Proceedings of 1992 International Computer Sympoisum
December 13-15, Taichung, Taiwan, ROC

Human Face Recognition by Image Processing and Pattern Recognition Techniques Using Both Front and Side Views*

Pai-Jou Chen and Wen-Hsiang Tsai†

Institute of Computer and Information Science
National Chiao Tung University, Hsinchu, Taiwan 300, Republic of China

Abstract

A new approach to face recognition by image processing and pattern recognition techniques using both front and side views is proposed. The basic idea is to extract effective features from the side and front views of a person, and to search the most similar person in a feature database. First, the side-view profile silhouette of a person is obtained by boundary tracing, and interesting face points are acquired. Based on a side-view-to-front-view image correspondence process, the front-view facial organs are located accordingly, and front-view features are extracted. The recognition process consists of rough classification according to a height feature, followed by detailed matching using facial features. The proposed recognition process is fully automatic, requires no artificial background, and runs fast enough for real-time applications. Experimental results with high recognition rates prove the feasibility of the proposed approach.

1 Introduction

Human face recognition has become an important research topic in computer vision. It has a lot of applications, such as criminal identification, entrance security control, credit card verification, etc. Human beings are good at face identification, can acquire information such as the mood, sex, age, and expression from a person's face, and are able to recognize faces despite of head orientations and dressing. But it is difficult for a computer to have such abilities, although human face recognition has been studied for more than twenty years. However, it is considered that more facial information can be obtained for more effective recognition if both side-view and front-view face images are used simultaneously. The goal of this study is to develop a new face recognition approach using both front and side views.

The earliest research related to face recognition was done by Galton[1,2] and is based on face profiles. Five cardinal points were extracted from profile silhouettes, and features derived from them were used to compare faces. Harmon et al.[3] used a similar approach to identifying human faces. The profile silhouette was acquired from artist's tracings. Nine fiducial marks were used to represent the profile. The fiducial points correspond to the cardinal points in Galton's work. Wu and Huang[4] used B-spline fitting to extract interesting points from face profiles, from which a set of 24 features was derived. The distances between the interesting points, the angles between them, and the areas of the triangles formed by the points are used as the features. A degree of similarity based on a normalized Euclidean distance is used for feature matching. Yulie et al.[5,6] proposed an approach to detecting eyes in human face images using deformable templates. An energy function is defined using the parameters of the edges, peaks, and valleys in the input image and the template. The template interacts with the input image by modifying the parameter values to minimize the energy function (in the same sense as getting the best fit). The template is flexible enough to handle changes in size and orientation, and so it can locate eyes despite variations in scale, tile, and lighting conditions. Osamu Nakamura[7] used isodensity lines, instead of feature points extracted from the face, for human face identification. Isodensity lines are the boundaries of constant gray level areas resulting from quantizing an image. Template matching was used to match individual isodensity lines. Kirby and Sirovich[8] applied the Karhunen-Loeve procedure to characterize human faces. The goal of the approach is to represent the picture of a face in terms of an optimal coordinate system.

Proposed in this paper is a new approach to recognizing human face by image processing and pattern recognition techniques using both front and side views. The system includes two CCD cameras. Each of the optical axes of the two cameras is arranged to

*This work was supported partially by National Science Council, Republic of China under Grant NSC81-0404-E009-017.

†To whom all correspondence should be addressed.

be orthogonal to the other and the viewpoints of the two cameras are all fixed. An unknown person to be recognized is asked to stand on a pair of black footprint marks. The recognition system will first detect the existence of the person. This is aimed to simulate a door entrance control system. After the system senses the existence of a person, it will take the person's front-view and side-view images. From the side-view image, the face boundary is traced and seven feature points are detected according to boundary curvatures. A long polyhedral bar is used for establishing the correspondence of front-view and side-view image points. A mapping procedure is designed to estimate the positions of front-view organs. From the front-view image, additional feature points from the mouth, nose, chin, cheeks, and eyes are extracted. The existence of glasses is also checked. If the person wears glasses, the features relative to eyes are omitted. A set of 20 feature values is derived from these feature points, and 15 of them are analyzed to be the most effective for face identification. The system first performs rough preclassification using a certain feature value, namely, height, and then recognizes the person by feature matching according to the remaining feature values using a similarity measure.

