SIRIO high performance decision support system for wildfire fighting in alpine regions: an integrated system for risk forecasting and monitoring

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Abstract

In order to optimize performances and resources operating in wildfire fighting in complex orography regions, **SIRIO**, an integrated monitoring system for high performance decision support has been developed. SIRIO is built up of four modules: risk forecasting, monitoring activities, image interpretation and geo-referencing and decision support products generation. The previsional evaluation of the fire risk has an addressing function on surveillance and monitoring activities. The monitoring system operates with low cost optical sensors scanning Visible, Near Infrared and Thermal Infrared bands and a high precision low cost moving system. The system is equipped with a Micro Weather Radar operating as a super gauge and is able to nowcast weather conditions. Processed data are transferred to the central server via a very flexible communication system that can operate with GPRS standards, RF links or satellite connectivity. The image interpretation modules operate on the central server performing smoke detection and hot spot identification on the basis of a tailored radiometric model. The last block of the system is responsible for processed images geo-referencing and decision support products generation. The final products are a collection of scenario images sensed in the Visible band, geo-referenced images with highlighted alarm pixels with overlaying Digital Elevation Model (DEM) levels and topographic layers containing information to be used in the case of intervention, namely a field of view on the analysed area, hot-spot positions, helicopter landing spot positions, water supply positions and intervention squad localization. Monitoring sessions can be browsed on the official SIRIO website, which allows selected access for competent operators.

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SIRIO is a valuable aid in fire fighting management, allowing the involved agencies an efficient resources handling (both logistic and human), finalized territory monitoring and intervention planning oriented to operators' safety.

Keywords: forest fires, decision support, monitoring, alpine regions, fire risk.

1 Introduction

The probability of fires rising in the forested environment is steadily increasing owing to climate changes and human activities. Wildland fires are a very prevalent disturbance in the global landscape, causing many serious negative impacts on human safety, health, regional economies and global climate change, with several hundred million hectares of vegetation burning every year. In particular, forest fires in alpine regions are even more dramatic. Complex orography environments are characterized by high spatial variability of physical parameters, hard environmental and weather conditions for monitoring hardware and efficiency and by accessibility problems strongly limiting intervention activities and damage assessment. In order to optimize performances and resources operating in this framework, the Remote Sensing Group (RSG) of Politecnicodi Torino developed SIRIO, an integrated monitoring system for high performance decision support. SIRIO is built up of four modules: operating the risk forecasting (performed by **FIRECAST®**), monitoring activities, image interpretation and geo-referencing and decision support products generation. Combined fire risk simulation and fire statistic computation over the investigated region allow the system to automatically select critical areas to be monitored. Furthermore, the previsional evaluation of the fire risk has an addressing function on surveillance and monitoring activities. The monitoring system operates with low cost, multispectral optical sensors scanning Visible, Near Infrared and Thermal Infrared bands mounted on a high precision, high endurance, low cost moving system, equipped with IP68 sensors cases. The system is equipped with a weather station, in order to collect ancillary data concerning air temperature, air relative humidity, atmospheric pressure, rainfall amount and wind speed and direction. The weather data section is completed by micro weather radar, the **MicroRadarNet (MRN) SuperGauge®**, which is able to detect the actual rainfall from the cloud set and compute rainfall nowcasting. Monitoring scans and schedules, data acquisition, panoramic image composition and data transfer on a central server are managed by the **VM95® controller**, a high performance, low cost, low consumption; high flexibility control system. The sensed images, after being processed by VM95®, are transferred to the central server via a low cost, high performance, high flexibility communication system that can operate with GPRS standards, RF links or satellite connectivity, according to the location and coverage requirements. The image interpretation modules operate on the central server. Images transmitted by the monitoring stations are processed by the **Smoke Detection System**, a powerful tool performing a chromaticity analysis on images for a first step 'static' smoke plumes detection and a feature moving correlation on critical images in order to achieve a second step 'dynamic' smoke detection, which allow for the reduction of false alarms. The **Hot Spot Identification Tool** analyses images within a radiometric model and implements a tailored progressive thresholds system applied to a combination of different frequency band (Visible, Near Infrared, Thermal Infrared) images related to the same scenarios. The system is capable of the identification and localization of fire hot-spot pixels. The thresholds system is customizable by the user, according to the particular characters of the monitored territory. **The Decision Support System** is responsible for the geo-referencing of the processed images and for the generation of decision support products. The final products are a collection of scenario images sensed in the Visible band, geo-referenced images with highlighted alarm pixels with overlaying DEM levels and topographic layers containing information to be used in the case of intervention. Final images contain geo-referenced information about sensors' field of view on the analysed area, hot-spot positions, helicopter landing spot positions, water supply positions and intervention squad localization. The processed images and final products related to active monitoring sessions can be browsed on the official SIRIO website (www.incendiboschivi.com), which allows selected access for competent operators.

