Towards an integrated system for planning and decision support in forest fire management

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Abstract

New services for forest fire prevention, management and suppression support, based on digital technology applications, have been made available. However, diversity of relevant data and application architectures is still a shortcoming of current practice. Furthermore, in-situ measurements are difficult to obtain due to the infrastructure investment required and technological restrictions; integration of information services, operational logistics, simulation models, knowledge management and real-time data flows still lags behind. A new integrated system for forest fire management is introduced, and a pilot implementation is presented. The system offers services ranging from in-situ temperature measurements, to optimization, risk assessment, and decision support; its primary focus is on decision and operational support in forest fire suppression using advanced operational logistics, fire simulation models, along with knowledge management techniques. The elements of the system provide real-time functions to detect, monitor and predict the evolution of forest fires, assist in the suppression operations, and also provide decision support to civil protection authorities and fire suppression services. A state-of-art self-organizing expandable fire sensor network is used for real-time in-situ measurements, along with a package of software applications. The network uses in-situ sensors deployed camouflaged on trees, which implement a self-organizing RF data network that broadcasts the forest temperature distribution using redundant local control nodes and dynamic-re-routing algorithms. This integrated system can be used as a tool to create fire suppression scenarios, in training of professional and volunteer squads, to raise the preparedness of the public, to simulate extreme operational situations, and solve combinations of operational logistics problems and fire evolution cases, created as part of operational planning scenarios; the system will locate fire ignition points in close to real time and support the deployment of tactical forest fire suppression services in real time. Open XML data architectures are used both for representing all the relevant data, including maps and fire simulation scenarios, and for defining the software application services. A first pilot implementation is also briefly discussed.

Introduction

Forest fire management currently employs digital tools that assist stakeholders both in suppressing and decision making regarding the threat of forest fires. Traditional logistics can be integrated with forest fire evolution models to provide more sophisticated decision support. Knowledge management techniques can also be integrated to provide tools to embed expert knowledge in forest fire management. Finally, in-situ measurements can fill the remaining gap to form an integrated system for forest fire management and decision support. Such a system has been developed

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and put into pilot action by a consortium headed by the National Technical University of Athens, and support by the Hellenic Government's operational program "Competitiveness". The system developed has been named "*Firementor*", in which the second compound "mentor" in Greek means "tutor, advisor", to denote that the system is a hand-by-hand advisor for fire management and operation support. *Firementor* can be classified as an operational logistics application to support fire brigades, forest authorities as well as volunteers in performing better at fire management. A description of the *Firementor* system along with early results and lessons learned is presented in this paper.

Firementor addresses applications ranging from Natural Environment Preservation and Risk Management, to Civil Safety and Protection; its primary focus is the provision of services for decision and operational support in forest fire suppression. Several functional elements fall within its scope, all of which set up an integrated system to detect, monitor and predict the eruption of forest fires, assist in the suppression operations, and provide decision support for planning and preparation of the authorities. *Firementor* consists of a state-of-art self-organizing fire sensor network, along with a set of sophisticated software applications. By deploying *Firementor*, authorities and targeted users will have at their disposal a tool to create fire suppression scenarios, train professional and volunteer teams as well as the public, simulate and get prepared for extreme operational situations, and solve operational logistic problems using advanced heuristic techniques; the system will also locate fire ignition points and support the deployment of tactical forest fire suppression services in real time. Potential users of the system are Forest Fire Suppression Services, local authorities, civil protection authorities, as well as the Command and Control Centers in-charge of operations.

This paper is organized in two main sections. The architecture and services of the *Firementor* system is discussed in the first one, while lessons learned and ideas for future actions are discussed next.

The *Firementor* integrated system

In this section the *Firementor* integrated system is presented. First, the self-organizing expandable sensor network for getting in-situ measurements is presented. A description of the software services and architecture follows.

The system is constituted by individual structural elements as shown in Figure 1. These are the network of sensors, the core system services node and the software objects which provide optimization, decision support and other value-added services. The communication of all sub-systems is achieved via terrestrial and satellite communication services. The required meteorological data can either be input using real-time data feeds, provided that meteo stations are available, or can be manually entered by the user.

