DRDC-RDDC-2014-P47

Robust Face Detection from Still Images

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***Abstract*—Facial recognition is one of the most studied topics in the field of biometrics because of its varied applications. Detection of dark colored faces and poorly illuminated faces are not well studied in the literature due to several challenges. The most critical challenge is that there is inadequate contrast among facial features. To overcome this challenge, a new face detection methodology, which consists of histogram analysis, Haar wavelet transformation and Adaboost learning techniques, is proposed. The extended Yale Face Database B is used to examine the performance of the proposed method and compared against commonly used OpenCV's Haar detection algorithm. The experimental results with 9,883 positive images and 10,349 negative images showed a considerable improvement in face hit rates without a significant change in false acceptance rates.**

Keywords*— *face detection; illumination; skin color variation; Haar-like features; OpenCV

I. Introduction

As computing power increases, biometric systems have become an increasingly popular solution for security related applications. Retina and fingerprint scanners are relied upon to accurately perform a wide range of tasks including authentication of personnel to restricted sites and identification of individual persons. Facial recognition is a rapidly growing area in the field of biometrics with increasing potential because of its non-contact nature. However, due to the complexities of a human face, detecting a face in an image, the first step to perform facial recognition, is by no means a simple task.

Many methods exist to address this issue, such as Principal Component Analysis (PCA), Hidden Markov Models (HMM), and Haar-like features. Viola and Jones proposed a method using Haar-like features to rapidly detect faces within an image [1]. The features are calculated based on the changes in contrast values between adjacent rectangular groups of image pixels, but not the intensity value of a single pixel. However, when the brightness intensities of an image are very similar, and show little variation, the detection algorithm is unable to accurately detect faces. This is often the case in poorly lit images or in people who have darker skin tones [2–4]. As indicated in [5], "it is an open secret that the performance of current face detection and expression recognition systems tends to be much lower when applied to individuals with dark skin". This is no exception for the widely used Haar detection method as it relies on the contrast between facial features, such as forehead-to-eyes, eyes-to-nose, etc.

In this paper, we present a new method for face detection. The objective is to improve the performance in detecting dark coloured faces or faces captured in suboptimal lighting conditions. We examined the skin color properties in several common color spaces such as RGB, Normalized RGB, YCbCr, and HSV, investigated different image enhancement techniques [6–8], and developed an image transformation algorithm. The efforts were focused on rescaling face images with increased contrast and therefore making them detectable by the Haar face detection method. The experiments were carried out on both color and grey scale images, which demonstrated significant improvements in terms of face detection hit rates. The rest of the paper is organized as follows. Haar-like features, integral image, and AdaBoost learning are described in Section 2. The proposed approach is presented in Section 3. Experimental results are presented in Section 4 and the paper is concluded in Section 5.

II. Haar-Like Features

A. Introduction to Haar-like features

Object detection is performed by identifying intensity patterns common to a positive image set. When run against a test sample, a positive match is found if the image possesses enough of the same features.

Haar-like features have been widely used in different boosting algorithms and object detection, especially face detection [1]. The method contains three main ideas to achieve real-time object detection performance: integral images for fast computation, AdaBoost for feature selection, and classifier cascades for fast rejection of non-face windows.

An integral image is created to quickly calculate the sum of intensity values in a rectangle subset image. It is a representation of the original image where the resulting value at any location is the sum of all the intensity values contained within the rectangle formed by the x and y coordinates of the original image. Figure 1 shows an example in which integral image value 658 equals to 122 + 245 + 215 + 76 in the subset image.

122	245	56
215	76	198
52	119	210

→

122	367	422
337	658	911
389	829	1292

Fig. 1. Conversion of greyscale values to integral image

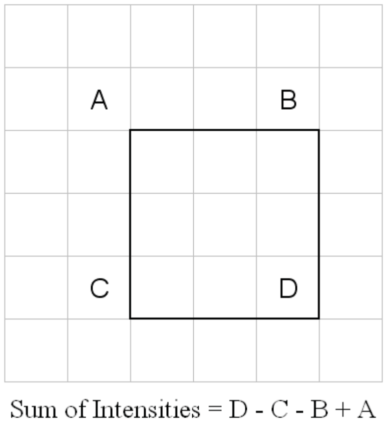


Fig. 2. Method of calculating intensities with the integral image

The integral image is useful because it allows for the sum of intensity within a rectangle of any size to be calculated in constant time through the formula shown in Figure 2. As Haar-like features focus on differences in the average intensities between object rectangular image subsets, integral image is a valuable representation for fast calculation.