2 The system devices

The monitoring platform implemented in SIRIO is the Conway C995 moving system, which guarantees high performances in precision, reliability, long endurance and consumption. The moving engine operates pan and tilt movements with 0.1° precision. Monitoring sensors work onboard the moving system, protected inside IP68 cases. The cases are equipped with Gallium lenses in order to optimize the performances of the Thermal Infrared (TIR) sensor, avoiding flare occurrences on the lens. SIRIO operates a multispectral scan in Visible (VIS), Near Infrared (NIR) and Thermal Infrared bands. The TIR sensing is performed with a common thermal camera. Taking advantage of the sensitivity of CCDs ([400÷1200] nm) in both VIS and NIR bands, SIRIO mounts commercial sensors for the VIS and NIR monitoring. After the removal of the inner CC1 filters from the common photo cameras and video cameras, external CC1 and IR filters are applied to the sensors for the selection of the sensing frequency band. In order to perform a monitoring activity, taking into account the territory orography, video cameras and photo cameras are equipped with zoom lenses. The VM95® controller manages the power supply for the whole system, the moving system, the communication system, the weather station, the sensors settings, the scans, the image acquisition and composition, the data flows, the data storage, the fire risk forecasting system, the image interpretation tools, the decision support system and the user controls. VM95® operates inside an IP68 case and is equipped with solar panels and an emergency battery pack. The VM95® controller is a high performance, low cost, low consumption, high flexibility control system. VM95® is remotely programmable for automatic sessions and the user can remotely control it for real-time off-schedule scanning and statistical analyses. Small dimensions, low cost, low computational needs and low consumption features allow the VM95® to be installed onboard the monitoring stations. Processed data are transferred to the central server via a low cost, high performance, high flexibility communication system that can operate with GPRS standards, RF links or satellite connectivity, according to the location, coverage and bandwidth requirements. SIRIO collects ancillary weather data concerning air temperature, air relative humidity, atmospheric pressure, rainfall amount and wind speed and direction. These data are used in the evaluation of fire statistics and risk forecasting. Furthermore, weather data are crucial in the management of intervention activities and in the generation of decision support products. The weather section is completed by MRN SuperGauge®, a low cost short-range X band micro weather radar that is able to evaluate rain fields, detect the actual rainfall from the cloud set and compute rainfall nowcasting.

3 The system architecture

SIRIO optimizes technological, logistic and human resources in wildfire fighting, assuring high performance and maximum flexibility thanks to its modular architecture, which is based on independent operative modules and on embedded communication system. Each sensor is equipped with a computational module that is responsible for data acquisition and metadata integration. Acquired data are radiometric images, jpeg images, video streams, geographical metadata and weather metadata. Data and metadata are transferred to the central server, which runs the image interpretation (fire risk evaluation, hot spot detection and smoke detection), the data storage, the alarms management and the decision support product generation. The user terminals access the central server for the evaluation of the statistical analysis of data stored in the database, for manual control and survey operations and for calibration and diagnostic operations. After the image interpretation, the central server sends confirmed alarms to the responsible agencies and operators as SMS messages, e-mail messages and the activation of signalling devices. The radiometric images represent the thermal distribution of the monitored scenario and are processed for hot spot detection. Jpeg images represent the chromatic distribution of the monitored scenario and are processed for the smoke detection, the false alarm reduction in hot spot identification and the visualization of the monitored scenario. Metadata are ancillary information concerning local time, geographical position, sensor orientation, weather data and system operative conditions.

