A comparative study of various binarization schemes for flame-front detection in a S.I engine

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Abstract. This paper formulates a new mathematical algorithm for automated flame detection in high-speed image. The proposed algorithm is simple, unsupervised and computationally inexpensive to segment a sequence of such images into two levels which correspond to flame and background. Flame images are used as input to calculate and predict the threshold value of the image based on Otsu’s method. The threshold value of the current image is corrected to compute the flame boundary. The main idea is to exploit the images' correlation in time to predict a suitable binarization threshold from the previous image. The algorithm is expected to compute the projected burnt area, which will be used to obtain the flame characteristics in a fast, robust, and reliable way. Then the proposed scheme was compared with two famous different methods and explore their effects on detection characters in scene images. It is found that the proposed method outperforms the other two prior methods in detection flame edges with respect to the flame radius versus time.

1. Introduction

Edge detection is a critical step in image processing [1]. An image is considered to be effectively segmented if we can find the boundary of the object by locating all of its edges [2]. [3] in his paper, stated that simplification of image analysis can be achieved through edge detection process by a drastic reduction in the amount of data to be processed and preservation of structural information about object boundaries that are useful. In general, edges may be used to measure the size of the objects in the image; to isolate particular objects from their background; to recognize or classify objects [4]. Besides, edges are simply regions of intensity transition between one object and another, which makes the edge detection seems to be a relatively straightforward affair. However, despite its simplicity, gradient filters used in most edge detection such as (the Prewitt and Sobel operators) do not find edges per se but rather only give some indication of where they are mostly to occur [5]. In edge detection, feature extraction process and the criterion in the final edge map is the most important part. In the image extraction process, the first step in the process is based on a convolution of an image with a given operator, followed by the thresholding of the feature image in order to obtain an edge map [6]. Various image processing techniques exist for individual flame segmentation in single-shot images. The simplest type of approach is background subtraction, using a mean or median image computed from the overall set of images, and the global threshold. These techniques produce satisfying results of images with flames with intensity values that are significantly different than those of the background. However, they are very sensitive to noise and spatial changes and temporal illumination. Enhanced techniques provided by adaptive thresholds (local thresholds) or by Otsu’s method increase segmentation accuracy, but this method suffers as far as the connection between neighboring pixels is not included [7]. Edge detection methods based on image gradients (first order derivatives), for example, Sobel, Prewitt, and so on, are used to
detect cell boundaries. The methods involving the second derivative (LoG, DoH, DoG) used to detect the clumps and the advantages of linear filtration techniques are that it is quick and easy to calculate. However, the disadvantages of this method are that they usually need additional steps after processing. Edge thinning and connecting are examples of Canny's edge detectors. Non-linear filtering used in morphological operations relies heavily on morphology and flame form and requires knowledge of these features as the foregoing assumptions. Therefore the application potential for non-rigid objects is very limited [8].

In this paper, we explore the novel scheme which exploits the images' correlation in time to predict a suitable binarization threshold from the previous image. The threshold value of the current image is corrected to compute the flame boundary. The algorithm is expected to compute the projected burnt area, which will be used to obtain the flame characteristics in a fast, robust, and reliable way. The proposed method is able to find the flame edges accurately comparing some existing methods which fail to find these edges.

2. Related work

Comparative studies of various binarization methods have been carried out extensively. Most of these studies consist of two or three of the above methods (gradient and cluster-based method). This is to make use of the benefits of each method [9,10,11]. In our previous study [8], we applied this predictor-corrector scheme for 50 high-speed image sequences which were collected from different datasets. In this study, we improve the algorithm and compare the thresholding technique with other methods to show the effect of the benefits of the previous algorithm in this work. [6] did a comparative study to evaluate the performance of the proposed fusion of Haar Wavelet and Prewitt operator compared to the gradient edge algorithms and Canny edge detector. The performance of these edge detection algorithms was tested in different cases which are in noisy and blurred conditions. The image results of applying each detection algorithm were then compared through direct visualization. Their study came up with a conclusion that the proposed Haar based Prewitt edge detection does not perform better than the classical methods and Canny Edge Detector, but it performs better in blur condition. In contrast, Canny Edge Detector performs better in both noisy and blur conditions, but it depends highly on the adjustable parameters [6,13,12]. J. Saif et al. 2012 in their paper compare the two techniques of segmentation algorithms which are Canny edge detection and Otsu thresholding. Both methods were tested with a variety of color images. In their paper, the effectiveness of the two methods was evaluated and their suitability for natural as well as medical images was tested. As a result, they have found that Otsu’s method is more suitable for those images with uniform background illumination and have a clear distinction between object and background. In contrast, Canny edge detector is more suitable for the medical images as the images have no clear distinction of objects from the backgrounds [8,14,16]. Neeta Nain et.al 2008, studied on adaptive thresholding based edge detection using morphological operators, which is by applying efficient adaptive efficient peak detection of the image histogram. Their study come up with a conclusion that their adaptive multi-level thresholding method extracts precise one pixel thick seamless, continuous (in a segment) image boundary which is very important to extract prominent and significant corners in images and also in computing image semantics compared to the existing edge detectors such as Canny and Robert’s operator [9,15].