Good recognition rates prove the feasibility of the proposed approach. In the remainder of this paper, a description of the overall system is given in Section 2. Side-view and front-view feature selection and computation are described in Section 3 and 4, respectively. The learning and recognition procedures are presented in Section 5 and 6, respectively. The experimental results are given in Section 7, followed by conclusions and suggestions for furture study.

2 System description

The proposed approach includes two phases: the first is the learning phase and the second the recognition phase. In the learning phase, all training samples are shown to the system one at a time and two databases (one for persons who wear glasses, and the other for those who do not) are automatically generated according to these training samples. In the recognition phase, a two-level decision-tree approach is applied. First, an unknown person is imaged and the existence of glasses is detected. After that, the unknown person is compared only with those persons in the database who have similar heights. A distance measure is employed in the detailed matching. The person in the database with the minimum distance to the unknown is considered as the match. This strategy speeds up the recognition process.

2.1 System Environments

To simulate a real automation environment, a prototype system as shown in Figure 1 is built for this study. It includes two CCD cameras, a multiplexier, and a PC386 as the host computer. The lighting condition of the experimental environment is well controlled and each person to be identified is asked to stand on a pair of black footprint marks.

Because not everyone is the same in height, in order to fit the faces of most persons into the camera views, two wide-angle 16mm CCD cameras are used. The two cameras are arranged in the following manner : one for front-view image taking and the other for side-view image taking. The optical axes of the two cameras are orthogonal, as illustrated in Figure 2,

In order to segment the face of a person from background, most existing methods put a black curtain behind the person as background. But as a simulation of a door entrance control system, this is not suitable because this requires a change of the environment around the door in real applications. Instead of darkening the background, the foreground is brightened, and the apertures of the cameras are narrowed. With this method, the background can be eliminated by thresholding and the person's face can be segmented conveniently.

As mentioned above, a brighter lighting condition is needed. However, a door entrance control system must be in a working status at any time. If lights are always turned on, it is power-consuming. So, a PC interface card is specially designed to receive control signals from the computer to turn on the lights momentarily. When the cameras "see" someone standing on the footprint, it will issue a signal to this interface card, and the interface card will turn on the lights for about 0.6 second. The front-view and side-view cameras will take pictures during this period.

2.2 Correspondence between Side-View and Front-View Images

Because the side-view image is closely related to the front-view image, in order to extract facial features conveniently, it is necessary to know the correspondence between the front-view and side-view images. That is, it is desired to know the position of a point in the front-view image according to the position of this point in the side-view image.

Because the optical axes of the two cameras are orthogonal, a long polyhedral bar with a rectangular-shaped cross section as shown in Figure 3 is used for calibration of image correspondence. Equal-spaced black points are marked on its front side and lateral side. Each black point on the front side has a corresponding point on the lateral side lying on a position with the same height.

During the calibration procedure, the bar is first arranged at a suitable position in between the footprint marks, and the two cameras are then initiated to take pictures. In this way, the front-view camera can take the picture of the front side of the bar, and the side-view camera can take that of the lateral side of the bar. In order to locate the black points on the bar in the images, the images are processed using a spot detection mask[9] (shown in Figure 4) The black points detected are circled in the images, as shown in Figure 5. Figure 5 (a) shows the detection result of the front-view image, and Figure 5 (b) shows that of the side-view image. In fact, the ith spot detected in the front-view image and the ith spot detected in the side-view image lie on the same height. According to this information, the correspondence of side-view and front-view images can be established, with the details described in the following, which basically is an interpolation process to computes the y-coordinates of each corresponding discrete image point pair in the side-view and front-view.

Algorithm 1. Image correspondence procedure.
Input. Results of spot detection.
Output. A y-coordinate correspondence table.
Method.
Step 1. Let $y_f(i)$ and $y_s(i)$ be the y-coordinates of the ith points detected in the front-view and side-view images, respectively.
Step 2. Make a 1-D array M. The value of $y_s(i)$ is used as the index and that of $y_f(i)$ as the content of M, i.e., $M(y_s(i))=y_f(i)$, $i=1, \ldots, n$, where n is the number of spots detected, as shown in Figure 6.
Step 3. Let $i=1$.
Step 4. Let $j=y_s(i)+1$.
Step 5. Let $M(j) = [y_f(i+1) - y_f(i)] / [y_s(i+1) - y_s(i)] * (j - y_s(i)) + y_f(i)$.
Step 6. If $j < y_s(i+1)-1$, then let $j=j+1$, and go to Step 5.
Step 7. If $i < n-1$, then let $i=i+1$, and go to Step 4.
Step 8. Stop.