4 FIRECAST®

FIRECAST® [1] is a computing system for forest-fire-danger-index forecasting, which elaborates weather parameter maps to evaluate fire danger indicators in the area of interest. FIRECAST® uses as a starting point the previsional Canadian Fire Weather Index (FWI), adjusted for continental Europe latitudes and climatology according to [2–7], and adapted for alpine region orography. The system improves the danger estimation by evaluating orographic parameters,

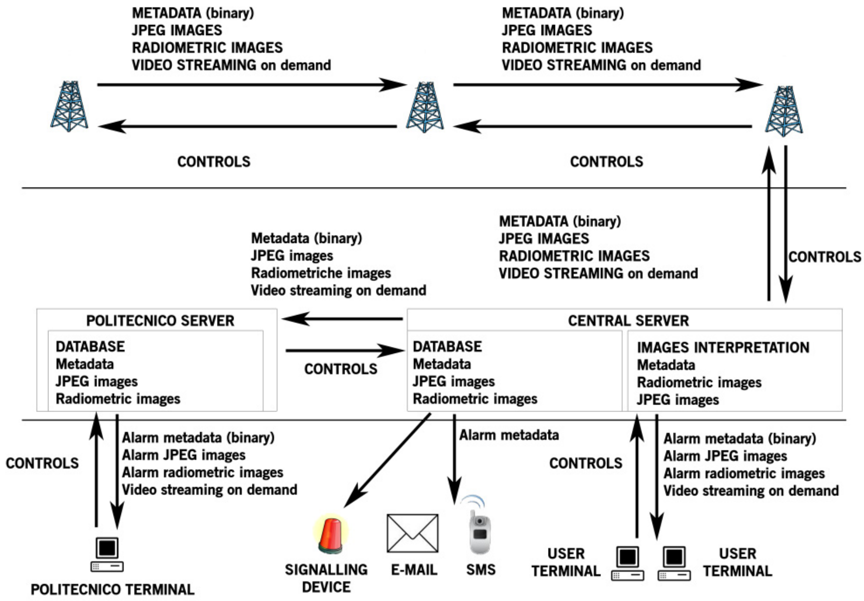

Figure 1: SIRIO architecture diagram.

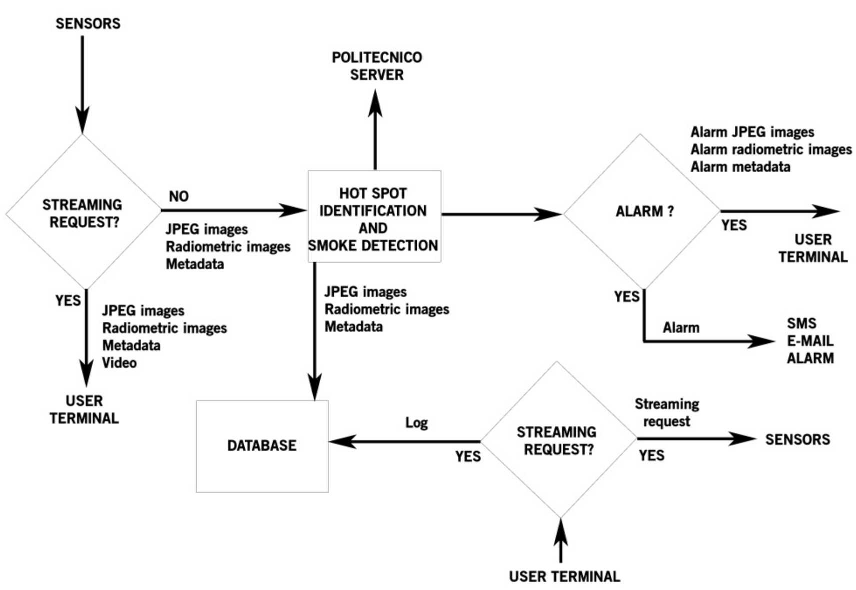

Figure 2: Server operational diagram.

