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DeitY-TU face database: its design, multiple camera capturing, characteristics, and evaluation

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Abstract. The development of the latest face databases is providing researchers different and realistic problems that play an important role in the development of efficient algorithms for solving the difficulties during automatic recognition of human faces. This paper presents the creation of a new visual face database, named the Department of Electronics and Information Technology-Tripura University (DeitY-TU) face database. It contains face images of 524 persons belonging to different nontribes and Mongolian tribes of north-east India, with their anthropometric measurements for identification. Database images are captured within a room with controlled variations in illumination, expression, and pose along with variability in age, gender, accessories, make-up, and partial occlusion. Each image contains the combined primary challenges of face recognition, i.e., illumination, expression, and pose. This database also represents some new features: soft biometric traits such as mole, freckle, scar, etc., and facial anthropometric variations that may be helpful for researchers for biometric recognition. It also gives an equivalent study of the existing two-dimensional face image databases. The database has been tested using two baseline algorithms: linear discriminant analysis and principal component analysis, which may be used by other researchers as the control algorithm performance score. [DOI: 10.1117/1.OE.53.10.102106]

Keywords: face recognition; DeitY-TU face database; database characteristics; soft biometrics; anthropometry; classification.

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1 Introduction

The human face is considered as the most salient feature for biometric identification compared to other biometric features such as finger geometry, iris, retina, signature, keystroke, etc., as it can also be acquired without the person's knowledge. It continues to be the most popular and fast growing research area of computer vision and machine learning. In recent years, the development of different face image databases has greatly increased. Some of these databases have been designed for the specific needs of the algorithm under development.

Here, various databases have been reviewed based on key features such as number of subjects, total number of images available in the database, conditions under which the images were taken, resolution, image type, i.e., whether the image is visual or thermal; whether the image is color or gray level image, etc.

This paper briefs the creation of the DeitY-TU visual face database, which is being created in the Biometrics Laboratory at the Department of Computer Science and Engineering of Tripura University (TU), India, under a project with a grant from the Department of Electronics and Information Technology (DeitY), Ministry of Communications and Information Technology, Government of India. It contains 524 individuals' face images under a controlled environment. These individuals cover the different tribe and nontribe people of the northeastern states of India. The database contains a total of eight expressions, including neutral expression, closed eye, and six basic expressions; four different types of illumination variations; and images with glasses, and each of these variations are being clicked concurrently from five different angles to provide pose variations. The linear discriminant analysis (LDA) and principal component analysis (PCA) algorithms have been tested on the DeitY-TU face database. The summarized features of the database are listed below:

i. This database contains images of persons with interclass variation as it has individuals from different communities and subgroups, which results in the existence of facial structural differences.
ii. It contains images with three different resolutions, which provides size variation.
iii. Database images are captured with the combined challenges of illumination (4), expression (8), and pose (5). Five different poses are available for each combination of illumination and expression in the database.
iv. Images with spectacles are also available in the database.
v. Many of the face images contain partial occlusion, which adds up to a more difficult situation for face detection and identification.
vi. The database contains 49,780 images of 524 subjects collected from five different states of northeastern India.
vii. For each person, a total of 95 images have been collected, which give the researchers wide facility to use plenty of images to experiment on various aspects of the human face images.
viii. Soft biometric features such as moles, scars, and freckles are also present in 126, 39, and 17 individuals' faces, respectively, and the ground truth coordinates for

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these will also be available along with the final database release.

All these features of the DeitY-TU face database reflect its significance in the domain of face identification as well as in facial characteristics and anthropometric analysis as it contains faces from different races (including Mongolian people) with all the prime difficulties of face identification, along with the presence of natural occlusion and slight rotation in some cases. The database will be publically available soon after getting permission from the authority of the Department of Electronics and Information Technology under the Ministry of Communications and Information Technology (MCIT), Government of India.

