A HYBRID INFRARED/VISUAL SYSTEM FOR IMPROVING RELIABILITY OF FIRE DETECTION SYSTEMS


Departamento de Ingeniería de Sistemas y Automática.
Escuela Superior de Ingenieros. Universidad de Sevilla.
Avenida Reina Mercedes, 41012 Sevilla (Spain).
Fax: +34-5-4556849. Email: aollero@cartuja.us.es.

Abstract: This paper presents a system that combines infrared and visual image processing techniques for the detection of fires in open areas. The paper emphasizes forest fire detection from field observatories appropriately located. The proposed system improves the reliability of infrared detection by eliminating a large number of false alarms. The paper includes experiments carried out in forest fire detection and in urban areas.

Keywords: Image Processing, Pattern Recognition, Integration, Components, Implementation.

However, the detection reliability continues being a very important problem. In fact, the False Alarm Rate continues being too high. This lack of reliability has a significant impact because human expert operator has to be involved to validate the alarm. Furthermore, this validation is not always easy.

This paper propose a new hybrid technique that combines infrared and visual image processing techniques to increase the reliability of fire detection systems in open areas. In the next section some reliability problems of the infrared detection techniques are pointed out. The third section presents the structure of the proposed hybrid system. Sections 4 and 5 are devoted to the visual and thermal matching for automatic detection, and to the operator aiding functions included in the system. The conclusions and references are in sections 6 and 7.

2) from several kilometers (between 10 and 20). Several commercial systems exist (Gandia, et al., 1994); Laurent and Neri, 1996). The main drawbacks are the cost and maintenance of thermal cameras, and the reliability. The expected decreasing of cost and maintenance of the infrared cameras could benefit the application of the infrared detection techniques.

2. RELIABILITY OF INFRARED FOREST FIRE DETECTION TECHNIQUES.

Forest fire detection systems are constituted by observatories that perform surveillance cycles searching hot spots covering a large area.
Observatories are located in wide view locations so that the coverage is maximized. Basically there can be found two typical sensors: visual cameras and infrared cameras. Infrared cameras are used to detect regions that produce sufficient amount of energy at the range of frequencies the camera admits. Most of commercial automatic forest fire detection systems only use the visual camera to validate false alarms in a manual way. An experienced human operator checks the visual image and validates the alarm.

Once a high intensity region has been detected on the infrared image, the positioning system stops. Some regions are discarded to be caused by forest fires because of the application of some rules based on stored information about the heat sources found during the last surveillance cycles. The remaining regions are considered to be alarms and they need to be validated and confirmed by the human operator. The operator looks for the heat source on the visual image and decides, using the zoom manually, whether the alarm corresponds to a forest fire or not.

It should be noted that conventional automatic systems do not get profit from the redundancy of information given by the use of both visual and thermal cameras. This paper proposes the application of this redundancy of information to implement methods to discriminate some kind of false alarm sources.

Furthermore, conventional systems do not offer aids to the operator in his task of locating the heat source on the visual image. Experience with commercial systems have shown that this task is not always easy. Then, the reliability of the process is always limited by the perception capability of the human operator. Psychological and physiological research have demonstrated that perception capability depends not only on subject capabilities but also on the concentration and effort that the task demands. Operators aids also improves the reliability of the system because the efficiency of the human operator increases since he is released from doing repetitive boring actions.

In the next section an alternative hybrid visual/ infrared system is presented. This new method shows a much lower probability of false alarm in automatic detection of fires. Furthermore, it implements useful operator aids in locating heat sources on the visual image.

3. HYBRID INFRARED/VISUAL SYSTEM.

It is intended to combine the information provided by thermal and visual cameras to reduce false alarms. The basic structure of the proposed system is shown in Figure 1. This system combines infrared processing analysis with visual image analysis in a hybrid processing block. The information obtained from this block along with the inputs from other sensors (such as meteorological sensors, and maps including topographic and fuel maps) helps to the decision block to classify the alarm.

In the detection process (see Fig 1.), the generation of alarms is done by means of a threshold based detection function. The method calculates the brightness level above which the region is considered to be a potential alarm. If the average bright level is lower than the threshold, it is discriminated as a false alarm. The threshold must be calculated in a dynamic and adaptive way because it must adapt to solar conditions.

Inside the alarm filtering block, the characteristic information (such as location, size, shape and average brightness level) obtained from the region that has been detected, is compared to the previous ones detected in the same location. This allows to avoid well known alarms. Discrimination of moving objects have been carried out using motion filter techniques.