such as terrain slope and orientation. Since the FWI is a meteorological index, it represents fire danger levels only due to present and past weather conditions, not considering contingently human presence and actions. FIRECAST® operates on meteorological forecast input data maps, in order to obtain output maps representing expected fire danger on the examined area with a forecasting time interval of up to 72 hours. To compute the final indices, the method also uses the historical evolution of these quantities. As explained in [8], the FWI system is composed of six codes, representing the daily changes in the moisture content of three classes of forest fuels with different drying rates: the rate of spread, the assumed fuel weight consumed and the fire intensity. In order to integrate input weather data with spatial variability information, FIRECAST® introduces correction factors related to slope (terrain inclination with respect to horizontal direction) and aspect (cardinal direction of surface's normal) in fire risk evaluation. Output fire risk is represented using four danger classes: EXTREME, HIGH, MODERATE and LOW. The validation results highlight the excellent capability of the system in forecasting reliable fire danger estimations and, most of all, in precise positioning of the alarm zones, with a good protection from false alarms. FIRECAST®, by evaluating combined fire risk simulation and fire statistics computation over the investigated region, allows the system to automatically select critical areas to be monitored. Furthermore, the previsional evaluation of the fire risk has an addressing function on surveillance and monitoring activities.

5 Hot spot detection system

The core of the hot spot identification algorithm is a radiometric model implementing a tailored progressive thresholds system that is applied to a combination of different frequency band (VIS, NIR, TIR) images related to the same scenario. The radiometric model evaluates the sensed scenarios by the integration of radiometric, climatologic, environmental, meteorological, orographic and vegetative characters with the sensor technical specifications. The model is based on a DEM and allows the tailoring of the identification method on the territory to be monitored. The model settings are customizable by the user, who can programme the territory analysis on the basis of specific monitoring requirements and of particular characters of the area to be monitored. The model is set when the system is installed and it operates during the monitoring activities in order to be updated to the current conditions. The radiometric model evaluates the sets of multispectral images (related to the same scenario) to be processed and automatically defines the best set of identification thresholds on the basis of the overall conditions. This procedure is applied to any set of sensed images. The system is thus capable of the identification and localization of fire hot-spot pixels. Often, particular 'non-dangerous' features and elements (e.g. sky, houses, farms, bridges, rivers, etc) occur in the sensors' field of view. The radiometric behaviour of these elements could affect the performance of the identification system. The algorithm features a masking tool in order to eliminate the 'non-dangerous' elements from the images, thus

Table 1: Hot spot detection performance.

HOT SPOT IDENTIFICATION			
KIA	POD	POFD	FAR
0.58	0.74	0.15	0.30

reducing the false alarm rate and the computational load of the automatic procedure. The masking tool is completely programmable by the user, and masks can be added or removed in a moment. Table 1 shows the identification performances of the module (KIA: K Index of Agreement – POD: Probability of Detection – POFD: Probability of False Detection – FAR: False Alarm Rate).

6 Smoke detection system

The presence of smoke, and therefore its early detection, is crucial as it is the first reminder or warning that an outbreak is about to degenerate. In many cases, the flame may not be easily seen and not detected by a hot-spot detection algorithm, as for example the burning of underbrush. In order to achieve low false alarm and missed detection rates, the Hot Spot Detection System outputs are processed by the Smoke Detection System, which evaluates images in the VIS and/or NIR domains. The smoke detection algorithm examines chromaticity changes and spatial and temporal patterns that characterize the smoke dynamics at an early stage of development. In order to detect the sudden irruption of smoke in the images, the system performs a two-step analysis on images. According to [9], the Blue (B) component of the RGB matrix has greater sensitivity to the changes generated by smoke in areas in which vegetation is predominant. The *static* block detects sudden increases in the B component with respect to a reference image. The *dynamic* block processes the images labelled with one or more alarm pixels by the static block output and through spatial and temporal correlations isolates effective smoke plumes from other moving features (birds, airplanes, etc.), thus reducing false alarms that may occur at the first stage of the process. At time t=N*Tc, where Tc is the image's sample interval, a set of N images is processed by the static and the dynamic blocks in order to reduce the false alarm rate. This phase is called the *detection phase*. At the end of this phase, the *confirmation phase* starts and static and dynamic blocks process a set of M images in order to eliminate any remaining false alarms. At the end of this phase (N+M images) an alarm is sent if smoke dynamics appear on the scene. After the initial warm up phase, the system is able to send an alarm every N-M images. Every Tr, a new reference images is loaded to prevent errors that could occur due to illumination changes throughout the day. Algorithm tests show very high reliability and robustness in the detection process. Combined with the hot spot detection, the smoke detection system enhances the fire rising detection and early warning efficiency, as depicted in Table 2 (KIA: K Index of Agreement – POD: Probability of Detection – POFD: Probability of False Detection – FAR: False Alarm Rate).