An AdaBoost-based algorithm is used to select features that are used for facial classification. This algorithm functions by weighting weak features (slightly better than random selection) and combining a collection of them to form a stronger and more reliable classifier. Each classifier is a set of patterns commonly found in faces. A Haar cascade is a collection of these pattern groupings. AdaBoost-like algorithm is a training process that combines weak features into a strong classifier to maximize the hit rate for a positive set of images. A Haar cascade is trained on a collection of images demonstrating the properties which the user wishes the cascade to look for, and a second group of images which do not contain the desired information. AdaBoost takes both image collections and adjusts the classifiers to match the positive images as closely as possible while excluding patterns that match the negative images. The cascade is composed of several stages each of which filters out different non-faces. These stages are arranged in such a way that the more complex the stages are, the later the operations will be. This makes fewer images be processed by complex stages to increase computational efficiency. This multistage process is both fast and accurate with a reported detection rate as high as 15 frames per second [1].

B. *Issues with Haar-like features*

It has been mentioned that low illumination and varying brightness have a negative effect on various face detection methods [2–4]. This issue also factors into Haar face detection as faces that are in unconstrained lighting conditions return inconsistent results. A similar concern is that people with darker skin also tend to display fewer differences in the light patterns on their skin [2], making it difficult for specific facial features to be matched. When there is little difference in the intensity of the image, it becomes problematic for the Haar feature detection algorithm to match patterns to faces. In these circumstances, the algorithm will often fail to return favourable results.

In the literature, one common approach to address this problem is histogram equalization [8–10]. Histogram equalization is a method that creates an image in which the number of intensity values is evenly distributed. This is accomplished by adjusting the intensity of the image based on the occurrences of each distinct intensity value.

The drawback of global histogram equalization is that an image with faces of different skin tones ranging from dark to fair never shows such a distribution. Another major issue occurs when a strong bias towards one end of the spectrum exists (such as a well-illuminated face on a dark background). In such a case, the image produced by histogram equalization appears quite unnatural [11].

III. Proposed Method

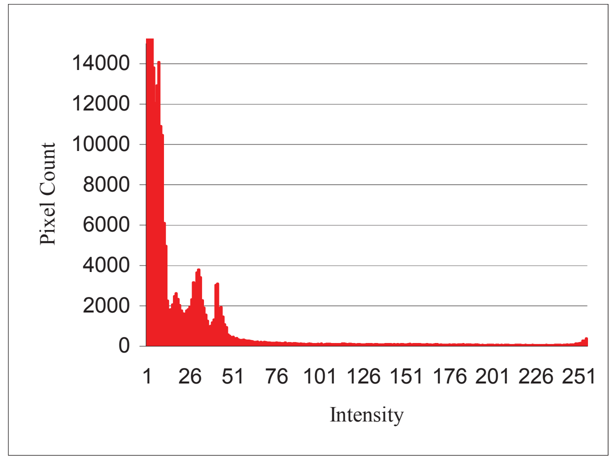
Due to the low detection rate of using Haar-like features on faces under poor or irregular lighting conditions, we have developed a new algorithm based on the histogram specification technique to improve the appearance of extra dark and extra bright faces. As mentioned above, there is difficulty in detecting dim or dark-skinned faces due to the small difference in intensity values. Therefore, a non-linear transformation algorithm is proposed that uses a decreasing exponential function to increase variation of low intensity values while preserving high intensity areas.

First, the image is converted to the hue, saturation, and value colour scheme (HSV). The algorithm is then applied to the value channel. Our algorithm alters the value raising the spread and intensities of dark pixels while maintaining the difference at the midrange. The new image is converted to grayscale and the Haar detector is used to search for faces.

Different from histogram equalization, the proposed method provides a non-linear transformation on the brightness of pixels allowing a detectable difference in intensity values for Haar-like features. In addition, it does not depend on the rest of the image assuring that the brightness values of a face are always shifted in the right direction.

