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Transforming and enhancing irregular facial features' images while constructing a human face

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ABSTRACT

The aim of this work is to extract the irregular shaped image of different human facial components and then apply transformations on them. This process will be done through constructing a human face according to verbal description supplied by some people (witnesses). This process starts by selecting basic facial components from a pre-defined database, and then position these components into their target place, each of these components will be manipulated as an image of various shapes (no regular width and length for them). This happens by applying edge detection process, which is used to detect the boundaries of the selected component. In this way only pixels which are available within the detected boundaries will be picked to compose that component's image. Different transformations (like scaling and rotation) are applied on the selected irregular shaped facial components to facilitate forming and reshaping these components until reaching the desired shape. The reshaping process is accomplished by using vertical and horizontal scaling factors. These factors are applied unequally on different portions of the facial components to change their shape as needed. In the other part of the work, the resulted image of the constructed face will be enhanced by applying some smoothing techniques like linear special filters (mean and plus-shaped filters), and other nonlinear filters (median and mode filters). Other extra tools like darkening, lighting and hand drawing are also applied on the resulted facial image.

It is found that dealing with the original irregular shape of each individual facial component image (rather than managing the extra undesired region imposed by the regular (rectangular) image) gives more flexibility and efficiency in formulating the desired face. It also found that applying unequal scaling factors on different parts of the irregular images produces better reshaping results, which in turn helps the police artist to reach the desired face easily.

Keywords*:* *Irregular shaped images; Image-transformation; Image-reshaping; Image-enhancement, feature-based.*

1. INTRODUCTION

Computers have several potential uses in manipulation of images. This makes it possible to implement the face construction problem and develop the designing capabilities needed for this task, so that it can be accomplished better, faster, and more efficient. One aim of this work is to perform the duty of the police artist who composes a recognizable facial image on the basis of verbal description and interactively-supplied feed-back information provided by a witness who does not have the perceptions of an artist. In the usual cases, sketching a recognizable human face involves artistic talents [3, 5]. This man-machine system provides facilities with which a non-artist can create a facial image on the screen. These facilities involve using initial featureless face as a starting point, database containing the basic elements of the face, transformations tools to enable reshaping the selected facial components' images until reaching the desired face, and smoothing methods for further enhancement for the produced face if needed.

An important objective of this work is, taking the part of the facial component's image which represent that feature itself rather than the extra pixels in its background, and then applying transformations on that part only. Another objective is reshaping the facial features by applying different values of scaling factors on different parts of the specified facial component in the same time, so that the width or height will be reduces or increases unequally on different parts of that irregular image. This will make it easier to reshape (like make it thinner or wider from one part of the image only rather than the other parts).

2. The overall work

The face construction process, which has been implemented in this man-machine system is based on making series of decisions about the overall shape of the target face and choosing the basic elements for that face from the system's database to obtain facial features which are most closely match the corresponding ones of the target face. During the construction process, either the shape of the face or any of the contained features can be adjusted using the modification tools provided by the system as an attempt to improve the similarity to the original features. After finishing this step, another need may appear, that is trying to enhance the regions between the tailored elements by applying one of the smoothing filters (after displaying the effect of each one) either to a local area or to overall of the face. Other tools are provided to lighten or darken the selected elements or to add external gray colors or shadows as needed. Figure (1) shows the main steps of this system.

