FALSE ALARM REDUCTION IN FOREST FIRES DETECTION WITH LOW-COST COMMERCIAL SENSORS

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***Abstract*— Ecological systems, human communities and infrastructures are constantly threatened by forest fires. The only way to minimize damage caused by forest fires is to efficiently combine preventive measures and early detection systems and fast reaction procedures. Although great efforts have been spent to improve and empower early forest fire detection (in particular automatic surveillance) false alarms remain the critical issue for automatic monitoring. This paper presents an innovative system for false alarms reduction in automatic forest fires surveillance, combining radiometric analyses and image graphical and motion processing. The algorithm is intended to operate on images sensed in Thermal Infrared (TIR) band and is based on an accurate radiometric model analysing various types of forest fires and integrating different types of opto-thermal sensors operating in different frequencies bands. The model in programmable on the basis of climatologic and orographic characters of the location to be monitored and manages the threshold system responsible for the hot-spot detection. The false alarm reduction procedure is based on real-time integration in the model and image processing of images sensed in the Near Infrared (NIR) band. As any CCD (Coupled Charged Device) is sensible both in Visible band and in NIR band, low cost commercial sensors are used, after the removal of the internal NIR filter. NIR processed images integration in detection procedure reduce occurrences of false alarm instances in images in which 'TIR-based' alarms are detected. The algorithm is operating for test activities onboard the integrated monitoring system for high performance decision support SIRIO (Sistema Integrato per il Rilevamento di Incendi bOschivi) developed by EST S.r.l. and SVM S.r.l.). Results of the validation of the system highlight how the algorithm improves the reliability of TIR detection by eliminating a large number of false alarms.**

Keywords: Forest fires, Fire Detection, False Alarms Reduction, Radiometric Model.

I. INTRODUCTION

Protection of forests from fires is a critical issue to preserve our environmental heritage. It is also necessary to develop systems facing early warning and prevention issues to help the operator's safety in case of fire.

The present work describes a system operating within a monitoring system in Piedmont Region and processing images sensed by a ground station equipped with commercial sensors. In particular, the core of the system is an innovative early smoke detection algorithm implementing an integrated processing (Static and Dynamic) and a pattern recognition methods which eliminate or reduce false alarm and missed detection generated by hot-spot detection.

In the scientific landscape there are many existing project to monitor areas in order to prevent forest fires; some of these are based on remote ground station where human operators control a large portions of vegetation 24 /24 - 7/7. Other applications are based on sensors mounted on trees across forest and monitoring little portions of vegetation. Both types are effective but expensive, especially when applied in automated way in a complex orography environment. In order to monitor a large portion of territory automatically, with a good cost/performances trade-off, it is necessary to develop new early warning systems. In particular, we propose an innovative method operating within a integrated surveillance system located in Italian alpine region. The system processes the images sensed by a remote ground station. Every station has several commercial sensors piloted by an engine which permits to scan the areas of interest. The sensors can also switch in three different frequency bands: visible, near IR and thermal, as shown in the 'Figure 1'.

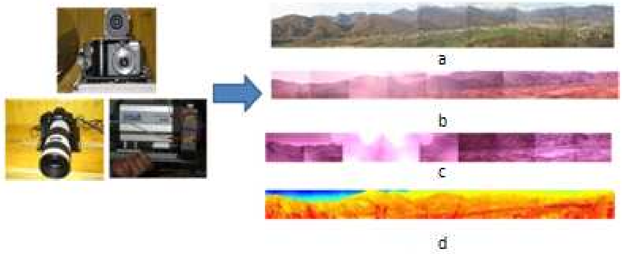


Figure 1. Images sensed by commercial sensor. a) Visible b) Near IR c) IR d) Thermal

The system is able to automatically generate panoramics format to be sent, through GPRS communication, to the related server station. TIR images are processed by hot-spot detection algorithm. The algorithm identify an event of fire on an image in which each pixel has a certain temperature detected by thermal camera. Concerning early warning frameworks, the presence of smoke, and therefore its early detection, is crucial as it is now 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 hot-spot detection algorithm, as for example the burning of underbrush. In order to achieve low false alarm and missed detection rate, the results are processed by smoke detection system which evaluates images in visible and/or NIR domain.

