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PERFORMANCE ANALYSIS OF FACE RECOGNITION ALGORITHMS ON KOREAN FACE DATABASE

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Human face is one of the most common and useful keys to a person's identity. Although, a number of face recognition algorithms have been proposed, many researchers believe that the technology should be improved further in order to overcome the instability caused by variable illuminations, expressions, poses and accessories. To analyze these face recognition algorithm, it is indispensable to collect various data as much as possible. Face databases such as CMU PIE (USA), FERET (USA), AR Face DB (USA) and XM2VTS (UK) are the representative ones commonly used. However, many databases do not provide adequately annotated information of the pose angle, illumination angle, illumination color and ground-truth. Mostly, they do not include large enough number of images and video data taken under various environments. Furthermore, the faces on these databases have different characteristics from those of Asian. Thus, we have designed and constructed a Korean Face Database (KFDB) which includes not only images but also video clips, ground-truth information of facial feature points and descriptions of subjects and environment conditions so that it can be used for general purposes. In this paper, we present the KFDB which contains image and video data for 1920 subjects and has been constructed in 3 years (sessions). We also present recognition results by CM (Correlation Matching) and PCA (Principal Component Analysis) which are used as baseline algorithms upon CMU PIE and KFDB, so as to understand how recognition rate is changed by altering image taking conditions.

Keywords: Face recognition; Korean face database; performance evaluation of face recognition algorithms.

1. Introduction

The face is one of the most useful keys to identify a person. Thus far, many algorithms have been developed for automatic face recognition; PCA (Principal Component Analysis), LDA (Linear Discriminant Analysis), KPCA (Kernel PCA), SVM (Support Vector Machine), LFA (Local Feature Analysis), NN (Neural Network).[1,2,8] Some of them have demonstrated excellent results. However, there are still many technical limitations due to the variety of illumination, expression,

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pose and accessory. Understanding the limitations of the current face recognition technology is a key to develop successful face recognition systems. Many researchers have been developing face recognition algorithms on databases. To develop and test efficiently, database is essential, which can provide realistic and extreme environments. Many databases have been constructed and have made a contribution to the development of systematic face analysis researches. CMU PIE (USA), AR Face DB (USA), XM2VTS (UK), Yale Face Database B (USA) and CAS-PEAL (China) are representative databases.[3,4,11–13] Gross *et al.* presented 20 publicly available databases for face recognition.[5] Table 1 shows the overview of the databases.

FRVT (Face Recognition Vendor Test) is among the most representative tests to understand the limitations of face recognition analysis.[9] In FRVT, a vendor is given some images and is asked to compare each image to all of the other images. The data set is so composed as to show how well a system responds to numerous variables. Gross *et al.* evaluated the performance of PCA and LFA under various conditions on the CMU-PIE, the Cohn-Kanade and the AR database.[4]

In this paper, we introduce the KFDB (Korean Face Database) which is designed to include face images and videos which are taken under various conditions and present results of face recognition experiments under various conditions using baseline face recognition algorithms upon the KFDB and the CMU-PIE. From these results, we expect to understand the fundamental capabilities and limitations of the baseline face recognition methods.

Table 1. Overview of the recording conditions for 20 databases. Cases where the exact number of conditions is not determined (either because the underlying measurement was continuous or the condition was not controlled during recording) are marked with "++".[5]

Database	No. of Subjects	Pose	Illumination	Facial Expressions	Time
AR	116	1	4	4	12
BANCA	208	1	++	1	12
CAS-PEAL	66–1040	21	9–15	6	2
CMU Hyper	54	1	4	1	1–5
CMU PIE	68	13	43	3	1
Equinox IR	91	1	3	3	1
FERET	1199	9–20	2	2	2
Harvard RL	10	1	77–84	1	1
KFDB	1000	7	16	5	1
MIT	15	3	3	1	1
MPI	200	3	3	1	1
ND HID	300+	1	3	2	10/13
NIST MID	1573	2	1	++	1
ORL	10	1	++	++	++
UMIST	20	++	1	++	1
U. Texas	284	++	1	++	1
U. Oulu	125	1	16	1	1
XM2VTS	295	++	1	++	4
Yale	15	1	3	6	1
Yale B	10	9	64	1	1

