Research Paper

Face Detection and Facial Feature Localization for Human-machine Interface

人間機械系インタフェースのための顔画像検出と特徴部位の位置検出

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ABSTRACT

This paper presents a robust and precise scheme for detecting faces and locating the facial features in images with complex backgrounds. The system is based on visual and geometrical information of the face from the image sequences and is commenced with the estimation of the skin area depending on the similarity measure of the hue and luminance components of the images in the YIQ color space. Facial features, such as eyes, nose, mouth, eyebrow, etc. are then localized from face skeleton with the knowledge of the face geometry.

A genetic algorithm has also been developed for the detection of face and different facial features in gray scale mode. Experimental results demonstrate that this face detector provides successful results for the images of individuals which contains quite a high degree of variability in expression, pose, and facial details.

要約

本論文では、人間機械系のインタフェースへの利用を目標に、複雑な背景を持つ画像に対する、頑健で高精度な、顔画像の検出方法、および顔の各種特徴部位の位置検出方法を提案する。提案する方法では、一連の画像系列中の顔の皮膚領域抽出を目的に、顔の視覚的・幾何学的特長を利用すると共に、YIQ 空間における色調、明度の類似性を利用している。また、目や鼻、口、眉などの顔の特徴部位の位置は、顔の幾何学的な知識を用いたスケルトンを利用して同定する。さらに、異なる顔の特徴検出を目的に、グレースケール画像を対象に遺伝的アルゴリズムを導入した方法を開発した。最後に、実環境における実験システムを用いた、これらの手法の有効性確認について述べる。

[Keywords]

Face detection, Facial feature extraction, YIQ color model, Genetic algorithm, Morphological operation

[キーワード]

顔画像検出，顔の特徴抽出，YIQ カラーモデル，遺伝的アルゴリズム，モーフォロジカル操作

1 Introduction

Face is the most distinctive and widely used key to a person's identity. Face detection and facial feature extraction have attracted considerable attention in the advancement of human-machine interaction as it provides a natural and efficient way to communicate between humans and machines. The problem of detecting the faces and facial parts in image sequences has become a popular area of research due to emerging applications in human-computer interface, surveillance systems, secure access control, video conferencing, financial transaction, forensic applications, pedestrian detection, driver alertness monitoring systems, image database management system and so on.

Various approaches to face detection and facial feature extraction have been reported in literature over the last few decades, ranging from the geometrical description of salient facial features to the expansion of digitized images of the face on appropriate basis of images[1]. Different techniques have been introduced recently, for example, principal component analysis[2], geometric modeling[3], auto-correlation[4], deformable template[5], neural networks[6], elastic bunch graph matching[7], color analysis[8] and so on. Face detectors based on Markov random fields and Markov chains[9] make use of the spatial arrangement of pixel gray values. Model based approaches assume that the initial location of the face is known. Color based approaches reduce the search space in face detection algorithm. The neural network-based approaches require a large number of face and non-face training examples, and are designed primarily to locate frontal faces in grayscale images. Sung and Poggio[10] have developed an example-based approach for locating frontal views of human face in complex scenes. Since this method has been developed for vertical frontal view faces, faces with other orientations cannot be detected. Rowley et al.[11] have developed a neural network-based frontal face detection system where a retinal connected neural network has been employed to justify the small windows of size 20×20 of an image whether it contains a face or not. The most interesting aspect of this system is the use of a bootstrapping technique to collect non-face training examples for neural network learning. Lam and Yan[12] have used snake model for detecting face boundary. Although the snake provides good results in boundary detection, but the main problem is to find the initial position. Moghaddam and Pentland[13] employed principal component analysis for describing the face pattern with lower-dimensional feature space. Yang et al.[14] proposed a three-level hierarchical knowledge-based approach in mosaic images for detecting human face region but the computational cost of this method is too high. Lee et al.[15] have developed a method for extracting the facial part from the homogeneous background by tracking the face boundary by assuming the face part to be located at the center of a captured image. Then they applied knowledge-based feature extraction and neuro-fuzzy algorithm to carry out the face recognition task. Wang et el.[16] have employed genetic algorithm to detect human faces where the fitness value for each face candidate is calculated by projecting it onto the eigenfaces space. Lee et al.[17] have proposed an illumination invariant face recognition method using photometric stereo technique, where they have reconstructed the surface normal and albedo of a face using photometric stereo images, and then used them as the illumination independent model of the face.

This paper explores a face detection system which integrates the detection of human faces in complex backgrounds and localization of facial features such as eyes, nose, mouth, eye-brow, etc. on it. Face detection is established by two approaches: (i) skin color segmentation and (ii) genetic searching. The system is based on the determination of the approximate location of the face area and thresholding the image by color segmentation. The exact location of the face is then determined by employing genetic algorithm in the grayscaled image of the face area. Facial features are then detected and localized by the geometrical analysis of the facial skeleton. Experimental results indicate that the system is capable of detecting and locating the face parts from complex backgrounds with a high degree of variability in expression, pose, and facial details.

2 Face Detection

Face detection is concerned with determining which part of an image contains face. This is the first step of face recognition which requires both high and low-level visual and geometric information processing. This paper presents two approaches for detecting human faces: (i) color segmentation and (ii) genetic searching.

The system is commenced with the determination of the estimate location of the face area by skin color segmentation and thresholding the resulting image. Then the face, containing a couple of eyes, nose and mouth, is being searched for around the largest connected area of the skin color zone by genetic algorithm in gray scale mode.