3. Methodology

In this paper, we propose a new binarization scheme to segment sequence of flame images into two classes; background and foreground (flame). Flame images are used as input to calculate and predict the threshold value of the image based on Otsu’s method. The threshold value of the current image is corrected to compute the flame boundary. The main idea is to exploit the images' correlation in time to predict a suitable binarization threshold from the previous image. The algorithm is expected to compute the projected burnt area, which will be used to obtain the flame characteristics in a fast, robust, and reliable way. We summarize the entire process of the algorithm in Figure 1.
4. Results and discussion

In this section, two image series from endoscopic high-speed imaging was qualitatively discussed. Each image was binarized via predictor-corrector thresholding technique to obtain the instantaneous location of the projected burned area. The identification of the correct flame boundary allows calculating the projected flame area and thus flame growth rate. The accuracy of each detection scheme is presented in terms of the calculated flame radius versus propagating time.

4.1. Comparison between different binarization schemes

In this section, the proposed binarization algorithm is compared with three different algorithms in terms of detecting the boundary of the projected burned area based on the computed threshold value.
Figure 2. Computed threshold value from each binarization scheme for two sample images (I and II). The corresponding projected burnt area (PBA) is indicated in the upper right-hand corner of each image.

Figure 2 shows the histogram of the respective image (I and II). The computed threshold value from each thresholding algorithm is presented by a different color of solid lines on the histogram. In case I, it shows that the computed threshold values by the proposed algorithm and multi-thresh Otsu’s give the most accurate values on detecting the projected burned area. The results of binarization are represented by the red line on the flame images as shown in Figure 2I(a-d). However, in case II, only the proposed algorithm gives the most accurate threshold value as compared to others. The detected flame boundary is shown in Figure 2II(a). The multi-threshold Otsu’s and global Otsu’s methods fail to detect the correct flame boundary in case II as the algorithm strongly depends on the shape of the image’s histogram. [10]. Dynamic gradient method gives the worst result in terms of detecting the flame boundary as it is very sensitive to the image noise during the derivative of image gradient operation. Through direct visualization, it can be seen clearly that the automatic dynamic thresholding method is the best method of detecting the edge of the flame as compared to other schemes.
Figure 3. Sample of flame propagation image series. The red line in each image indicates the flame front as detected by the binarization schemes. (a) the proposed algorithm, (b) multi-level Otsu’s, (c) dynamic gradient.

4.2. Equivalent flame radius
Figure 4 shows the equivalent flame radius as function of crank angle for 3 different binarization schemes. As it can be seen clearly in Figure 4c, the plot scatter is low, and lines mostly do not cross, which is physically plausible [11,8]. However, the other 2 methods show higher fluctuating, lines cross each other, and inconsistent over the propagating time. This is consistent with the visual appearance of the images in Figure 3(a-c).

Figure 4. Flame radius for 100 consecutive cycles (coloured lines) and the multi-cycle mean of these 100 cycles (solid black line). Type of edge detection schemes is indicated in each graph. The blue and red lines in the graphs indicate the fast and slow cycles respectively: (a) global Otsu’s method, (b) dynamic gradient method, (c) automatic dynamic thresholding (predictor-corrector).

5. Conclusion
This study presented a new edge detection scheme based on image’s time correlation for detecting the early flame-front propagation in a spark-ignition engine. The projected burnt area was derived by morphological post-processing. The frequency filtering process was introduced to increase the robustness of the algorithm for detecting the flame boundary at low light conditions. The basic flame characteristics such as flame radius were computed based on the detected flame burned area and the results obtained from each edge detection schemes were compared with three different algorithms. By
comparison, automatic dynamic thresholding method is the most accurate algorithm in detecting the flame boundary area in a spark-ignited engine, as compared to multi-level thresholding, global Otsu’s and dynamic gradient methods. Thus, the proposed algorithm is seen to have a strong potential to accurately detect and measure flame boundary with a low chance of false edge detections.

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