2. Related Works

FRVT2000 is the most representative facial recognition vendor test. The main goal of FRVT2000 is a technical assessment of the capabilities of commercially available facial recognition systems and to educate the biometrics community and the general public on how to present and analyze results.[9] This test evaluated commercial systems using the FERET and HumanID databases. It evaluated the performance of face recognition for various parameters such as lighting, pose, expression and temporal variations. The similarity file scoring algorithm, used for the recognition performance portion of the FRVT2000 evaluations, follows FERET program.[7] In the period between August 1993 and July 1996, the FERET program collected 14,126 images from 1199 individuals. For each subject, two frontal views were recorded (sets fa and fb), where a different facial expression was requested for the fb image. For a subset of the subjects a third frontal image was taken using a different camera and under different illumination (set fc). A number of subjects were brought back at later dates to record duplicate images. For the duplicate I set the images were taken between 0 and 1031 days after the initial recording. A subset of this set, the duplicate II set, contains images of subjects who returned between 540 and 1031 days after the initial recording. Gross analyzed the results of face verification and evaluated the performance of PCA and LFA under various conditions with CMU PIE, Cohn-Kanade and AR databases.[4] The CMU PIE database contains a total of 41,368 images taken from 68 individuals. The images of subjects were taken in the CMU 3D Room using a set of 13 synchronized high-quality color cameras and 21 flashes. The resulting images are 640×480 in size, with 24-bit color resolution. This database includes 13 poses, 43 illuminations and 4 expressions images. Gross conducted a series of tests using two states of art face recognition systems on three face databases to evaluate the effect of face pose, illumination, facial expression, occlusion and subject's gender on face recognition performance.

3. KFDB (Korean Face Database)

There are several representative face databases, such as CMU PIE (USA), FERET (USA), HumanID (USA), XM2VTS (UK) and AR Face DB (USA).[4,7,10–12] The faces in these databases have definitely different characteristics from those of Asian. Moreover, those databases have their own characteristics fitted with their needs. Thus, we designed KFDB (Korean Face Database) which contains face images under various environments and ground-truth information and which can be used for a more general purpose. KFDB includes images taken under various environments, video clips, ground-truth information files of facial features and description files.

3.1. *Overview*

The KFDB consists of face images and video clips which are taken from 1920 subjects with its ground-truth information and description, and has been constructed in 3 years (3 sessions). 100 subjects were duplicated in the first session, second session and third session. In the third session, video clips of 100 subjects as well as images were taken. Face images were taken in a studio where an operator can control lighting conditions and cameras. Each condition for taking face image is a combination of various environmental factors; illuminations, accessories, expressions and camera's position. Video data of rotating head, changing expressions at close range and walking toward cameras at far range were taken in an office or corridor. Table 2 shows a summary of the data in the KFDB for each session.

3.2. *Studio overview for capturing image data*

A studio for capturing image data was designed so that an operator can easily control lighting condition and can take images at different camera directions, simultaneously. This platform consists of an octagonal prism frame with nine cameras (NTSC, CCD camera), 16 lights in eight directions, and an LCD monitor in front of the subject for the purpose of seeing her or his face directly. In order to separate foreground easily, blue screen was set up as a background. Figure 1 shows the

Table 2. Summary of the KFDB.

		1st session				
	Sex	Age				
Demographic		∼19	20∼	30∼	40∼	50∼
	Male	25	150	150	150	25
	Female	25	150	150	150	25
Conditions	21 illumination changes 10 Expression changes 21 Pose changes wearing 3 types of accessory					
		2nd session				
	Sex	Age				
Demographic		∼19	20∼	30∼	40∼	50∼
	Male	13	78	78	78	13
	Female	13	78	78	78	13
Conditions	21 illumination changes 10 Expression changes 28 Pose changes wearing 4 types of accessory					
		3rd session				
	Sex	Age				
Demographic (Image/Video)		∼19	20∼	30∼	40∼	50∼
	Male	3/10	15/60	15/60	15/60	2/10
	Female	3/10	15/60	15/60	15/60	2/10
Conditions	Image : Same as the 2nd session Video : 3 motions with one or two camera directions					

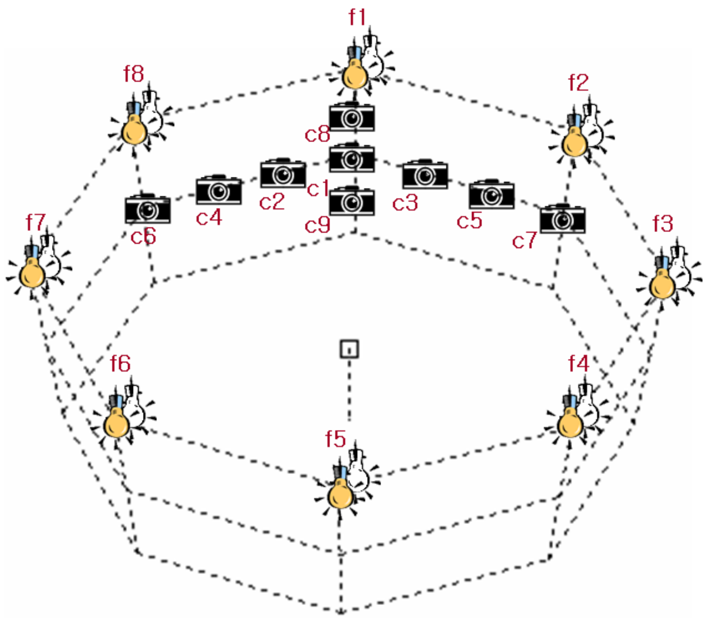


Fig. 1. Frame of the studio for capturing image data. f1–f8 represent positions of the fixtures coupled on fluorescent and glow lamps, and c1–c9 represent positions of the cameras.

