2004 International Conference on Image Processing (ICIP)

An Early Fire-Detection Method Based on Image Processing

Thou-Ho (Chao-Ho) Chen, Ping-Hsueh Wu, and Yung-Chuen Chiou

Department of Electronic Engineering, National Kaohsiung University of Applied Sciences,
Kaohsiung, Taiwan 807, R.O.C.

ABSTRACT

The paper presents an early fire-alarm raising method based on video processing. The basic idea of the proposed of fire-detection is to adopt a RGB (red, green, blue) model based chromatic and disorder measurement for extracting fire-pixels and smoke-pixels. The decision function of fire-pixels is mainly deduced by the intensity and saturation of R component. The extracted fire-pixels will be verified if it is a real fire by both dynamics of growth and disorder, and furtherly smoke. Based on iterative checking on the growing ratio of flames, a fire-alarm is given when the alarm-raising condition is met. Experimental results show that the developed technique can achieve fully automatic surveillance of fire accident with a lower false alarm rate and thus is very attractive for the important military, social security, commercial applications, and so on, at a general cost.

1. INTRODUCTION

Generally, the fire accident frequently causes economical and ecological damage as well as endangering people's lives. To avoid the fire's disasters, many early fire-detection techniques have been explored and most of them are based on particle sampling, temperature sampling, relative humidity sampling, air transparency testing, smoke analysis, in addition to the traditional ultraviolet and infrared fire detectors. However, those detectors either must be set in the proximity of a fire or can't provide the additional information about the process of burning, such as fire location, size, growing rate, and so on. Thus, they are not always reliable because energy emission of non-fires or byproducts of combustion, which can be yielded in other ways, may be detected by misadventure. This usually results in false alarms. To provide more reliable information about fires, the visual-based approach is becoming more and more interesting.

In point of the segmentation of fire features, the color processing will have less false alarms from the variation of lighting conditions, e.g., natural background illumination, than that of the gray-scale processing. To increase the fire-detection capability during the night, Cappellini et al. [1] introduces the color video to recognize the fire flame from smokes. Recent color-video based researches [2]-[5], propose some enhanced color image processing techniques for achieving a real-time detection of fire flame. However, the above methods all focus on recognition of a fire but can't provide a reliable validation of a real fire and any information about whether the flame will burn up or low. This is very important when the commercial cost is considered, since human operators must manually validate each false alarm. To reduce false alarm rate in forest-fire detection, a complex hybrid system with multiple inputs provided by the visual camera, the infrared camera, meteorological sensors and a geographical information database is presented [6]. Without losing the generality, a hybrid approach always brings a higher cost and maintenance on combination. This motivates that the attractive fire-detection method may be aimed at the general purpose, high reliable and low cost features [7]. It uses a 2-stage decision strategy that the first decision stage is to detect if there is a existing fire and the second decision stage is to further check whether the fire will spread out or not later on. Anyway, some fire aliases may make the first decision stage to be failed and the second decision stage needs to be refined for reducing false fire-alarm rate.

To overcome the previous problems mentioned above, we improve a real fire validation by verifying the extracted fire-pixels and smoke-pixels through RGB chromatic segmentation and disorder measurement. The decision function of fire-pixels is obtained by deducing with the intensity and saturation of R component, and the R, G, B as compared with each other and intensity is utilized to deduce that of the smoke. Based on iterative high reliable checking of flame if a fire flame will burn up or down can be achieved. If a fire is considered to be burning up, a fire alarm will be immediately given became the fire may lead to a disaster.