2.1 Color Segmentation

Face detection is achieved by means of skin color segmentation. This section introduces a color segmentation based approach for determining the facial parts in an image. Different dominant and perceptually relevant colors of face images are extracted in RGB space from each image and are converted into the YIQ space. Images are being searched in YIQ space depending on the amount of color content of these dominant colors, that is, whether the skin color value is substantially present in an image or not. The overview of the color segmentation based face detection method is shown in Fig. 1.

In the YIQ color model a color is described by three attributes: luminance, hue and saturation. The YIQ, a universal color space used for color television transmission, have been adopted in recent color picture systems whose components are Y, I, and Q. The YIQ produces a linear transform of RGB which generates Y representing luminance channel and I,Q representing two chrominance channels to carry color information. The transformation matrix for the conversion from RGB to YIQ is given by[18]:

$$\begin{bmatrix} \mathbf{Y} \\ \mathbf{I} \\ \mathbf{Q} \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.275 & -0.320 \\ 0.212 & -0.523 & 0.311 \end{bmatrix} \begin{bmatrix} \mathbf{R} \\ \mathbf{G} \\ \mathbf{B} \end{bmatrix} \qquad (1)$$

where **R,G,B** are the red, green, and blue component values which exist in the range [0,255].

Since the human skin colors are clustered in color space[19] and differ from person to person and of races[20], so in order to detect the face parts in an image, the skin pixels are thresholded empirically. In this experiment, the threshold value is chosen by the following equation:

$$(60 < \mathbf{Y} < 200) \ \text{AND} \ (20 < \mathbf{I} < 50) \qquad (2)$$

The detection of face region boundaries by such a hue segmentation process is illustrated in Fig. 2. The exact location of the face is then determined from the image with largest connected region of skin-colored pixels[21]. The connected components are being determined by applying a region growing algorithm at a coarse resolution of the segmented image[22]. In this experiment, 8-pixel neighborhood connectivity is employed. In order to remove the false regions from the isolated blocks, smaller connected regions are assigned by the values of the background pixels[23].

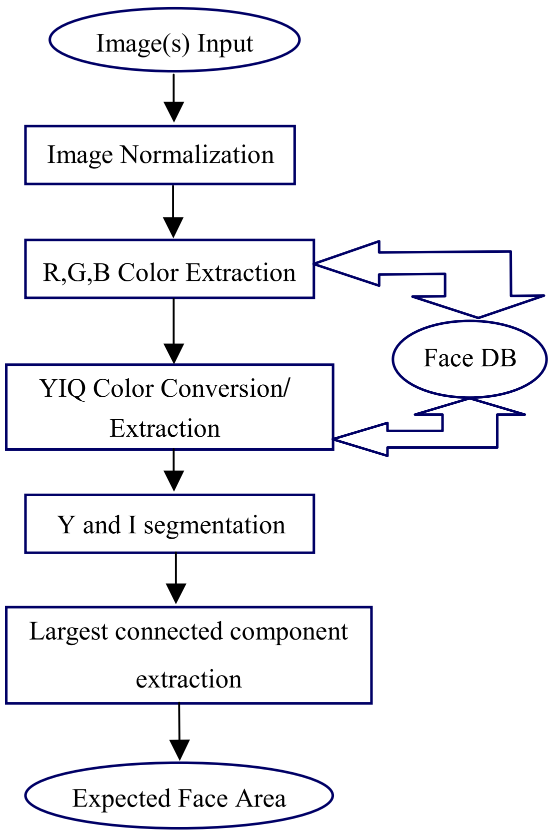
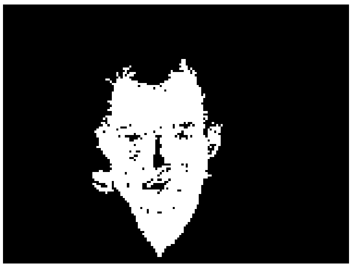


Fig. 1: Block diagram of the face detection method.

(a) A typical face image.

(b) Skin color segmentation.



(c) Largert connected area.

Fig. 2: Detection of face region by skin color segmentation.

2. 2 Genetic Searching

Genetic Algorithms (GAs), based on the simulation of the biological model of evolution and natural genetic systems, are randomized searching methods. They have been found to be robust and efficient way of solving optimization problems[24-26]. As the GA is computationally intensive, the searching space is reduced by applying it to search for the expected face regions (approximate face area as found from the color segmentation process) of the image in grayscale mode.

To apply GA for face detection, a template of the face image obtained from averaging the gradation level of pixels of a number of similar looking face images of several persons is constructed. The template face image is then moved through the whole image to find the location where the most suitable match exists. This process applies GA for the optimization of five parameters such as, center position of the template image, scaling of the template, rotation of the template, and matching rate between the input image and the template image. The genetic algorithm and different genetic operations are shown by a flowchart in Fig. 3.

