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A NEW HYBRID ALGORITHM FOR FIRE DETECTION USING CCTV

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This paper proposes a new method to detect smoke and/or flame in real-time by processing the video data from CCTV. Distinctive features of the algorithm is employment of spatial and temporal wavelet analysis for both flame and smoke on the stage of classification and reducing a possibility of false detection by chaotic movement estimation in revealed areas in terms of movement vectors. Experimental results show that the proposed method is successful in detecting fire.

Now CCTV systems are open to a wide class of users and solve effectively many tasks in people's practice [1, 2]. The developing of such systems is connected not only with the increase in video cameras' specifications, but also with the automatization of detection-concerned events that occur in a control area. This automatization is achieved through the development of image sequence (dynamic images) processing methods and algorithms, when images are received from a video camera. Automatic fire detection (including fires in open space) is one of the applied problems of current interest that has recently been solved via machine vision systems and CCTV. In this case, methods of dynamic images procession are focused on automatic detection of basic fire factors that can be caught by a video camera – smoke and free flame [1]. In connection with high actuality and difficulty of the task there is a number of dynamic images processing algorithms for video smoke and flame detection [1, 3]. As a rule, they are focused on the detection of one of the fire features: either flame or smoke. It can be explained primarily by different characteristics of these objects. At the same time, the analysis of intelligent video systems' development and corresponding fields of scientific researches show us that an invention of dynamic images processing algorithms with enhanced functionality, which would be able to detect both fire features, is essential.

To solve the task, a hybrid algorithm was developed. This algorithm enables the detection of smoke, free flame and their complex on dynamic images. The algorithm includes the following operations: colour segmentation, pre-processing, interframe differencing, background update, foreground segmentation, morphological operations, contour analysis, optical flow calculation, random movement estimation, contrast analysis, spatial and temporal wavelet analysis.

Movement is a characteristic of both smoke and flame, therefore the algorithm considers it as a common feature for their detection. Extracting of moving pixels is performed on the basis of adaptive background subtraction.

The background image B_t at time *t* is estimated recursively using a frame I_{t-1} and a background image B_{t-1} as follows [4]:

$$B_t(x,y) = \begin{cases} \alpha B_{t-1}(x,y) + (1-\alpha) I_{t-1}(x), if\ (x,y) \in moving\ region \\ B_{t-1}(x,y), otherwise \end{cases},$$

where (x,y) – frame pixel and α is adaptation parameter on interval (0; 1).

The mixing parameter (called alpha-channel) was introduced by Porter and Duff to control the mix of background and foreground images [5]. Mathematically, frame I_{t+1} is a linear combination of foreground F_{t+1} and background B_t components:

$$I_{t+1}(x,y) = \beta F_{t+1}(x,y) + (1-\beta) B_t(x,y),$$

where β – blending parameter.

Further combining of pixels in connected areas is performed with the help of morphological operations and contour analysis. A distinctive feature of this algorithm that enables us to reduce the possibility of false detection is random movement estimation in revealed areas in terms of movement vectors, which are specified by the Lucas–Kanade method of optical flow calculation. The algorithm estimates whether the vectors of the object's movement are codirectional or not. The Lucas–Kanade method assumes that the displacement of the image contents between two nearby instants (frames) is small and approximately constant within a neighbourhood of point *p* under consideration. Thus the optical flow equation can be assumed to hold for all pixels within a window centred at *p*. Namely, the local image flow (velocity) vector (V_x, V_y) must satisfy

$$\begin{aligned}
&I_x(q_1)V_x + I_y(q_1)V_y = -I_t(q_1)\\
&I_x(q_2)V_x + I_y(q_2)V_y = -I_t(q_2)\\
&\vdots\\
&I_x(q_n)V_x + I_y(q_n)V_y = -I_t(q_n)
\end{aligned}$$

where $q_1, q_2, \dots, q_n$ are the pixels inside the window, and $I_x(q_i), I_x(q_y), I_t(q_i),$ are the partial derivatives of the image *I* with respect to position *x, y* and time *t*, evaluated at the point q_i and at the current time.

These equations can be written in a matrix form $Av = b$, where

$$A = \begin{bmatrix} I_x(q_1) & I_x(q_1) \\ I_x(q_2) & I_x(q_2) \\ \vdots & \vdots \\ I_x(q_n) & I_x(q_n) \end{bmatrix}, \quad v = \begin{bmatrix} V_x \\ X_y \end{bmatrix}, \qquad \text{and} \quad b = \begin{bmatrix} -I_t(q_1) \\ -I_t(q_2) \\ \vdots \\ -I_t(q_n) \end{bmatrix},$$

This system has more equations than unknowns and thus it is usually over-determined. The Lucas–Kanade method obtains a compromise solution by the least squares principle. Namely, it solves the 2×2 system

$$A^T A v = A^T b$$
$$v = (A^T A)^{-1} A^T b,$$

where A^T is the transpose of matrix A. That is, it computes

$$\begin{bmatrix} V_x \\ V_y \end{bmatrix} = \begin{bmatrix} \sum_i I_x(q_i)^2 & \sum_i I_x(q_i) I_y(q_i) \\ \sum_i I_y(q_i) I_x(q_i) & \sum_i I_y(q_i)^2 \end{bmatrix}^{-1} \begin{bmatrix} -\sum_i I_x(q_i) I_t(q_i) \\ -\sum_i I_y(q_i) I_t(q_i) \end{bmatrix}$$

with the sums running from *i*=1 to *n*.

