A Real Time Image Processor for Automatic Bright Spot Detection

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Resumé

Les techniques de traitement des signaux bidimensionels ont été appliquées aux images infrarouges pour la detection et la localization des incendies de la végétation.

On a développé un système qui fournit aux services des forets des alarms immediats, et toutes informations concernant la position du feu et ses dimensions.

Les techniques de filtrage spatial et temporel adoptées ont permis d'obtenir une sensibilité élevée avec un faible débit de fausse alarme.

Summary

Techniques of image processing have been applied to infrared TV images to detect and locate vegetation fires.

A fully automatic system has been implemented which supplies the fire control service with ready alarms, and all data on the location of fires and their extents.

Space and time filtering techniques substantially contribute to attain high sensitivity levels with very small false alarm rates.

Introduction

A new infrared image processing system for the immediate and reliable detection of vegetation fire starting points has been implemented and operated.

The system, called B.S.D.S. (Bright Spots Detection System) supplies the fire control service with all data on the location of fires, their kind and any other information useful to the suppression units, thanks to the integration of all available environment informations with the image processing.

The System

The automatic fire surveillance system is constituted by a set of apparatus whose block diagram is shown in Fig.1.

A peripheral station is equipped with some TV infrared cameras mounted in protecting shells (see Fig.2). The cameras and the inner part of the shells can rotate over a 180° degrees in the azimuthal plane. Another TV camera is installed for surveillance in the visible band. The electrical power supply is provided by some photovoltaic panels with accumulators which assure one week survival in case of bad weather.

The peripheral station is connected via a microwave radio link and a bidirectional UHF radio link to a control station, where the whole surveillance operation takes place. Here, a

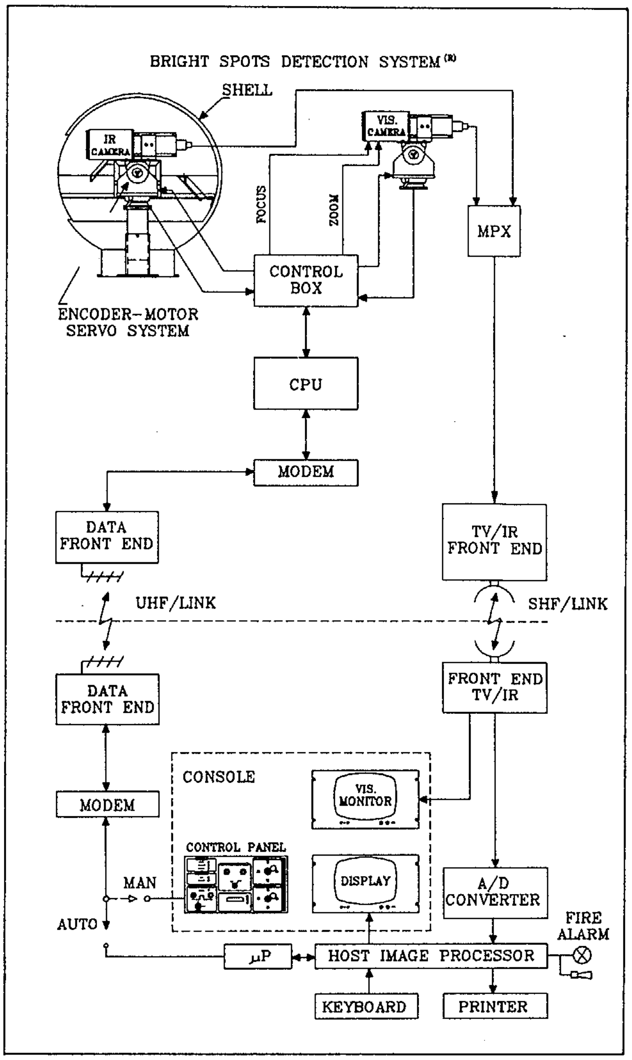

Fig.1 Block diagram of the system. The upper-half refers to the peripheral station, the lower-half to the control station.