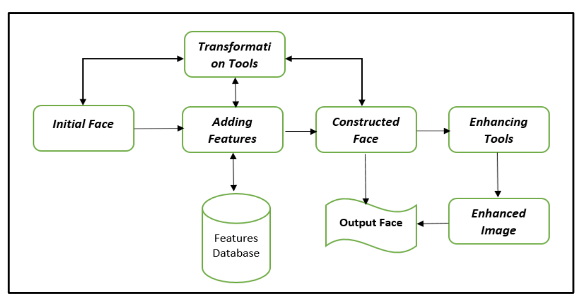

Figure 1: Construction steps

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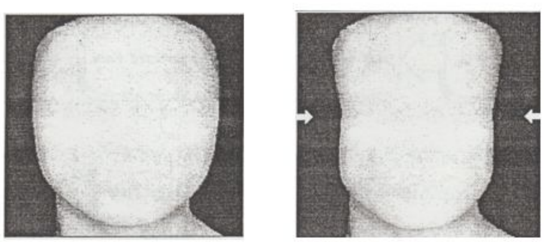
To implement this work, the first thing to do is collecting a set of frontal view images of human faces (which cover the most familiar features in the community), and then each individual facial components will be extracted to be saved later in a database. These images will be saved and manipulated as a Gray level images. The details of the facilities contained in the system are as follows:

2.1. The initial featureless face

An average face has been chosen to be the initial point (for both male and female faces). All features (eyes, eyebrows, nose, mouth, ear, hair) have been removed from it, so that it is ready to accept any of the selected features.

The main activity needed to be performed on this face is the shape manipulation. The gross shape of this face can be modified using two types of scaling routines. In the first type, the gross length or width can be shrunk or stretched as required. In the second type, the scaling process shrinks or stretches the width of a specified horizontal axis (as selected), and this shrink or stretch will be reduced gradually when continue applying them on the rest horizontal lines of the shape of that feature as shown in figure(2). These adjustments can be applied before and after setting these features on the face.



(a) (b)

a) The original shape of the initial face.

b) The resulted shape after shrinking it in the axis specified by the arrows

Figure 2: Applying Local Scaling to the initial face

2.2. The feature set (basic components of the database)

Since the basic strategy consists of making a choice from a set of pre-stored features and then manipulating the chosen features, then the specifications of the feature sets to be stored are of critical importance.

The features (or facial elements) are obtained from a collection of different real facial images, and stored in a database. Each feature with its background color will be stored and displayed as a rectangular image. And since each individual feature has its own particular irregular shape, this shape is needed to be detected to pick this feature by itself without the background augmentations. In this way the additional undesirable background colors will be avoided, and more efficient manipulations can be applied to these features.

Edge detection is used to detect the object (i.e. the individual shape of the feature) using Sobol operator which utilizes two 3 × 3 masks as following:

$$x - window = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} \qquad y - window = \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ -1 & -2 & 1 \end{bmatrix}$$

The edges (which are boundaries between regions having different gray level values) are detected after applying these masks on each pixel $f(x,y)$ of the image. The intensity gradient is calculated in two orthogonal directions, x and y as follows:

$$\Delta_y f(x,y) = f(x-1,y+1) + 2f(x,y+1) + f(x+1,y+1) - [f(x-1,y-1) + 2f(x,y-1) + f(x+1,y-1)] \quad \ldots \text{Eq(1)}$$

$$\Delta_x f(x,y) = f(x+1,y-1) + 2f(x,y+1) + f(x+1,y+1) - [f(x-1,y-1) + 2f(x-1,y) + f(x-1,y+1)] \quad \ldots \text{Eq(2)}$$

The digital approximation for the resultant gradient of f(x,y) will be:

$$\Delta\, f(x,y) = \sqrt{\Delta_x f(x,y)^2 + \Delta_y f(x,y)^2} \quad \ldots \text{Eq(3)}$$

If $\Delta f(x,y)$ greater than a threshold T, then an edge is detected [Gonzalez 2016]. Figure (3) shows an example for edge detection.

(a) (b)

a) An individual eye image.

b) Edge detected image with threshold = 4.

Figure 3: Example of Edge Detection

For the selected feature, the pixels inside the detected boundary (which constitute the individual feature), can be manipulated as follows:

1. Translating it to the target location.
2. Applying a scale routine to it, so that its width or length can be shrunk or stretched as needed. (in case of the nose, local scaling, as explained in the featureless face) is provided, so that the width of the upper part can be scaled rather than the lower part and vice versa).
3. The colors can be darkened or lightened.
4. The paired features such as eyes, eyebrows, and ears are stored and displayed in a single form (e.g. for each pairs of eyes, one eye displayed). After making a selection, the first selected part of the pair is flipped horizontally to obtain the

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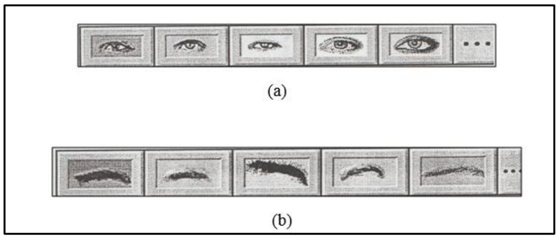
other part, which can be manipulated as the original one exactly.

