Fire and Smoke Detection Using Wavelet Analysis and Disorder Characteristics

Ali Rafiee
Assistant Professor, Electrical Department
Islamic Azad University-Kazeroun Branch Kazeroun, Iran
Alirafiee_2000@yahoo.com

Reza Tavakoli
Islamic Azad University-bushehr Branch bushehr, Iran
r_tavakoli_npc@yahoo.com

Reza Dianat
Assistant Professor of Persian Gulf University
Bushehr , Iran , dianat@pgu.ac.ir

Sara Abbaspour
Islamic Azad University-Kazeroun Branch Kazeroun, Iran
S_pour@yahoo.com

Mehregan Jamshidi
Islamic Azad University-Kazeroun Branch Kazeroun, Iran
Jamshidi_mehregan@yahoo.com

***Abstract*--The fire and smoke monitoring systems are useful in different industry such as military, social security and economical. The recent methods for fire and smoke detection are used only motion and color characteristics thus many wrong alarms are happening and this is decrease the performance of the systems. This research presents a new method for fire and smoke detection through image processing. In this algorithm all objects in an image is considered and then check them to figure out which objects are smoke and fire. The color, motion and disorder are useful characteristics in fire and smoke detection algorithm. Smoke of fire will blur the whole or part of the images. Thus by processing of the video frames, different objects will detect. Due to evaluate the features of objects, the goal objects (fire and smoke) can be defined easily. Two-dimensional wavelet analysis is used in the presented method. The results of this research present the proposed features that can reduce the wrong alarms and increase the system performances.**

***Keywords*: Fire and smoke detection, Wavelet analysis, Disorder features, Color and motion features.**

I. Introduction

There are different methods for detecting smoke and fire in different features and applications. Sensors are used to measure the desired parameters [1] [3] in most of the methods. Applying several sensors is essential in order to cover all desired area while it is not cost-effective. The sensors are contact sensors. They should be install near the ceiling, thus it causes delay until the smoke reach to them and detect by them.

These restrictions lead to the image processing in fire and smoke detection. The characteristics that are used in image processing, are color and motion [1] [2]. If a motion happens in background and the object is the same color as smoke and fire, it is consider as smoke or fire object but these features cannot produce the required performance. For instance if a red car has a movement in a garage, the system will assumes the motive object as fire. Therefore, an image processing system uses both color and motion characteristics for proposed applications in different conditions. Moreover, the other features such as dynamic movement and disorder, in the shape of fire and smoke, should be used for high performance detection [5]. The color feature is a static characteristic and it depends on the fuel [3] [4]. The motion is a dynamic characteristic and it highly depends on the airflow. The growth and disorder features are also dynamic characteristics and they depend on fuel and airflow [5] [7]. The fire pixels have a frequency between 0.5-10 Hz [8]. Detecting the frequency of flicker in different frames can be accomplished by using the wavelet analysis, hence it is independent of fuel and fire range. Two-dimensional wavelet analyze is one of the static characteristics and it depends on the fuel material and fire scale [6].

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II. Fire and smoke detection method

The proposed method has two phases for performing the proposed method: detecting the deferent objects in an image and discerning smoke and fire objects among the detected objects.

a. Detecting motion in sequent frames

Detecting the object or objects in sequent frames is considered as motion detection. For comparing the different image frames in image processing, a unique background should be defined, hence the firs frame of captured images is considered as the background image and the other captured images are compared and measured with it. Each image was included one or more labeled objects. If there was one object in the image then means there was a motion in that image. In order to decrease the calculation time and creating the online system with better performance the small area object was ignored. For each object some of its important properties such as area, perimeter and center point were calculated. If there was at least one object in a frame or the area of object was increased, it was shown a movement in the current frame.

b. Detecting the color of motive area

Detecting the color for each detected object was done in this step in order to distinguish the fire and smoke. The following sub-sections explain two methods for finding the color of the fire and smoke objects separately.

1. Detecting the color of the smoke

The color of smoke can be gray, light gray, white, dark gray and black. The R, G and B values of pixels for a grey smoke object are equal however are not equal for the less density. Due to the less density of smoke, the color of background or behind image of the smoke object is visible. Thus, the collected data should be evaluated by comparing the pixel of each object with the same pixel of background. It performs in this way:

$$\Delta_{obj} = |R_{obj} - G_{obj}| + |G_{obj} - B_{obj}| + |R_{obj} - B_{obj}| \quad (1)$$

$$avg_{obj} = \left(R_{obj} + G_{obj} + B_{obj}\right)/3 \quad (2)$$

$$color\ \ diff\ \ cof_{obj} = \frac{\Delta_{obj}}{avg_{obj}} \quad (3)$$

$$\Delta_{backg} = |R_{backg} - G_{backg}| + |G_{backg} - B_{backg}| + |R_{backg} - B_{backg}| \quad (4)$$

