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Illumination - Invariant Facial Components Extraction Using Adaptive Contrast Enhancement Methods

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors collaborated in designing the study, performing the statistical analysis, writing the protocol and writing the first draft of the manuscript and managing literature searches and managing the analyses of the study and literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

The process of accurate localization of the basic components of human faces (i.e., eyebrows, eyes, nose, mouth, etc.) from images is an important step in face processing techniques like face tracking, facial expression recognition or face recognition. However, it is a challenging task due to the variations in scale, orientation, pose, facial expressions, partial occlusions and lighting conditions. In the current paper, a scheme includes the method of three-hierarchal stages for facial components extraction is presented; it works regardless of illumination variance. Adaptive linear contrast enhancement methods like gamma correction and contrast stretching are used to simulate the variance in light condition among images. As testing material a subset consists of 1150 images belong to 91 different subjects was taken from Cohn-Kanade AU coded dataset (CK); the subjects images hold different facial expressions. The test results show the effectiveness of the proposed automated localization scheme in different illuminations conditions; it gave accuracy of about 95.7%.

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Keywords: Facial components; illumination invariant; adaptive gamma correction; adaptive contrast stretching; image segmentation.

1. INTRODUCTION

Face is the most important visual identity of a person, which mostly attracts our attention. We often describe a person in terms of the characteristic features of important face components like eyes, eyebrows, nose and lips, together with the overall shape of the face [1]. Recently, component-based approaches have shown promising results in detection of various objects, and recognition tasks such as face detection, person detection, and face recognition [2].

One of the very first operations that are needed for facial components extraction is the face detection [3]. Face detection is difficult mainly due to a large component of non-rigidity and textural differences among the faces. The great challenge for the face detection problem is the large number of factors that govern the problem space. The long list of these factors include the pose, orientation, facial sizes found in the image, luminance conditions, occlusion, structural components, gender, ethnicity of the subject, the scene and complexity of image's background [4]. However for single face image face localization is used. The purpose of face localizing is to extract the face region from the background; this is a simplified detection problem with the assumption that an input image contains only one face. While in face detection, one does not have this additional information [5].

Numerous methods have been proposed to detect faces in an image. Face detection methods can be classified into four categories: knowledge-based methods, feature invariant methods, template-based methods, and appearance-based methods [6]. Knowledge based methods are based on human knowledge of the typical human face geometry and facial features arrangement. Taking advantage of natural face symmetry and the natural top-to bottom and left-to-right order in which features appear in the human face, these methods find rules to describe the shape, size, texture and other characteristics of facial features [7]. These methods are designed mainly for face localization which aims to determine the image position of a single face [8]. Accurate extraction of facial components is an important step in geometric-based feature extraction methods; which are commonly adopted in many research areas like face recognition and facial emotion recognition. In these methods the location of key facial components (such as mouth, eyes, eyebrows and nose) are being tracked and the geometric relationship between certain key points (fiducial points) on the face (as distances, angles and shapes) are determined when making cognition decision. The established feature vectors for performing facial cognition tasks usually transmit the extracted facial components at these key geometric regions on face [9].

Dewi et al. in 2010 [10] have developed a model that defines face components by determining the distance of face components and other facial components by detecting the based skin color, cropping to normalize face region and extracting eyes, nose, and mouth components. The proposed model has been tested using 150 Indonesian face samples and has successfully determined the face components. Kahraman and Gokmen in 2006 [11] have combined the concept of component-based approach and face alignment to develop component-based Active Appearance Model (AAM) method for fine facial components extraction.

The goal of the present investigation is to extract the basic facial components for images containing one face in front position regardless of image illumination.

2. PROPOSED METHODOLOGY

The overall design of facial components extraction module (as shown in Fig. 1) consists of three hierarchal stages:

1. Head Area Allocation Stage.
2. Face Area Allocation Stage.
3. Facial Components Extraction Stage.

In head allocation stage, head region is located and the background area is removed. While, the goal of face allocation stage is to allocate face region (ROI) using knowledge based methods.

In facial components extraction stage the most important facial parts are extracted using adaptive illuminate correction methods and rules are encoded to extract these parts.