3 Side-View Feature Selection and Computation

The selection and computation of the side-view features of the human face are discussed in this section. First, the position of the human face is estimated and a starting point is obtained for boundary tracing. Then a boundary tracing algorithm is performed to extract the profile silhouette. After that, some interesting points are extracted from the side-view profile silhouette.

3.1 Extraction of interesting feature points

Seven interesting points in the side-view image are extracted using the *k-curvature* method[10]. The first point extracted is the nose peak. The extraction process includes tracing the profile curve, searching the prominent points, and then choosing the leftmost one of the prominent points as the nose peak.

After having located the nose peak, the *k-curvature* method[10] is used to detect the turning point of the nose bottom, the mouth point, and the chin point (marked by P1, P2 and P3, respectively, in Figure 10(a)). Then the concave point on the profile from P2 to P3 are found by the *k-curvature* method again (marked by P6). After that, we locate the forehead point (marked by P4 in Figure 10(a)) by letting the distance between the forehead point and the nose peak equal to 0.8 times the distance between the nose peak and the chin point. After having located the forehead point, it is desired to detect the notch point (marked by P5 in Figure 10(a)) between the forehead and the nose peak. This is done by computing the farest point on the profile curve in between the forehead point FP and the nose peak NP to the line joining FP and NP.

3.2 Computing height value

In this study, a two-level decision-tree approach is applied. Each unknown person is compared first only with those persons in the database who have similar heights. An erroneously computed height value will cause a wrong decision. Thus the feature of height is a crucial one.

Among the interesting points mentioned in Section 3.1, the nose peak is found to be the stablest one. Thus, the y-coordinate of the nose peak in the side-view image is chosen to represent the height of a person.

4 Front-View Feature Selection and Computation

After extracting side-view features, the front-view image is processed. Front-view feature computation is more difficult than side-view feature computation. First, a boundary tracing algorithm is applied to exclude the background. Then, the symmetry line of the face is computed. After that, the chin, nostrils, cheeks, and mouth are processed. Then the system checks whether the person wear glasses or not. If no, it will search for the two eyes; otherwise, it will skip the procedure of eye searching.

4.1 Computing face range

As mentioned above, the correspondence of the front-view and side-view images is completed using a long polyhedral bar. Thus, the interesting points extracted from the side-view image can be mapped to those in the front-view image in order to estimate the y positions of the front-view facial organs, reduce the range of searching, and speed up the processing work. In Figure 7, the horizontal line level0 is the mapping result from the nose peak in the side-view image, and level1, level2, level3, level5 are the mapping results from the nose bottom, mouth, chin and eyes in the side-view image, respectively.

After the process of mapping, the face boundary is traced. The left and right face outlines can be obtained. Let the x-coordinates of the left and right outline points in terms of y be denoted as $lb(y)$ and $rb(y)$, respectively.

4.2 Extraction of front-view feature points

There are 7 steps in front-view feature processing. They are: 1. computing the symmetry line; 2. searching for the chin; 3. searching for the nostrils; 4. searching for the cheeks; 5. searching for the mouth; 6. check if the person wears glasses; 7. searching for the eyes. They are described in detail in the following. An example of the processing result is shown in Figure 10.

1. Computing symmetry line.

After finding out the facial boundary of the front-view face, the part outside the face area can be excluded. The next step is to compute the symmetry line. The symmetry line is calculated using the left and right outlines. In fact, the x-coordinate of the symmetry line is equal to the average of the x-coordinates of the left and right outline points.

2. Searching for chin.

Assume that the chin point in the side-view image has been extracted successfully. The point can be mapped to the front-view image in order to estimate where the chin is, resulting in a possible chin range. The x-coordinate of the chin is assumed to be the x-coordinate of the symmetry line, and the y-coordinate of the chin is calculated by finding a point which is the most similar to a line edge point in the possible chin range.