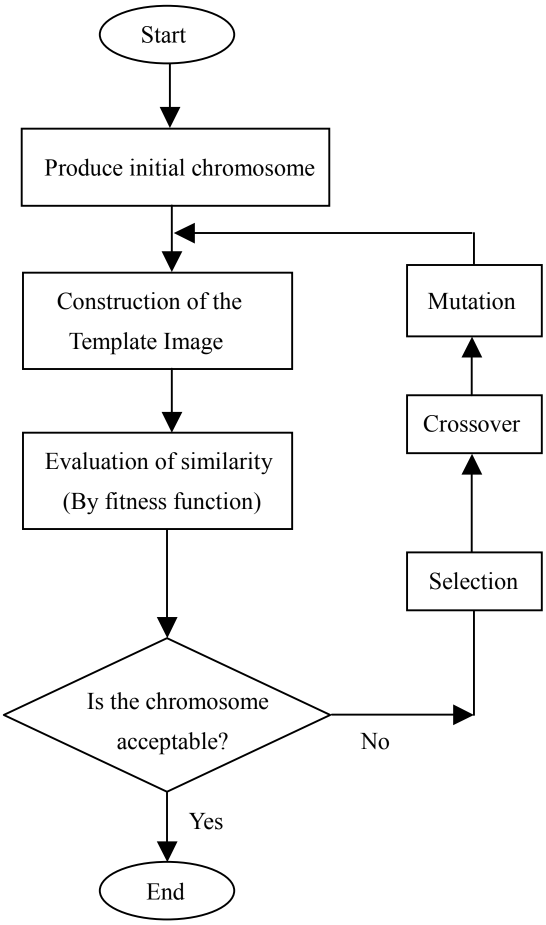


Fig. 3: Flowchart of the genetic algorithm.

The algorithm starts with an initial set of random solutions called the population. Each individual in the population, known as chromosome, represents a particular solution of the problem. Each chromosome is assigned a fitness value depending on how good its solution to the problem is. After fitness allotment, the natural selection is executed and the 'survival of the fittest chromosome' can prepare to breed for the next generation. A new population is then generated by means of genetic operations: cross-over and mutation. This evolution process is iterated until a near-optimal solution is obtained or a given number of generations is reached. However, different steps employed for the genetic algorithm are given below.

Chromosome encoding scheme:

The chromosome is represented as a binary string of the set {0,1} of fixed length N (here it is 40 bit). A chromosome consists of five optimization parameters, $\{\mathbf{P}_i, i = 0,1,....,4\}$ representing the x-coordinate of the center of the template image, y-coordinate of the center of the template image, scaling of the template, rotation of the template, and matching rate between the input image and the template image, respectively, each consisting of 8-bit length. The example of the chromosome structure and encoding mechanism is illustrated in Fig. 4.

A population with a set of chromosomes is defined by the strings as: $\{\mathbf{C}_j, j = 0,1,...., M-1\}$, where M is the number of the chromosomes or the population size (here it is chosen as 180). The genotype data structure stores an entire population in a matrix of size MXN, where M is the number of chromosomes in the population and N is the length of the genotypic representation of each chromosome. Initially the set of chromosomes in the population are chosen randomly.

Fitness function

In order to identify the best individual during the evolutionary process, a function needs to assign a degree of fitness to each chromosome in every generation. So in order to determine whether the assumed region of the input image is a face or not, the fitness value of the possible face region is computed by means of intensity similarity.

The fitness of a chromosome is defined as the function of the difference between the intensity value of the input image and that of the template image measured for the expected location of the chromosome. That is, for each chromosome z, fitness function is defined as:

$$f(z) = 1 - \frac{\sum_{(x,y) \in W} \left| f(x,y) - f_{z,t}(x,y) \right|}{B_{\max} \times xSize \times ySize} \quad (3)$$

where $B_{\max}$ is the maximum brightness of the image, $xSize$ and $ySize$ are the number of pixels in the horizontal and vertical directions of the template image, f and $f_{z,t}$ are the intensity values of the original image and the template image when it is justified for the the z-th position of the chromosome, respectively.

Selection:

Selection operator is a process in which chromosomes are selected into a mating pool according to their fitness function. Good chromosomes that contribute their gene-inherited knowledge to breed for the next generation, are chosen. Here we use conventional elitist selection scheme to select an elitist chromosome with the highest fitness value, which is copied directly into the new population of next generation. The other chromosomes are selected by a roulette-wheel selection process, where the selection probability of each individual is proportional to its fitness value.

Cross-over:

This operator works on a pair of chromosomes and produces two offsprings by combining the partial features of two chromosomes. Here we have studied single point cross-over, two point cross-over and uniform cross-over operators. The cutting points are selected randomly within the chromosome for exchanging the contents. In this experiment, the cross-over rate was chosen as 0.75 for all cases.

Mutation:

This operator alters genes with a very low probability, p_M. For each chromosome, generate a random value between [0,1]. If the random value is less than p_M, then choose a bit at a random location to flip its value from 0 to 1, or 1 to 0. The mutation rate for our method was chosen as 0.08.

The fundamental steps employed for the genetic algorithm are as follows.

Step 1 Initialization. Generate an initial population with M chromosomes randomly.

Step 2 Evaluation. Evaluate the fitness function for each chromosome in the population.

Step 3 Selection: Use the roulette wheel selection procedure.

Step 4 Cross-over. Produce two off-springs from two chromosomes with better fitness function values.

Step 5 Mutation. Apply the conventional mutation operation to the population with a mutation rate p_M.

Step 6 Termination test. If a predefined termination condition is satisfied, go to **Step 7**, else go to **Step 2**.

Step 7 Preservation. Keep the best chromosome.

Step 8 End.