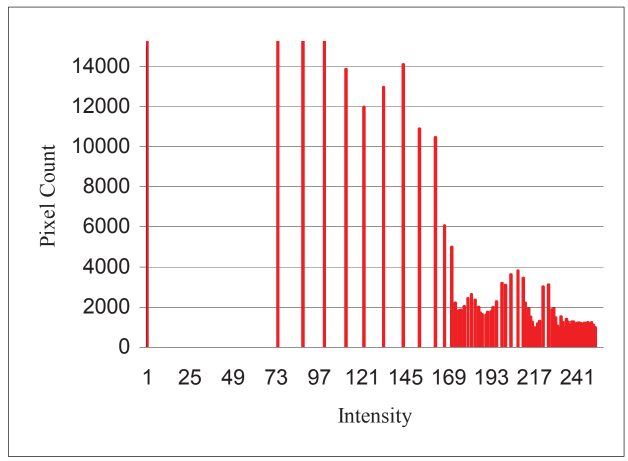
Figure 3(a) shows an example of a face image captured under low illumination condition. Histogram equalization is performed and the resulting image and corresponding histogram are shown in Figures 3(c) and 3(d), respectively. Since many pixels fall in the low intensity range, the histogram equalized image has unevenly spread brightness values. Although the low intensity range has been greatly increased, the high intensity range is narrowed down, which decreases the image quality and may make it difficult to detect Haar-like features. From the resulting histogram generated by the proposed method, it can be seen that the spread of low intensity pixels has also been increased, and the high intensity areas are not compressed (Fig. 3(f)). Therefore, both dark facial features and bright facial features are mostly preserved (Fig. 3(e)). A number of experiments have been carried out to determine the accuracy and advantages of the proposed method.

(a) Original image (from Yale B database)



