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FACE DETECTION WITH EULER NUMBER ALGORITHM BASED ON MORPHOLOGICAL OPERATORS

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Abstract
This work conducts a practical study devoted to the Euler number utilization in face detection from binary and morphological processed images. Binary images are affected by noise and texture variability. Morphological operations change and reorder the pixel without acting on their values but generate a new image by either stripping away a layer of pixels or adding a layer of pixels to the boundaries of region of interest. The proposed algorithm binarized the images and then morphologically maps these images to establish the efficacy of different morphological operators. We investigated the performance of the algorithm on a database consisting of 95 face images rotated in the range of 0° to 90°. A similarity comparison study is performed by using an image quality metric called structural similarity index.

Keywords: Euler number, morphological operations, similarity index.

1. INTRODUCTION

The main goal of the human vision is to distinguish meaningful shape information from irrelevant one. Binary images are easier to understand in terms of line, geometrical shape or other features by human vision. Also, handling binary images requires less processing time and smaller memory space. It should be mentioned that noise and particular textures induce numerous imperfections in binary images. Morphological operations are used to remove these ‘defects’ in binary images [1]. Mathematical morphology is a shape-based approach and morphological operations are shift-invariant logical operations on binary images [2]. The elementary operators of mathematical morphology are erosion and dilation. A better approach involves closing and opening operations that are derived from erosion and dilation based on their associative properties. Morphological operations are useful in many applications such as hole filling, boundary extraction of discrete objects, extraction of connected components, thinning and thickening.

Face detection (FD) algorithms are widely used in the areas of entertainment services, video coding, machine object recognition or pattern recognition. Moreover, FD is a preliminary step for more sophisticated operations like face alignment, face relighting, face modeling, face verification/authentication, facial expression recognition etc. There are many limitations affecting FD.

The best known are pose (frontal, profile), structural components (beards, mustaches, and glasses), orientation or in-plane rotation and imaging conditions (illumination, camera features, resolution). The morphological operators have a wide application range in face detection [3, 4, 5]. They can remove noise, detect edges, identify components or demodulate boundaries [6]. Lapides and Hateley [7] implemented an algorithm that is able to identify face regions having black holes inside them that are assimilated to eyes, nose, mouth, ears, etc. If the number of detected holes is above a chosen threshold, the region is considered as being a face. Makaremi and Ahamdi [8] proposed a method based on mutual information for face recognition. The left and right sides of the face images were analyzed separately in order to minimize the effect of illumination. Then, smaller sections in strip shape of the images were compared based on mutual information as a similarity measure. Kakarwal and Deshmukh [9] used mutual information for feature extraction and Feed Forward Neural Network and Self Organizing Map Neural network for classification purpose to test 50 faces of FACE94 database. Vretos et al. [10] used face clustering for face recognition purposes. Clustering is performed based on mutual information and joint entropy to increase the robustness of the algorithm against some standard noisy transformations. The degree of differences between individual faces based on surface correspondences and metrics that is used to measure differences in facial geometry and expressions were investigated in [11].

In a binary image, some topological features can be evaluated using the Euler number (EN) [12, 13]. Snidaro and Foresti [14] established an optimal threshold using the so called fast Euler numbers in a binary image computed in a single image raster scan. Vatsa et al. [15] presented an online signature verification algorithm and Euler numbers have been used to analyze the topological features.

Face processing technology allows the anatomical face feature extraction when the face images are properly processed without losing the information or avoiding the redundant information. Binary images are affected by noise and texture. Morphological operations change and reorder the pixel without acting on their values but generate a new image by either stripping away a layer of pixels or adding a layer of pixels to the boundaries of region of interest. Therefore, the morphological operations with EN concept were adopted in this paper. Also, the Euler number utilization in face detection from binary and morphological processed images is proposed. A similarity comparison study is performed by using the structural similarity index (SSIM). It considers the edges and complex boundaries and allows one to generate the matching score between the processed face images when various morphological operators were utilized.