position of cameras and lights and the whole configuration of the studio platform. Figure 2 shows a picture of the studio platform. Two lights of a fluorescent and a glow lamp were positioned in each direction.

3.3. *Studio overview for taking video data*

Two cameras were set up for taking video data with a blue screen. The height of one of the cameras was adjusted to subject's height so that the whole frontal face image can be captured. Another one was set up at the 2.25 m height to capture the whole body in walking motion from a distance and it provided a surveillance view. Video clips were of 640×480 pixel resolution and 5 s in length.

3.4. *Dataset*

The database consists of images, video clips, ground-truth information files and description files. Each ground-truth information file corresponded to one image, which describes feature points' locations in the image. Also, for each image data and video clip, a description file is provided, which describes subjects' information and conditions such as age, gender, birth-place of subjects, imaging condition and date.

The images are of 640×480 pixel resolution and 24 bit color depth. They are stored in two formats, BMP and JPEG. Description files and ground-truth files

Fig. 2. A picture of the studio for taking image data.

are stored in ASCII text format. Additionally, for each image data, thumbnails are provided in JPEG format.

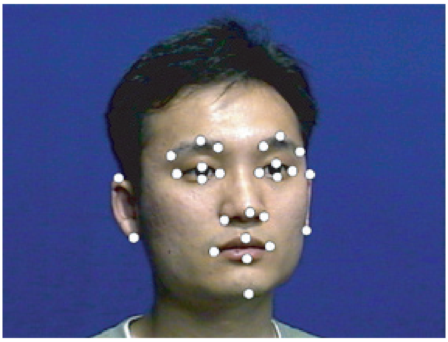
The video clips are of 640 × 480 pixel resolution and decoded using Motion JPEG including Hoffman tables. Thumbnails and description files are provided in JPEG and ACSII text format, respectively. Especially, for the walking video, two clips of different views are recorded, one being positioned in front and another at 2.25 m height. These two cameras operated simultaneously.

3.5. *Ground-truth information*

KFDB contains ground-truth information for all face images. This information represents the validity information and the locations of each of 26 feature points. The feature points of a face are independently defined by the poses and are denoted as a coordinate (x, y) following the name of each feature. When a feature point of facial component is not seen, the coordinate of that feature point is represented as (0, 0) and the validation flag is set as FALSE. Figure 3 shows an example of ground-truth information for an image.

3.6. *Various conditions for capturing image data*

Pose, illumination angle and color, facial expression and accessory variations are the environment factors for capturing image data. The conditions are set up combining these factors.



```
right_eyebrow_valid TRUE
right_ear_valid TRUE
left_ear_valid FALSE
⋮
left_reyebrow 396 187
left_ceyebrow 425 179
⋮
```

Fig. 3. Examples of image with feature points and ground-truth file.

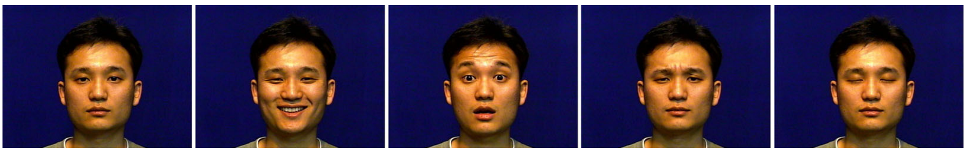


Fig. 4. Example color images of expression changes under glow light. It presents neutral, happiness, surprise, anger and blink expressions from left to right.

Expression varied data were captured under two different lighting colors (fluorescent and glow). The subjects were instructed to make expressions which are neutral, happiness, surprise, anger and blink expressions in turns. Figure 4 shows some examples of expression data.

Illumination varied data was captured under eight different lighting directions with two different lighting colors. In addition, five images were captured under five different full-frontal lighting directions ($0°$, $\pm 45°$ and $\pm 90°$) with fluorescent lamp while the subject was wearing a pair of glasses. Figures 5 and 6 show examples of illumination data with and without glasses.