2. FIRE FEATURES

Most fuels will burn under appropriate conditions, reacting will oxygen from the air, generating combustion products, emitting light and releasing heat. Flame is a gas phase phenomenon and, clearly, flaming combustion of liquid and solid fuels must involve their conversion to gaseous form. In the point of general fires [8], the flames usually display reddish colors; besides, the color of the flame will change with the increasing temperature. When the fire temperature is low, the color shows range from red to yellow, and it may become white when there is a higher temperature. This reveals that a low-temperature flame emits a light of high color's saturation and a high-temperature flame emits a low-saturation light. Furthermore, the color of fires during the day or with the extra light source has a stronger saturation than that of during the night or no light source. It should be pointed out that both the flame with a very high temperature and some special combustible materials may generate bluish flame. Another feature of fires demonstrates the changeable shapes due to the fact that airflow caused by wind will make flames oscillate or move suddenly, as shown in Figure 1. Based on video processing, this dynamic feature will reflect the corresponding effect especially on a variable flame area in an image. Besides, smokes are always generated with a burning fire and have various quantities and colors because of burning different combustible fuels. Based on the above analyses of fire, these features will be used to identify a real fire.

2.1. Chromatic Analysis of Flames

To simulate the color sensing properties of the human visual system, RGB color information is usually transformed into a mathematical space that decouples the brightness (or luminance) information from the color information. Among these color models, HSI (hue/saturation/intensity) color model is very suitable for providing a more people-oriented way of describing the colors, because the hue and saturation

0-7803-8554-3/04/$20.00

components are intimately related to the way in which human beings perceive color [9]. Based on the discussion of fire features as described in the above, it is reasonable to assume that the color of general flames belongs to the red-yellow range. This will map the value of hue of general flames to be distributed from 0° to 60°. As mentioned previously, the saturation of a fire will change with various background illuminations that the saturation obtained during the day is larger that that of during the night when the visual image is captured with a color video camera. This is because that the fire will become the major and only illumination if there is no other background illumination. In this situation, the fire-flame will display as more white in the hue according to the operation of cameras. On the other hand, the fire color in an image has less white in the hue when the background illumination is comparable with the fire-light. For providing sufficient brightness in video processing, the intensity should be captured over someone threshold. To avoid leading to a fire disaster, the fire-alarm should be given as soon as detecting a burning fire early. In spite of various colors of fire flames, the initial flame frequently display red-to-yellow color. To reduce computational complexity, the previous fire-detection algorithm [7] is based on RGB color model for extracting the fire region from an image. The corresponding RGB value will be mapped to the conditions: $R \geq G$ and $G>B$, i.e., the color range of red to yellow. Thus, the condition of fire's colors to be detected is defined as $R \geq G > B$ for the fire region in the captured image. Furthermore, there should be a stronger R in the captured fire image due to the fact that R becomes the major component in an RGB image of fire flames. This is because that fire is also a light source and the video camera needs sufficient brightness during the night to capture the useful image sequences. Hence, the value of R component should be over a threshold, R_T. However, the background illumination may affect the saturation of fire flames or generate a fire-similar alias, and then result in a false fire-detection. To avoid being affected by the background illumination, the saturation value of fire-flame extracted needs to be over someone threshold in order to exclude other fire-similar aliases. This will deduce three decision rules [10] for extracting fire pixels from an image, as described in the following:

rule 1: $R>R_T$
rule 2: $R \geq G>B$
rule 3: $S \geq ((255-R)*S_T/R_T)$
IF (rule1)AND(rule2)AND(rule3)=TRUE
THEN fire-pixel
ELSE not fire-pixel

In *rule* 3, S_T denotes the value of saturation when the value of R component is R_T for the same pixel. Based on the basic concept, the saturation will degrade with the increasing R component, and thus the term of $((255-R)*S_T/R_T)$ illustrates when R component increases toward the upmost value 255 and then saturation will decrease downward to zero. The relation between R component and saturation for the extracted fire pixels can be plotted in the Figure 2. In the decision rules, both values of R_T and S_T are defined according to various experimental results, and typical values range from 55 to 65 and 115 to 135 for S_T and R_T, respectively.