In this paper methods which are implemented on the Visible domain will be take in to account. As a matter of fact, this algorithm examines chromaticity changes and spatial and temporal patterns in the scene that are characteristics of the smoke dynamics at an early stage of development. In order to detect the sudden irruption of smoking in the images, the system performs a chromaticity analysis on images for a first step 'static' smoke plumes detection and features movement correlation on critical images in order to achieve a second step 'dynamic' smoke detection which allows reducing false alarms. The two steps of image interpretation are performed by two different modules.

The first block, called 'Static', identifies possible plumes of smoke rising from an outbreak with a scan of the color pixel of captured images compared with a reference image. The second block, called 'Dynamic', processes the images labeled 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. If the smoke is detected, the system sends an alarm message. The algorithm is a part of a more complex system in which it complements a hot-spot identification system, in order to enhance the fire rising detection and early warning efficiency. The aim of the method is to detect smoke plumes coming from forest fires with a high temporal and spatial resolution in order to solve the spatial variability problems related to complex orography. Obtained results show very high reliability and robustness in the detection process.

II. HOT SPOT DETECTION ALGORITHM

The system is constituted by fixed stations located in the areas where the fire risk is high. The fire risk is calculated according to Canadian index FWI modified for alpine environment [7,8]. Every station has several commercial sensors, as for example: DIGITAL photocamera, videocamera, and thermal camera.

Our purpose is develop an algorithm which is able to process and elaborate the temperature data and to obtain results as reliable and robust as possible.

Concerning hot-spot detection, we consider an algorithm which detect sudden increases of temperature with respect to the threshold temperature setted a priori.

Defining T_{MIN_FIRE} as the thermal threshold, T_{AMB} as the ambient temperature and DIM_{WIN} as the pixel's size processed: the lower boundary condition to consider the pixel as "event of fire" is represented by the following empiric relation:

$$T_{MEDIA} = \frac{8(T_{MIN\_FIRE} - 10) + (DIM^2_{WIN} - 8)T_{AMB} + T_{MIN\_FIRE}}{DIM^2_{WIN}} \quad (1)$$

For each pixel, an arithmetic thermal average of DIM_{WIN} pixel has been considerated around it. The thermal average must be bigger than (1) in order to recognize hot-spot pattern. 'Figure 2' show an example of thermal image in which fire is detected by the algorithm.

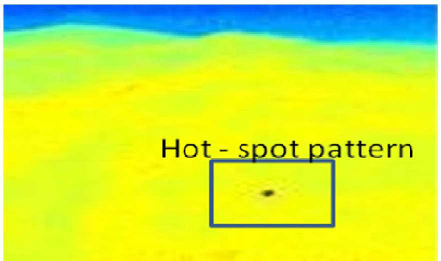


Figure 2. Example of fire detected on thermal image

III. SMOKE DETECTION ALGORITHM

As shown in the 'Figure 3', the algorithm for smoke detection is based on two principal blocks: the first calculating different chromatic changes (called static block) and the second calculating the correlation spatial and temporal patterns (called dynamic block). The algorithm is conceived to eliminate or reduce false alarm rate introduced by hot-spot detection.

Before carrying out the process it is necessary to "binarize" the images, by dividing into regions or bin the pixels of the images. Each bin is represented by mean value of its pixel. The dimension of the bin depends on the resolution of the images and I's chosen to tracks the dynamic of the smoke as well as possible.

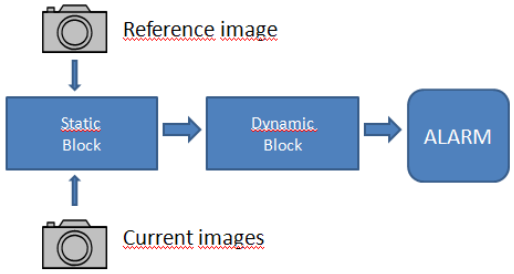


Figure 3. Block diagram of the Algorithm Smoke Detection

IV. STATIC BLOCK

Concerning smoke detection, we propose a method, defined in [1], which detects sudden increases in the B component of RGB matrix, with respect to the vegetation background . The algorithm is suited for complex orography and related hard environmental conditions which could occur. The B component has greater sensivity to the changes generated by smoke areas in which the vegetation is predominant. Defining $Ib_r(i, j)$ as the intensity of the B component at the bin (i,j) of the reference panoramic and $Ib_c(i, j)$ as the intensity of the B component at the bin (i,j) of the current panoramic, the condition to consider the bin (i,j) as "smoked bin" is :