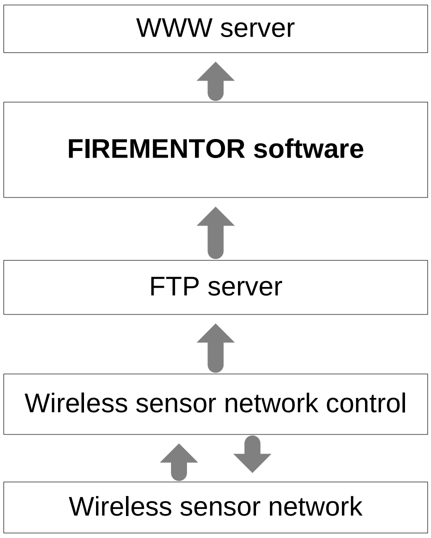

Figure 1. Block structure of the *Firementor* system

Self-organizing in-situ fire sensor network

The concept of self-organizing sensor networks deployed in large areas can be implemented in many real world applications, since the required technology of electronics now exists and is well-proven. In this case, *Firementor* deploys a self-organizing fire-sensor network over forest areas. Each sensor employs an electronic thermometer, a wireless communication unit and a microprocessor. In user-defined time intervals, sensors transmit a status signal to the network which is then carried via neighboring sensors to local control nodes, which in turn broadcast the entire network status to main central control station. Thus, the spatial distribution of the temperature in a forested area is known in real time. In case of a fire eruption, sensors can be destroyed having first dispatched a message which is routed via other sensors to reach the local control node of the network. A sensor's lifecycle is shown in Figure 2.

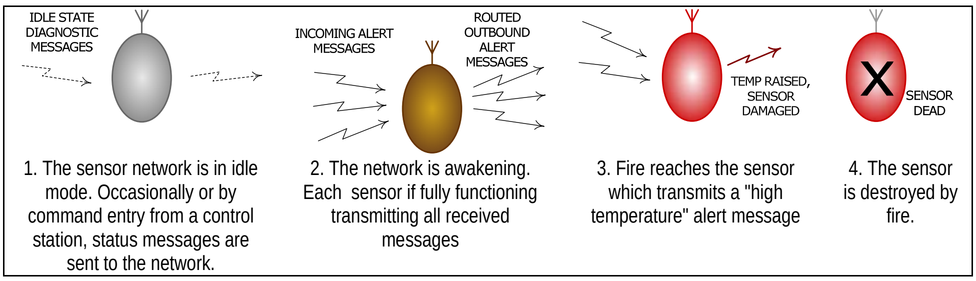

Figure 2. The lifecycle of a sensor

Sensors are camouflaged within the tree canopy and spatially distributed at a density of 40 to 150 m. The exact geographic location is inventoried by the use of a portable GPS unit. Around 400 sensors are required to be deployed per square kilometer at an average density of 40-50 meters. Each network has at least two local control nodes which communicate with the central node of the system with alternative redundant communication links; one local control node is responsible for transmitting the status of the sensor network. When a sensor stops responding, having earlier declared a temperature raise, the network is automatically reorganized to ensure that status messages from the rest functioning sensors will continue to be transmitted via the active local control node. Thus, even in the event of multiple sensors damage, the information reaches the central system node via alternative, dynamically re-configured routes. If the active local control node is also damaged, then an alternative local control node automatically takes over the network message transmission role, as shown in Figure 3.