2.1 Head Area Allocation Stage

In head area allocation stage a series of image processing methods are applied to crop head region from the image and remove the irrelevant background part; this stage is vital to reduce the process time of searching for face pattern in the "face allocation stage". Fig. 2 illustrates the taken steps of this stage.

First, the edges images are extracted using Sobel edges detector. This operator consists of a pair of 3×3 convolution kernels each kernels is simply the rotated variant (by) of the other. The kernels can be applied separately upon the input image, to produce separate measurements of the gradient (G) component in each orientation (G_x and G_y) [12]. Because the images that are used in our experiments contain background with horizontal edges texture, so the vertical gradient (G_x) component is extracted to produce vertical edges image and, then, ignoring undesirable background texture.

However, the result of applying vertical edges detector may contain small noisy regions. So, the produced image is needed to be cleaned. Seed filling algorithm is used to assemble the entire image into sub regions or large regions based on white pixel locations in bottom up fashion [13]. Small regions (e.g., regions with size less than or equal to 20 pixels) are removed to produce more clean binary image.

For allocation head area and cropping it, Image clipping is used. Clipping is responsible for eliminating those parts of the scene which do not lay onto the window rectangle, because they are outside the interesting volume for next stage task. This process is done by making four separated scans (i.e., along the four directions: right, left, up, & down), to capture the first hit of white pixel along each direction. The search is done using a window of specific height (we have used height of 60 pixels) from the middle of the image (30 pixels above the middle and 30 pixels below it) in each direction to achieve more accuracy for clipping head region. Then, the locations of the four hit points are used to define the clipped region coordinates. More description for head clipping step is shown in Fig. 3.

2.2 Face Area Allocation Stage

For the purpose of facial components extraction, the whole face region must be allocated first. Knowledge-based method is used for this purpose by exploiting the human knowledge about the structure of the face such as symmetry property and morphology of face to build face pattern (as shown in Fig. 4) and encoding rules that could simulate this pattern.

Fig. 1. Overall proposed module design

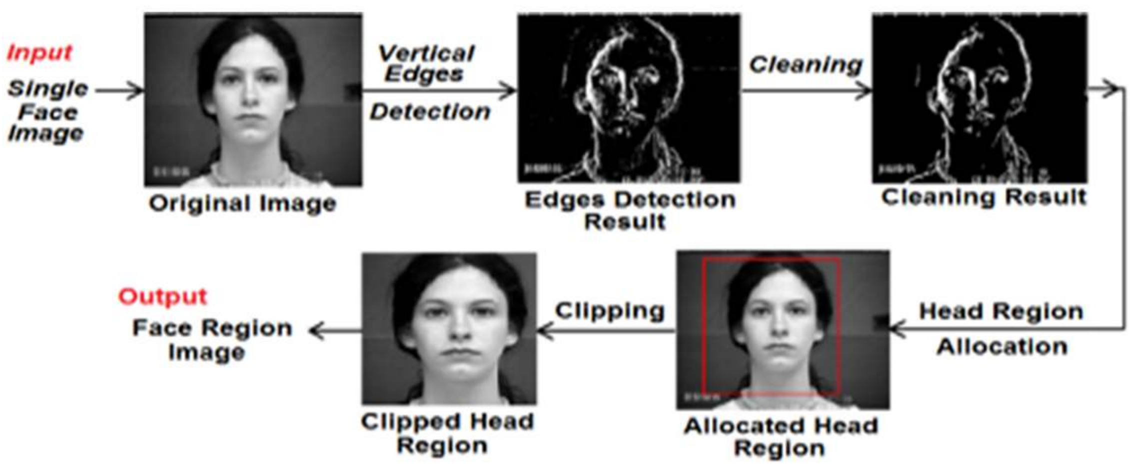


Fig. 2. Block diagram for head area allocation stage

Before searching for face pattern in head region image, we must first make head image appropriate for such search task. First of all, the entire image is down sampled using bilinear interpolation technique with scaling factor equal to 0.6 to reduce the computational complexity and increase the speed of the next steps.

After that, illumination compensation step is applied to reduce the effectiveness of light differences and to compensate the differences in skin colors.