5. The distance between the paired features can be manipulated also.

Figure (4) shows samples of the contents of the feature's database.



a) Some of the components of the eyes' database.

b) Some of the components of the eyebrows' database.

Figure 4: Database Samples

2.3. The transformation Utilities

The objective of this work is to "home-in" the face being constructed to its target. Therefore some graphical techniques are needed to aid the interactive construction process. Various options are provided to select and manipulate the facial features independently.

The applied transformations are:

Translation:

The selected feature object will be placed in its initial position on the featureless face. This position can be adjusted at any direction by adding/ subtracting appropriate factor to x and y coordinates of all its pixels [6, 8].

That is:

$$x^{new} = x^{old} \mp vertical\_translate\_factor \qquad \dots \text{Eq(4)}$$

$$y^{new} = y^{old} \mp horizontal\_translate\_fact \qquad \dots \text{Eq(5)}$$

This process can be performed during the overall construction time, even after setting all the features. (E.g. minimizing the space between the eyes or change the position of the nose).

Scaling:

The scaling process is needed to change the size and shape of the selected feature objects by stretching or shrinking their dimension. This is accomplished by multiplying each of the coordinates of the object's pixel by a scale factor [2], as following:

$$x^{new} = x^{old} * vertical\_scaling\_factor \qquad \dots \text{Eq(6)}$$

$$y^{new} = y^{old} * horizontal\_scaling\_factor \qquad \dots \text{Eq(7)}$$

Scaling Regular Image:

The output of these equations may be a fractional value which cannot be represented physically on the screen therefore the value of the corresponding pixels in the scaled image may be lost.

In most systems this problem has been overcome by considering the scaled version of an image as an entirely new mage that must be filled in from the original image. This is done by mapping each scaled pixel position back to the source bitmap and uses the pixel value found at the source location for the value at the corresponding scaled pixel [7], as follows:

1. Calculate the new number of rows, let it be scaled_hight.
2. Calculate the new number of columns, let it be scaled_width.
3. For each row and column in the scaled image, find the row and column in the scaled pixel in the source image.

$$source\_row = scaled\_row * \frac{source\_hight}{scaled\_hight} \qquad \dots \text{Eq(8)}$$

$$source\_column = scaled\_column * \frac{source\_width}{scaled\_width} \qquad \dots \text{Eq(9)}$$

4. The value of the pixel with the scaled row & column will be the same value of the pixel in the source row & column

But the problem is, such a solution can be implemented only when the source and the scaled images have regular dimensions that is m_rows × n_columns.

Scaling Irregular Image:

In this system, the objects needed to be scaled are facial features which have irregular shapes. This means that the position of a specific pixel in the new scaled version of an object's image cannot be found to be found to be mapped back from the position of its corresponding pixel in the source image to get its value. Therefore we will go back to the equations (6) & (7) and perform the following algorithm to apply them.

Algorithm: scaling irregular shaped image

Step 1: for each pixel *p(i,j)* in the source object

Step 1.2 :{ multiply its coordinates by a vertical & horizontal scaling factors}

$scaled\_i = i * vertical\_scaling\_factor$

$scaled\_j = j * horizontal\_scaling\_factor$

Step 1.2.1: if there is a previous scaled pixel *f(x,y)* prior the new one in the same row, that is *scaled_j=y* then:

Step 1.2.1.1: if *scaled_i –x > l* then

{let the values of the pixels in between be as the value of the pixel *p(i,j)* and set them to the new scaled image}

For *l* = *x*+1 to *scaled_i* – 1

f(l, scaled_j)=p(i,j)

Step 1.2.2: if these is a previous scaled pixel *f(x,y)* prior to the new one in the same column that is *scaled_i=x* then

Step 1.2.2.1:if *scaled_j* – *y* > 1

{let the values of the pixels in between be as the value of the pixel p(i,j) and set them in the new scaled image}

For *l* = *y*+1 to *scaled_j* – 1

f (scaled_i,l)=p(i,j)

Step 2: display the produced image.