2. METHODOLOGY

2.1 Otsu's Binarization

The Otsu method is a global thresholding method based only on the gray level values in the image [16, 17]. It is the best known and used binarization algorithm, because it has a strong mathematical foundation for the proposed threshold value for binarization, namely the algorithm chooses a threshold value that maximizes the inter-class variance or minimizes the intra-class variance. The inter-class variance σ is defined as follows:

$$\omega_b^t(t) = \omega_1(t)\omega_2(t)[\mu_1(t) - \mu_2(t)]^2 \tag{1}$$

where $\omega_1(t), \omega_2(t)$ is the class probability and $\mu_1(t), \mu_1(t)$ represent the class means. The class probabilities are computed using the following relationships:

$$\omega_1(t) = \sum_{i \le t} c(i) \quad , \quad \omega_2(t) = \sum_{i > t} c(i) \tag{2}$$

whereas the class mean is given by:

$$\mu_1(t)=\sum_{i\le t} c(i)\cdot i \quad , \quad \mu_2(t)=\sum_{i>t} c(i)\cdot i \tag{3}$$

c(i) denotes a function indicating the number of pixels in the image that have the value i. The optimal threshold established by Otsu’s method t* is as follows [18]:

$$t^* = \arg\max_t \sigma_b^2(t) \tag{4}$$

2.2 Morphological operators

Image enhancement, as a part of image processing, provides solutions to reconstruct damaged regions of an image. Some usual solutions for enhancement are based on mathematical morphology. Similarly to filtering operations based on kernels, morphological methods apply a structuring element to an input image and give an output image of the same size.

In binary morphology an image is represented by a scalar function $f(x,y)$ with $(x,y)\in\Re^2$. The structuring element B is a small image or a small matrix of pixels in $\Re^2$ that determines the neighborhood relation of pixels with respect to a shape analysis task. The dilation of an image *f* with a structuring element B, denoted as *f*⊕B, replaces the grey level values of the image $f(x,y)$ by its supremum within a mask defined by B [19]:

$$(f\oplus B)(x,y):=\sup\{f(x-x',y-y')\,|\,(x',y')\in B\} \tag{5}$$

Usually, dilation adds a layer of pixels to both the inner and outer boundaries of selected regions.

Erosion operation builds a smaller object by removing its outer layer of pixels. It is defined as:

$$(f\Theta B)(x,y):=\inf\{f(x+x',y+y')\,|\,(x',y')\in B\} \tag{6}$$

The opening operation, denoted by ◦, as well as the closing operation, indicated by the symbol •, are defined by utilizing the processes of erosion and dilation and using the same structuring element:

$$(f\circ B)(x,y):=(f\Theta B)\oplus B$$
$$(f\bullet B)(x,y):=(f\oplus B)\Theta B \tag{7}$$

The opening operation in an image smooths the edges, removes small holes from the image *f* and breaks narrow block connectors. The closing operation also smooths the edges but it fuses the narrow blocks and fills in holes [20, 22].

2.3 Euler number

In image processing, the Euler number is defined as EN = N-H, where N describes the number of regions of the image or number of connected components of the object, and H denotes the number of holes in the image or that isolated regions of the image’s background.

2.4 Structural Similarity Index (SSIM)

Let’s consider two aligned images x and y. The similarity measure is a quantitative measurement of the quality of one signal if the second one is considered to have a perfect quality being considered as a reference image [23]. For two images x and y, the SSIM similarity measure is defined as:

$$SSIM(x,y) = [l(x,y)]^{\alpha} \cdot [c(x,y)]^{\beta} \cdot [s(x,y)]^{\gamma} \tag{8}$$

SSIM corroborates the following three components $l(x,y)$ luminance, $c(x,y)$ contrast and, $s(x,y)$ structure. α, β and γ are positive parameters used to adjust the relative importance of the three components [24]. This index analyses the edge information between the test and reference images, variability in edges preservation, and structural similarity of the images.