$$avg_{backg} = \left(R_{backg} + G_{backg} + B_{backg}\right)/3 \quad (5)$$

$$color\ diff\ \ cof_{backg} = \frac{\Delta_{backg}}{avg_{backg}} \quad (6)$$

Δ difference between the RGB colors quantities of one pixel, avg the average of RBG color quantities, $color\_diff\_cof_{obj}$ color variation coefficient for each point of each object, $color\_diff\_cof_{backg}$ color variation coefficient for each point of background. Color variation coefficient should decrease for smoke. If the smoke and the selected points for color testing in the background are the same color, these two coefficients become equal. As shown in the following formula, with low-density smoke, the color values (R, G and B) for each pixel are closed to each other and with high-density smoke, the color values are exactly equal. Therefore, the smoke cause the R, G and B values for each pixel less than the background values.

$$color\_diff\_cof_{obj} \geq color\_diff\_cof_{backg} \quad (7)$$

Moreover due to the high density of smoke, the R, G and B values became equal to each other then $\Delta_{obj} = 0$ and $color\_diff\_cof_{obj} = 0$.

2. Detecting the color of the fire

The color quantities are not necessary for detecting the fire objects, because the fire hides the background image. Some points of each object were selected to apply the color property for the detected objects and then the color values of the pointes were extracted and reviewed. One of the most important points for each object is centriod point of the object. For selected points the following conditions for detecting the fire were checked.

$R_{obj} > R_T$: The red value of each pixel is bigger than the threshold value.

$R_{obj} \geq G_{obj}$: The red value of each pixel is bigger or equal with green value of the pixel.

$G_{obj} > B_{obj}$: The green value a pixel should be bigger than the blue value of the pixel.

If the results of 80% of selected points by the proposed condition were satisfied then the related object was considered as a fire object.

c. Applying two-dimensional Wavelet

The image also can be considered as a two-dimensional signal that is a matrix with arranged different rows and columns. The color property of each row or column was considered as a one-dimensional signal. therefore, the wavelet transform on each row or column of the image was done by this method. In order to apply two-dimensional wavelet transformation to image, first, one-dimensional wavelet transformation was applied to the rows, then the columns was down sampled with the rate of two, for keeping the samples on the places with even coordinate. Then the one-dimensional wavelet transformation was applied on columns the rows was down sampled with the rate of two. As shown in Fig. 3 four sub-bands were achieved as the multiples of wavelet transform.

Like the one-dimensional mode, the first sub-band of the multiples of wavelet transform were belonged to the approximation multiples. It was as same as the first image in quantity and shape. Rather than approximation sub-band, there were three sub-bands: one for horizontal details of image, second for vertical details of image and the last one was belonged to the other details of image (diagonal details).

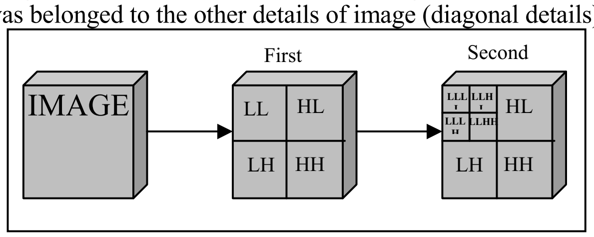


Fig. 1: Two-dimensional wavelet transform for an image

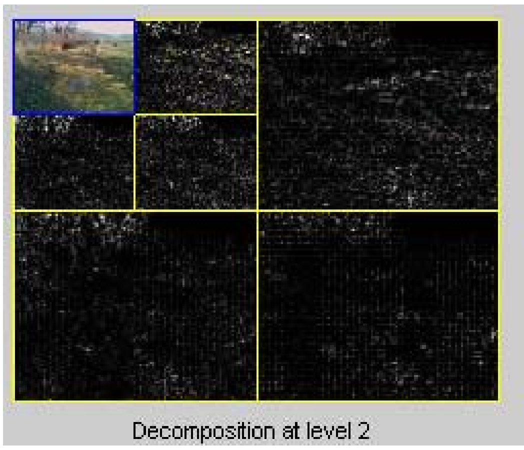
As shown in Fig.1, the result of the first stage was four separate sub-bands. LL was the low frequency data of row and column, HL was the high frequency of row and low frequency of column (horizontal wavelet), LH was the high frequency of column and low frequency of row (vertical wavelet) and HH was the high frequency of column and high frequency of row (diagonal wavelet). For the second stage of wavelet transforms, the process was similar to the first stage. Moreover, the total wavelet energy of high frequency items of image was calculated as follow:

$$E_{wavelet} = \frac{1}{M \times N} \left\{ |I_{LH}(k,l)|^2 + |I_{HL}(k,l)|^2 + |I_{HH}(k,l)|^2 \right\} \quad (8)$$

Where I is the value of wavelet energy and $M \times N$ is the dimension of motive area.