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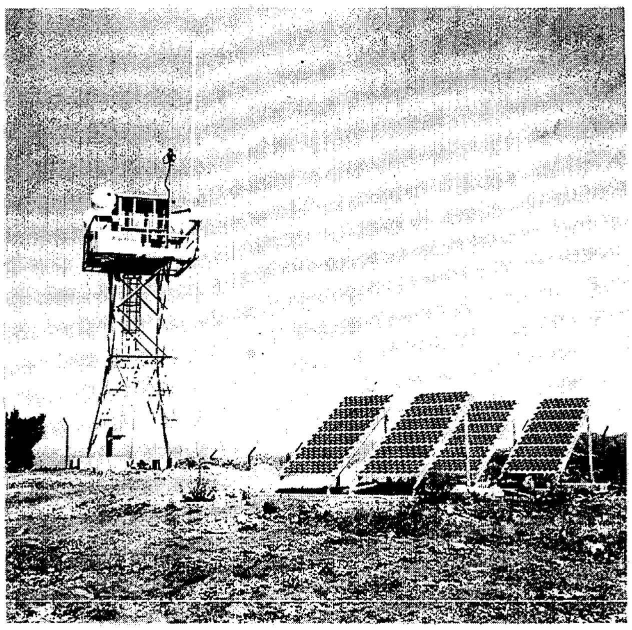

Fig.2 A view of the peripheral station: the metal tower with the peripheral equipment and the photovoltaic panels

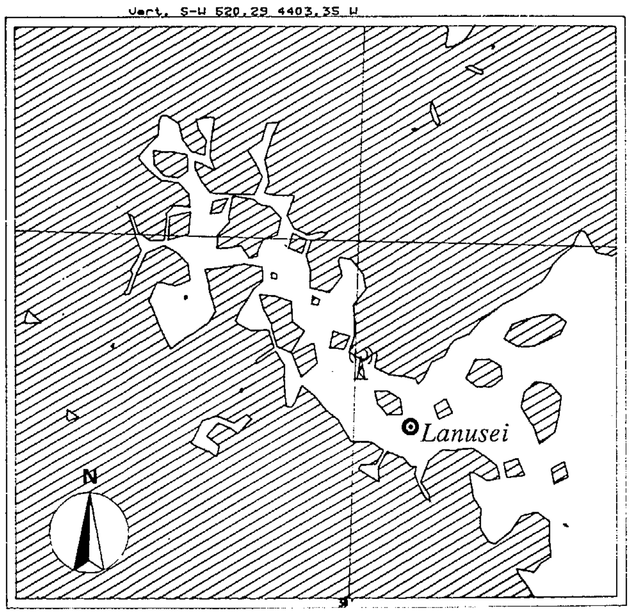

Fig.3 Coverage map of the zone under automatic surveillance (unshaded areas). The scale is 1:500.000

microcomputer-based device is devoted to the remote control of the position of cameras and to the hardware supervision. The main processor unit (host computer) provides commands for the survey scan of the cameras over the surveilled zones, and processes the images received through the radio link. The resulting fire prealarms and alarms are reported on the operator console in acoustic and visual formats, and are printed in a system report. Moreover, they are stored along with the interesting parameters on a disk unit for hystorical and statistic evaluation purposes. A special panel on the console allows for the manual control of direction, zoom and focus of the visible band TV camera. A back-up supply unit and redundant devices provide continuity of operation.

A control station can be connected to several peripheral stations when the estimation of the fire starting point and of the fire extent over large zones is required.

The Operation

The infrared cameras mounted into the rotating shells provide the desired coverage of the zones under automatic surveillance (see Fig.3, where the coverage map of the system installed at Lanusei (Sardinia, Italy) is displayed).

The azimuthal position of the cameras is driven by the microcomputer-based remote control system, which sends the numerical code of the wanted azimuth through the radio link and checks the correct position of the line of sight by reading the code received by an optical encoder mounted on the turning axis of the cameras.

The microcomputer operation is under the control of the main processor, and is programmed to scan the surveilled zones in a systematic way through a sequence of steps forming the "survey cycle".

During the survey cycle, infrared images are sent through the radio link to the main processor, where they are labeled with the number of the camera and the azimuth position. The images are stored into a frame memory in a 256 x 256 pixels and 8 bit/pixel format.

Here, a real time image processing is implemented in order to detect and locate infrared sources (bright spots) and, finally, to decide whether they correspond to a fire and to generate alarms.

The operation of the camera in the visible band is implemented with a remote control of both azimuthal and zenithal angles and of the focus and zoom parameters through the radio link and a servo loop. This allows the personnel to directly perform panoramic as well as particular visual surveys of the entire zone under automatic surveillance.

The Image Processing

The detection of fires from the sequences of infrared images proceeds through two basic procedures:

- the frame processing, devoted to the extraction of bright spots in each received image of the survey;
- the inter-frame processing, which purpose is to filter bright spots on the basis of dynamic criteria, and so generate "fire alarms".