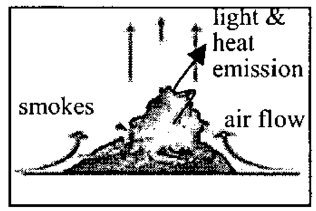


Fig1. Burning flame.

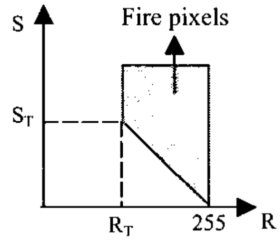


Fig 2. Relation between R and S

2.2. Dynamics Analysis of Flames

Unfortunately, some fire-like regions in an image may have the same colors as fire, and these fire-similar areas are usually extracted as the real fire from an image. These fire aliases are generated by two cases: non-fire objects with the same colors as fire and background with illumination of fire-like light sources. In the first case, the object with reddish colors may cause a false extraction of fire-flames. The second reason of wrong fire-extraction is that the background with illumination of burning fires, solar reflections, and artificial lights has an important influence on extraction, making the process complex and unreliable.

To validate a real burning fire, in addition to using chromatics, dynamic features are usually adopted to distinguish other fire aliases. These fire dynamics include sudden movements of flames, changeable shapes, growing rate, and oscillation (or vibrations) in the infrared response. In [1], fire boxes with the growth rate are used to check a real burning fire and then release a specified action. Another approach [5] defines the degree of fire disorder as the difference between two consecutive final contour images after color masking.

For improving the reliability of detection, we utilize both the disorder characteristic of flames and the growth of fire pixels to check if it is a real fire. Since the shape of flames is changeable anytime owing to air flowing, the size of a fire's area in an image can't maintain to be constant. And, in point of the fire accident, the flame always has a growth feature. The disorder of fires can be measured with the pixel quantity of flame difference between two consecutive images. The decision rule on disorder measurement is deduced as:

IF $\left(\left| FD_{t+1} - FD_t \right| / FD_t \right) \geq FTD$
THEN real flame
ELSE flame alias

where $FD_t = F_t(x,y) - F_{t-1}(x,y)$, $F_t(x,y)$ and $F_{t+1}(x,y)$ denotes the current and previous flame image, respectively. FD_t and FD_{t+1} denote the disorder values of current flame image and next flame image, respectively. *FTD* means a disorder threshold, which will distinguish from other fire-like objects. If the above condition (4) is satisfied, it implies that the flame may be likely a real fire, not fire-alias. For increasing the reliability, the disorder checking process should be performed for d times. It should be noted that both parameters of *FTD* and d are dependent on the statistical data of experiments.

Generally, the growing of a burning fire will be mainly dominated by the air-flow and fuel type. The flame size is changeable anytime due to air flowing, but it always gets toward the increasing approach, especially for initial burning flame. To identify a fire's growth feature, we calculate the fire-pixel quantity of one image frame at each time interval and compare every two continuous quantities. Let m_i and m_{i+1} denote the fire-pixel quantities of the current image frame and next image frame, respectively. If the comparing result of $m_{i+1} > m_i$ is more than g times at intervals of t_F during a time period T, where g, t_F and T rely on statistical data of experiments.

This reveals that there is a likely fire's growth feature and this will increase the validating process of a real fire. Based on the above decision rules from the chromatic and dynamics analyses of fire, Figure 3 and 4 show the extractions of fire-pixels for burning the paper-type fuels and gasoline-type fuels, respectively.