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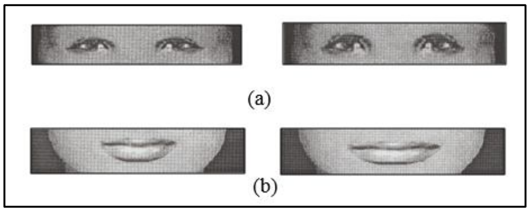
The scaling process is applied in two ways:

The vertical_scale_factor (which controls the width) and the horizontal_scale_factor (which controls the length) are uniform for all pixels in the image. So that the entire width or length in the image is changed, as the example shown in the figure (5)



(a) The eyes: before and after stretching their length.
(b) The mouth: before and after stretching its width.

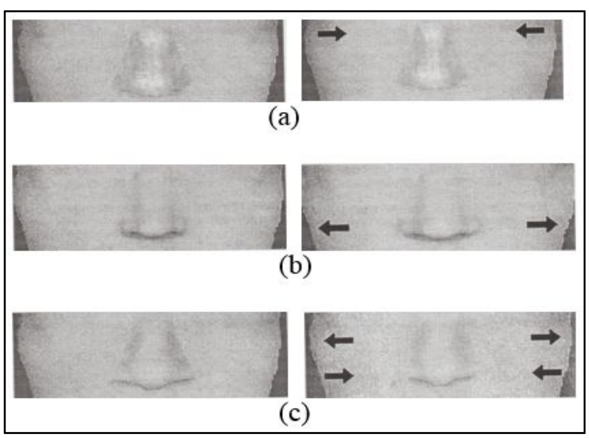
Figure 5: Examples of implementing the first type of

1. In the other case the horizontal_scale_factor has different values for different rows in an object. This is explained by the following example: if the shape of the nose is needed to be changed, so that the upper part be smaller than the lower part (nose till) stay as it is as in figure (5.a), or the upper part stay as it is and the lower part be larger as in figure (5.b), or the lower part be smaller and the upper part be larger as in figure (5.c) …. etc. the following steps should be followed:

a) The horizontal row of the object is selected by the user to be either shrunk or stretched.

b) Then the specified horizontal_scale_factor is applied for all pixel in this row, having a value less than one for shrinking and more than one for stretching.

c) The value of the horizontal_scale_factor decreases gradually (when stretching) or increases gradually (when shrinking) until reaching 1.0 for the other row coming before and after the selected one.



(a) The nose: before and after shrinking its upper part at the arrows' axis.
(b) The nose: before and after stretching its lower part at the arrows' axis.
(c) The nose: before and after stretching its upper part at the axis of the upper arrows, and shrinking its lower part at the axes of the lower part.

Figure 6: Examples of applying Local Scaling to some noses

Notes:

- The first type of scaling can be applied to any of the selected features or to the gross shape of the face independently. The second type is applied to the width of the entire shape of the face and the width of the nose only.
- Any change performed on the paired features is applied to both parts

Rotation

Another useful transformation is rotating the selected object (feature element) through an angle θ either in the clockwise or in anti-clockwise direction. To achieve this process, every point p(x, y) in the object should be rotated by applying the following transformations on it [1]:

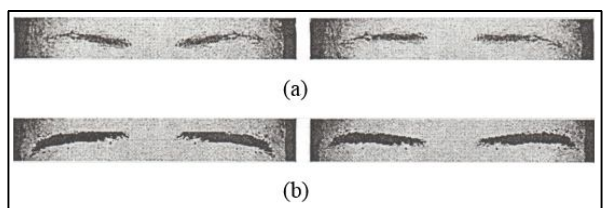
$$x^{new} = x^{old} * \cos(\theta) - y^{old} * \sin(\theta) \quad \text{...Eq(10)}$$

$$y^{new} = x^{old} * \sin(\theta) + y^{old} * \cos(\theta) \quad \text{... Eq(11)}$$

The positive value of angle θ implies the clockwise rotation, while the negative value implies the anti-clockwise rotation.