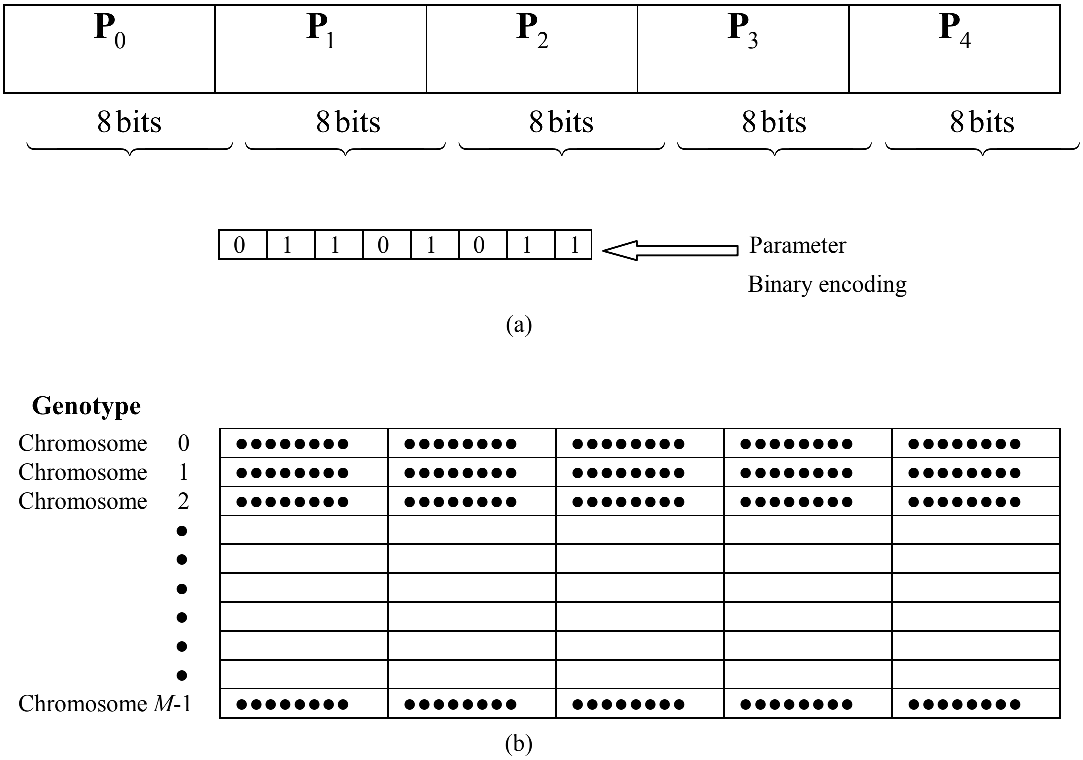


Fig. 4: Structure of (a) Chromosome (b) Genotype.

3 Facial Feature Extraction

After the face detection procedure, the rough locations of the facial feature points are obtained. These locations are then used as the initial information for finding the exact locations of facial features. Six facial features are localized in this experiment. These are the left and right pairs of eyes, eyebrows, tip of the nose and the center of the mouth.

Facial features are extracted from the face profile depending on their geometrical arrangement on the facial skeleton. Before performing feature extraction, the original face images are subjected to some image processing operations, as shown in Fig. 5 and Fig. 6.

(i) Image Enhancement: The face images may be of poor contrast because of the limitations of the lighting conditions. So histogram equalization is used to compensate for the lighting conditions and improve the contrast of the image[27]. Let the histogram $h(r_i)=\frac{p_i}{n}$ of a digital face image consists of the color bins in the range $[0, C-1]$, where r_i is the i-th color bin, p_i is the number of pixels in the image with that color bin and n is the total number of pixels in the image. For any r in the interval [0,1], the cumulative sum of the bins provides with some scaling constant. Histogram equalization is performed by transforming the function $s = T(r)$, which produces the mapping with the allowed range of pixel values, i.e., a level s for every pixel value r in the original image[18] and $0 \le T(r) \le 1$ for $0 \le r \le 1$, as shown in Fig. 7.

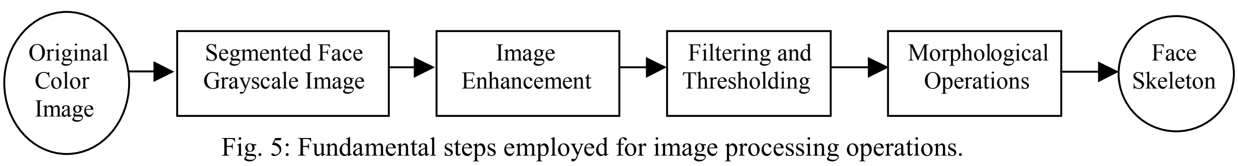


Fig. 5: Fundamental steps employed for image processing operations.

(a) Original image (b) Prewitt filtering (c) Thresholding (d) Morphological operations

Fig. 6: Different image processing operations.