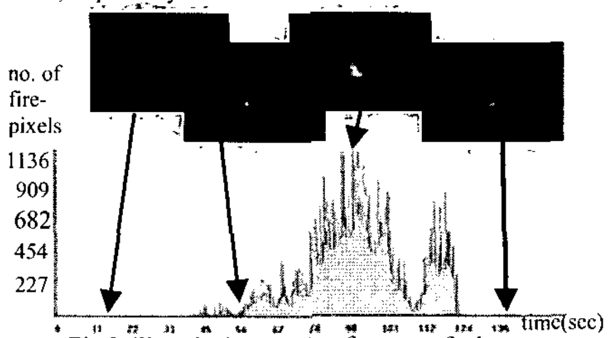


Fig 3. Fire-pixel extraction for paper fuels burning with no background illumination

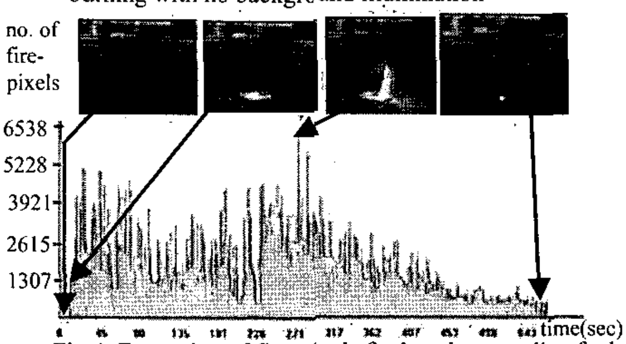


Fig 4. Extraction of fire-pixels for burning gasoline fuels.

2.3. Smoke Detection

Burning with various combustible materials will generate different colors and quantities of smokes, which are composed of particles. For most of smokes, they usually display some grayish colors, which can be classified into two gray level regions: light-gray and dark-gray. This implies that three components R,G, and B of the smoke are equal or so. Therefore, these grayish colors can be described with I(intensity) component of HIS color model. The intensity of light-gray region and dark-gray region ranges from L_1 to L_2 and D_1 to D_2 graylevels, respectively. Thus, the condition $R \pm r = G \pm g = B \pm b$ and $L_1 \leq I \leq L_2$ and $D_1 \leq I \leq D_2$ where $0 \leq r,g,b \leq a$, can be used as one decision function of smoke recognition, when considering chromatic analyses. In the above condition, those values of a, L_1, L_2, D_1 and D_2 depend on statistical data of experiments.

In point of smoke's dynamics, the movement belongs to diffusion of particles and is mainly affected by airflows. This makes the shape of smoke to be changed anytime. For brevity, dynamics of smoke can be described with the disorder and growth, like as fire. The disorder can be also described with the pixel quantity of smoke-image difference between two continuous frames. So, the following condition can be used to validate a real smoke extracted by the color feature from captured image sequences.

IF $((|SD_{t+1} - SD_t|)/SD_t) \geq STD$
THEN *real smoke*
ELSE *smoke alias*

In the above condition, $SD_t=S_t(x,y)-S_{t-1}(x,y)$, $S_t(x,y)$ and $S_{t-1}(x,y)$ denotes the current and previous smoke image, respectively. SD_t, SD_{t+1} and SDT denotes the disorder of the current smoke image, next smoke image and threshold distinguishing from other smoke aliases, respectively. Times required for repeating the checking process and SDT value will depend on experimental results, as that of fire.

Considering the mature of burning, the smoke growth is mainly dependent on the fuel type and air flows and usually larger than that of fire flames. Let n_i denote the quantity of smoke pixels extracted from the image at time t_i. Based on iterative comparing two consecutive smoke quantities, a real smoke can be verified if the condition of $n_{i+1} > n_i$ is satisfied for h times, where h is according to experimental results.

3. FIRE-ALARM RAISING

The early fire-detection can help to avoid leading to a disastrous fire. But a false fire-alarm is always discouraging and bothering since the human operator must manually validate the alarm. To avoid generating a false fire-alarm, a real fire-detection should be further checked whether the fire will cause a disaster or not. This motivates that more decision rules are needed to verify a fire-alarm. Generally, in the detection process, alarm generation comes from an adaptive threshold-based detection function. This adaptive threshold is usually computed according to the visual image's statistical parameters, such as average and variance. The main difficulty of adaptive thresholding is the threshold value's high sensitivity to change. To cope with the above inherent problem of high-sensitive adaptive thresholding. In [7], it presents an iterative checking process based on growing-rate of fire pixels to improve the reliability of a fire-alarm raising. The basic idea is that when a flaming fire is initially detected, the number of fire-pixels extracted at an interval of burning time will be used to compare with a specific threshold. Although, various distances from the camera to burning site will make the threshold value specified to be ineffective. This will reduce the reliability of fire-alarming and may limit the method's applying surroundings of the method.