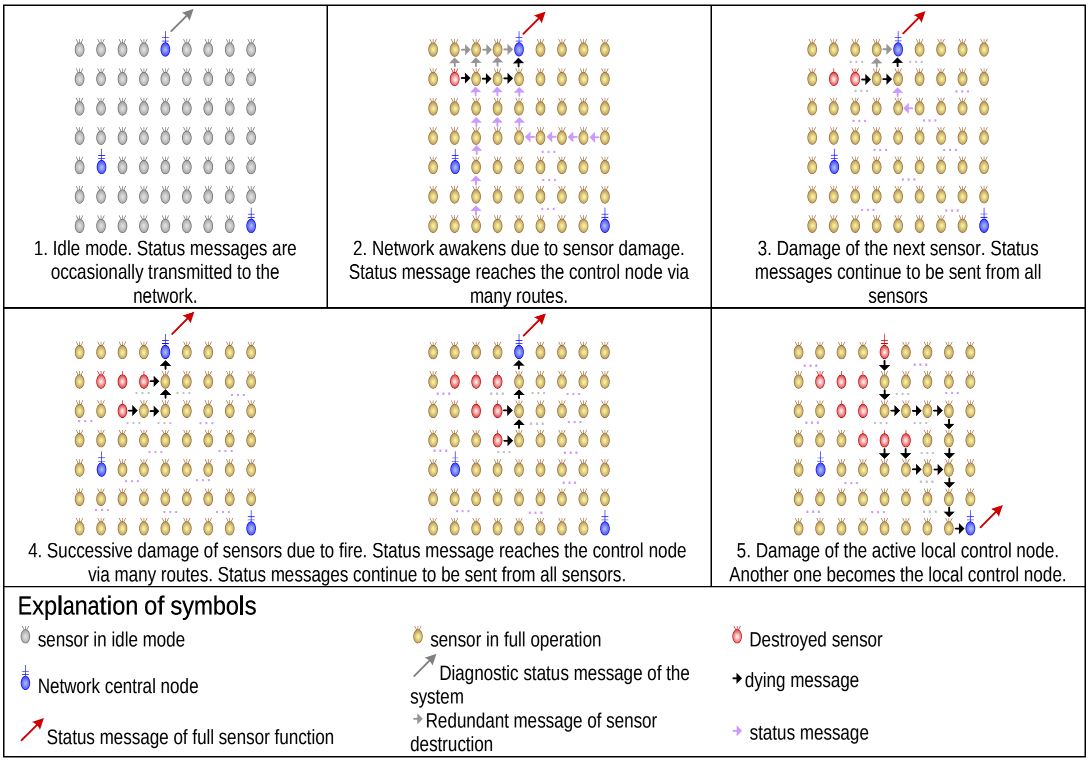

Figure 3. Message routing in the *Firementor* in-situ measurement network

Software services

The *Firementor* software package is a mission-critical application, designed and implemented by the National Technical University of Athens, using software quality assurance techniques. The software communicates with the fire sensors network via a custom web-based communication protocol. This software can be used in the operational support of forest fire suppression, in the development of forest fire propagation scenarios, in the training of volunteer fire fighters, in the planning of actions to be taken by Civil Protection Agencies, as well as in the decision support of local competent authorities. The main functions of the *Firementor* software package that achieve the aforementioned services are the following:

- Real-time monitoring of the sensors network
- Early detection and visualization of fire propagation
- Forest Fire propagation simulation
- Risk assessment during panic evacuation

- Optimal spatial distribution of fire suppression services
- Fire suppression services optimal routing
- Rule-based knowledge representation
- Management of forest fire scenarios

A brief description of these services follows next.

In-situ sensor network monitoring. *Firementor* visualizes the status of the networked sensors that are spatially distributed in a surveillance area, by utilizing high resolution satellite imagery or a large scale digitized map, as shown in Figure 4. The change of the sensor thermal status can trigger the automatic execution of predefined alert communication scenarios, specified by the system administrator.