2.5 The hardware experiment and algorithm description

The experiment uses a computer with Intel (R) Core (TM) 2 Duo CPU T 5900, 2.20 and internal storage of 3G RAM. The experiments have been carried in the Matlab R2016a environment.

The algorithm consists of the following steps:

Step 1. The input of the algorithm is a grayscale image belongs to the FACE94 free database;

Step 2. Binarization of the image using the Otsu's method and the output is a binary image having the same size as the input image;

Step 3. Morphological opening and closing operators act on each binary image;

Step 4. Euler number is computed for each binary image;

Step 5. The performance measurement for specific parameters behavior is performed based on the random pixels distribution generated by morphological operators.

Step 6. Structural Similarity Index (SSIM) computed between the reference images (i.e. images processed using the Otsu's method) and test images (i.e. images processed using morphological operators).

2.6. Image dataset

The proposed algorithm has been tested on 90 face images freely downloaded from Databases for Face Detection and Pose Estimation[1]. Images were rotated in the range of 0° to 90° with a step of 5° from the right profile (defined as +90°) to the left profile (defined as -90°) in the rotation plan.

3. EXPERIMENTAL RESULTS AND DISCUSSION

To analyze the effect of morphological operators, the basic idea is to extract information corresponding to Euler number values. In a first step the image binarization using the Otsu's algorithm is performed. In the second part, the morphological operators act in the images, then EN is computed and similarity studies are conducted.

In the experiments, a set of sequence images such as those displayed in figure 1 are selected. To enhance the algorithm robustness, the image samples are rotated in a range of 0° to 90 °. In our study, 95 images for five subjects are analyzed.

The binarized images in figure 2 are efficient in morphological operators processing. For a fast running, the structuring element is in disk shape with the radius imposed to be smaller than 5 pixels. The effect of dilatation and erosion operations is shown in figures 3 and 4.

[1] http://robotics.csie.ncku.edu.tw/Databases/FaceDetect_PoseEstimate.htm#Our_Database_

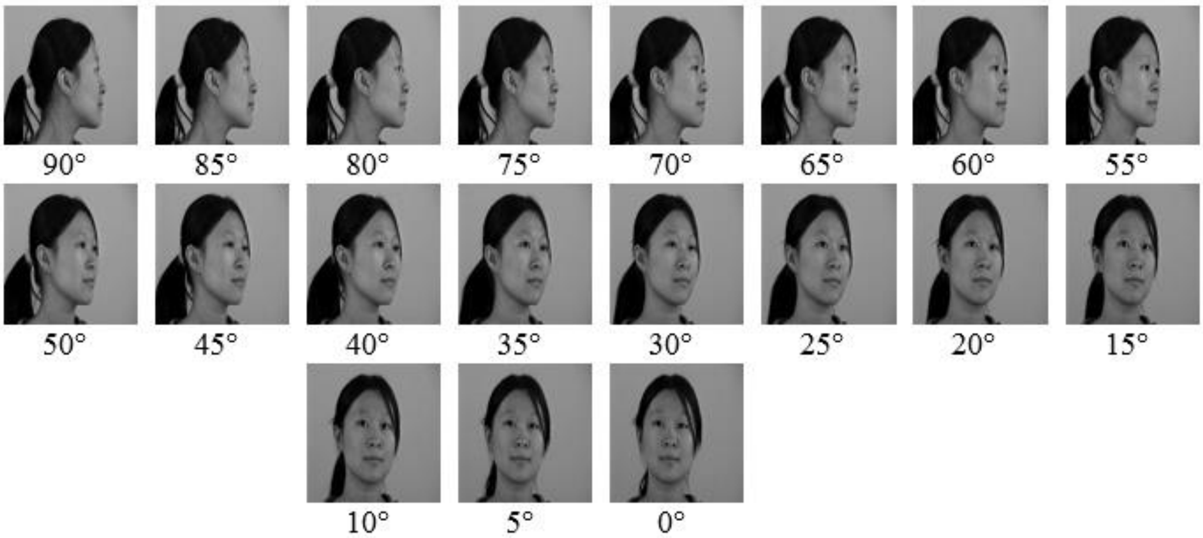

Figure 1. Example of face images. Note the variation starting from 0° (frontal) to 90° (left profile).