The image is, then, subtracted from its mean image to remove any shadow effect. Then, the offset value 128 is added to all pixels of image subtraction step, this offset addition will make the mean of produced image is mid-gray (i.e., 128).

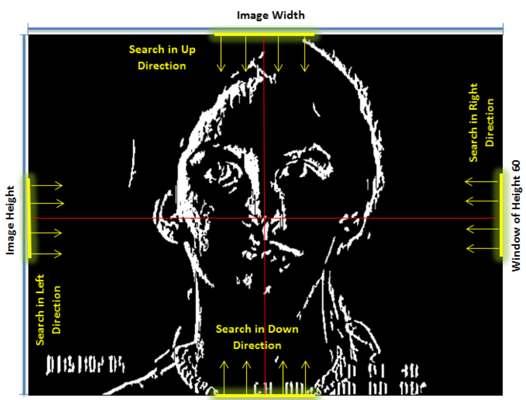


Fig. 3. Description of head region clipping step

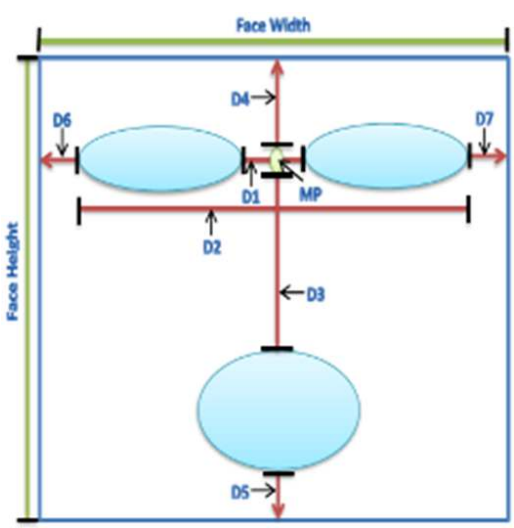


Fig. 4. Typical human face pattern

After that, the averaging smoothing filter of size 3x3 is applied to replace each pixel value in the image by the average value of its neighbors including itself. The main reason behind choosing mean filter from other noise reduction filter types is "the mean filter could blur any texture and highlights objects". So that we used mean filter to achieve blurring and removing the noise of salt type that is generated due to subtraction process.

The image resulted from smoothing operation is linearly stretched to make the contrast of the image covers the full range of available brightness values. This step is applied globally and the selection of stretching parameters is focused mostly on darkening the facial components to find facial pattern easily.

To convert the image into binary version and make the objects highlighted in dark background; thresholding operation is applied. Then, closing morphological operation is applied on the binary image to fill small gaps. The block diagram for previous steps is shown in Fig. 5.

To search for face pattern the binary image is segmented into isolated regions using region growing method.

Now we can search for face pattern within face segments using the typical human face pattern that shown in Fig. 4. The following rules are adopted to define the face pattern:

A. The shape of eye segments is long. In other words the standard deviation of x-coordinate of the segment pixels is higher than the standard deviation of y-coordinate for same pixels.
B. The two eye segments must lay, approximately, on same horizon.
C. The distance between these two segments should be not less than D1 and not more than D2.
D. The midpoint between eye segments (MP) is generated to search from it for mouth segment.
E. Mouth segment must be on the same symmetric line of the face and its distance from MP point must be greater than D3.

The search is continued till an acceptable match level is met. When match is occurred, the face image is extracted with the following coordinates:

*Top=MP- D4, where D4=0.1*Image Height*

*Down=Max pixel in the mouth segment within the y-coordinate + D5, where D5=0.1*Image Height*

*Left= Min pixel in the left eye segment within the x-coordinate–D6, where D6= 0.05*Image Width*

*Right = Max pixel in the right eye segment within the x-coordinate + D7, where D7=0.05*Image Width*

The width and height for face image are:

Face Width=Bottom-Top

Face Height= Right-Left

The block diagram for the process of searching about face pattern and face detection is shown in Fig. 6.

2.3 Facial Components Extraction Stage

In this stage a set of procedures has been applied to extract facial components regardless of the skin and hair colors and regardless of the light condition especially the effect of shadow produced from bad illumination in eyebrows and eyes regions.