3. Searching for nostrils.

After finding the position of the chin, the nostrils are seeked. Template matching is employed in a specific window to search for the nostrils. The specific window is enclosed by four lines: 1. $x = mid\_x - 20$, 2. $x = mid\_x + 20$, 3. $y = level0$, 4. $y = level1$, where mid_x is the x-coordinate of the symmetry line, and level0 and level1 are the mapping results from the nose peak and the nose bottom in the side-view image, respectively.

4. Searching for cheeks.

Because the cheeks of a human face have no apparent mark, so the y-coordinates of the cheeks are assumed to be the average of the y-coordinates of the nose and chin. That is, $cheek\_y = (nose\_y + chin\_y)/2$, where $cheek\_y$, $nose\_y$ and $chin\_y$ are the y-coordinates of the cheek, nose, and chin, respectively. On the other hand, recall that the boundary of the face has been extracted by the *boundary tracing* method, with the x-coordinates of the boundary points being denoted as $lb(y)$ and $rb(y)$.As a result, the left cheek and right cheek points are located at $(lb(cheek\_y), cheek\_y)$ and $(rb(cheek\_y), cheek\_y)$, respectively.

5. Searching for mouth.

Assume that the mouth in the side-view image has been found. After the mapping process, $level2$ is obtained, which specifies a rough estimation of the y-coordinate of the mouth in the front view. The correct y-coordinate of the mouth, denoted as $mouth\_y$, can be acquired by a projection method as described in the following way:

$$mouth\_y = \{ y \mid proj(y) = \max proj(y'), \; level2 - 10 < y' < level2 + 10 \}$$

with

$$proj(y') = \sum_{k=-20}^{20} f(mid\_x + k, y'),$$

where mid_x is the x-coordinate of the symmetry line, and $f(x, y)$ specifies the gray value at (x, y).

Then the two side corners of the mouth are searched. According to the shape of the corners of the mouth, two masks are designed, as shown in the Figure 8. The two masks are used to "glide" in a proper range set up by the use of the coordinates,$mouth\_y$ and mid_x, and the corners of the mouth can be detected successfully by template matching.

6. Checking if the unknown person wears glasses.

The proposed approach has no restriction on wearing glasses. An efficient method for checking glasses is to detect the existence of a glass frame at about 1/4 and 3/4 width of the face. If the person wears glasses, a clear edge will appear in a specific window as shown in Figure 9. Contrarily, there will be no edge if the person does not wear glasses.

7. Searching for eyes.

Proceedings of 1992 International Computer Sympoisum
December 13–15, Taichung, Taiwan, ROC

More image processing steps are required to search for the eyes if the person does not wear glasses, including the methods of projection and template matching. According to the side-view information, the y-coordinate of the eyes can be estimated. To speed up the processing, the x-direction and y-direction projection methods are applied to get a search range for the eyes. After that, template matching using a circular mask for the eye is employed to locate the two eyes correctly.

An example of image processing of the side-view and front-view images is shown in Figure 10.

4.3 Effective Feature Selection

A set of 32 feature is initially used according to these feature points. It is later reduced to 20 since not all features are mutually independent and efficient. The 20 features can be grouped into three types: (1) distance feature, (2) angle feature, and (3) area features. The definitions of these features are given in the following.

For side-view images :

f_1 = distance from P0 to P1,

f_2 = distance from P0 to P3,

f_3 = distance from P1 to P2,

f_4 = distance from P2 to P6,

f_5 = distance from P6 to P3,

f_6 = distance from P1 to line P0_P3,

f_7 = angle P0_P2_P3,

f_8 = angle P0_P1_P2,

f_9 = area enclosed by profile trace and line P6_P3,

f_{10} = distance from P0 to P5,

f_{11} = distance from P0 to line P1_P5,

f_{12} = angle P0_P5_P3,

f_{13} = area enclosed by profile trace and line P5_P1,

For front-view images :

f_{14} = area of face,

f_{15} = length of mouth,

f_{16} = width of face,

f_{17} = angle (left corner of mouth)_(chin)_(right corner of mouth),

f_{18} = angle (left cheek)_(chin)_(right cheek),

f_{19} = distance from left eye to right eye,

f_{20} = angle (left eye)_(nose)_(right eye),

The six features, f_{10} through f_{13}, f_{19}, and f_{20}, are used merely for the person without glasses.