To avoid the above problems and improve the reliability, this research proposes an iterative growth-checking based method to check if the burning fire will spread to cause a accident. The basic concept is that if the extracted fire-pixels increase with the burning time, the flame is considered to spread out and hence a fire-alarm should be given in the while. As described in the subsection 2.2, checking of $m_{i+1} > m_i$ for many times will imply it is a real fire. For early fire-detection, these checkings should be performed at the initial burning time, But for checking if the fire will spread out, those comparisons need to be performed later. Let N denote the times of comparing m_i with m_{i+1} at intervals of t_R during a time period T and R denote the times of $m_{i+1} > m_i$. The experimental result shows that if the fire is going to spread out, the ratio R/N should be more than at least 0.7. If the value of R/N is more than 0.9, the fire will surely spread out. The ratio R/N between 0.7 and 0.9 is mainly determined by the material of fuel and air-flows. The above checking way of spreading is only suitable for the general burning, as shown in Figure 3.

However, the gasoline fuel will burn rapidly and violently, as shown in Figure 4. In such a burning process, the above decision function of fire-alarming based on checking $m_{i+1} > m_i$ is not allowable because it requires some time for the iterative processing. Therefore, another checking strategy by using the condition of $((m_{i+1} - m_i)/ m_i)>S$ is introduced to examine the spreading of explosion-like burning fires. In the condition, S

denotes the growing rate of flames and will be more than at least 2 based on experimental results, where S mainly relies on the quantity of fuels. Using such a decision rule, only less times of iterative checking are required for examining if the fire will spread out.

4. AN EARLY FIRE-DETECTION ALGORITHM

Based on the above discussions, the proposed early fire-detection algorithm can be concluded in Figure 5. Firstly, moving regions are segmented from the captured image sequences and thus used as candidates for checking if they are fires or smokes. By chromatic features as described in subsections 2.1 and 2.3, fire-pixels and smoke-pixels are extracted form these moving regions. To distinguish from fire-aliases and smoke-aliases, dynamic features including growth and disorder are utilized for validating these fire-pixels and smoke-pixels extracted. It should be pointed out that if these fire-pixels and smoke-pixels satisfy the dynamic features, there is a real fire surely. But if only fire-pixels satisfy the dynamic features, there may be a real fire due to the fact that the burning of some special fuels will generate nearly transparent smokes, which can't be captured by the video camera. Finally, fire-alarm raising conditions $m_{i+1} > m_i$ and $((m_{i+1} - m_i)/ m_i)>S$ are inspected simultaneously to check if the fire is going to spread out, not only for the general burning but also for the explosion-like burning. As soon as anyone raising condition is satisfied, the fire-alarm is given. With the above algorithm, the experimental result is demonstrated in Figure 6.