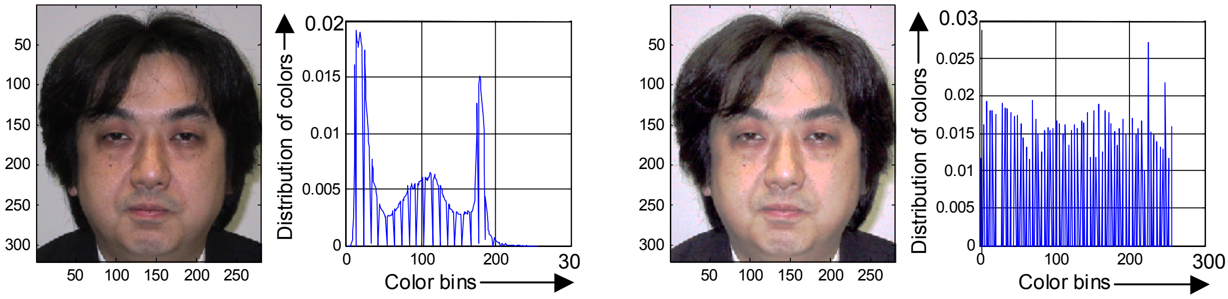
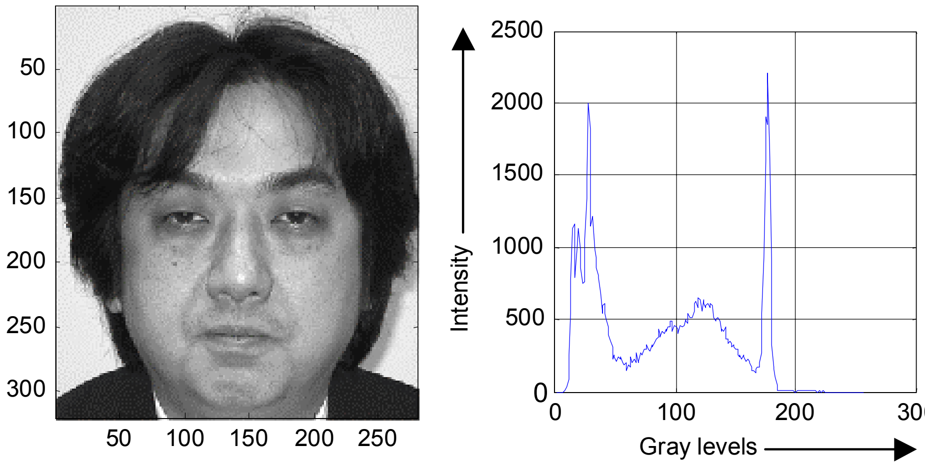


Fig. 7: Histogram equalization of a face image.



(a) Grayscaled face image. (b) Intensity histogram.

Fig. 8: Intensity histogram of the face image.

(ii) Filtering and Thresholding: Various sources of noise may exist in the input image. The fine details of the image represent high frequencies which mix up with those of noise. So low-pass filters are used to obliterate some details in the image. In this experiment, Prewitt filtering is used to suppress the noise. It has been found from observations that under normal illumination conditions, the facial features, such as eyes, nose, mouth, etc. possess relatively lower gray level and the intensity histogram of the face image produces the shape of twin peaks[28,29], as shown in Fig. 8. One peak, corresponding to the lower gray levels of the intensity histogram, is due to the darker parts of the face, for example, hair, eyes, eyebrows, mouth, etc. and the other peak corresponds to the lighter parts of the facial features such as cheeks, foreheads, etc. Therefore, the threshold value is chosen in such a way that the facial features become distinct with respect to the lighter parts of the face.

(iii) Morphological Operations: After thresholding, the segmented image may be encountered by some holes in the face skin region. In order to remove these false regions, two types of morphological operations are employed in this experiment. The face region is filled by applying morphological dilation operation with a 3×3 structuring element several times followed by the same number of erosion operations using the same structuring element. The dilation operation is used to fill the holes and the erosion operations are subjected to the dilation results to restore the shape of the face[28].

After the image processing operations, as shown in Fig. 6, the frontal view face produces an oval profile with a number of facial elements. Different facial elements are then extracted from this face profile, assigning a unique tag to each isolated candidate block by labeling the binarized image[30,31], as shown in Fig. 9. These tag points are the representatives of each image feature block.

Let $\mathbf{P}_i = (x_i, y_i), (i \in [1,6])$ be the six tag points of the image blocks of facial components, such as left eye, right eye, left eye brow, right eye brow, nose and mouth, respectively. Since in the binary image, all of the pixels have got the intensity value of 0 and 255 only, these tag points are assigned with their respective representative numbers. The first tag point is determined as follows:

[Step 1] Compute the center point of the face.

[Step 2] Starting from the center point, search the first black pixel and assign it with the value of '1' (first tag value) as follows:

$$For\ \ i \to x_{\max} / 2 \text{ to } 1 \text{ step } -1$$
$$For\ \ j \to y_{\max} / 2 \text{ to } 1 \text{ step } -1$$
$$If\ \ \mathbf{Pixel}[i][j] == 0\ \ then\ \ \mathbf{P}_i = 1$$

return

[Step 3] Search the entire window for the tag value '1' and assign all connected pixels with '1'.

Similarly, all of the tag points and their associated connected pixels are determined from their respective searching areas and assigned with their representative numbers. These tag points and representative numbers are then used for the localization of different facial elements.

Fig. 9: Facial features' localization.

3. 1 Eye, Eyebrow, Nose and Mouth Detection

An eye is characterized by its pupil and iris and is represented by a circle. The radius range $[r_{\min}, r_{\max}]$ is estimated according to the assumption of the face size. The precise eye positions are determined from the respective eye windows. The eye windows, represented by the top left and bottom right points, $[x_1, y_1], [x_2, y_2]$, are obtained from the eye tag points and the eye representative numbers. The pupil is then extracted from this area by searching for the white pixel surrounded by maximum number of black pixels. For this, a two dimensional voting box of size 7×7 is moved through the eye window and each white pixel inside that area is allowed to cast vote for the neighboring black pixels. Obviously, the pupil $\mathbf{P} = (P_x, P_y)$ would be the most suitable white point capable of contributing maximum number of votes. Then all valid circles surrounded by this pupil is justified by performing the traditional Hough Transform on $\mathbf{P} = (P_x, P_y)$. Each black pixel (x_i, y_i) votes for the circle C_i if[32]:

$$\left| \sqrt{(x_i - P_x)^2 + (y_i - P_y)^2} - r_i \right| \leq \delta, \qquad (4)$$

where (P_x, P_y) and r_i are the center and the radius of the circle C_i respectively, and $\delta = 0.1 r_i$.