The effectiveness of the 20 features f_1 through f_{20} defined above have been checked and sorted in this study. The ratio of the *interclass distance* over the *intraclass distance* is used as the criterion[11]. The result is shown in Table 3.1, which says that f_{13} is the best feature and f_1 is the worst among the twenty.

5 Learning Procedure

The purpose of the learning procedure is to extract relevant features from the images of all the persons to be identified and store the features in two databases for use in the recognition phase. In this study, 31 persons are chosen, including 16 persons with glasses and 15 persons without glasses. Each person is imaged for 3 times. So, 93 samples are used in the learning phase. The learning algorithm is described as follows.

Algorithm 2. Learning.

Input. A face of a person.

Output. Part of the database for use in the recognition phase.

Method.

Step 1. Take three images of the person.

Step 2. Compute the height of the person and extract the side-view and front-view features except those related to the eyes. Each of these feature is computed as the mean of the three features extracted from the three images.

Step 3. Determine whether the person wears glasses or not. If not, search for the two eyes and compute the related features.

Step 4. Insert the feature vector into the databases in the order of the height of the person. If the person wears glasses, insert it to database DB1; otherwise, insert it to database DB2.

Step 5. Stop.

6 Recognition Procedure

Whenever a person stands on the black footprint marks, the average gray value of a small window in the field of view of each of the two cameras will change, since the background is darker than all persons to be recognized. So, to determine whether a person is standing on the footprint marks, it only needs to watch the change of the average gray value of the specific small window in each image. On the other hand, because everyone stands when pictures are taken, the feature of height is prominent for use in the first step of identifying a person.

The similarity measure used for feature matching in the recognition procedure is the Euclidean distance (normalized by the standard deviation) between the feature vector of the unknown face and that of each reference face in the database. The reference face with the smallest distance to the unknown face is taken to be the best match. Let P denote the feature vector of the unknown identity, and R denote the mean vector of a reference in the databases, then the Euclidean distance(normalized by the standard deviation) between P and R, denoted as D(P,R), is defined by

$$D(\mathrm{P},\mathrm{R}) = \sqrt{\left(\sum_{i=1}^{20}\left[\frac{\mathrm{p}_i - \mathrm{r}_i}{\sigma_i}\right]^2\right)} \tag{1}$$

where p_i and r_i are the ith feature components of P and R, respectively, and σ_i is the standard deviation of the ith component which is computed from the use of the 93 sample vectors(3 for each of 31 persons) obtained in the learning phase according to the following equation:

$$\sigma_i = \sqrt{\frac{1}{31 * 3}\sum_{j=1}^{31}\sum_{k=1}^{3}(r_{ijk} - \mu_i)^2}$$

where

$$\mu_i = \frac{1}{31}\sum_{j=1}^{31}\left(\frac{1}{3}\sum_{k=1}^{3} r_{ijk}\right).$$

The detail of the recognition procedure is described in the following.

Algorithm 3. Recognition procedure.

Input. The face of an unknown person.

Output. The identification number of the person.

Method.

Step 1. Take the front-view and side-view images of the unknown person after detecting the existence of the person.

Step 2. Extract the features from his face images.

Step 3. Determine whether the person wears glasses or not. If yes, go to Step 8.

Step 4. Select the references in database DB2 whose heights are close to that of the unknown person within a certain tolerance.

Step 5. Choose the person P in the selected references whose distance to the input unknown is the smallest.

Step 6. If the distance is smaller than a reject threshold, then output the identification number of P; else, reject.

Step 7. Go to Step 1.

Step 8. Select the references in database DB1 whose heights are close to that of the unknown person within a certain tolerance.

Step 9. Choose the person P in the selected references whose distance to the input unknown is the smallest.

Step 10. If the distance is smaller than a reject threshold, then output the identification number of P; else, reject.

Step 11. Go to Step 1.

7 Experimental Results

In the proposed approach, the entire process from picture taking to person recognition is fully automatic. The speed of the entire recognition procedure is also satisfactory. It takes about five to ten seconds to recognize, including the human action of stepping on the footprint marks and the system's voice announcement of the recognition result.

How many features are enough to identify a person's face is a problem worth investigation. Thus, the recognition rates of using different numbers of features are computed. Table 1 has shown the order of the effectiveness of the 20 features. Accordingly, different numbers of more effective features are selected for use in the experiment. 24 persons (include 14 persons with glasses and 10 without) were tested. Each person is imaged for three times. So, totally 72 samples are tested. The result is described in Table 2, which indicates that the best effect is to use approximately the first 15 features of Table 1 and the corresponding recognition rate is about 95.8% the errors mainly come from erroneous extractions of the feature values due to inconsistency of the face expressions during learning and recognition.