Notes:

- Applying this transformation on the object's points result on rotating the object about the origin of the coordinates of the object. Therefore it is need to be translated back to its position.
- In case of the paired objects (e.g. eyebrows, eye …), when rotating one part of it in a direction, the other part is automatically rotated through the same angle but in the opposite direction which keeps the symmetrical view of these objects on the face, as shown in figure (7)
- The orientation of each facial feature can be changed at any time during the construction process.



(d) The right eyebrow is rotated in anti-clockwise direction, while the left one is rotated in the clockwise direction at 10 degree.
(e) The right eyebrow is rotated in clockwise direction, while the left one is rotated in the anti-clockwise direction at 10 degree.

Figure 7: Examples of rotating paired features

2.4. Enhancement Utilities:

Since the construction of the facial image is based on gathering and tailing different features, the resulted image may contain variations among the color levels of these features as well as the background color of the initial face which may cause undesirable edges.

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Therefore some enhancement techniques may be needed due to their ability to process a given image so that the result is smoother than the original image.

Smoothing enhancement techniques implemented here, are based on spatial operations performed on the local neighborhoods of the input pixels. The smoothing filters seek a compromise removing as much noise as possible while still preserving the detailed edge information [1].

Spatial averaging (neighborhood averaging)

This is one of the simplest approaches for smoothing, and it operates by replacing each pixel by the average or the mean of its immediate neighborhood.

a) Mean Filter:

Each pixel is replaced by the average of its 8-neighboors' value including the pixel p(i,j) itself. This is achieved by using a 3×3 window with all its weights set to 1/9, then convolving it with the original image, as follows:

$$mean\_mask \begin{bmatrix} 1/9 & 1/9 & 1/9 \\ 1/9 & 1/9 & 1/9 \\ 1/9 & 1/9 & 1/9 \end{bmatrix}$$

$$the\ threshold\ value\ of\ p(i,j) = \frac{1}{9} * \sum (neighborhood\ values)$$

b) Plus-shaped Filter:

Each pixel is replaced by the average of its 4-neighbors' values including itself by applying a 3×3 window with the following weights:

$$mean\_mask = \begin{bmatrix} 0 & 1/5 & 0 \\ 1/5 & 1/5 & 1/5 \\ 0 & 1/5 & 0 \end{bmatrix}$$

$$the\ threshold\ value\ of\ p(i,j) = \\ = \frac{1}{5} * \sum (p(i-1,j) + p(i,j-1) + p(i,j) + p(i,j+1) + p(i+1,j))$$

The averaging process has the effect of removing significant differences between pixels in a neighborhood. So that it reduces noise but in expense of significant image blur as it degrades the edges o\f objects in the image [4]. This blurring effect can be reduced by using a threshold procedure, that is:

$$the\ value\ of\ p(i,j) = \begin{Bmatrix} use\ the\ smoothed\ value\ if\ |smoothed\ value - original\ value| < T \\ otherwise\ use\ the\ original\ value \end{Bmatrix}$$

Where T is a non-negative threshold. In this way the blurring is reduced by leaving the facial regions with large variations (compared to T) [1].

Mode Filter:

This filter replaces a pixel by the value of its most common neighborhood. This is useful when trying to label a large similar areas within an image. The mode has the advantage of reducing noise and preserve the edges to the smoothed image.

Median Filter:

This filter replaces each value in the original image by the median of the pixels in a 3×3 window centered on that pixel.

In order to find the median value it is necessary to sort the nine pixel values into either ascending or descending order, the middle or median value is selected to be the smoothed value of the pixel. This smoothing filter removes the noise and preserve the edges in the original image (because it doesn't allow extreme values "high or low" to influence the selection of a pixel value which is truly representative of the neighborhood [4].