Similarly, eyebrows, nose and mouth are localized by their tag points and representative numbers. The connected component analysis of the binary image is carried out for each region for the exact localization of each component.

4 Experimental Investigation and Results

Face images are analyzed to demonstrate the feasibility of the proposed method. The effectiveness and robustness of this approach is justified using different images with various kinds of expressions. Experiments are carried out on a Pentium III 900MHz PC with 256 MB RAM, and the SONY VISCA camera. The algorithm has been implemented using Visual C++. When a complex image is subjected in the input, the face detection result highlights the facial part of the image, as shown in Fig. 10. The system can also cope with the problem of partial occlusion of mouth and wearing sunglasses. Results for the occluded face images are shown in Fig. 11. Images of different persons are taken at their own work places and at different environments both in shiny and gloomy weather. Most of the images are taken using a digital camera, but some are from scanner, and some from video tapes recorded from different television channels. The algorithm is capable of detecting single face in an image. For multiple faces, the system finds the dominant face only, that is the face containing more number of skin colored pixels. Detection results for multiple face images are shown in Fig. 12. These images are captured by video camera. A total of 223 images, including more than 150 different persons, are used to investigate the capacity of the proposed algorithm. Among them only 7 faces are found false. Experimental results demonstrate that the success rate of approximately 97% $\left(\frac{216}{223} \times 100\% = 96.86\% \right)$ is achieved. The main reason behind the failure of those images in finding face regions is the substantially presence of pink, reddish or yellowish background regions in the image which are much larger than the true skin regions.

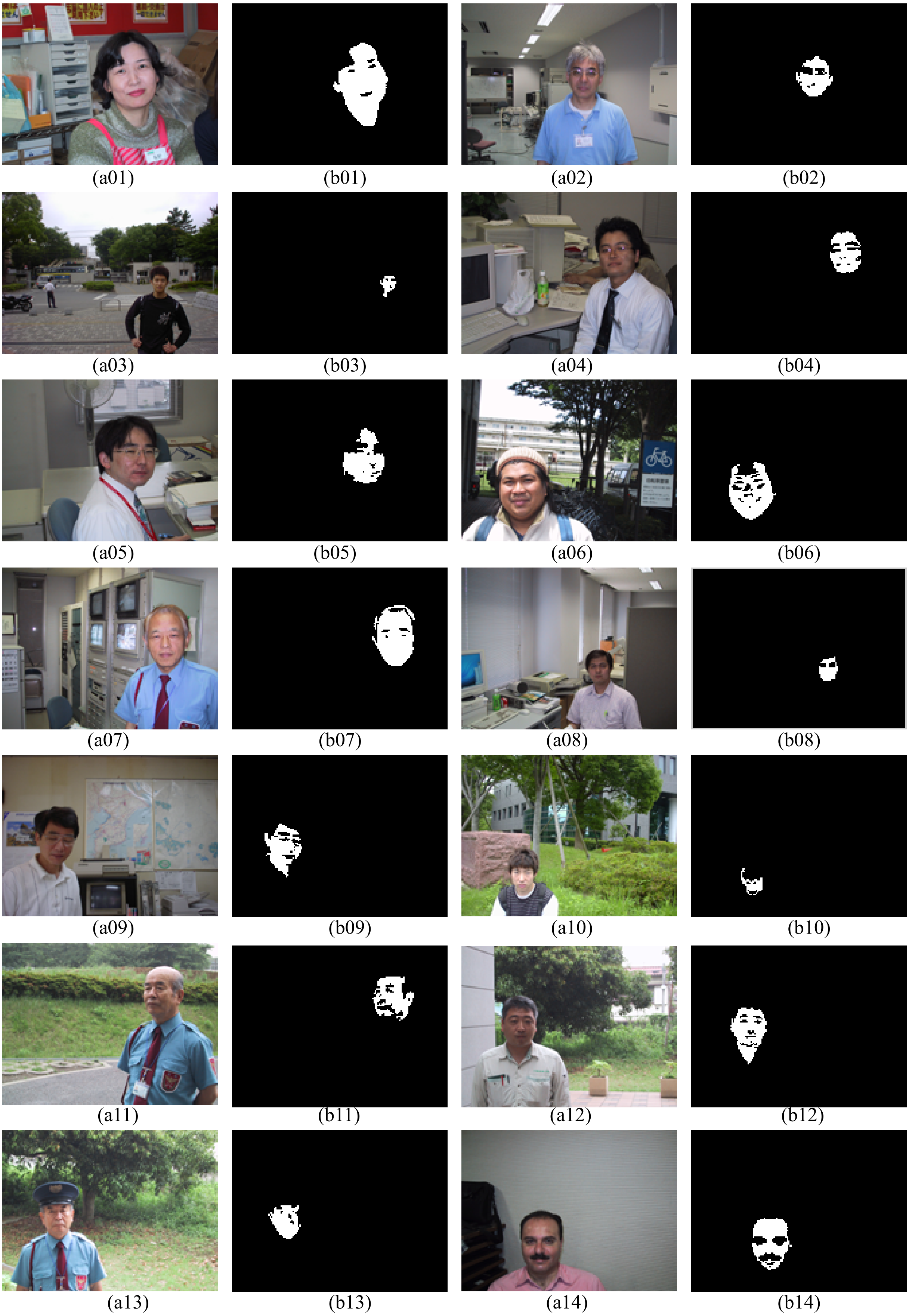


Fig. 10: Face detection for the persons at their work places: (a01)-(a14): original image, and (b01)-(b14): detected face image.