The organization of this paper is as follows: a description of the two-dimensional (2-D) face images is given in Sec. 2, Sec. 3 contains a brief description of the DeitY-TU face database, Sec. 4 includes the evaluation of the database with a comparative analysis, and Sec. 5 concludes the present work and discusses future aspects.

2 Database Survey

The development of various face databases is increasing rapidly. Based on different purposes, different face databases have emerged, such as databases for face recognition, expression recognition, face detection, determination of age, etc. In this section, a total of 20 databases are described. The main highlights of the characteristics associated with each database are depicted in Table 1.

2.1 *Face Recognition Databases*

The Hajj and Umrah dataset[1] contain at least six images per person of a large number of pilgrims taken in Makkah during the 2011 to 2012 Hajj and Umrah season. Images are provided with varying poses, expressions, facial details (glasses/no glasses), and illumination against arbitrary backgrounds.

The PubFig database[2] is a large, real-world face dataset collected from the internet. The images are taken in completely uncontrolled situations with noncooperative subjects. Thus, there is a wide variation in pose, lighting, expression, scene, camera, imaging conditions, and parameters.

The Radboud faces database[3] contains eight expressions (happy, angry, sad, contemptuous, disgusted, neutral, fearful, and surprised) of 67 models (Caucasians and Moroccans) with three gaze directions (looking left, frontal, and right) for each expression, and each picture was taken from a different camera angle (180, 135, 90, 45, and 0 deg) simultaneously.

The Pose, Illumination, and Expression (PIE) database[4] was collected at Carnegie Mellon University. Due to some limitations (few subjects, limited expressions, and single recording session), they created the multi-PIE database,[5] with 337 people using four recording sessions over a period of 5 months and with a wider range of expressions, poses, and illuminations.

The Surveillance Cameras Face (SCface)[6] is a database of static human face images captured in an uncontrolled indoor environment using five video surveillance cameras from various distances. By placing the camera slightly above the subject's head, a real life surveillance scenario is provided; during the recordings, subjects were not looking at a fixed point.

The Imaging, Robotics, and Intelligent Systems (IRIS) database contains simultaneously obtained unregistered visual and thermal face images with various expressions (surprised, laughing, and angry), illuminations (left light on, right light on, both lights on, dark room, left and right lights off, glass_off_bright, glass_off_off, glass_off_medium, and glass_off_dark), and poses.[7] There are 176–250 images per person. Each expression and illumination has 11 thermal and 11 visual images.

The Chinese Academy of Sciences-Pose, Expression, Accessory, and Lighting (CAS-PEAL) database[8] contains 1040 individuals with six expressions (neutral, laughing, frowning, surprise, eyes closed, and mouth open), 15 lighting conditions, poses (nine cameras), and accessories (three glasses and three caps). Subjects were asked to look up and down for extra recordings with five backgrounds. Sixty-six subjects were recorded in two sessions at an interval of 6 months.

The Korean face database[9] was collected under controlled conditions. Seven cameras were used for pose variation (-45, -30, -15, 0, $+15$, $+30$, and $+45$ deg) with three different styles (with hair bands, glasses, and neutral) and five expressions (neutral, happy, surprise, anger, and blink). Eight lights in two colors (fluorescent and incandescent) were used for controlling the illumination conditions.

The Indian face database[10] contains images of 40 subjects with 11 poses. For some individuals, they included a few additional images, as well. For upright frontal faces, they used different poses (looking at front, left, right, up, up toward left, up toward right, and down) and four expressions (neutral, smile, laughter, and sad/disgust).

The extended Yale face database B contains 16,128 images of 28 human subjects under nine poses and 64 illumination conditions.[11] They captured 64 images per subject in a particular pose in about 2 s, so there is not much change in head pose and facial expression.