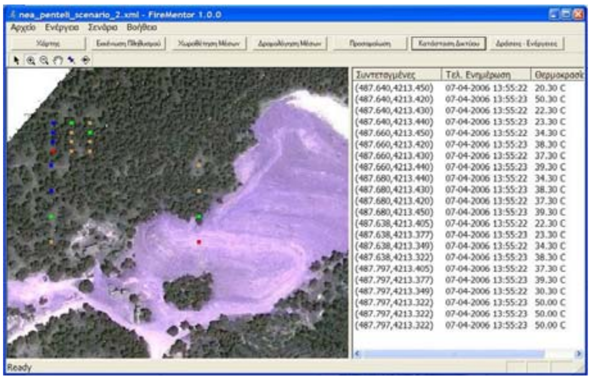

Figure 4. In-situ sensor monitoring

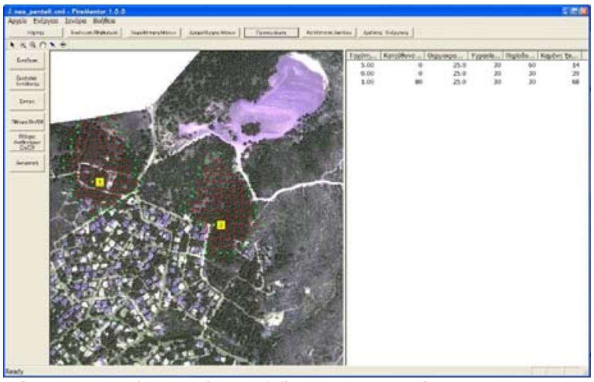

Figure 5. Simulation of fire propagation

Simulation of forest fire propagation. Having an overview of all sensors status, the *Firementor* software is capable to recognize fire ignition points and simulate the fire evolution using the current meteorological conditions and the region's fuel map, employing appropriate mathematical models. The meteorological data required are temperature, humidity, wind speed and direction. Forest fire simulation can either be triggered by the sensor network, or manually by the user, in which case a hypothetical fire can be simulated. Meteorological conditions may change over simulation time intervals. In the case of a real event, the status of the sensors network can also be considered. The fire propagation is depicted in map format as in Figure 5 and can be saved and used for further management in a scenario.

Risk assessment during panic evacuation. An important element of the preparation of public protection bodies for the confrontation of forest fire is the assessment of risk during panic evacuation procedures. By using population distribution data and the road network digital map of the corresponding region, the *Firementor* software calculates the peak that each road will suffer in the event of panic and visualizes the results in varying colors as in Figure 6. The capability of the software to provide scenarios management, allows the user to assess the impact resulted either from the construction of new roads in the urban fringe, or from the possible exclusive use of a number of roads by fire brigade and civil protection services.

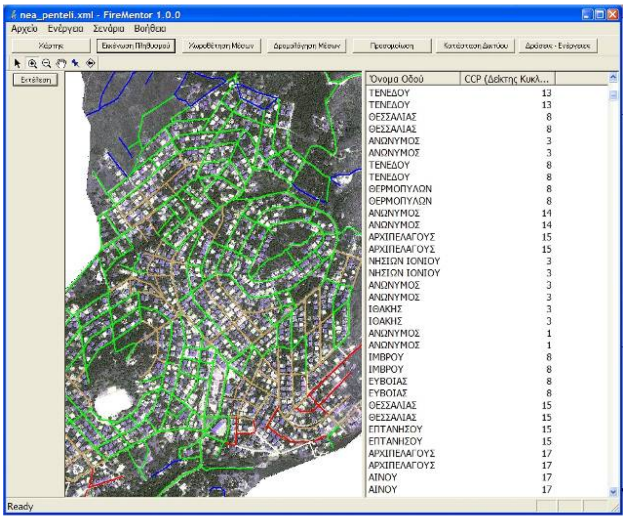

Figure 6. Risk assessment

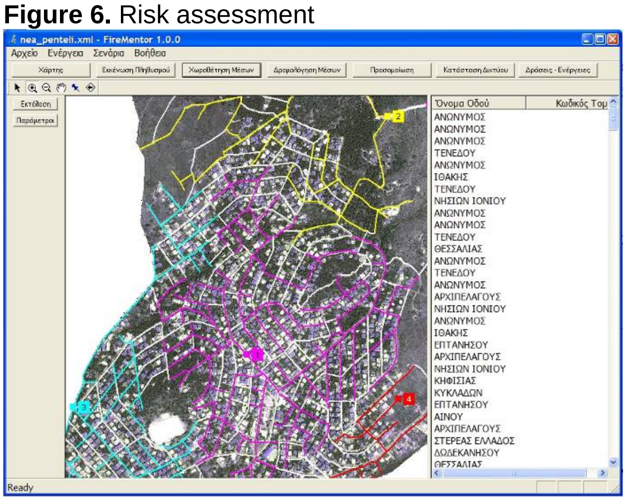

Figure 7. Service unit optimal positioning

Optimal spatial distribution of service vehicles. In the suburban areas where residential cores co-exist with either natural or human planted vegetation clusters, the location of provisional transportable fire suppression stations and emergency units so as to achieve an optimum operational range, is also considered to be useful. The optimization problem is to determine the minimum number and the location of service vehicles, required to achieve full coverage of a given geographical area, in a way that some service vehicle should be able to reach any location in that area, at a minimum time. The *Firementor* software solves this optimization problem using advanced meta-heuristic algorithms. The user determines the maximum distance that each vehicle should cover and the system calculates the number and the exact positioning of vehicles required to achieve the desired optimal coverage, as can be seen in Figure 7. Through the scenarios management functionality, the software allows users to visualize the impact of a possible construction of a new road, or of the exclusive use of an existing one by the authorities, and save the results in a scenario.