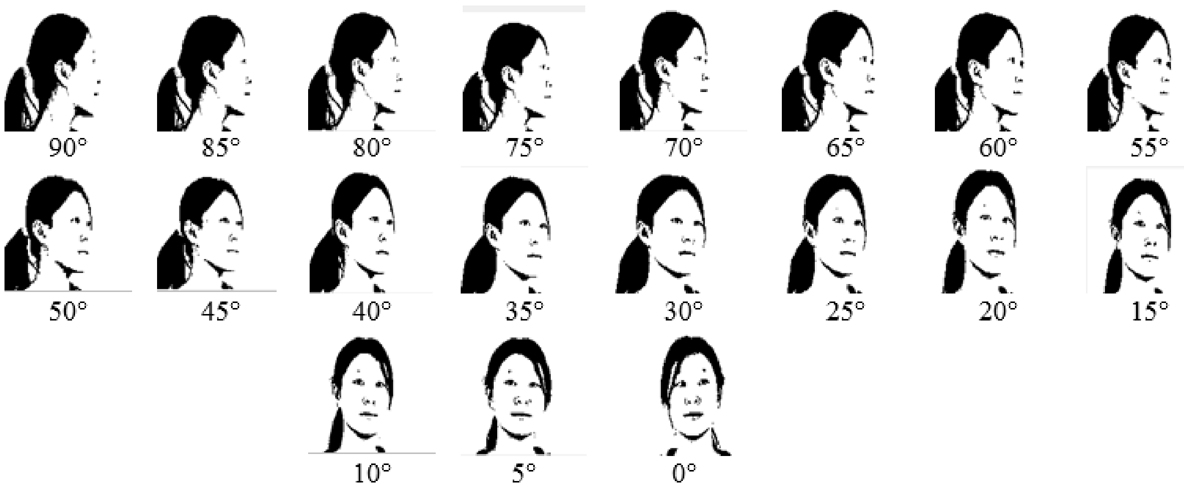

Figure 2. The binary images produced by Otsu's method

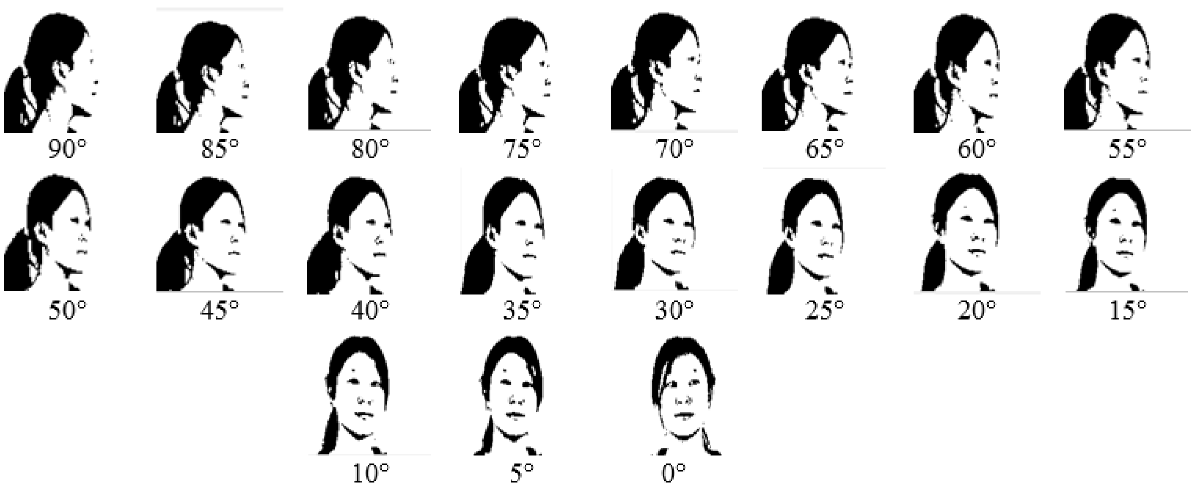

Figure 3. Dilated images with structuring element B = 2 disk shape with radius less than 5 pixels