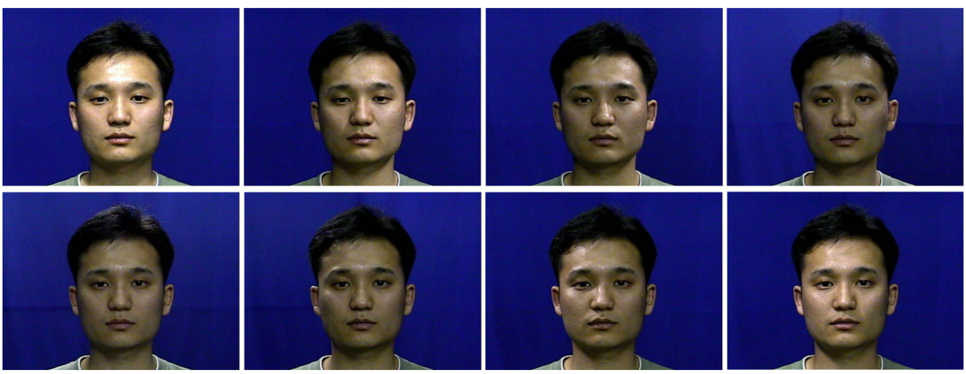


Fig. 5. Example color images of illumination changes under fluorescent light.

Fig. 6. Example color images of illumination changes under fluorescent light wearing glasses.

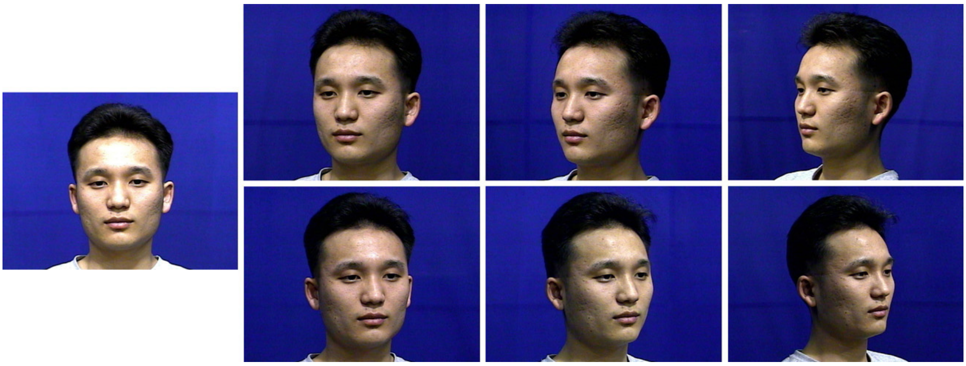


Fig. 7. Example color images of pose changes.

Pose varied data was captured wearing four different accessories. In the first and the second sessions, seven different cameras were located at frontal $\pm 45°$ range in $15°$ intervals horizontally. In the third session, additional two cameras were positioned at front $\pm 15°$ vertically. And the accessories considered were a hair-band, a pair of glasses and natural style in the first session, and a hair-band, a pair of glasses, natural style and a hat in the second and the third sessions. Figure 7 shows examples of pose data.

In total, 52 image data for the first session, 59 image data for the second session and 67 image data for the third session were collected for each subject. Table 3 shows various conditions for image data.

Table 3. Various conditions for image data.

Conditions	Description
Illumination	8 directions ($45°$ interval for full $360°$) 2 colors (fluorescent and glow lights)
	5 directions with wearing glasses — For a frontal fluorescent light
Expression	5 expressions under 2 illumination colors — Neutral, smile, blink, anger, surprise and happiness
Pose	7 poses with 3 accessories ($15°$ interval for frontal $\pm 45°$) — Natural, hair-band and glasses. (A hat is added in the second and the third sessions)

3.7. *Various conditions for taking video data*

In taking video data, three situations are considered; rotating head, talking and walking. Rotating head and talking video clips are taken at close-distance. In taking videos of rotating head, the subject was asked to rotate their head to the left, right, top and down in turn (Fig. 8, first row). In taking videos of conversations, the subject was asked to pronounce "a", "e", "i", "o" and "u" in turn (Fig. 8, second row). The talking video clip is useful to generate images of small facial variations. The videos of walking are captured by using two cameras as we presented previously (Fig. 8, third and fourth rows). In taking videos of walking, the subject was asked to walk toward the frontal camera from 5 m distance. Table 4 shows various conditions for video data.

3.8. *File naming rules*

The file naming rule of the KFDB is designed to be so easy as to understand the contents of the images easily. Tables 5 and 6 show the file naming rules for the image data, and Tables 7 and 8 show the file naming rules for the video data.

Fig. 8. Examples of video clip.

Table 4. Various conditions for video data.

Conditions	Description
Rotating head	Rotating head to left, right, top and down in turn
Talking	Pronouncing "a", "e", "i", "o" and "u" — Capturing facial expressions while pronouncing
Walking	Walking toward a front camera from 5 m distance — Two camera views at front and overhead

Table 5. Naming format for the image data.