Fire suppression services routing. Taking as parameters the position of the local stations of fire brigade and emergency units, ambulances etc, as well as the fire front and other locations that are of significant interest for the civil protection, the *Firementor* software provides routing solutions for the vehicles to and from these locations, as in Figure 8.

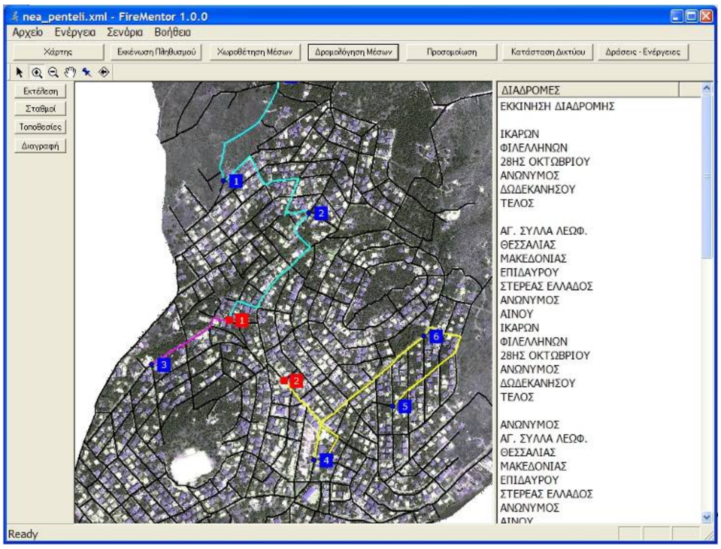

Figure 8. Service unit routing

The available roads can be different for each forest fire development scenario. The system allows the user to implement trials of selecting alternative locations of stationary and mobile fire brigade and emergency units, and then study the way the routing is changing especially close to predefined locations of hypothetical fire fronts and special points of interest such as schools, hospitals etc. As is stated above, the scenario management capability of the software can save all parameters, Figures and results produced for subsequent training or further processing.

Rule-based knowledge representation and scenario management. The results produced from executing the aforementioned functions can be exploited in combination with inventoried knowledge, for the confrontation of forest fires, for the development of risk management plans as well as for training of operational units and civilians. All these elements of data are also of importance for the decision support to the competent authorities. The *Firementor* software provides this capability through intelligent management of "conditions-actions" sets which can also be incorporated into scenarios and recalled for further use.

In this context, a condition is a hypothetical real world state that is described by certain assumptions, rules and values for temperature, humidity, wind and vegetation; a condition can also be a hypothetical operational or population situation. An action is an activity that can take place for the suppression of a forest fire or for the civil protection. Conditions can be related to actions with varying degrees of confidence.

A scenario is a hypothetical situation in which certain conditions of forest fire eruption are in force, along with the results of executing one or more functions of the software. The *Firementor* software functionality of scenario management supports HTML reporting which can then be further used as needed. Report material created using this approach can improve the readiness and operational deployment for real conditions that are similar to processed scenarios, the awareness in Civil Protection Issues, the training of forest fire volunteers and the decision-making of operational planning for local authorities.

Software architecture

Firementor is a stand-alone software application, the architecture of which is shown in Figure 9. The operations modules, such as the fire simulation and risk assessment services, are controlled by a GIS-like interface, which is the system control module. Data from the current implementation of the wireless in-situ sensor network is fed to the system using the ftp service and a proprietary protocol. Reporting is made using a web server, or any program that accepts HTML data feeds such as any current word processor. It is important to notice that all the service communication protocols are proprietary XML data models as clearly shown in Figure 9.