Fig. 11: Detection of occluded faces at different environments: (c01)-(c14): original image, and (d01)-(d14): detected face.

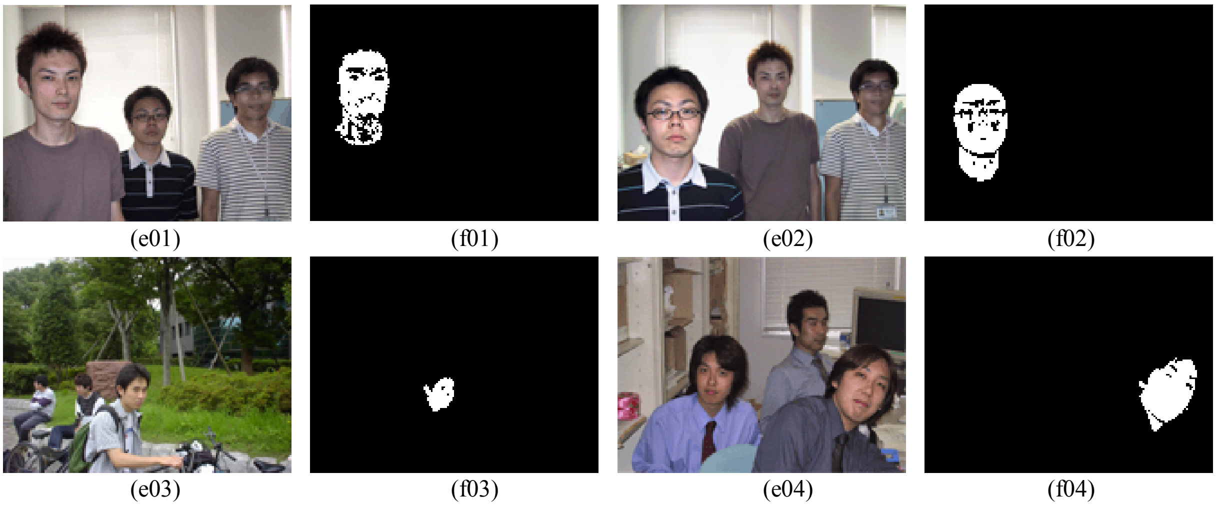


Fig. 12: Detection of larger face from multi-face environments: (e01)-(e04): original image, and (f01)-(f04): detected face image.

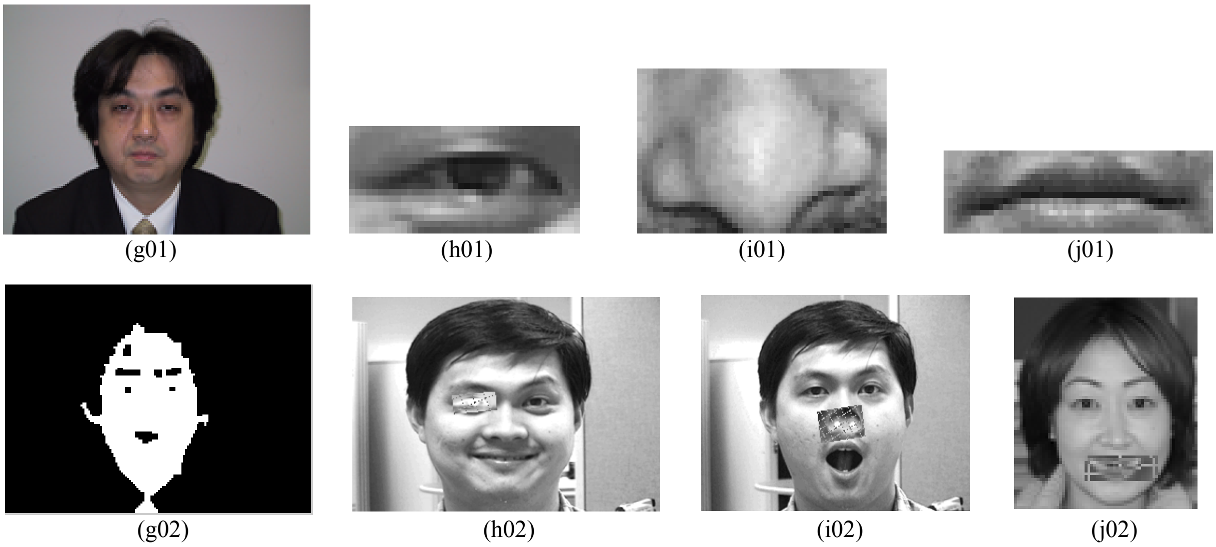


Fig. 13: Face detection and feature detection results.

(g01) – (j01) Face, eye, nose and mouth samples; (g02) – (j02) Detected face, eye, mouth, nose, respectively.