Gamma Correction function is often used in image processing to compensate the nonlinear responses in imaging sensors, displays and films by raising the image pixels intensity to power called gamma (γ). The general form for gamma correction (G_R) for image pixels intensity (I) is [14]:

$$G_R(x,y) = 255 \times \left(\frac{I(x,y)}{255}\right)^{\gamma} \quad (1)$$

Linear contrast stretching technique attempts to improve the contrast of an image by linearly stretching the pixel values of a low-contrast image or high-contrast image by extending the dynamic range across the whole image spectrum. The applied mapping function for this enhancement type can be found in equation (2); it linearly maps the lowest gray level (G_{min}) and highest gray level (G_{max}) to lie at certain extent from the mean of the image.

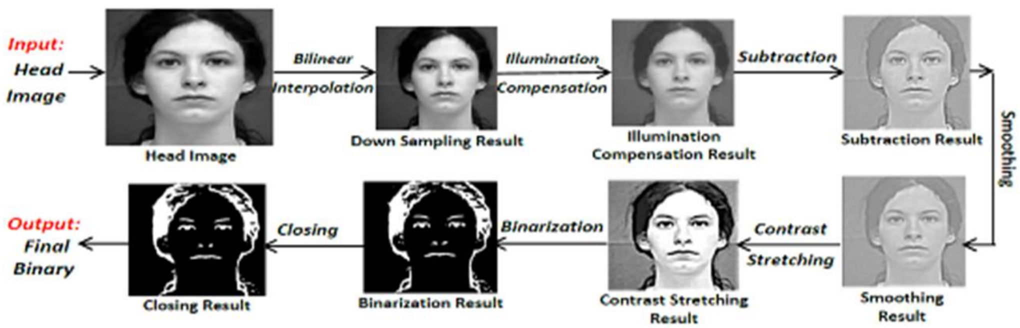


Fig. 5. Block diagram of Image preparation for face pattern searching

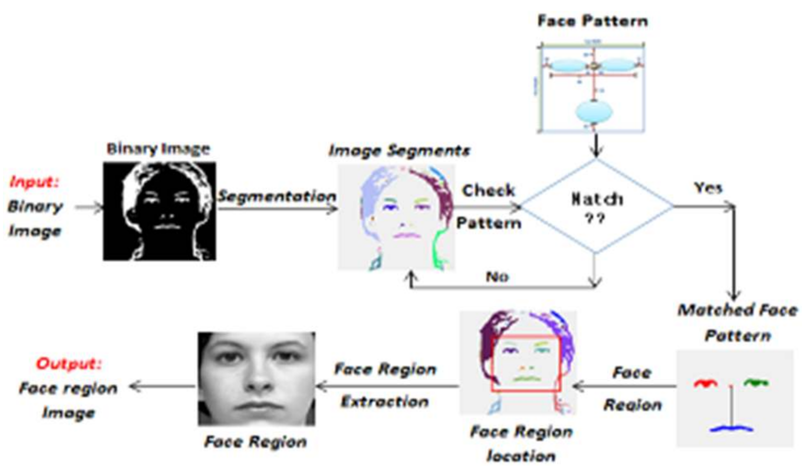


Fig. 6. The steps of facial components extraction stage

The other gray levels are remapped linearly to be between G_{min} and G_{max} limits [15]:

$$I_s(x,y) = 255 \times \left(\frac{I(x,y) - G_{min}}{G_{max} - G_{min}}\right) \tag{2}$$

The values of G_{min} & G_{max} are determined using the following equations:

$$\mathrm{G_{min}} = \mu - \alpha\,\sigma \tag{3}$$

$$\mathrm{G_{max}} = \mu + \alpha\,\sigma \tag{4}$$

Where μ, σ are the mean and standard deviation values, respectively, of the image. The parameter α used to control the strength of achieved linear extent.

When each of the traditional (non-adaptive) contrast enhancements methods (i.e., linear stretching and Gamma Correction) was used to enhance the images, the results showed high difference in illumination condition and skin color. It was noticed that the task of extracting the basic facial components is no longer successful because no fixed gamma or alpha values could be used to make all dataset images ready to give us the desired segmentation results. Table 1 shows the results of applying gamma correction (with two gamma values γ=0.5 or 1.5) and the results of applying contrast stretching (with two alpha values α=0.5 or, 1.5) on the original facial image for four different images (from Cohn-Kanade dataset) which are differ in illumination condition and skin color. The resulted images hold different brightness behavior in facial elements areas which causes difficulty in achieving the desired segmentation results.