Format	Indx-E-SAgCDEPA_T.ext

Table 6. Symbols and its meanings for the image data naming format.

Symbol	Meaning
Indx	**Index** of a subject
E	s**E**sion : {1, 2, 3}
S	**S**ex : {M, F}
Ag	**Ag**e
C	Illumination **C**olor : {W, Y} (**W**hite (fluorescent light), **Y**ellow (glow light))
D	Illumination **D**irection : {0, 1, . . . , 8} (Index of light: 0 represents index 1 of a light at pose variation)
E	**E**xpression : {N, E, H, A, B, S} (**N**ormal, n**E**utral, **H**appiness, **A**ngry, **B**link, **S**urprise ; E represents a normal expression in expression variations)
P	**P**ose : {1, 2, . . . ,7} (Index of camera)
A	**A**ccessory : {N,H,G} ({N (**N**atural), H (**H**air-band), G (**G**lasses), H (**H**at)}
T	file **T**ype : {O, C, T, D, G} (**O**riginal image, **C**ompressed image, **T**humbnail, **D**escription, **G**roundtruth)

Table 7. Naming format for the video data.

Format	Indx-E-SAg-B-H.ext

Table 8. Symbols and its meanings for the video data naming format.

Symbol	Meaning
Indx	**Index** of a subject
E	s**E**sion : {1, 2, 3}
S	**S**ex : {M, F}
Ag	**Ag**e
B	**B**ackground type : {0, 1, 2} (in front of a blue scree (0), in an office (1), in the corridor (2))
H	be**H**avior : {W, R, S, T} (**W**alking, **R**otating head, Walking behavior taken by **S**uveillance simulating camera, **T**alking)
T	file **T**ype : {O, T, A, D} (first frame of **O**riginal video (Representative frame), **T**humbnail of the first frame, **A**vi file, **D**escription)

4. Recognition Protocol

For evaluation purpose, Correlation Method (CM) and Principal Component Analysis (PCA) which are commonly used as baseline face recognition algorithms, are considered. The CM method is the simplest method of classifying images. This method identifies the images by measuring the correlation of images. Human faces, however variable they may be, will not be randomly distributed in the huge image space and thus can be described by a relatively low-dimensional subspace. The idea of PCA is to find the low-dimensional subspace which can efficiently describe the variation of the face images.

Following Phillips *et al.*, we divided test images into two sets of gallery and probe images.[7] The gallery contains the images used for the training of algorithms. The algorithms are tested with the probe images. We used the closed universe model for evaluating the performance, meaning that every individual in the probe was also presented in the gallery. For the PCA experiments, we used one third of the data for training and tested with others. In total, 400 individuals on KFDB and 60 individuals on CMU PIE were used for the experiments. Face image normalization was easily done by using ground-truth information. Each face image was cropped by 200×180 and applied histogram equalization.

5. Evaluation and Analysis

In this section, we present experimental results on the KFDB and the CMU-PIE with CM and PCA. We are not to know which method is better than another one, but to understand how recognition result is changed under varying conditions. For notational simplicity of the images on the KFDB, we describe the environment condition by the last five characters of the file name except extension (".BMP") and the file type ("_T"); for an example, "W0N6N" means that a fluorescent light of index number zero, neutral expression, a camera of index number six and natural style of accessory are considered as a condition by Table 6.

5.1. *Pose*

The performance change with varying viewpoint is an interesting topic in most practical applications. For this experiment, we have used a frontal image as a gallery for each individual and the pose-varied images as probes. Figure 9 shows the recognition accuracies of the different camera views. The X-labels, {1, 2, 3, 4, 5, 6, 7} correspond to the conditions of {W0N6N, W0N4N, W0N3N, W0N1N, W0N2N, W0N5N, W0N7N}, respectively. In addition, Fig. 10 shows the experimental result on the CMU-PIE. The recognition rate declines greatly even for a small departure from the frontal pose. The X-axis on the CMU-PIE is labeled by following

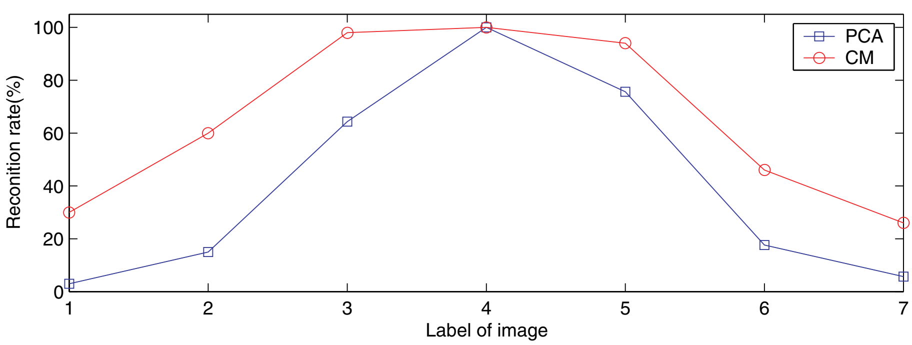


Fig. 9. The recognition rates with pose variations on the KFDB.