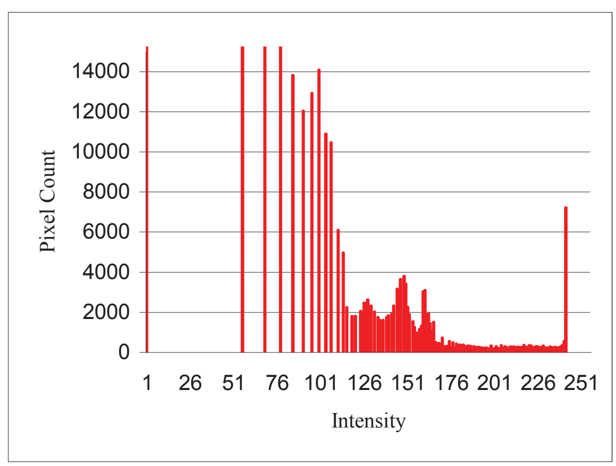
(b) Histogram of original image

(c) Resulting image of histogram equalization



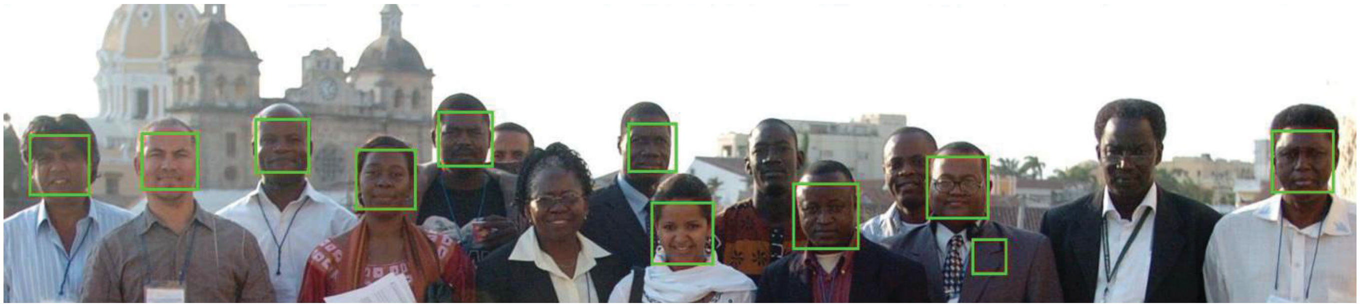
(d) Equalized histogram

(e) Resulting image of proposed method

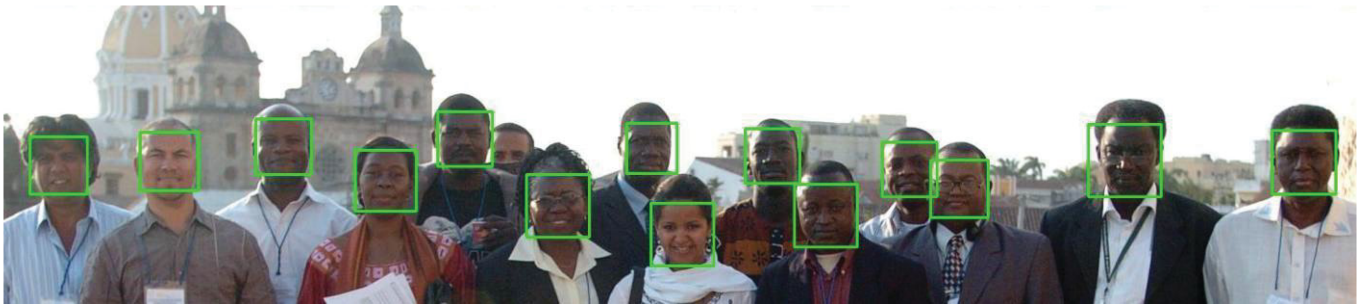


(f) Specified histogram

Fig. 3. Histograms of a sample face (top: low illumination, middle: histogram equalized, bottom: proposed method)



(a) Faces detected by original Haar algorithm



(b) Faces detected by the proposed method

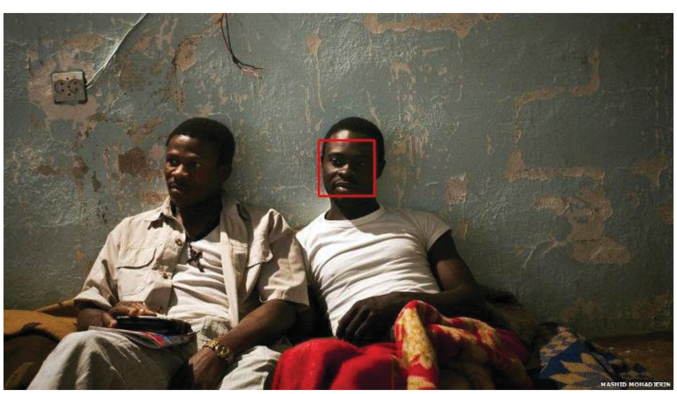
Fig. 4. Comparison of Haar detector to proposed method

IV. Experimental Results

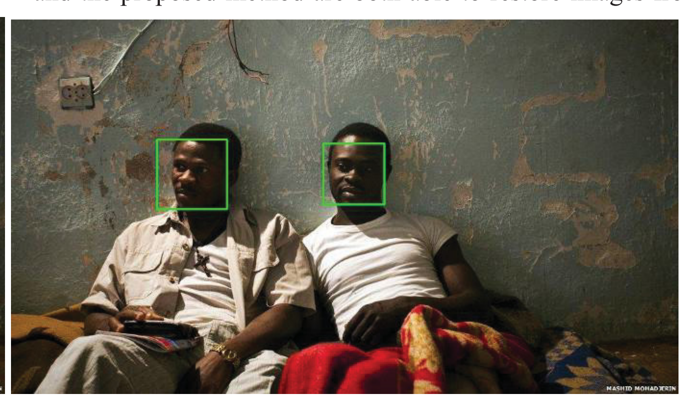
In order to evaluate the performance of the proposed approach, several experiments have been conducted with both color and greyscale images. In the test, two measurements, hit rate and false acceptance rate (FAR) are used. The hit rate is defined as the total number of detected faces over the total number of faces in the test images. While the FAR is defined as the total number of non-face objects that are mis-detected as faces over the total number of faces in the test images.

First, we collect a set of images of human faces from Internet [12, 13] to test the ability of the proposed approach in detecting dark-skinned faces. Figure 4 presents an example that demonstrates the algorithm's improvement to Haar-like features detection. Since they have small intensity differences between darker areas (e.g. eyes, nostrils) and skin, some faces cannot be detected by original Haar algorithm (Fig. 4(a)). The proposed algorithm addresses this issue by increasing the range of low intensity pixels. Therefore, the hit rate on dark coloured faces has considerably increased (Fig. 4(b)). Figure 5 shows a more difficult example of detecting half-shadowed faces. The Haar detector picked up one of the half-shadowed faces (Fig. 5(a)), while the proposed approach detected both half-shadowed faces successfully (Fig. 5 (b)).

