calculation mode. Preliminary results based on average parameter adjustment in preset position (Bugaric et al, 2009) were promising, so in this moment we are experimenting with more advanced system based on variable parameters adjustment for every preset position. An example shows Figure 5 (right).

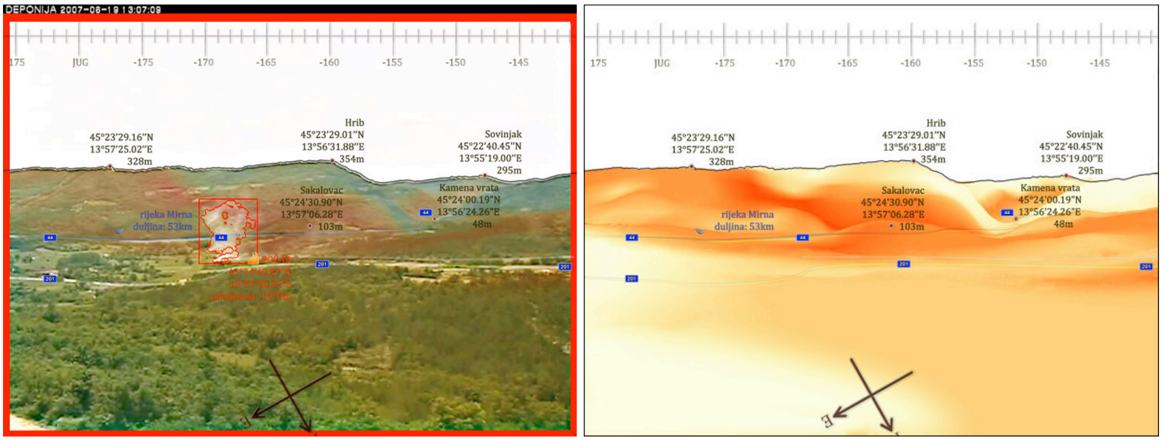


Figure 5 — (left) Augmented Reality based iForestFire alarm screen where all important geo information are presented on alarm video image. (right) Fire risk index map perspective transformed to correspond to appropriate preset position view on the left.

Figure shows computer-generated image of landscape that corresponds to actual preset position view shown on the left side of the same image. Grades of yellow-orange-red colors correspond to various wildfire risk indexes calculated on micro-location level, taking into account not only meteorological parameters, but also sociological and historical risk factors. According to this wildfire risk layer, sensitivity factors of detection algorithms are calculated individually for (almost) every pixel. This work is in experimental phase, results are promising and final results will be presented in the future.

5. Integration of data extracting from video monitoring system in GIS (video – GIS integration)

Another important GIS integration is video (camera) – GIS integration where data extracted from video monitoring system are utilized and presented in GIS. Examples of such integration are: a) determination of azimuth, elevation and field of view of actual video camera viewing direction, and b) location determination of detected wildfire.

Extraction of actual camera viewing direction, including azimuth, elevation and field of view and its presentation as dynamic GIS layer, as Figure 6 shows, is simple video – GIS integration. In automatic mode, when video camera cyclically passes through predefined preset positions, this task is straightforward, but in manual mode it could be more complicated. Anyway, if standard camera control protocols, like Pelco D, are utilized than its commands for query pan, tilt and magnification could be used.

Wildfire location determination is far more sophisticated. The challenge is to find relations between image pixel and its corresponding three-dimensional world coordinates. Mathematically it is the linear camera calibration problem (Grosky et al., 1990) based on direct linear transformation (DLT) algorithms. The problem of DLT algorithm is that it requires numerous calibration points, but more simple, and of course, less accurate algorithms could be derived from nautical navigation techniques or combination of trigonometry calculations and elevation profile extraction from GIS data.

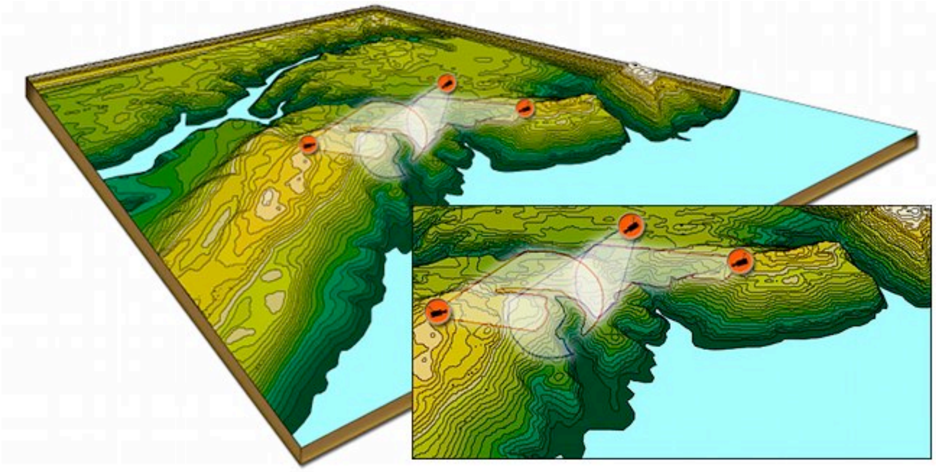


Figure 6 — Viewing directions and field of view of multiple cameras belonging to one region

Regardless of methods for wildfire three-dimensional world coordinates determination, the first step is always wildfire smokes contour extraction as Figure 5 (left) shows. Smoke contour is then represented by one characteristic point, and finally corresponding world coordinates are calculated and presented on Web GIS screen. If the wildfire is seen from multiple cameras the problem is simpler, because classical triangulation method could be used.

6. Conclusions

Wildfires represent a constant threat to human lives, infrastructure and ecological system, so a lot of efforts are made to minimize the damage caused by wildfires. Apart from preventive measures, early fire detection and quick and appropriate intervention are of vital importance for wildfire damage minimization. Great efforts are therefore made to achieve early wildfire detection, which is traditionally based on human surveillance, but nowadays more advanced video based wildfire monitoring and surveillance systems are also widely in use. The paper describes iForestFire, the system that belongs to the last generation of advanced video based wildfire monitoring and surveillance system. Beside the features of automatic wildfire detection, the described system has two important features, it belongs to 'cloud computing' or 'Web information systems' and it is totally integrated with Geographic Information System (GIS). Web information system based architecture allows simple organization of wildfire monitoring networks and the network is far more effective than a collection of single units. On the other side, full system integration with GIS gives to the wildfire monitoring and surveillance system a lot of additional and interesting features in both manual and automatic modes. iForestFire has a lot of them and few of them are discussed in this paper. Last but not least it is important to emphasize that iForestFire is not just another laboratory prototype; it is a real time working system, widely used in Croatian National and Nature Parks and Adriatic Regions.

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