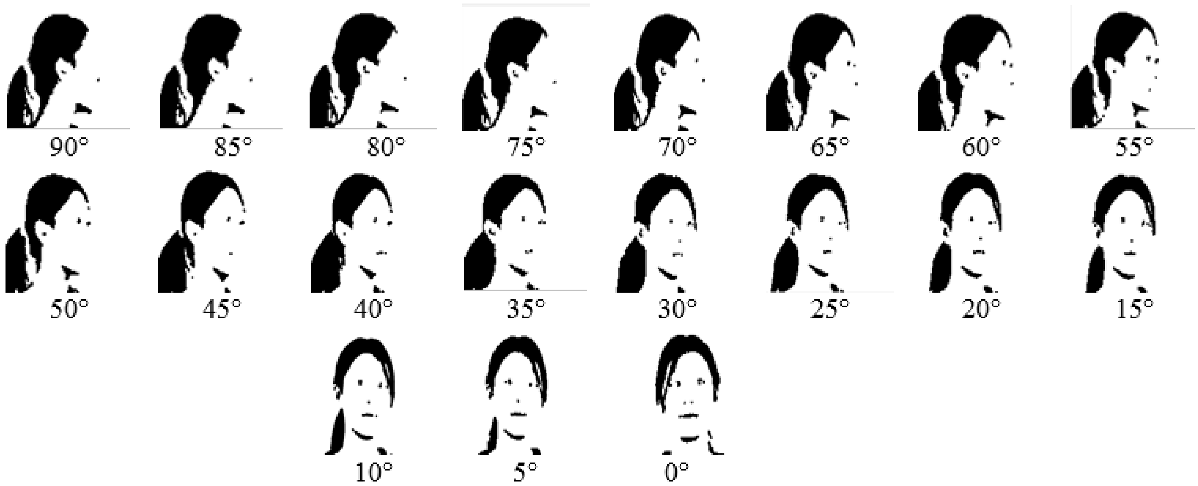

Figure 4. Eroded images with structuring element B = 2 disk shape with radius less than 5 pixels

As a feature prone to be extracted in face detection, the EN is computed for each processed image as the difference between number of connected components and isolated regions of the image's background. The average value of EN for five subjects is shown in figure 5. The averaging operation is performed for each image with respect to the rotation degree. Figure 6 displays the average values of the SSIM for each image with respect to the rotation degree from 0° to 90° and for both experimental conditions: the Otsu method and close operator (OM-CO) and the Otsu method and open operator (OM-OO).