$$Ib_c(i, j) - Ib_r(i, j) \geq \frac{p}{100}(Ib_{\max} - Ib_{\min}) \qquad (2)$$

where p represent the percentage of B component set by ($Ib_{\max}$ - $Ib_{\min}$), $Ib_{\max}$ is the maximum value of the bin (i,j) in the current panoramic and $Ib_{\min}$ is the minimum value of the bin (i,j) in the reference panoramic. The equation is fulfilled if the bin (i,j) is covered by smoke. This is the first step of the algorithm called static block where is calculated chromatic changes.

V. DYNAMIC BLOCK

Considering large areas to be monitored by the sensors could be very critical. Problem to face are related to objects moving too fast or too slow to respect the smoke dynamics, the luminance, the shadow of the clouds, the resolution of images etc and could generate on the 'Static Block' false alarms, false detections and missed detections. In order to work out the problem Dynamic block is been implemented.

Dynamic block analyzes the bins just captured, through spatial and temporal correlation patterns, in order to verify if the bins considerated is identified as smoke event. In other words, we are going to check out if the bins, discovered by static block, are identified as "smoked bins" or as false alarms. At the first, once bins are discovered on the current image, we check out if it is formed by compact regions of candidate bins. The compact condition is:

$$Z(t) >= Zmax \qquad (3)$$

Where Z(t) is the number representing how many bins are connected each other at the bin just captured. Zmax represents the maximum value of connected bins and it is indeed proportional of the bin resolution.

The maximum value permitted is obviously 8, because each bin has maximum 8 regions to be connected. In other words, failing (3) means that a different and spread source is generating the changes, as for example strong wind shaking the tree top. This could reduce the number of candidate bins as smoke.

After that, in order to consider the presence of smoke in the scene, there are several checks to reduce false alarm rate. Before that, a pattern recognition method is implemented in order to recognize the areas of interest. This is important to check out a minimum and maximum number of bins covered by smoke. Let us define Nmin as minimum number of bins in the current panoramic considerate as smoke.

N(t) represent the number of bins on the current image at the instant t. The condition:

$$N(t)>=Nmin \qquad (4)$$

must be fulfilled. The parameter t changes every Tc, in other words Tc is a new image just captured. In the mean time, let us define Gmax as the maximum permitted growth of smoke bin between two consecutive panoramics captured.

The condition:

$$Gmax >= G(t) \qquad (5)$$

where:

$$G(t)=N(t)-N(t-Tc) \qquad (6)$$

must be fulfilled in order to consider bins affected by smoke, G(t) represents the growth at the instant t between two consecutive images, t changes every Tc interval.

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 Detection phase. At the end of the Detection, the Confirmation phase starts and a set of M images is processed by static and dynamic blocks in order to eliminate remaining false alarm. At the end of this phase (N+M images) an alarm is sent if smoke's dynamic appears on the scene. As shown in the example in 'Figure 4', the algorithm, after the initial warm up phase, sends an alarm every N-M images. The algorithm is automatic and every Tr, a new reference images is loaded to prevent error which could occurred by illumination changes throughout the day.