Adaptive operation can be considered as a good solution when the images, belong to the tested dataset, highly differ in their lighting conditions (as shown in Table 1).

At first, the facial image is divided into two equal parts (i.e., upper & lower parts). The upper part should contain eyebrows and eyes regions, while the lower part contains the mouth region.

Adaptive gamma correction is performed in a way that allows us to drop down the gray values of the pixels lay in the central two-thirds of the upper part of the facial image. The dropped down values will be less than or equal to intensity value 100; this step is important since it facilitates the next steps by making histogram distribution of different images, which have different brightness distributions, are close to the distribution that is highly focused on the first 100 gradients of dark intensities. Algorithm 1 illustrates the implementation steps of the adaptive gamma correction.

Table 1. Non- adaptive contrast enhancement results for four different subjects with two different parameters values for each method

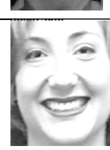
#	Original facial image	Gamma correction		Contrast stretching	
		γ=0.5	γ =1.5	α=0.5	α=1.5
1					
2					
3					
4					

Fig. 7 shows an example of the original smoothed face image (the upper part) histogram and the histogram of it after applying adaptive gamma correction (with adaptive gamma which is equal to 4.2).

Now after restricting the histogram on dark region, then it is redistribute it to occupy the full dynamic range [0-255] by using histogram equalization method. The purpose of this step is to facilitate the isolation of eyebrows from eyes segments especially in images with bad illumination. Fig. 8 shows the result of histogram equalization when applied on gamma corrected image, that shown in Fig. 7, with its histogram.

Algorithm 1. Adaptive gamma correction
Input:
SImage(); smooth image array of the upper part of the facial image
Wid,Hgt: width & height of the upper part of the facial image respectively
Output:
GImage: The upper part of the facial image after applying adaptive gamma correction
Begin
Step1: **Set** His()←Histogram of SImage
Step2: // Initialization
Set N1←Sum of the first 100 elements values of His()
Set N2←Sum of the remaining values of His()
Set Ratio←N1/N2
If (Ratio<0.6) **Then**
Set GImage←SImage
Goto Step 4
Else Set Set EG←1
Set Gstep←EG*0.2
End If
Step3: Set EG←EG+Gstep
Set GImage←Gamma_Correction on SImage with EG value
Set His()←Histogram of GImage
Set N1←Sum of the first 100 values of His()
Set N2←Sum of the remaining values of His()
Set Ratio←N1/N2
If (Ratio<0.6) **Then Goto** Step 4 **Else Goto** Step3
Step4: End

Algorithm 1. Implementation steps of adaptive gamma correction

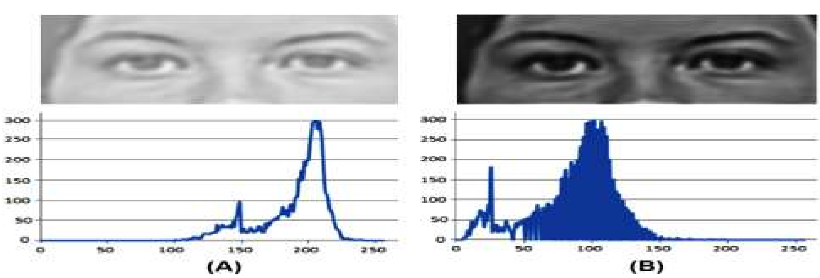


Fig. 7. (A) Original smoothed image with its histogram, (B) Gamma correction result with its histogram