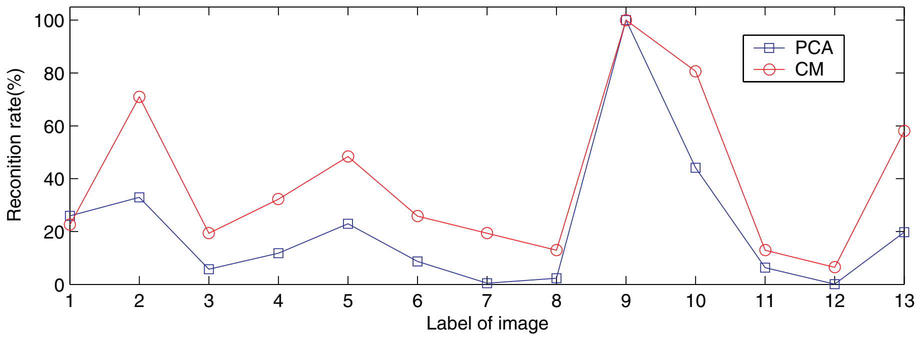


Fig. 10. The recognition rates with pose variations on the CMU-PIE.

the order of names of the images on the database. The X-label "9" represents the frontal image on the CMU-PIE database and "7" and "12" present profile images.

5.2. *Accessory*

Occlusions can occur owing to various accessories worn. KFDB for the first session has two kinds of occlusion images, involving hair-band, and glasses. For the accessory test, W0N1N image is used as gallery and a set {W0N1G, W0N1H, W0N1N} are used as probes. Figure 11 shows the recognition result. The X-labels, {1, 2, 3} correspond to the conditions of {W0N1G, W0N1H, W0N1N}, respectively. In this experiment, the recognition rate for the occlusion images with hair-band is lower than that of occlusion images with glasses, because the cropped region for recognition includes not only facial components such as eyes, nose and mouth, but also forehead and hair.

5.3. *Expression*

Human faces are characterized by facial expressions, showing typical deformation patterns. Thus, it is natural to evaluate a face with various expressions. W1E1N

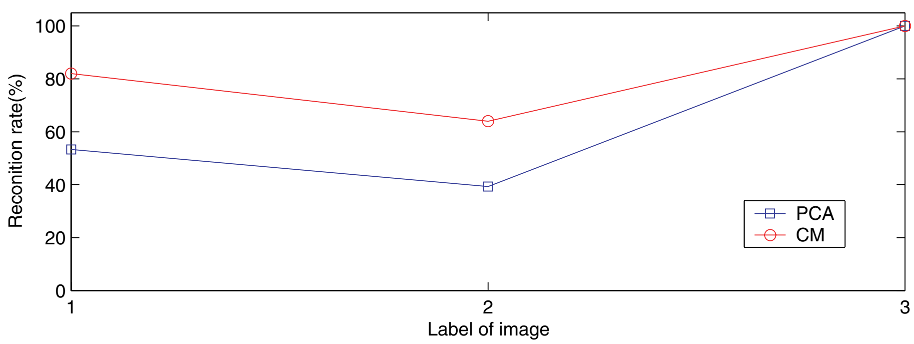


Fig. 11. The recognition rates with accessory variations on the KFDB.

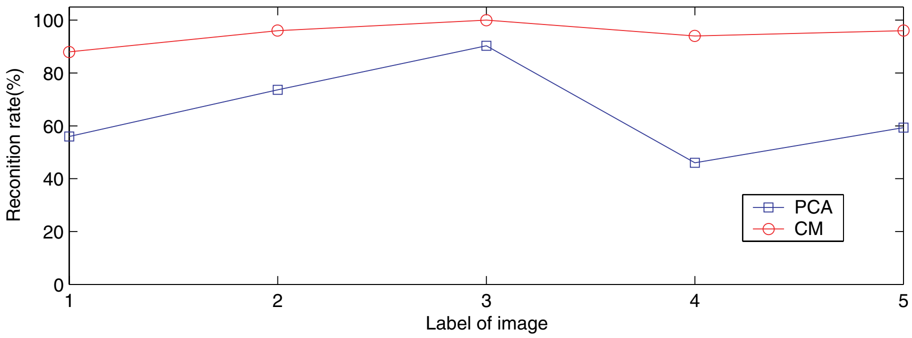


Fig. 12. The recognition rates with expression variations under a fluorescent light on the KFDB.