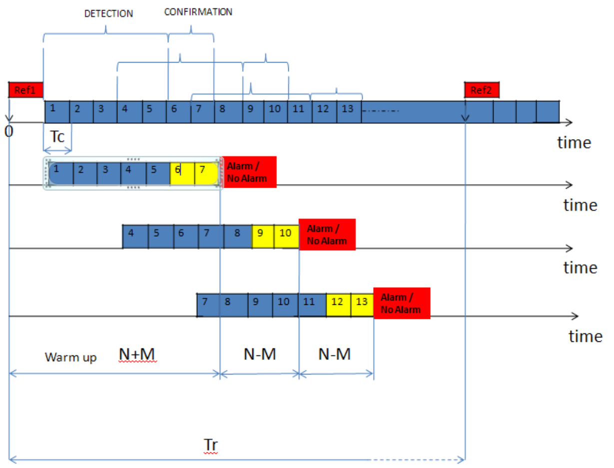


Figure 4. timeline Schedule smoke detection algorithm

Ref1 Reference image

X Current image Detection Phase

X Current image Confirmation Phase

Figure 5 Legend of Figure 4

VI. PRELIMINARY TEST AND RESULTS

In order to test the algorithm we realized some images which are taken from our test monitoring system located on the roof of Politecnico di Torino. Validation are done through contingency tables [4,5,6]. The contingency table in 'figure 6' is a useful way to understand system's performances. A perfect Detection system would produce only hits and correct negatives, and no misses or false alarms.

	Smoke	No Smoke
Alarm	*hits*	*false alarms*
No alarm	*misses*	*correct negatives*

Figure 6. Contingence table

In order to validate the algorithm indices will be take in to account. Considered indices are: POD (Probability Of Detection), POFD (Probability Of False Detection) KIA (Index of Agreement) and Accuracy. Regarding hot-spot detection the contingence table is shown in 'Figure 7a'.

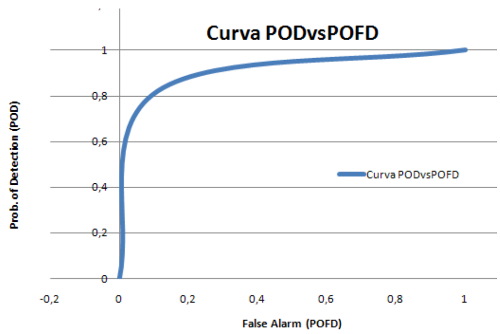
HOT-SPOT DETECTION		
	SMOKE	No SMOKE
ALARM	32	9
No ALARM	7	68

(a)

The indices for hot-spot validation are shown in figure 7b and 7c. The indices POD and POFD are also important component of Relative Operating Characteristic (ROC) . The best system performance is reached when the ROC's curve tends to POD=1, POFD=0.

POD	POFD	HSS o KIA	Accuracy
0,82	0,11	0,69	0,86

(b)



(c)

Figure 7. (a) Contingence Table (b) Hot-spot detection Results (c) Relative Operating Characteristic (ROC)

Using only hot-spot detection the detection rate is 82%

while the false detection is 11%. In order to reduce the probability of false detection, smoke detection has been implemented. The images on 'Figure 8' and the 'Figure 9a' show the reference image at the time instant t=0 and the current image at time t=Tc. Furthermore the 'Figure 10' shows the smoke detection algorithm behavior during detection and confirmation phase.

Figure 8. Reference image

(a)

(b)

Figure 9. a) Current image b) Current image after detection phase

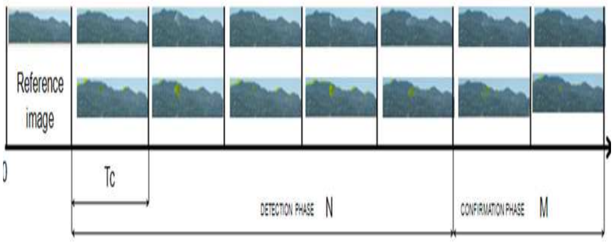


Figure 10. Time schedule behavior smoke detection algorithm

After N images the Detection phase find out the pattern as bins covered by smoke . In this phase false alarms could be present. After N+M images the confirmation phase reduces or eliminate false alarm which could occur on the scene during N images, as shown on 'figure 11'.

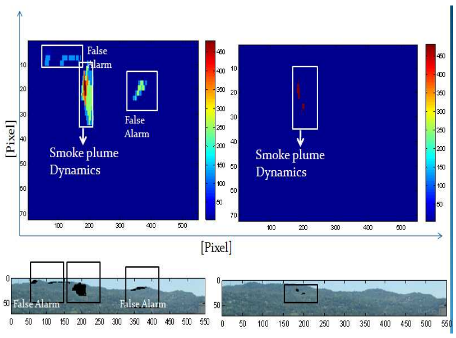


Figure 11. Pattern on the scene after N images (Detection Phase) and Pattern on the scene after N+M images (Confirmation Phase)

The pattern on 'figure 11' gives us the position where the smoke plume is generated. The 'figure 12' summarizes the parameters used and the figure 13a' shows the contingence table using only smoke algorithm.