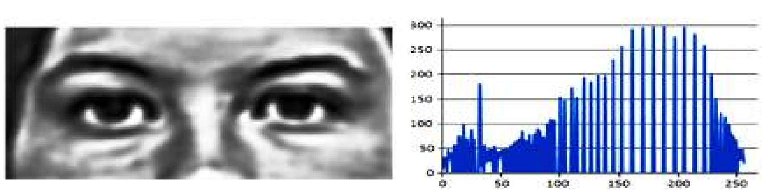


Fig. 8. Histogram equalization result with its histogram

An adaptive contrast stretching is proposed with minimum value (Min) set to 0 and maximum value (Max) equal to:

$$Max = \mu + \alpha\sigma \qquad (5)$$

Where, (μ, σ) are the mean and standard deviation values, respectively, of the image pixels, α is the adaptable multiplication parameter. The proposed adaptive contrast stretching method has been used to search for two pairs representing the eyebrows and eyes segments. This search is done by converting the image into binary form; then the region growing method "seed filling" is used to segment the binary image into isolated regions. By counting number of existing pairs we can optimize the search for the adaptive contrast stretching parameter (α); if the number of existing black segments is more than two we need to decrease the (α) value by changing the direction of alpha change (i.e., set Δα=- Δα). While, if the number of segments is less than two then there are two possibilities. The first is the eyes and eyebrows segments may be integrated and in such case we need to increase alpha value. The second possibility is one of the two pairs may actually not appeared in the segmentation result, and in this case we need to decrease alpha value. Algorithm 2 demonstrates the steps of this optimization task in order to obtain eyes and eyebrows segments.

Fig. 9 shows an example result for the process of searching the eyebrows and eyes segments using adaptive contrast stretching. In this image example the segments are founded when α (i.e., EA) is set (2.4).

After extracting the eyes and eyebrows segments we can now search for nose position. To find the position of nose point we need to search for light reflection spot (bright region) in the face image; which is normally founded in nose area. A window (for example of size 20*20) is opened on that region (i.e., at predefined distance from MP) and a search for bright pixels, that form nose position, is done. Algorithm 3 describes the steps of the applied process for noise area detection.

Algorithm 2. Adaptive contrast stretching
Input:
HImage(): The upper part of the facial image after applying histogram equalization.
Wid, Hgt: width & height of the upper part of the facial image respectively
Output:
E,EB: Eyes and Eyebrows pairs segments respectively
Begin
Step1: // Initialization
Set EA ←2
Set SImage()←Contrast stretching on HImage with EA
Set BImage()←Binarization on SImage
Set CImage←Closing on BImage
Set Segments←Image Segmentation on CImag
Set PairNo←Pairs count exist in Segments
If (PairNo>2) **Then Set** Sign←-1 **Else Set** Sign←1
Set itr←0: AStep←EA*0.2
Step2: Set EA←EA+Astep*Sign
Set SImage()←Contrast stretching on HImage with EA
Set BImage()←Binarization on SImage
Set CImage←Closing on BImage
Set Segments←Image Segmentation on CImag
Set PairNo←Pairs count exist in Segments
If (PairNo>2)**And** (Sign=1) **Then Set** Sign←-1
Else If (PairNo<2) **And** (Sign=-1) **And** (itr<10) **Then Set** Sign←1
Else If (PairNo<2) **And** (Sign=1) **And** (itr>=10) **Then Set** Sign←-1, EA←2
End If
If (PairNo=2) **Or** (itr>40) **Then Go to Step3**
Else Set itr←itr+1: **Go to Step2**
End If
Step3: End

Algorithm 2. Implementation steps of adaptive contrast stretching

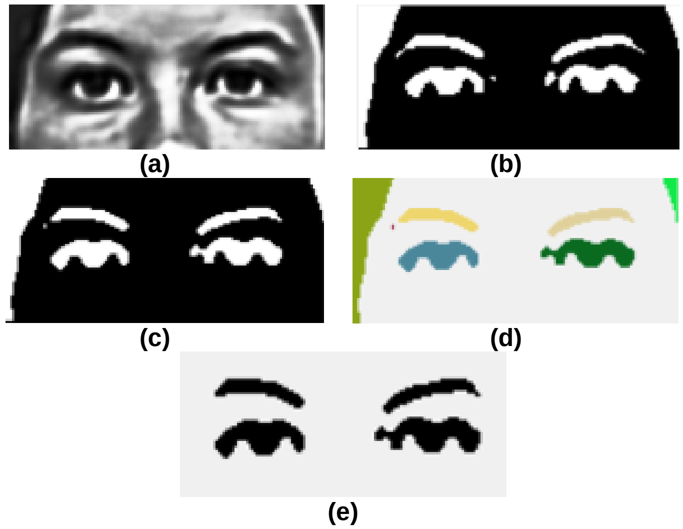


Fig. 9. (a) Original linearly stretched image, (b) Binarization result, (c) Closing result, (d) Segmentation result, (e) Eyes and eyebrows segments