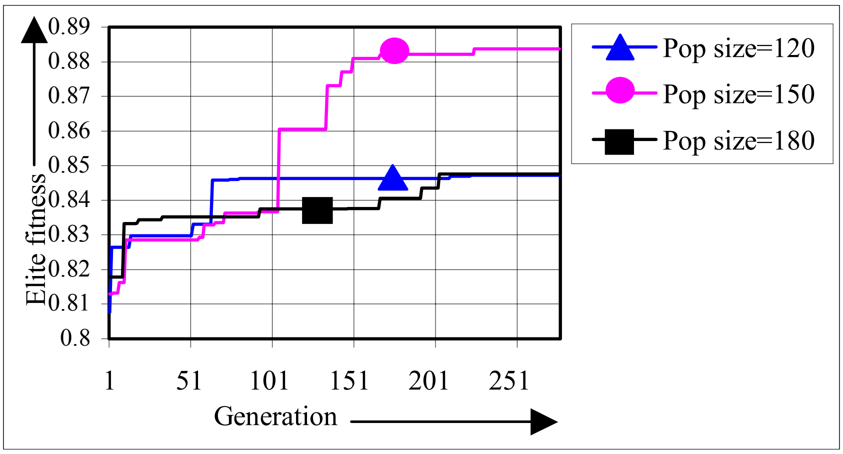


Fig. 14: Elite fitness versus generation (single point cross-over).

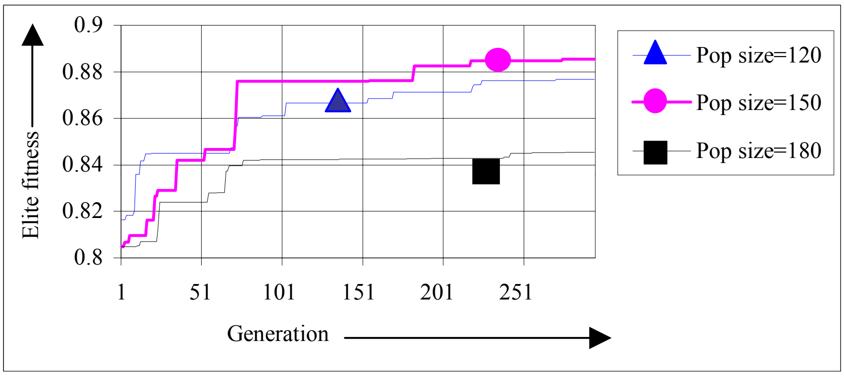


Fig. 15: Elite fitness versus generation (two point cross-over).

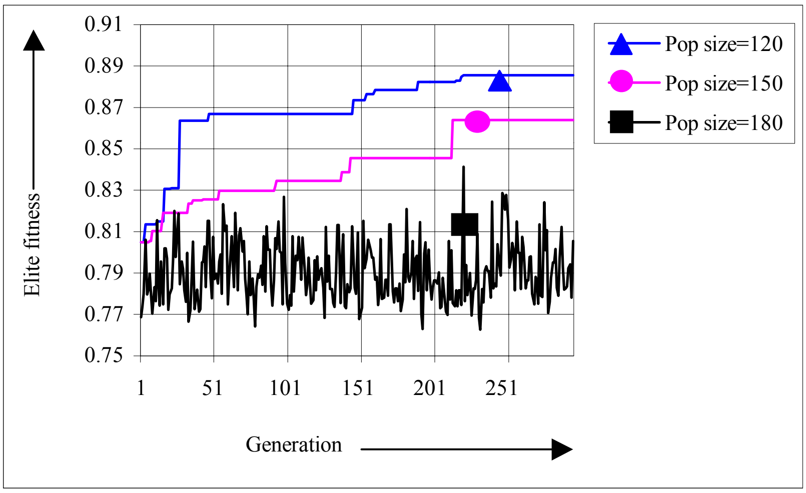


Fig. 16: Elite fitness versus generation (Uniform cross-over).

The result of the facial feature extraction process is to affect the facial area with that component in the given face image, as shown in Fig. 13.

Face detection is performed by using both color and grayscale modes, and facial features are extracted in grayscale mode. The existence of facial features like eyes, nose, mouth and so on are the evidences that the candidate region is indeed a face. The genetic algorithm is examined using single point, two point and uniform cross-over with different population size and the results are illustrated graphically in Fig. 14, Fig. 15, and Fig. 16, respectively, which reveals that larger population size offer better performance because of the larger pool of diverse schemata available in the chromosome but the inertia of larger population also boils down a problem of poorer initial.

Smaller population size, on the contrary, have the ability to change more rapidly and thus exhibit better initial on-line performance. Fig. 16 shows that smaller population size is better for uniform cross-over, whereas larger population size suffers from fluctuations. So a trade off is always taken between population size and the way of cross-over. Therefore, we adopt single point cross-over with a population size of 150 during face detection and facial feature extraction process.

5 Conclusion

Detection of faces and facial features using machine vision techniques has many useful applications. Though human beings accomplish these tasks countless times a day, they are still very challenging for machine vision. Most of the researchers attack this kind of problem with face localization and feature selection with frontal view faces and without facial expression and normal lighting conditions although the variation between the images of the same face is too large due to facial expression, hair style, pose variation, lighting conditions, make-up, etc. In this paper, face detection has been implemented using skin color analysis and genetic algorithm to search for the face of a particular individual in an image. The effectiveness of the face detection algorithm has been tested both in simple and complex backgrounds for different types of face and non-face images of 320×240 resolution. The algorithm is capable of detecting the faces in the images with different backgrounds and lighting conditions. Our next approach is to extend the algorithm for multi-face detection and overlapping faces in images and detect facial poses and develop a gaze estimation algorithm that will be able to detect an eye in a face image and estimate the gaze direction. Our main target is to instruct operations to robots and make them understand the human's intentions and interests over facial expressions so that they would be capable of grasping with more intelligence while working cooperatively with human beings.

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