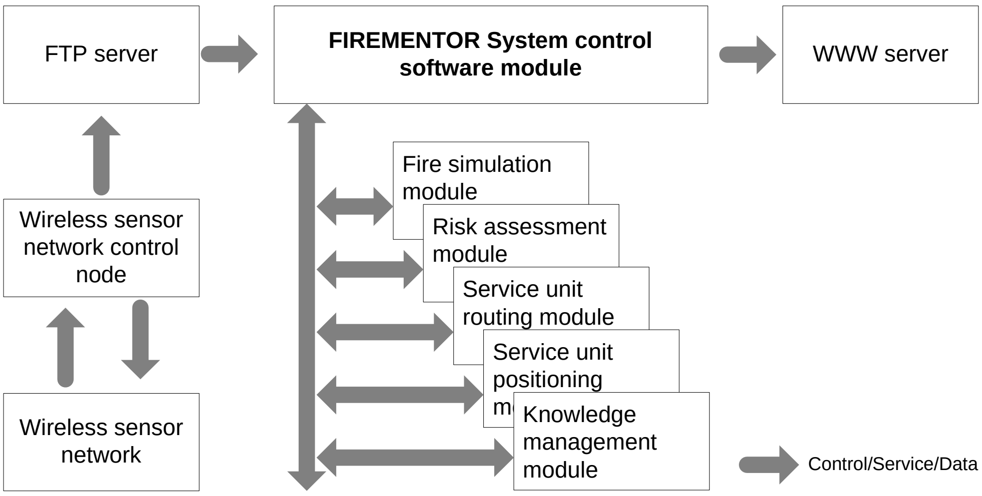

Figure 9. *Firementor* software modules architecture

The quality of services of *Firementor* depends on the completeness and accuracy of the digital data required for the area under supervision. The required digital data can be collected from several sources, whereas the capability of use of each specific function of the software and the quality of results are determined by the quality of the available digital data set. The system processes all spatial information in XML format, thus allowing for open and transparent spatial data management which guarantees its easy deployment anywhere, although the development of appropriate software connectors might be required.

The *Firementor* system can be exploited and used as a full version, or as a subset of its services for either operational or non-operational use. Possible users of the system are Environmental Protection authorities, Forest Management Agencies, Local Authorities, Civil Protection Agencies, Fire Brigade Units, Volunteer units, NGOs etc. Table 1 below summarizes some of the characteristic usages of the system.

Table 1— *Possible applications for Firementor*

OPERATIONAL	NON-OPERATIONAL
• Detection of fire and forest monitoring • Early fire detection, natural forest fire eruption warning • Accurate guidance of the air suppression means to the fire front • Fire Simulation • Early warning indications of the civil protection threats • Exploitation of real time data from the operations theater • Knowledge Management • Support and provision of operational action plans • Scenario Management • Interrelation of operational field situations with lab based pre-processed scenarios	• An Interactive training tool • Support forest fires understanding • Train volunteer and tactical forest fires suppression teams • Public Awareness in high risk areas for fire eruption • A Policy-making Tool • Support local authorities in forest fires prevention and management • A Decision-support Turn-key System • Support forest fires suppression and civil protection planning

Early lessons learned and further work

A pilot implementation of the in-situ sensor system has been put into operation for 4 months in a forest area of about half a square kilometer at a density of 30-70 meters. This system has been based on a prototype sensor which has been programmed to operate in a self-organizing network. An embedded PC has been used as a local gateway to a ftp server through which all sensor data was fed to the software. Implementation and pilot deployment of *Firementor* system was an important source of experience and allowed to improve the functionality and reliability of the system. We examined several deployment methods and techniques. Performance evaluation of the self-organizing network proved the proper operation of the network for some chosen scenarios in difficult environmental circumstances such as high electro-magnetic noise from high voltage power lines which surround and cross the area of the field test.

The *Firementor* integrated system has been proven to implement a very interesting concept. Putting together operational logistics, knowledge management, fire simulation models and in-situ measurements, can create an integrated system, providing services for which a strong demand exists, due to its high added-value to the environment protection.

However, in this field there are currently several systems that offer stand-alone, proprietary services. Integration of such services has been accepted by users as a very useful concept, although the required data to properly operate such a system is not always readily available. So, it appears that such an integrated system that provides a wide range of services can be used to provide several services such as:

• Assessment of existing forest suppression operational plans and infrastructures

• Justifying the need for opening new forest roads or creating new infrastructures in general,

• Provision of guidelines for optimal positioning of service points of any type, so as to achieve better performance of assigned resources, especially in wildland-urban interface areas.

Generally speaking, many possibilities exist for using such tools as decision-support tools in all phases of forest fire management, from planning to operational support. Properly structuring such tools, would allow for the development of new services in the future, which would be a definite step towards a more efficient use of public resources assigned to forest fire prevention and management.

Having said the above, it is quite clear that a strong potential exists in

- Wireless sensor networks
- Open data and service specifications
- Integration with existing or future software services
- Integration with existing or future in-situ measurement networks

Research and development in the field should be targeted towards an open technology platform which will allow any service or sensing network to be easily embedded in tailor-made systems that provide unified, holistic operational support and knowledge management for forest fires.

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