To further evaluate the proposed approach, a comparison test is carried out that compares our face detection result to the results obtained from original Haar face detection algorithm provided by OpenCV and an algorithm which used histogram equalization. The test is performed against 17 subjects under 576 viewing conditions from the extended Yale Face Database B. Figure 6 shows a comparison of image enhancement and face detection results between histogram equalization and the proposed algorithm. It can be seen that histogram equalization and the proposed method are both able to restore images from

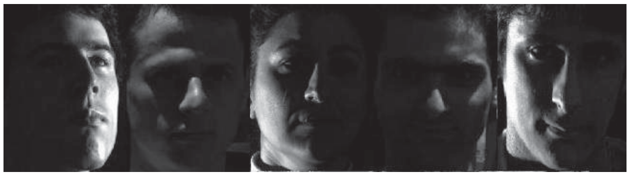


(a) Detection result by original Haar algorithm

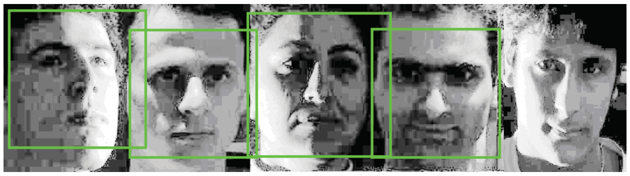


(b) Detection result by the proposed method

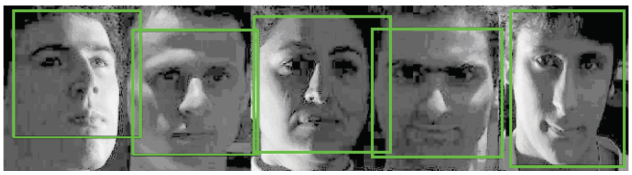
Fig. 5. Example of detecting faces under shadows



(a) Original facial images



(b) Histogram equalized images



(c) Images obtained by the proposed method

Fig. 6. Experiment results on the Yale B database.

dark conditions. However, the inconsistency of histogram equalization can be seen by the wide range of intensity values on the face. In Figure 6(b), due to the different background conditions, subject 5 (counting from left to right) appears brighter and the features on the left side of the face are indistinguishable. Therefore, subject 5 could be detected by the proposed algorithm (Fig. 6(c)), but not through the histogram equalized image Fig. 6(b). Comparing subject 4 in Figures 6(b) and 6(c), the image quality when enhanced by histogram equalization is poorer than that of the proposed method. The eyes are better defined and that the overall picture appears to be under a more consistent lighting.

TABLE I. COMPARISON OF FACE DETECTION RESULTS

Algorithm	#Positives	#Nagatives	Hit Rate (%)	FAR (%)
Basic OpenCV HAAR	7471	2608	75.6	25.2
Histogram Equalization	9255	2772	93.6	26.9
Proposed Approach	9615	2646	97.3	25.6

Table 1 shows a comparison of test results. Of the three methods tested, the original OpenCV algorithm proved the least accurate, having a hit rate of only 75.6%. It also had the lowest FAR but only by a slight margin at 25.2%. The histogram equalized images had the second-best positive acceptance rate of 93.6% and the worst FAR at 26.9%. The new method proposed in this paper outperforms the other two algorithms with a positive acceptance rate of 97.3% and a FAR only slightly worse than that of the original OpenCV Haar function at 25.6%. The images used in false acceptance test were a compilation composed of cows, cars, bikes, buildings, and toys.

V. CONCLUSIONS

In this paper, we have proposed a method to improve the performance of Haar face detector in OpenCV. The experiments demonstrate that the proposed method for face detection using Haar-like features by way of illumination correction presents superior results than the unaltered algorithm. The original Haar face detection method has difficulty in dealing with dark coloured faces or faces captured under poor lighting conditions. While histogram equalization is a commonly used method to improve these results, it is prone to overcompensation and the results are highly dependent on the background. The proposed transformation algorithm addresses this issue by increasing the spread of low intensity pixels while preserving the mid- and high-range areas. The returned image appears to be under a more consistent lighting and is more distinguishable. Experimental results from the proposed method prove to be an effective way of dealing with this issue with a considerable increase in hit rate without severely impacting the false acceptance rate.

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