The infrared recognition step includes several False Alarm Reduction (FAR) functions which process the thermal image. These functions have demonstrated that fires suffer temporal changes in the brightness of the pixels in infrared images (e.g., produced by heated
air flows). These vibrations can be observed on infrared images as oscillations on the brightness of the pixels. Hot spots that do not correspond to fires generally have static response on infrared images (except the ones caused by moving objects). Different methods based on temporal spectral changes analyses, and methods based on correlation techniques have been considered (Martínez, 1996). This paper is not concerned with the detailed description of these new methods.

The hybrid process block locate the thermal region obtained on the infrared analysis on the visual image. This location is performed using a matching algorithm based on the geometrical model of the system (Murillo, 96). Once the matching algorithm has been applied, this information is used by the visual region processing to compute the size of the matched region on the visual image and, at the same time, to perform a detection of the object segmented in the infrared image on the matched region.

Then, the decision block, using a rule based algorithm analyses the previous information together with the inputs from other sensors (such as meteorological sensors, and maps including topographic and fuel maps) with rules such as (e.g., concerning to the area):

\[ \text{IF there are detected regions and their area are similar and it is a cold day and it is not located in an important forest area THEN reflection ELSE fire.} \]

\[ \text{IF not detected region on the visual image THEN fire OR heated body.} \]

The previous functions are the basis to discriminate fires from false alarms. Some experiment results will be presented in section 6. The following section describes the method developed for achieving the identification of infrared regions on visual regions.

4. VISUAL / THERMAL MATCHING FOR AUTOMATIC DETECTION.

As explained above, the Hybrid infrared/visual system is based on the matching function. The technique consists of matching a detected high brightness level region with the corresponding region on the visual image. If the matched region on the visual image has a high intensity level, and the size and shape of both regions are similar (considering the scale factor differences and the zoom on the visual camera), the region is likely to be caused by a reflection or an artificial light.

The first step when comparing the images features is the correspondence on the visual image of the object observed on the infrared image. This matching of objects can also be applied to help the human operator to locate a hot source on the visual image so that he could decide in an easier way whether the hot source corresponds to a forest fire or to a false alarm.

Matching can be achieved by the application of stereo vision techniques. It is well known that these techniques have a considerable number of applications in several fields including surveillance processes. In this paper, instead of the conventional two video cameras arrangement, a video camera and an infrared camera system are used. The generic scheme used in stereo vision systems (Horn and Klaus, 1986) is showed on Figure 2. In this work it has been used the observatories of the Bosque system manufactured by FABA-BAZAN in Spain. This observatory is shown in Figure 3.

It is assumed without loss of generality, the infrared/visual camera arrangement shown in Fig. 2 (see Fig. 3 too, where the infrared camera is located at the left side), where both cameras have the parallel optical axis in the z direction and the same focal distance. The cameras baseline is in the x direction perpendicular to the optical axis. Let the distance between cameras be \( dc \). The origin of the coordinate system is in the baseline at \( dc/2 \) from each camera. Assume that both cameras have the same focal distance \( f \).

A point in the environment with coordinates \((x,y,z)\) is seen in the thermal and visual images in the coordinates \((x_I,y_I)\) and \((x_V,y_V)\) respectively.
The relations between coordinates are given by the stereo equations. By means of trigonometric relations it can be obtained the following equations (where \( z \) is the distance to the object):

\[
\frac{x_i}{f} = \frac{x + dc/2}{-z}, \quad \frac{x_v}{f} = \frac{x - dc/2}{-z}, \quad \frac{y_i}{f} = \frac{y}{z}, \quad \frac{y_v}{f} = \frac{y}{z} \quad (1)
\]

Similar expressions can be obtained assuming that the focal distance of both cameras is different and dealing with regions of images instead of points.

Distance between the cameras is typically around 0.5 m. Both cameras axes are aligned within a sufficiently little range of error. The distance to the object is always high (bigger than 250 m) and the average distance is higher than 10 km. In some cases the surveillance area can exceed 30,000 hectares.

The problem is to match certain regions segmented on an infrared image with certain regions on a visual image. It is very difficult to find a generic solution to this problem. Then, the method that has been implemented considers the advantages and difficulties imposed by the characteristics of the application.

Another difficulty is that the environment is unstructured. It is not always possible to structure such a large area of wild forest, or if it could be possible, it would not be very economically feasible. Another problem is that the method should work at day and at night with several meteorological conditions. The features of the system are, as have been mentioned previously, short distance between cameras, long distance from cameras to point under observation and alignment of optical axes of both cameras.