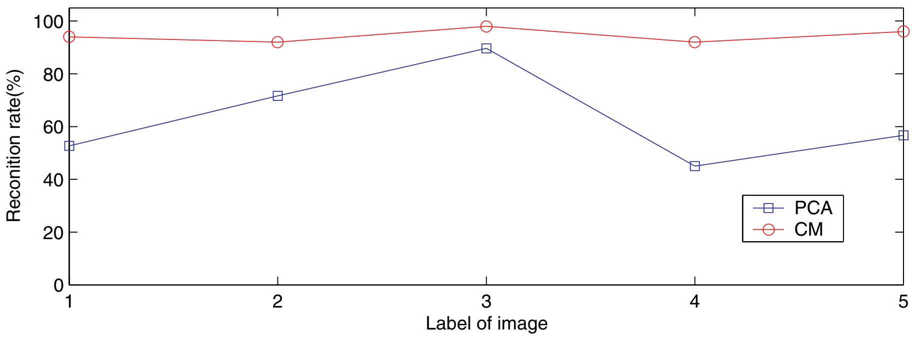


Fig. 13. The recognition rates with expression variations under a glow light on the KFDB.

image is used as a gallery and {W1A1N, W1B1N, W1E1N, W1H1N, W1S1N} are used as probes. Figures 12 and 13 show the results. The X-labels, {1, 2, 3, 4, 5} correspond to the conditions of {W(Y)1A1N, W(Y)1B1N, W(Y)1E1N, W(Y)1H1N, W(Y)1S1N}, respectively. For most facial expressions, we found that the facial deformation occurs mostly at the lower part of the face. Due to the large facial deformation, the recognition rates of "Happiness", "Anger" and "Surprise" are declined.

5.4. *Illumination*

The problem of algorithm sensitivity to illumination is one of the most studied factors affecting recognition performance. When an image of a subject is taken under different lighting conditions from those at his enrollment, we cannot avoid performance degradation to a certain extent. This point has been tested where W1N1N image is used as a gallery and {W1N1N, W2N1N, W3N1N, W4N1N, W5N1N, W6N1N, W7N1N, W8N1N} and {Y1N1N, Y2N1N, Y3N1N, Y4N1N, Y5N1N, Y6N1N, Y7N1N, Y8N1N} are used as probes. The former probe set comprises the images taken under the fluorescent light, and the latter probe set comprises the images taken under the glow light. Figures 14 and 15 show the results. As we can see from the results, the recognition rates are better under the illumination images than those in other conditions. In addition, Figs. 16 and 17 show the experimental result on CMU-PIE. For illumination varying image data, CMU-PIE includes the

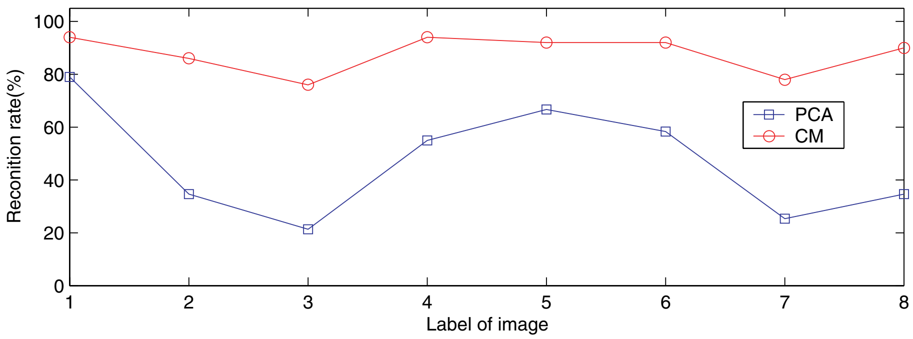


Fig. 14. The recognition rates with direction variations of fluorescent lamps on the KFDB.

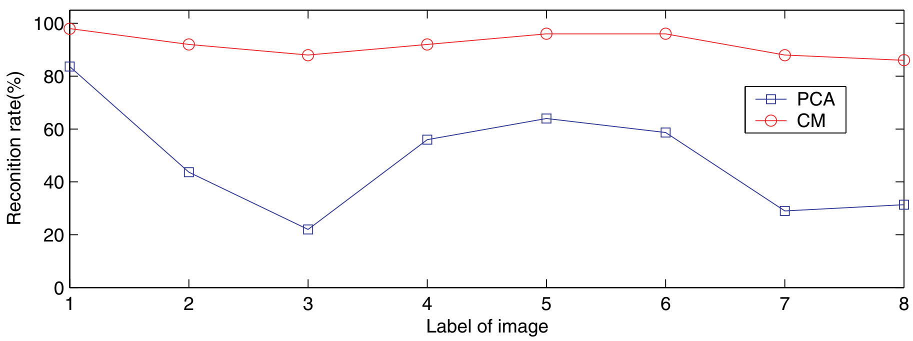


Fig. 15. The recognition rates with direction variations of glow lamps on the KFDB.