Note:

The effect of these filters on the constructed facial image can be displayed, so the user can choose the one with the best effect. The smoothing process maybe either applied to the total image's pixels or to a specific pixels specified using mouse pointer.

Other Utilities:

1. A hand-drawing utility is provided to add additional flexibility to draw more details on the face being constructed.
2. Shadows can also be added to the constructed face through darkening or lightening the selected areas of the resulted face.

3. Results

The construction facilities provided by this system are implemented to produce some different facial images, which are presented in the following figures as an experimental output.

In figure (8), the different stages of the construction process are shown, beginning from figure (8)(a), which represents the initial featureless face, then continue with performing the required modifications on it. These modifications are, first, changing the gross shape of the face (by shrinking the lower part of the face more than the other parts of it) as shown in figure (8)(b). after that the main facial features are selected to be added, where the eyebrows, eyes, nose, mouth, ears, and the head-hair are added, as shone in figure (8)(c), (d), (e), (f), (g), and (h). Finally the mustache is added and some shadows are added to the eyes and both sides of the face to produce the facial image shown in figure(8)(i).

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Figure(9) presents other samples of system's output with different set of feature in each one, and using the same basic featureless face as a starting point.

Figure (10) (a), shows a complete constructed facial image. This image could be enhanced to obtain a better one using the smoothing filters. Results of applying mean, plus-shape mean, mode, and median filters are presented in figures (10) (b), (c), (d), and (e) respectively.