In the context of the frame processing, the operation begins with the evaluation of some local statistical parameters of the kth image of the survey, I_k , to calculate an adaptive threshold for bright spots extraction. In particular, the image is subdivided in 16 squared regions of 64x64 pixels.

For each region R_{ij}, the mean level m_{ij} and the variance σ_{ij}^2 are evaluated.

To reduce the computation time, the variance is estimated by the AMDF fast technique [1], defined as:

$$\sigma_{ij}^2 = (\pi/2) \sum_n \sum_m | x(n,m) - m_{ij} |$$

where x(n,m) represents the value of the pixel in the n,m position into the region. Thus, only addition operations are involved, instead of multiplications required by conventional estimates.

Subsequently, the evaluation of the thresholds t_{ij} for each region takes place. This constitutes the most critical step of the whole processing. In fact, the typical structure of the infrared images in our environment often presents some basic large areas of different luminance due to the non uniform sun radiation of the earth surface throught the clouds, and to the different reflectivity characteristics of different zones in the infrared band. This fact may produce the simulation of bright spots toward the corners of regions due the luminance contrast.

To avoid such effects, the tresholds t_{ij} must be evaluated taking into account the statistical parameters of both the region R_{ij} and the surrounding ones. The adopted context-dependent thresholding rule is of the kind:

$$t_{ij} = a\, m_{ij} + b\, \sigma_{ij} + c \max_{k,l} (a\, m_{kl} + b\, \sigma_{kl})$$

$$k, l = i \pm 1, j \pm 1$$

where a, b, c are weghting factors, which have been experimentally optimized.

The image resulting from the tresholding contains detected bright spots (if any) plus a number of randomly distributed points. In order to obtain the maximum of sensitivity, the threshold is regulated so that the probability of casual detection for background noise is kept to about 10^{-3}. To filter out these random points, a fast region growing algorithm (see, for example, [2,3]) is then applied to each detected point in order to individuate connected clusters. During this algorithm, the extension, the energy and the centroid of each cluster are evaluated and stored into a list.

Then, a second threshold is applied to the frame, which eliminates the clusters with energy smaller than a prefixed value.

If any cluster survives to the second threshold, then, a "prealarm status" is set for the current frame, along with the parameters of the detected spot. The prealarm is sent to the printer. The rate of occurrence of a casual connected cluster due to the noise is negligible, from a practical point of view. Consider that the second threshold is usually set to cancel out clusters of less than 4 or 5 connected points.

At this point the interframe procedures are applied.

The frame status of the I_k image for two consecutive survey cycles are compared.

First, the persistence of a detected spot is checked by comparing the distances of the centroids of all the clusters from the ones of the preceeding survey. If any distance lies upper a prefixed value, then the prealarm status is updated on the basis of the new spots.

Otherwise, the energy of the persistent cluster is compared to the past measured value.

When the ratio of the two values exceeds a prefixed energy increase factor, then the alarm procedure is entered. The topographical coordinates of the fire, obtained by mapping the azimuthal and zenithal measured angles into a 3D model of the observed land, are calculated and displayed.

Then, both space and time parameters of the fire are compared with a set of windows identifying systematic infrared sources, such as lamps or highly reflecting surfaces. Possible alarms due to permanent or periodical sources are thus masked.

When a fire is finally recognized, an alarm status is declared and the personnel is immediately alerted. Both space and time parameters of the fire are sent to the output devices.

The entire procedure takes few seconds to examine one frame, depending on the number of detected points, so that the system takes few minutes for one survey cycle.

This corresponds to the half of the maximum time for recognizing a fire from the beginning of its detectability.

To give a visual example of the processing, in figs.4-7 the sequence of a fire detection event is displayed.

Results

The system has been installed during the entire summer 1986 in a North-East region of the isle of Sardinia, near Lanusei, on the Idolo mountain.

The peripheral equipment included three infrared cameras placed on a metal tower to cover 360° degrees around the mountain. The tests where carried out and recorded in various wheather conditions, by using different sets of parameters.