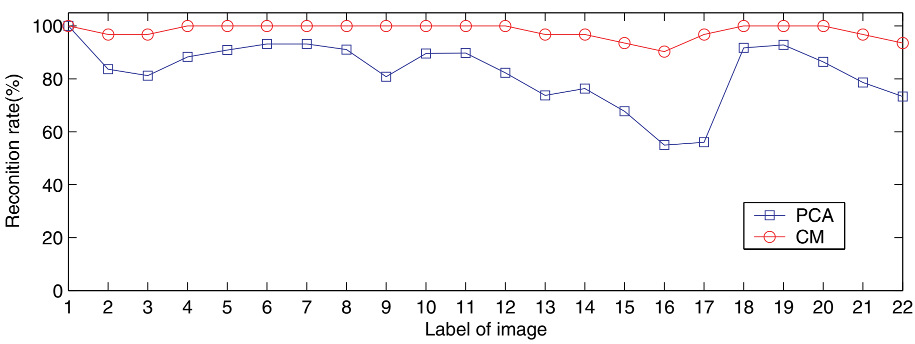


Fig. 16. The recognition rates with illumination 1 data on the CMU-PIE.

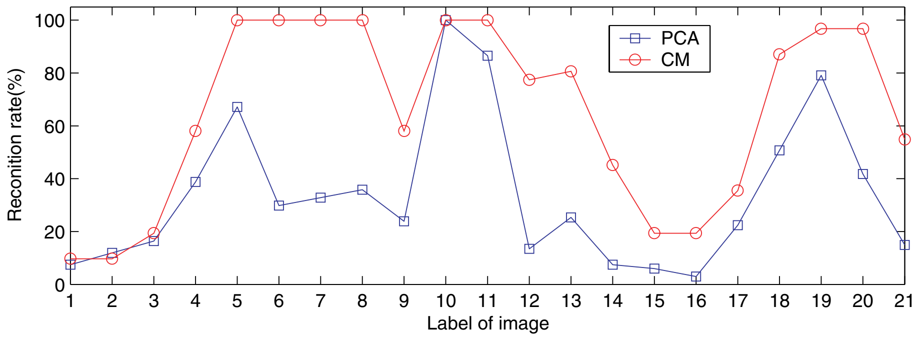


Fig. 17. The recognition rates with illumination 2 data on the CMU-PIE.

images with the room lights on (illumination 1) and with the room lights off (illumination 2). The X-axis on the CMU-PIE is labeled by following the order of names of the images on the database. The CMU-PIE provides 24 images from each camera, 2 with no flashes, 21 with one of the flashes firing, and then a final image with no flashes. However, in the illumination 2 environment, 3 images with no flashes have no meanings in our experiment. We used 21 images for illumination 2 experiment and 22 images including 1 image with no flashes for illumination 1 experiment.

5.5. *Analysis*

We conducted experiments by using baseline methods on the CMU-PIE and KFDB face databases. The experimental results have shown us clearly how recognition rate is changed by changing the environmental conditions. The recognition rates have changed when the condition is changed. In particular, the experiments of pose variation on both the databases and illumination 2 variation on the CMU-PIE showed drastic changes of recognition rate. However, the recognition accuracy curves indicated similar shapes for each method, although the recognition rates for different algorithms present different recognition rates.

6. Conclusions

In this paper, we have presented the KFDB which is designed to contain image data taken under various conditions, ground-truth information and video data of talking, walking and rotating head for 1920 subjects. The database was constructed in 3 years (3 sessions). The KFDB is designed to be used for general purposes on face recognition research.

We have also presented recognition results by CM (Correlation Matching) and PCA (Principal Component Analysis), which are used as baseline algorithms, on the CMU PIE and the KFDB, so as to understand how recognition rate is changed by changing image condition. An image of a face, viewed as a high-dimensional vector, occupies a single point in the huge space. The points of same faces are assumed to be located in a small region in the space. On the other hand, the points of different faces should occupy different areas in this smaller region. We can identify a face by finding the nearest known face in image space. However, the problem is that even tiny changes in lighting, expression or head orientation can change a large number of pixels, thus causing a dramatic change of the location in the space. To cope with these problems, we believe that 3D approaches should be used. Although there are many approaches with 3D, there still are many problems in practical domain.

Acknowledgments

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