Number of images	N	M	SxH [pixel]	Tc [second]	Tr [second]
116	5	2	110x550	100	3600

Warm up Phase (N+M)*Tc [second]	Regime (N- M) [second]
420 (7 minuts)	300 (5 minuts)

Figure 12. Parameters for the test results

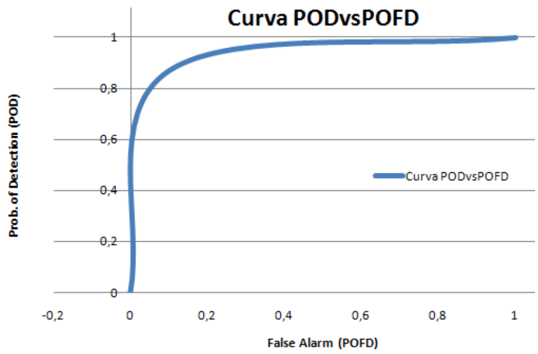
Smoke Detection		
	SMOKE	No SMOKE
ALARM	34	8
No ALARM	5	69

(a)

Smoke detection's results are summarize in the 'figure 13a and 13b and 13c'. remember that we consider four indexes: POD, POFD, KIA, Accuracy and the relative operating characteristic.

POD	POFD	HSS o KIA	Accuracy
0,87	0,1	0,75	0,88

(b)



(c)

Figure 13. (a) Contingence Table (b) Smoke detection Results (c) Relative Operating Characteristic (ROC)

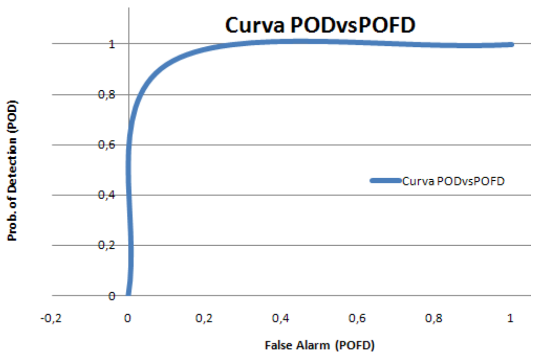
In order to reduce POFD and increase the correct detection we integrate both algorithms. The results are shown in 'figure 14', remember that POD should tend to 1 and POFD to 0.

Smoke and hot-spot Detection		
	SMOKE	No SMOKE
ALARM	36	6
No ALARM	3	71

(a)

POD	POFD	HSS o KIA	Accuracy
0,92	0,08	0,82	0,92

(b)



(c)

Figure 14 . (a) Contingence Table (b) Smoke and hot-spot detection Results (c) Relative Operating Characteristic (ROC)

As the results show, the combination of both algorithms reduces false alarms and missed detections. The errors may occur using hot-spot detection algorithm when the fire temperature is not well detected by thermal camera, as for example the burning of underbrush. By using the smoke detection system, at the beginning of the fire event a smoke plume is well detected on the images.

VII. Conclusions and Future Work

A system for false alarms reduction in automatic forest fires surveillance, based on commercial sensor has been proposed. Combining radiometric analyses, image graphical and motion processing the system can detect smoke plumes and hot-spots due to forest fires within time intervals of few minutes with a precise spatial location. In order to validate the feasibility of the system, a set of images was carried out in our test area. At the moment, our primary target is the successfully implementation of the smoke algorithm using only visible images in order to reduce or eliminate false alarm that may occur using hot-spot detection algorithm.

Nevertheless false alarms and missed detections due to environment and orography complex are present. Future target will be the implementation of a false alarm reduction method using NIR frequency domain. The algorithms are operating for test activities onboard the integrated monitoring system for high performance decision support SIRIO (Sistema Integrato per il Rilevamento di Incendi bOschivi) developed by EST S.r.l. and SVM S.r.l. Results of the validation of the system highlight how the algorithm improves the reliability of TIR detection by eliminating a large number of false alarms.

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