Algorithm 3. Nose point detection
Input:
  NImage(): The region of candidate nose position after histogram equalization
  Wid,Hgt: Nose region width & height respectively
Output: Nx,Ny : Nose point location (X,Y)
Begin
  Set His() ←Histogram of NImage
  Set T←Wid*Hgt, G←255, Sm←His(G)
  While ((Sm/T)<0.06) **Do**
    Set G←G-1
    Set Sm←Sm+His(G)
  End While
  Set NoseArr(Wid,Hgt)←0
  For all i,j {where 0≤i<wid,0≤j<Hgt}
    If NImg(i,j)<G **Then Set** NoseArr(i,j)←0 **Else Set** NoseArr(i,j)←255
  End For
  Set Segments←ImageSegmentation on NoseArr
  Set Sum←Sum of all Segments X-coordinates
  Set X←Sum/T
  Set Sum←Sum of all Segments Y-coordinates
  Set Y←Sum/T
End

Algorithm 3. Implementation steps of nose point detection

Histogram equalization is applied on face image to extract a point that works as reference to allocate the segment area contains the mouth region regardless of skin color. This point is taken from cheeks region. Mouth region is located by opening a window of size (pxq) under nose location and this region is converted into binary image using relative point and then closing is applied on it to fill small gaps. For the taken dataset taken in this research (i.e. Cohn Kanade dataset) the values of (pxq) are set (140x100). Then, Sobel edge detection is applied on the lower part of the facial image to generate the edges map. The binary image and edges map are combined to give better result and producing final binary image.

Finally, the region grown method is applied to segment the final binary image and the largest segment will choose as mouth segment. Fig. 10 shows the results of nose detection and mouth region allocation steps.

3. EXPERIMENTS RESULTS

The proposed system was tested using 1150 gray scale images taken from Cohn Kanade (CK) dataset. These images are chosen from 91 different subjects with different skin colors. These subjects show different face expressions. Also, the images have variant illumination conditions.

The proposed optimization task had succeeded in choosing the best parameters for each image based on its lighting condition. Table 2 shows the system performance on ten different subjects with different skin color, light condition, and different emotions as long as with the suitable gamma and alpha values those are determined by the proposed module.

The proposed module succeeded in extracting the facial components for 1101 images and gave accuracy of about 95.7%; it fail with the remaining 49 images. The reason behind the failure of these samples is that the segments of eye and eyebrow and the region between them are all of same gray intensity.

In Table 3 a comparison has been made with the results of other existing works, the table also includes the methodology that has been used and the total number of image samples used in each work for purpose of the proposed system performance evaluation.

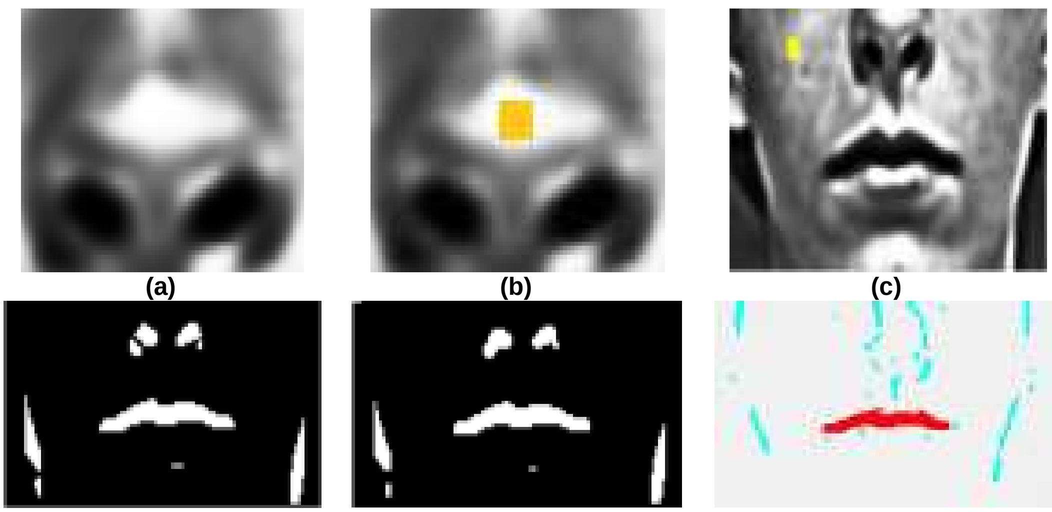
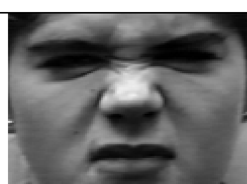
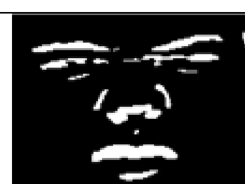