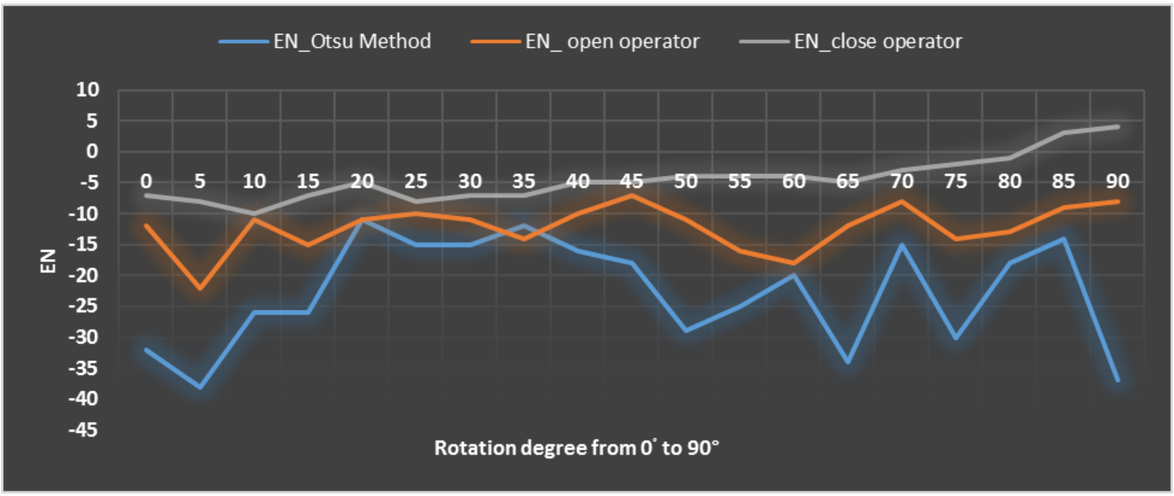

Figure 5. Average values of EN for each image with respect to the rotation degree from 0° to 90°.

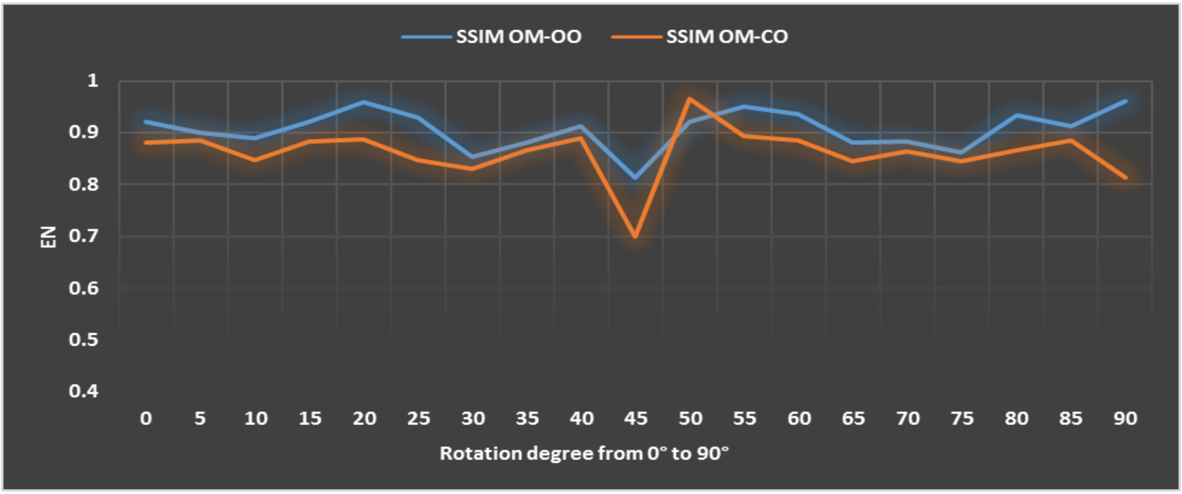

Figure 6. Average values of SSIM for each image with respect to the rotation degree from 0° to 90°. OM-CO means Otsu method – close operator, OM-OO is Otsu method – open operator

In the case of binary images (blue line in fig. 5), an important variability of EN values is observed and it is not possible to predict a connection between the number of regions, holes and connecting objects. As an alternative quantitative measure for characterization of structural properties, the EN has positive values in the case of images rotated with 85° and 90° degree that were processed with closing operation (gray line in fig. 5). It means that the number of connected components of the object N exceeds the number of holes in the image or that isolated regions of the image's background H and the better characterize and detect faces. Open operator fails to a lesser extent than Otsu's operator in face detection. SSIM data plotted as in figure 6 shows that morphological operations generate almost the same structural similarity between the binary image viewed as reference images and morphological images viewed as test images.

4. CONCLUSIONS

In this paper, we present a new algorithm for face detection based on Otsu's method and morphological operators. In face recognition algorithms, relationships between the number of regions, holes and connecting objects are very important the details. It is very important that the features of images to be conserved. The Euler number was used to quantify changes in images and SSIM index as a qualitative estimator of the similarity between processed images. With this work, we have shown that the closing operation can be used as a morphological operator conserving the structural image features with some advantages over opening operation.

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