In order to carry out the matching algorithm a geometric model has been used, where a point visualized on the infrared image can be located on the visual one using a translation and scaling factor. Figure 4, illustrates the idea and yields to the following equations:

\[
x_v = \frac{x_i - x_{ci}}{f_x} + x_{desv} + x_{cv} \quad (2)
\]

\[
y_v = \frac{y_i - y_{ci}}{f_y} + y_{desv} + y_{cv} \quad (3)
\]

where: \( x_v \) and \( y_v \) are the co-ordinates of the visualized point to be matched in the reference system associated to the visual image; \( x_i \) and \( y_i \) are the co-ordinates of the same point but in the system associated to the infrared image; \( x_{desv} \) and \( y_{desv} \) are the co-ordinates of the optical center of the infrared camera in the system associated to the visual image; \( f_x, f_y \) are the scale factors in both axes. In most cases, the optical properties of the cameras allow to set the values of \( x_{ci} \) and \( y_{ci} \) equal to zero and to make \( f_x \) equal to \( f_y \).

Therefore, the equations are as follows:

\[
x_v = \frac{x_i}{f} + x_{desv}, \quad y_v = \frac{y_i}{f} + y_{desv} \quad (4)
\]

where \( f \) is the scale factor between both images and this factor is independent of the distance. The values of \( x_{desv} \) and \( y_{desv} \) depend on the distance and are computed by using the optical model.

In the next section will be explained the developed visual matching algorithm to help an operator considering the zoom effects.

5. OPERATOR AIDS.

The matching algorithm discussed in the last section can be used to help the operator to locate infrared regions on visual images. The technique that has been developed to locate a region after introducing a zoom factor will be described in this section.

The optical characteristics of the visual camera and the zoom factors are assumed to be invariant. This assumption allows to study the trajectory of the image center along the different zoom factors of the visual camera.

Figure 5 shows a visual image without a zoom factor (Fig. 5(a)) and with the maximum zoom factor (Fig. 5(b)).

\[\text{Fig. 5. Zoom scale factor and center deviation.}\]
Let $f_{ei}$ and $f_{ef}$ be the minimum and maximum zoom factor respectively. For the particular zoom that is mounted in the camera, the zoom factor is unknown but it is in the range of $f_{ei}$ and $f_{ef}$. The image with the maximum zoom factor is scaled by factors within the range $1/f_{ef}$ and $1/f_{ei}$ (Fig. 5(c)). The white rectangle represents the uncertainty region in which the previous scaled image should be located on the image without a zoom factor. This process of localization is performed using a correlation technique.

A correlation technique is applied to every scale factor and the results obtained provide the center deviation of the image, the zoom factor and the region image location. Therefore, it will be possible to locate any point in an image without a zoom factor on the image with a zoom factor.

The previous technique and the method described in section 4 are the basis for human operator aid to validate false alarms. In the next section the results of some experiment are presented

6. EXPERIMENTS.

**Experiment 1:** This experiment shows the results of the Hybrid processing scheme shown in Figure 1. The images used, were taken from the Bosque system in the Forest Fire Fighting Center of the Andalucía Regional Environment Agency, see figure 6. The cameras used have different optical properties. Due to this difference, the scale factor between the infrared and visual image has a value of two.

It can be observed that the fire is detected in the infrared image and the region is located on the visual image. Then it will be classified as a fire. The visual image has a double rectangle around the located region allowing the operator to locate easily the matched area.

**Experiment 2:** Figure 7 shows a visual and infrared images taken in a city environment. In this experiment the scale factor between both images has a value of one. It can be observed that the located areas in the images are of similar size. Therefore, the system discriminates the detected region as a reflection and then the supervisor classify the object as a false alarm.

**Experiment 3:** Figure 8 shows a visual and infrared forest fire images taken in a city environment.

![Fig. 6. Infrared/visual images of the same forest fire.](image)

![Fig. 7. Infrared and visual images in experiment 2.](image)

![Fig. 8. visual image with no zoom and zoom.](image)
In this experiment the zoom characterization algorithm is applied to compute the center deviation of the image and the scale factor.

The scale factor obtained for these pairs of images is 6.31. The horizontal deflection is 39 pixels and the vertical one is -27 pixels. The black arrow goes from the initial center of the image to the new center.

6. CONCLUSIONS.

Reliability is the main difficulty of the performance of forest fire detection systems. A detailed study of these systems based on infrared devices has been developed. The study reveals that exist a great amount of false alarms. All these alarms must be validated by the human operator. The process of validation is a tedious task that must be done manually. The paper proposes an alternative hybrid infrared/visual system to overcome these problems. Various rule based false alarm reduction components have been developed.

A matching process between regions on infrared and visual image is introduced. The process consists of the identification of segmented infrared regions on the visual image. This procedure provides the system with richer information that permits a reduction in false alarm rate (more than thirty percent in the experiments carried out) by the comparison of characteristics of both infrared and visual images. The information obtained by infrared/visual matching, together with the zoom characterization, can also be used as operator aids. These algorithms developed are simple enough for their real-time implementation.

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