Table 2: Combined smoke and hot spot detection.

SMOKE DETECTION				COMBINED SMOKE AND HOT SPOT DETECTION			
KIA	POD	POFD	FAR	KIA	POD	POFD	FAR
0.77	0.89	0.12	0.16	0.84	0.92	0.12	0.06

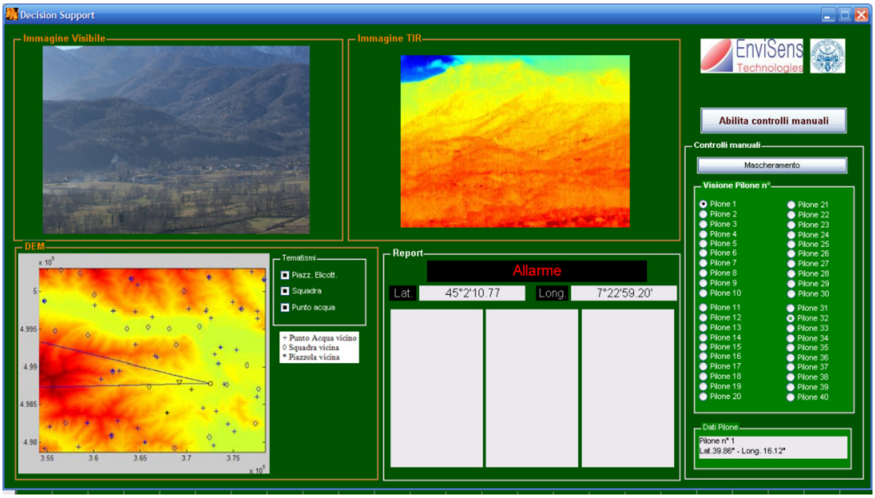

Figure 3: Decision support system user interface.

7 Decision support system

Forest fire prevention, monitoring and extinguishing operations in complex orography regions present dramatic problems related to hard environmental conditions, low population density and accessibility limitations affecting intervention activities and damage assessment. SIRIO operates an innovative projective geo-referencing algorithm that is able to geo-reference complex orography regions. As the Decision Support System is based on the evaluation of DEMs, it does not need the collection of Ground Control Points, which is a very hard task in complex orography environments. The algorithm is built up of three modules: sensor lens aberration correction, field of view localization on DEM and image geo-referencing. At the output of the system, each image pixel is linked to its Lat/Lon and UTM coordinates. The final products are a collection of scenario images sensed in the visible band, geo-referenced images with highlighted alarm pixels with overlaying DEM levels and topographic layers containing information to be used in the case of intervention. The final images contain geo-referenced information about sensors' field of view on the analysed area, hot-spot positions, helicopter landing spot positions, water supply positions, intervention squad localization, roads and so on. When fire is detected, the system identifies fire latitude and longitude, indicates accessibility to hot spots and puts in evidence territory characteristics and available resources. According to [10], the lens aberration correction algorithm evaluates and compensates for the sensors lens aberrations: astigmatism, curvature of the field, spherical aberration, geometric distortion and chromatic aberration. The system localizes the sensors' field of view on the DEM and applies the geo-referencing algorithm on the sensed images. The procedure is based on projective and geometric methods in order to achieve the best geographical linking trade-off. Elevation profiles and geographical information are extracted from the cone of view on the DEM. The decision support system presents a very friendly interface that allows for easy programming and makes management and intervention plans effective.

8 Conclusions and outlook

The SIRIO integrated system has been tested over different monitoring sessions and test areas and it is now operative in Piedmont and Liguria for wildfire monitoring and early warning. SIRIO achieves a high standard of performance in reliability, robustness, flexibility, cost and consumption. It guarantees accurate hot spot and smoke identification and produces geo-referenced information sets that are very useful for effective decision support activities. The RSG is under continuous development; at present, a new false alarm reduction tool based on combined VIS/NIR images is in the process of being implemented.

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