Fig.4 Image of an area, in the visible spectrum

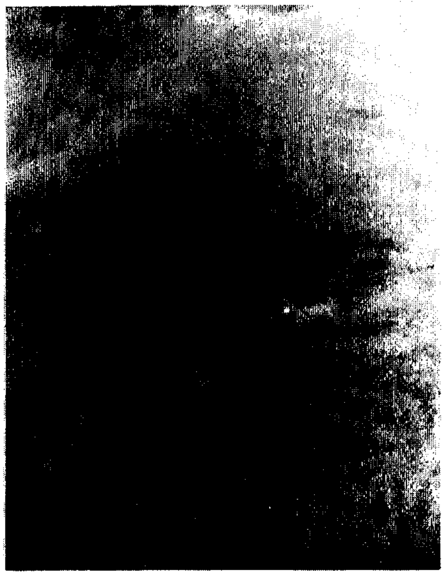

Fig.5 The same area as in fig.4, viewed in the infrared spectrum. Near the center of the image, a small bright spot is visible, indicating a starting fire point

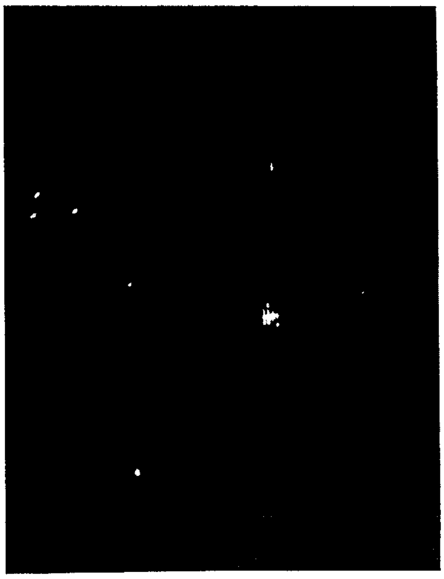

Fig.6 The result of the adaptive amplitude thresholding

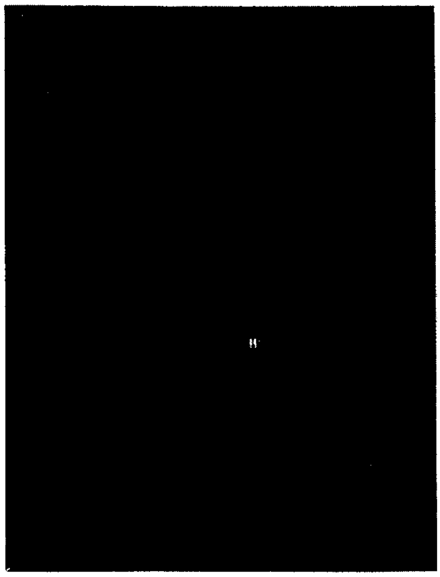

Fig.7 The final result of the frame processing, after the second thresholding. The bright spot is detected and a fire prealarm is set

Typical performance were the recognition of 2 m^2 fires by indirect infrared detection of the warm smoke column over the trees at a distance of about 3 km from the tower.

In these conditions of sensitivity, the rate of false alarms was quite small, about 1 per two days. The resulting delay of recognition was far shorter than the one of the conventional visual survey. Some initial problems arose with the diffusion of sunlight due to low altitude clouds and fog under particular circumstances. This problem has been resolved by adopting a context-dependent threshold, as described in the preceeding section.

Conclusions

Image processing techniques offer an effective solution to the problem of the automatic fire surveillance in the infrared band.

Algorithms designed to exploit the particular features of a fire related to the observed zones (connectivity, energy, position, migration, size growth, etc.) allow to reliably extract the searched event in a background of disturbances caused by different casual sources (car headlights, etc.). Further controls easily eliminate false alarms due to systematic infrared sources (such as sunlight reverberations from lake surfaces, field lamps, etc.).

Fire detection based on the adaptive processing of the infrared scenes exhibit a quite remarkable reliability when compared to earlier methods based on point by point scanning methods.

The whole system is fully automatically operated and works both day and night even with bad visibility due to the presence of smoke, fog, clouds and mist. The advantages offered by the ready and reliable detection contribute to limit fire damage as well as to modify the strategy so far adopted in surveillance.

The exact identification of fire topographic starting points and fire extent is possible thanks to a detailed mapping. This includes the entire area explored by the system, and can be modified and integrated with all data on vegetation, water, supply and transport resources, etc.

In spite of the electronic complexity, the system has proven to be of easy use for the personnel of the fire control service.

Further developments are currently in progress. In particular, a more sophisticated partitioning of the infrared scene into homogeneous regions defined by mean-level based region growing techniques is considered [4]. This method could replace the simple partitioning in squared cells, in order to obtain an even more accurate thresholding. Fast methods are under study to satisfy the real time requirements of the system.

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