Furthermore, all items in the mentioned formula were in power two in order to find the small changes of total wavelet energy even for small fire and smoke.

Fig.2 shows an experience, which is done in this research. Image A is the background image (without smoke), and Image B shows the background image with smoke. Wavelet energy is clear in both images. Two steps wavelet were executed in this experience and the wavelet analysis operation was applied for both steps. The results of the calculation are showed in table 1.



ImageA

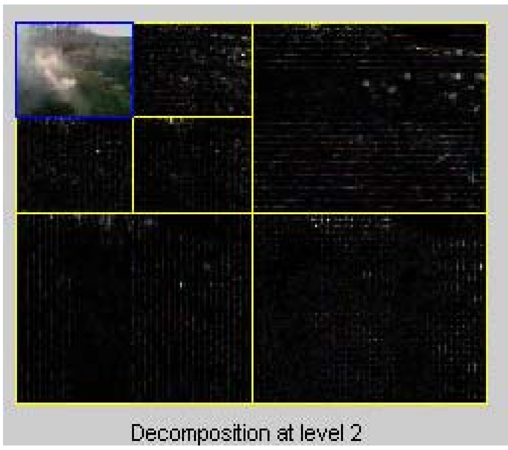


Image B

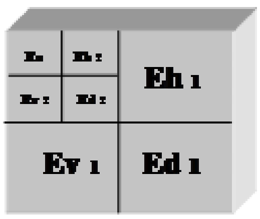


Fig. **2**: Wavelet experiment with two steps and Wavelet energy label

Fig. 2 shows that the E_a is increased and the other high frequency is decreased. The changes of the wavelet energy show that is an activity in this area. In other hand, a motive object with a same color as fire does not show all changes in wavelet energy because the quantity of fire pixels did not change.

d. Detecting the fire and smoke disorder

When the smoke and fire happens, it spread in different in each second and it does not have a specific format and shape. Disorder characteristic is a parameter to expresses the scale changing in spreading the fire and smoke. All uncontrolled fire and smokes have disorder characteristic. It is a dynamic characteristic of Fire and smoke and are depend on the fuel and the airflow.

Table 1: results of Wavelet energy

Without smoke	With smoke
E_a=99.8901	**E_a=99.2172**
E_{h1}=0.0099	**E_{h1}=0.1204**
E_{v1}=0.0086	**E_{v1}=0.0669**
E_{d1}=0.0004	**E_{d1}=0.0070**
E_{h2}=0.0489	**E_{h2}=0.3189**
E_{v2}=0.0375	**E_{v2}=0.2118**
E_{d2}=0.0045	**E_{d2}=0.0578**

The disorder parameter of fire and smoke. Are calculated as Follow:

$$Disorder = \frac{Perimeter}{Area} \quad (9)$$

$$STD_{(m,n)} = \frac{SEP_{(m,n)}}{STA_{(m,n)}} \quad (10)$$

Where m is Frame number , n is Object number, $STD_{(m,n)}$is disorder characteristic for nth object in mth frame, $SEP_{(m,n)}$ is perimeter of object n in mth frame and $STA_{(m,n)}$ is area of object n in mth frame.

Disorder characteristic was calculated for all frames and objects and it saved into a matrix [m, n] (m objects and n frames). Therefore, it was possible to access the disorder characteristic of last frame and use them in following formula.

$$\left| \frac{STD_{(m+1,n)} - STD_{(m,n)}}{STD_{(m,n)}} \right| \geq STD \quad (11)$$

$STD_{(m+1,n)}$ id disorder of an object in frame number $m+1$, $STD_{(m,n)}$ is disorder of the same object in frame number m. It is the disorder threshold, which is definable, depends on the sensitivity value. So if the disorder parameter for an object in a current frame was more than threshold value of last frame then it showed the shape of the object was changed more than the threshold. Therefore, disorder value is a unique property for fire and smoke. It is an important role for detecting the fire and increasing the system performance.

Conclusion

This research presents a new method for detecting the smoke and fire in video images. First, all objects were detected, and then removed the objects, which did not have the fire or smoke properties. It found by detecting the color of each objects. The proposed method usedthedynamic and static characteristics related to the smoke and fire. The two-dimensional wavelet analysis is a static characteristic. It was used for detecting the color and motion properties by checking the changes of two-dimensional wavelet energy. In addition, disorder characteristic of fire and smoke is one of the dynamic characteristics, which were used, in the proposed method. The combination of the obtain properties for detected objects in color and motion parameters made the fire and smoke detection systems with minimum wrong alarm for the indoor and outdoor systems. Moreover, the proposed method can be used for online video images or data base video images. It is also suitable for processing the satellite images in order to detect the fire in jungles. Therefore, it is completely useful to present an automatic surveillance.

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