Fig. 10. (a) Light reflection region in the nose, (b) Nose point position, (c) Mouth relative point position, (d) Candidate mouth region in binary form, (e) Candidate mouth region closing result, (f) Mouth segment and the supported edges map

Table 2. Adaptive contrast enhancement results for 10 different Subjects

#	Facial image	Adaptive contrat enhancement result	Binarization result	Gamma value	Alpha value
1				2.8	0
2				4.2	2.4

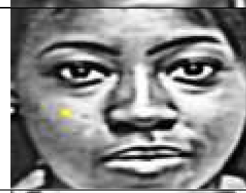
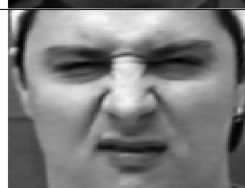
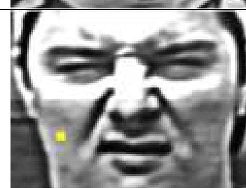
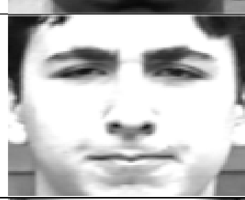
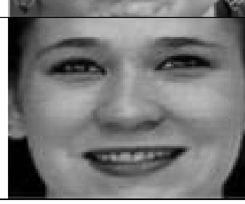
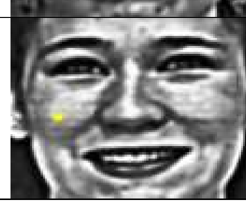
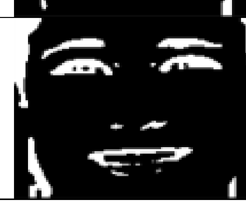
#	Facial image	Adaptive contrat enhancement result	Binarization result	Gamma value	Alpha value
3				3.4	0.4
4				2.6	2.4
5				3.6	0.4
6				4.4	0.8
7				2.6	0
8				3.8	2.4
9				4.8	-0.4
10				4.2	2.4

Table 3. Comparison with some of other published works

Authors	Method	Result (%)	No. of image samples
Dewi et al. (2010) [10]	Based on skin color	100	150 Indonesian face images
Khandait et al. (2010) [16]	Edge projection analysis	93.33	30 Images obtained from Sony make digital camera
Ali and Sedigheh (2011) [17]	Geometric distances between facial components	97.66	342 frontal color images from CVL database
Vijayarani and Priyatharsini (2015) [18]	Image decomposition using Gabor filters	100	15 images form JAFFE dataset
Our Approach	Adaptive contrast enhancement methods	95.7	1150 images from 91 different subjects from Cohn-Kanade dataset

4. CONCLUSION

An adaptive contrast enhancement method was proposed in the current paper to extract basic facial components regardless of illumination variation. The use of adaptive gamma correction and adaptive linear stretching led to high performance of the proposed system. The results of the conducted tests clearly indicated the effectiveness of the suggested model, when it is applied on Cohen Kanade (CK) dataset.

DISCLAIMER

The images used in this research belong to the public data base Cohn-Kanade (Ck) which can be downloaded from web site: The Affect Analysis Group At Pittsburgh (http://www.pitt.edu/~emotion/ck-spread.htm)

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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