The processing results of one of the tested samples are shown in Figure 11. The feature points extracted are marked on the pictures of Figure 11(a). In the bar chart shown in Figure 11(b), the axis "person id." specifies the reference samples in the databases and the axis "distance" specifies the computed distance values of the samples.

8 Conclusions

A new approach to human face recognition using two cameras has been proposed. An automation environment and a prototype system have also been established to verify the correctness of the recognition algorithm. In the proposed system, each person is described by a set of features obtained from the front and side views taken by two cameras. In order to work in real time, the employed processes for facial feature computations are chosen to be as simple as possible. The constructed prototype system has been designed to meet the requirements of a door entrance control system. For the sake of practicality, wearing glasses during recognition is allowed. In order not to change the environment heavily around the door, no artificial background need be provided. The experimental results show that the performance of the proposed system is good. The system is so feasible for practical applications.

References

[1] F. Galton, "Personal identification and description," *Nature*, vol. 28, pp. 201–202, June. 1888.

[2] F. Galton, "Numeralized profiles for classification and description," *Nature*, vol. 31, pp. 127–130, Mar. 1910.

[3] L. D. Harmon, S. C. Kuo, P. F. Ramig, and U. Raudkivi, "Identification of human face profiles by computer," *Pattern Recognition*, vol. 10, pp. 301–312, 1978.

[4] C. J. Wu and J. S. Huang, "Human face profile recognition by computer," *Pattern Recognition*, vol. 23, no. 3, pp. 255–259, 1990.

[5] A. L. Yulie, D. S. Cohen, and P. W. Hallinan, "Feature extraction from faces using deformable templates," *proc.CVPR*, pp. 104–109, 1989.

[6] C. L. Huang and C. W. Chen, "Human face recognition by using deformable template and active contour model," in *Proc. Workshop on Computer Vision, Graphics and Image Processing*, Taiwan, R.O.C., pp. 225–230, 1991.

[7] T. Sakaguchi, O. Nakamura, and T. Minami, "Personal identification through facial images using isodensity lines," *Proc. SPIE*, vol. 1199, pp. 643–653, 1989.

[8] M. Kirby and L. Sirovich, "Application of the karhunen-loeve procedure for the characterization of human faces," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 12, pp. 103–108, Jan. 1990.

[9] R. C. Gonzalez and P. Wintz, *Digital Image Processing*. Addison Wesley, Canada, 1987.

[10] A. Rosenfeld and A. C. Kak, *Digital Picture Processing*. Academic Press, New York/San Francisco/London, 1982.

[11] P. Devijver and J.Kittler, *Pattern Recognition A Statistical Approach*. Prentice-Hall International, Inc., London, 1982.

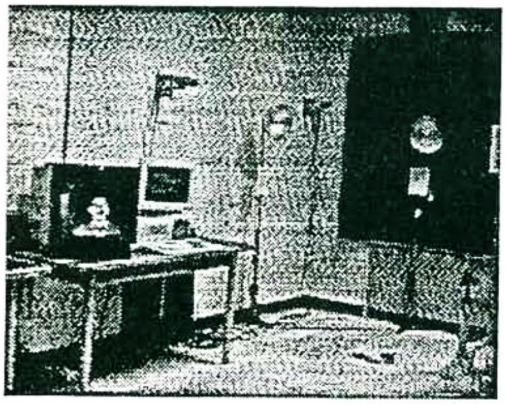


Figure 1. Proposed human face recognition system.

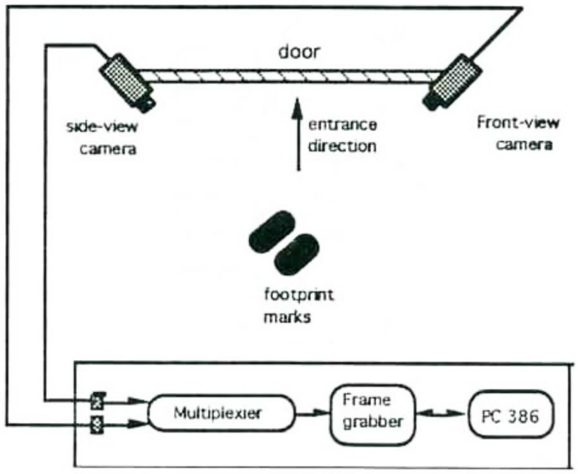


Figure 2. System configuration.