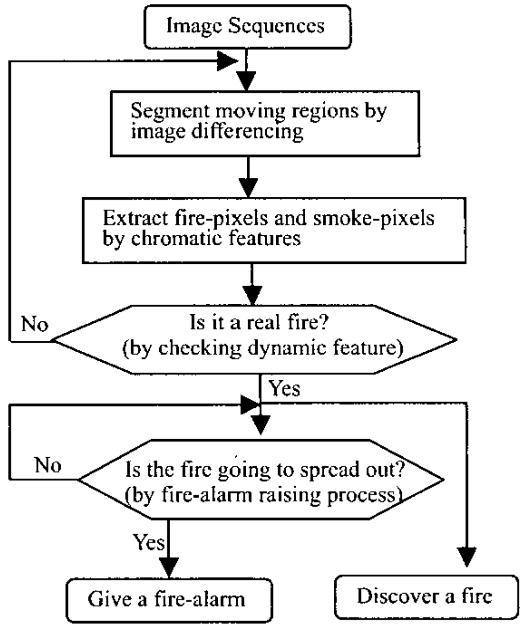
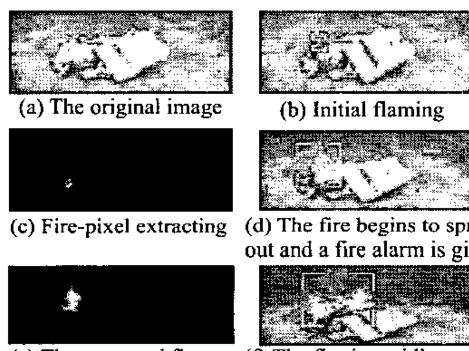


Fig5. The proposed early fire-detection algorithm



(a) The original image (b) Initial flaming

(c) Fire-pixel extracting (d) The fire begins to spread out and a fire alarm is given

(e) The extracted flame (f) The fire is rapidly spread

Fig6. Experimental results: (a) ~ (f)

5. CONCLUSIONS

The research proposes an early fire-detection method based on video processing. Both chromatic and dynamic features are used to extract a real flame and smoke that are adopted for helping the validation of that fire. Furtherly, a fire-alarm is given as soon as the fire-alarm raising condition is met. In the future, the fuzzy neural network will be applied to train the raising parameters composed of both fire-pixels and smoke-pixels extracted at time-interval for increasing the reliability of fire-alarming.

6. REFERENCES

[1] Y. Cappellini, L. Mattii, and A. Mecocci, " An Intelligent System For Automatic Fire Detection in Forests," *IEEE 3th International Conference on Image Processing and its Applications.*, pp. 563-570, 1989.

[2] G. Healey, D. Slater, T. Lin, B. Drda, and A. D. Goedeke, " A System for Real-Time Fire Detection," *in Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition.*, pp. 605-606, 1994.

[3] H. Yamagishi and J. Yamaguchi, " Fire Flame Detection Algorithm Using a Color Camara," *in Proceedings of the 1999 International Symposium on Micromechatronics and Human Science.*, pp. 255-260, 1999.

[4] W. Phillips III, M. Shah, and N. da Vitoria Lobo, " Flame Recognition in Video," *in Proceedings of the Fifth IEEE Workshop on Applications of Computer Vision.*, pp. 224-229, 2000.

[5] Wen-Bing Horng and Jian-Wen Peng, " Real-Time Fire Detection From Video: A Preliminary Report," *14th IPPR, Computer Vision, Graphics and Image Processing.*, pp. 1-5, 2001.

[6] Begona C. Arrue, Anibal Olero, and J. Ramiro Martinez de Dios, " An Intelligent System for False Alarm Reduction in Infrared Forest-Fire Detection," *IEEE Intelligent System.*, pp. 64-70, MAY/JUNE, 2000.

[7] T. H. Chen, C. L. Kao and S. M. Chang, " An Intelligent Real-Time Fire-Detection Method Based on Video Processing," *in Proceedings of the IEEE 37th Annual (2003) International Carnahan Conference on Security Technology*, pp.104-111,2003

[8] James G. Quintiere, *Principles of Fire Behavior*. Delmar, 1997.

[9] Rafael C. Gonzalez and Richard E. Wood, Digital *Image Processing, 2Ed.* New Jersey: Prentice Hall, 2002.

[10] Ivan Kopilovic, Balazs Vagvolgyi, Tamas Sziranyi, " Application of Panoramic Annular Lens for Motion Analysis Tasks: Surveillance and Smoke Detection," *IEEE International Conference on Pattern Recognition.*, pp. 714-717, 2000.