The matrix $A^T A$ is often called the structure tensor of the image at point *p*.

Then, colour segmentation and smoke contrast analysis is applied with taking into account a distinction of bright and colour properties of fire features. Flame segmentation is performed in the YCbCr area of colour considering a global frame analysis and an analysis of a local candidate-region. A distinctive feature of the algorithm is employment of spatial and temporal wavelet analysis for both flame and smoke on the stage of classification. Smoke and flame is semi-transparent, so the edges of image frames can lose their sharpness and this leads to a decrease in the high frequency content of an image. To identify smoke or flame in a scene, the background was estimated and any decrease in high-frequency energy was monitored using a spatial wavelet transform of the current and background image. Following the 2-D spatial wavelet transform, the whole image is separated into four regions: horizontal low-band vertical low-band (LL), horizontal low-band vertical high-band (LH), horizontal high-band vertical low-band (HL), and horizontal high-band vertical high-band (HH). The wavelet sub-images LH, HL and HH contain horizontal, vertical, and diagonal high-frequency information from the original image, respectively. If smoke or flame covers one of the edges of the original image, then the edge initially becomes less visible and it may disappear from the scene after some time as the smoke thickens. The spatial energy is evaluated block-wise by dividing the image into regular blocks of a fixed size and summing the squared contribution from each coefficient image, as shown on the following formula [6]:

$$E(B_k, i_t) = \sum_{m,n \in B_k} \left[LH(m,n)^2 + HL(m,n)^2 + HH(m,n)^2 \right],$$

where B_k is the *k*ht block of the scene and I_t is the input image at time *t*.

The energy value of a specific block varies significantly over time in the presence of smoke. This energy drop can be further emphasized by computing the ratio α between the image energy of the current input frame I_t and that of the background model BG_t. The energy ratio has the advantage of normalizing the energy values and it allows a fair comparison between different scenes when the block energy can itself vary significantly. The ratio of the block B_k is given by

$$\alpha(B_k, i_t, BG_t) = \frac{E(B_k, I_t)}{E(B_k, BG_t)}.$$

The application of the united methods of dynamic images processing for detecting smoke and free flame simplifies the algorithm structure, simplifies its realization and allows us to lower computational costs.

The algorithm is implemented in C++ in Microsoft Visual Studio 2010 development environment using a computer vision Open CV 2.2 library. Experiments were carried out on video successions received in real conditions using a Panasonic SDR-S50 video camera, which are also loaded on http://signal.ee.bilkent.edu.tr/VisiFire/Demo/SampleClips.html, http://www.openvisor.org, http://cvpr.kmu.ac.kr. The examples of detection are presented on fig. 1. The time costs for frame size 320x240 pixels are shown in table 1. The results of the research show that the algorithm allows a stable smoke, flame or their complex detection, including one on complicated dynamic background with moving objects, or objects with alike bright and color properties. The low speed of calculations is explained by single-thread computing.

Fig.1. Examples of smoke and flame detection with a hybrid algorithm

Table 1 – Time costs for frame analysis

Stage	Time cost (ms)
Preprocessing	4
Interframe difference calculation	11
Countour analysis	51
Optical flow calculation	23
Weber contrast calculation	6
Spatial and temporal analysis	22
Flame color segmentation	12
Total	129

Multithreaded programming with task parallelization is supposed to be applied on the further stages of the development. Preparatory frame processing tasks in video succession, segmentation of moving areas, morphological operations and random movement estimation can be hardly parallelized. In this case, parallel fulfillment of relatively low amount of computation is practical. Nevertheless after this stage a possibility of parallel fulfillment of two independent branches of the algorithm appears: smoke detection and free flame detection. Thus the time of frame processing reduces in a nonlinear way because it is not necessary to carry out all the steps when smoke or flame is detected, and the possibility of reducing a number of candidate-regions on initial stages of analysis rises. Hereby, the suggested approach allows reducing the frame processing time by 45% on average as compared to the fulfillment of the whole cycle of frame analysis in one thread, and it lets us increase a number of frames in processing in unit time, that means to increase the quality or quantity of input information.

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