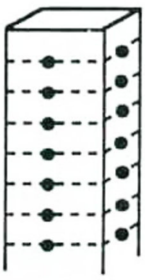
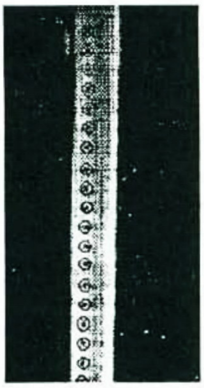


Figure 3. The polyhedral bar for image correspondence.

1	1	1	1	1
1	0	-3	0	1
1	-3	-4	-3	1
1	0	-3	0	1
1	1	1	1	1

Figure 4. Spot detection mask.



(a)

(b)

Figure 5. The results of black point detection. (a) The result of the front-view image. (b) The result of the side-view image.

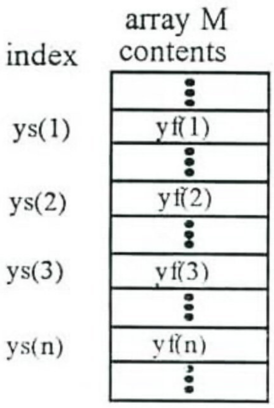


Figure 6. The array for correspondence.

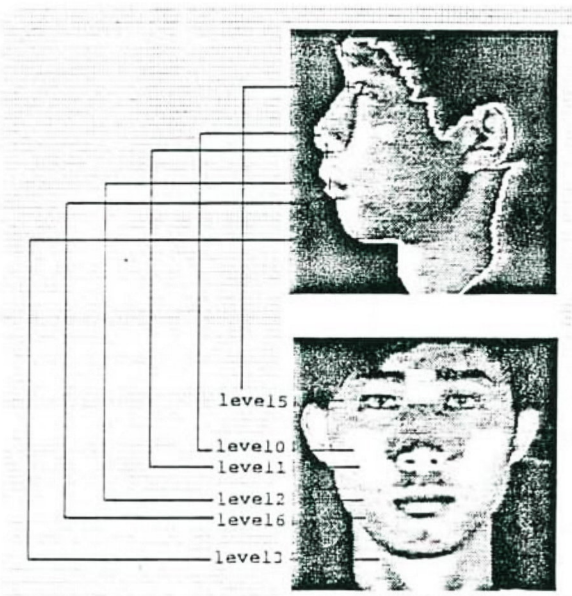


Figure 7. Mapping process from side-view image to front-view image.

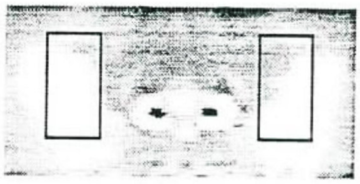
2	1	1	-1
1	1	-1	-2
1	-1	-2	-3
1	1	-1	-2
2	1	1	-1

(a)

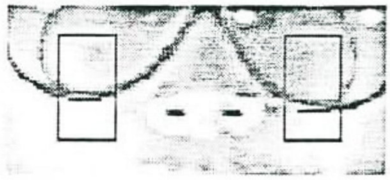
-1	1	1	2
-1	-1	1	1
-3	-2	-1	1
-1	-1	1	1
-1	1	1	2

(b)

Figure 8. The template of corners of mouth. (a) left template. (b) right template.

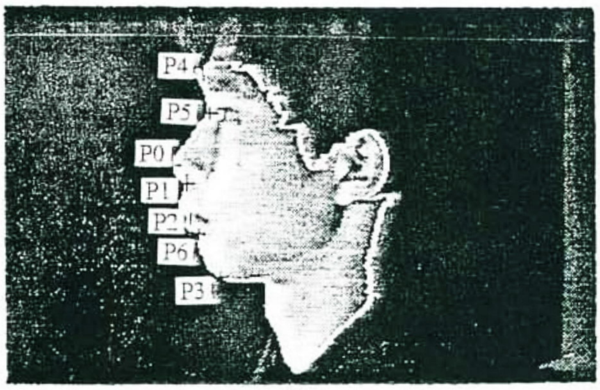


(a)