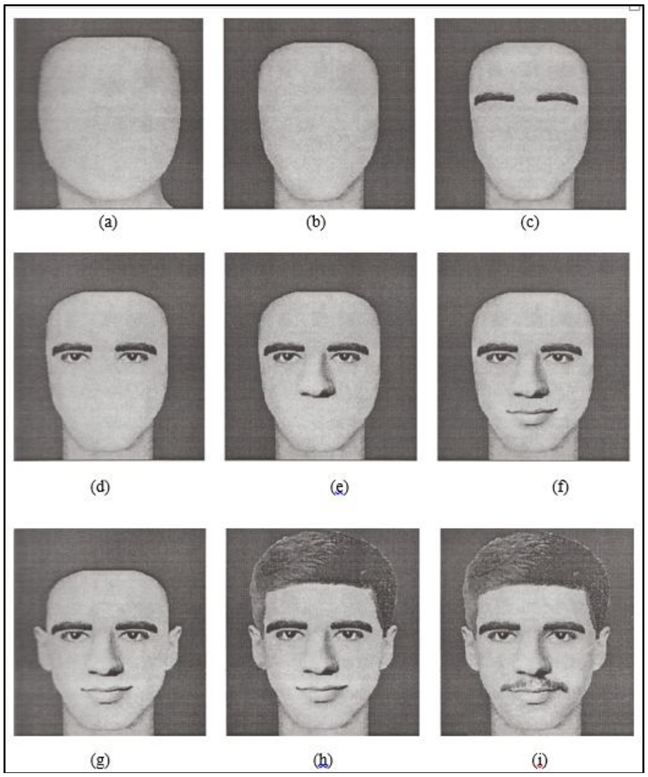


Figure 8: Sequence of construction steps needed to produce a facial

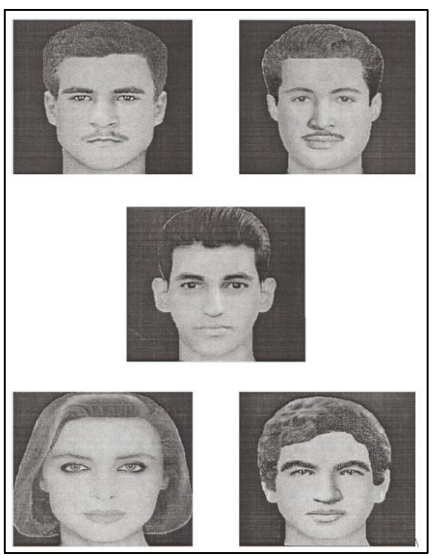
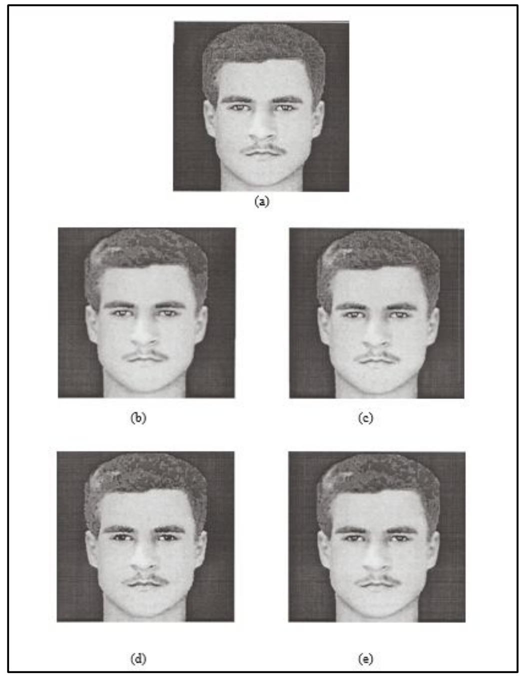


Figure 9: Some examples of constructed faces having different



a) The original constructed facial image.
b) The image after applying mean filter (with T= 6).
c) The image after applying plus-shaped mean filter (with T= 6).
d) The image after applying Mode filter.
e) The image after applying the median.

Figure 10: Results of smoothing filters

4. Discussion

Some conclusions could be obtained from the given results as follows:

a) Using irregular images which represent the actual shape of each individual facial feature makes easier and more flexible to position the facial components or when they overlap each other, rather than dealing with conventional images.
b) Applying unequal scaling factors on different parts of the facial component's image make it more efficient to reshape until reaching the desired shape.
c) It's important to note that, the more facial components saved in the system's database, the more efficiency in constructing various facial images.
d) The enhancement tools are important in smoothing the edges between the basic featureless face and the added facial components.

Until quite recently, the facial composite systems used by international police forces were exclusively based on a construction methodology in which individual facial features (eyes, nose, mouth, eyebrows, etc.) are selected one at a time

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from a large database and then electronically 'overlaid' to make the composite image. Such systems are often referred to as feature-based since they essentially rely on the selection of individual features in isolation. There are other types of systems which use "evolutionary mechanism" in which a witness's response to groups of complete faces (not just features) converges towards an increasingly accurate image [19].

Here is a general review of research into some studies and systems which use different techniques to compose a human face. Some mechanical template techniques are found in Davies and Valentine (2006)[10] A review of research into more modern 'feature' and 'recognition' systems, and into methods for improving the effectiveness of composites, are found in Frowd et al. (2008)[11] and (2009)[12]

Some academic studies in UK show that composing faces using E-FIT and PRO-fit procedures produce correctly identified faces and 20% of them could be named, either immediately or a few hours after construction, (see Brace et al. (2000)[13], Bruce et al. (2002)[14], Davies et al. (2000)[15] and Frowd et al. (2005)[16]).

Other fairly-recent academic trials, research on applying EvoFIT system which gave better results than before (see Frowd et al., 2010)[17]. Using more-recent construction and enhancement techniques,, the performance increased more (Frowd et al., 2012)[18] and (Frowd et al., 2013)[9]. Facial composite [19].

Sample of work in which an object is extracted and separated from its background can be found in (2008)[20].

5. conclusion and future work

Some of the systems mentioned before specially those who use E-fit and pro-fit procedures produce low level of identified facial images due to inability to accurately construct the internal features of the face. While in this proposed system the witness has the flexibility to formulate the internal features or add new features as required. The more saved facial features, the more different face can be composed from these features.

The use of the inner irregular shape of each individual feature made it easier to transform and formulate that feature until reaching the required shape.

As a future work, it is suggested to use "Bezier Curves" as a second step after composing the face to get better improvement in the similarity of the resulted composed image.

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