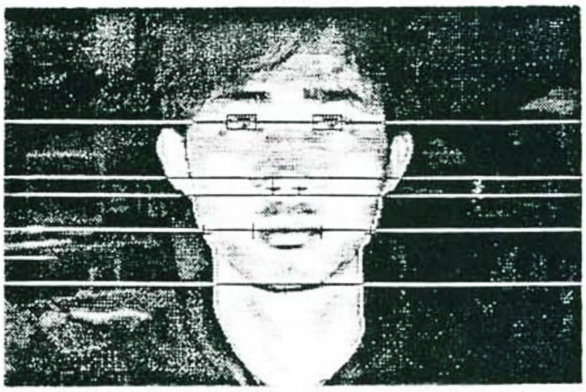


(b)

Figure 9. Checking if a person wears glasses. (a) A person without glasses. (b) A person with glasses.

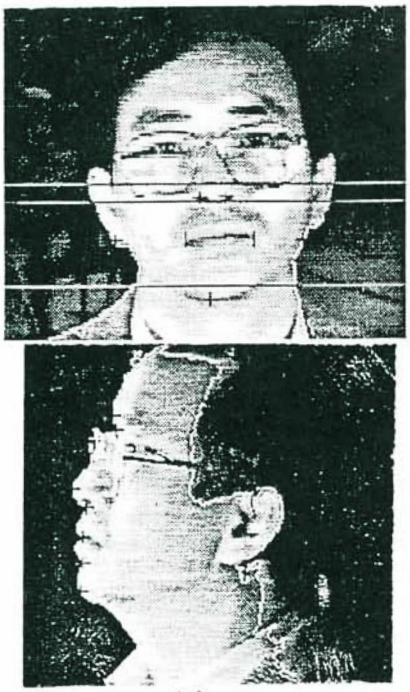


(a)

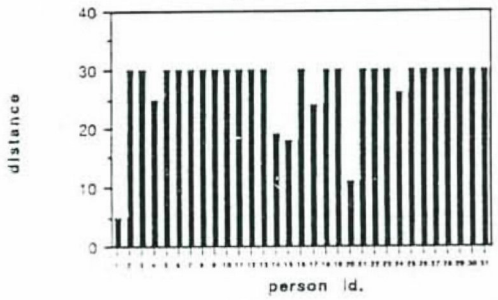


(b)

Figure 10. Result of image processing. (a) Side-view image. (b) Front-view image.



(a)



(b)

Figure 11. Processing results of a tested person with identification number 1. (a) The side view and the front view of the person. (b) The bar chart (indicating that the person no.1 has the smallest distance).

Table 1. Order of effectiveness of selected features

effectiveness order	feature	J
1	f_{13}	5.313915
2	f_{17}	3.503997
3	f_{14}	3.058725
4	f_{3}	3.025137
5	f_{11}	3.006904
6	f_{19}	2.491637
7	f_{18}	2.402003
8	f_{15}	2.347197
9	f_{20}	2.336172
10	f_{16}	2.320718
11	f_{4}	2.162691
12	f_{2}	1.998812
13	f_{10}	1.992304
14	f_{7}	1.952412
15	f_{5}	1.870706
16	f_{6}	1.788867
17	f_{12}	1.584795
18	f_{9}	1.555240
19	f_{8}	1.438595
20	f_{1}	1.267592

Table 2. Recognition results using different numbers of features.

Number of more effective features	misclassifications (with glasses)	misclassifications (without glasses)	Recognition rate
20	2	2	94.4 % (68/72)
19	4	1	93.1 % (67/72)
18	4	1	93.1 % (67/72)
17	4	0	94.4 % (68/72)
16	3	0	95.8 % (69/72)
15	2	1	95.8 % (69/72)
14	2	1	95.8 % (69/72)
13	3	1	94.4 % (68/72)
12	3	0	95.8 % (69/72)
11	4	2	91.6 % (66/72)
10	4	2	91.6 % (66/72)
9	4	2	91.6 % (66/72)
8	3	2	93.1 % (67/72)
7	7	1	88.8 % (64/72)
6	6	2	88.8 % (64/72)
5	7	2	87.5 % (63/72)