The AR database[12] was created by Aleix Martinez and Robert Benavente in the Computer Vision Center (CVC) at the Autonomous University of Barcelona. It contains a total of 3288 images of 116 individuals, where there are 63 males and 53 females. The subjects are captured under four different illumination conditions and four expressions (neutral, smile, anger, and scream). The images are taken as RGB color images with a resolution of 768×567 pixels. Two sessions were used with 2-weeks' interval.

The Facial Recognition Technology (FERET) database[13] was collected in 15 sessions between August 1993 and July 1996. It contains a total of 14,051 images that include 1199 individuals and 365 duplicate sets of images. Two duplicate sets were constructed by capturing images of persons already in the database.

The AT&T (or ORL) database of faces contains 10 different images for each of 40 distinct subjects.[14] These are 8-bit gray scale images with a resolution of 92×112 pixels. The images are captured with different facial expressions (neutral, open/closed eyes, and smiling/not smiling) and facial details (glasses/no glasses) under different illumination conditions.

2.2 *Facial Expression Databases*

In University of Science and Technology of China-Natural Visible and Infrared Facial Expression (USTC-NVIE) database,[15] the faces of 215 students (ages from 17 to 31) were captured. The number of subjects for images obtained under front, left, and right illuminations are 103, 99, and 103; while 107 subjects were captured for a posed database.

Table 1 Characteristics of various two-dimensional face image databases.

Database name/year of release	Total No. of images	No. of subjects	Imaging conditions[a]		Image resolution	Database type
			Particulars	Values		
Hajj and Umrah database/2012 (Ref. 1)	At least six images per person	Too many (exact information not available)	Ex, Il, Po/Gl/Bg	Variable/yes/ random	Variable	Visual, color
PubFig: public figures face database/2010 (Ref. 2)	58,797	200	Ex, Il, Po, scene	Variable	Variable	Visual, color
Radboud faces database/2010 (Ref. 3)	8040	67	Ex/Il/Po/Gz	8/1/5/3	1024×681	Visual, color
CMU multi-PIE database/2010 (Ref. 5)	More than 7,50,000	337	Ex/Il/Po	Variable/19/15	3072×2048	Visual, color
SCface database/2009 (Ref. 6)	4160	130	Ex/Il/Po	Variable/ uncontrolled (indoor)/9	Variable (3072×2048, 680×556, 426×320)	Visual and thermal, color
IRIS thermal/visual database/2004 (Ref. 7)	4228 pairs	30	Ex/Il/Po	3/5/varying	320×240	Visual and thermal, color
CAS-PEAL database/2003 (Ref. 8)	30,900	1040	Ex/Il/Po/Bg/Tm/ accessory	6/9-15/21/2-4/2/6	360×480	Visual, gray
Korean face database/2003 (Ref. 9)	52,000	1000	Ex/Il/Po	5/16/7	640×480	Visual, color
Indian face database/2002 (Ref. 10)	Information not available publicly	40	Ex/Po	4/11	640×480	Visual, gray
Extended Yale face database B/2001 (Ref. 11)	16,128	28	Il/Po	64/9	640×480	Visual, gray
AR database/(year of release not available publicly) (Ref. 12)	3288	116	Ex/Il/Po	4/4/1	768×567	Visual, color
FERET database/1996 (Ref. 13)	14,051	1199	Ex/Il/Po/Tm	2/2/9-20/2	256×384	Visual, color
ORL database/1994 (Ref. 14)	400	40	Ex/Il/Po/Gl	4/not provided/1/yes	92×112	Gray
USTC-NVIE database/2011 (Ref. 15)	Information not available publicly	215	Ex/Il/Gl	6/3/yes	768×567	Visual and thermal, color
MUG facial expression database/2010 (Ref. 16)	Information not available publicly	86	Ex	6	896×896	Visual, color
Japanese Female Facial Expression (JAFFE) database/1998 (Ref. 17)	213	10	Ex/Il/Po	7/1/1	256×256	Visual, gray
VT-AAST color face image database/2004 (Ref. 18)	286	1027	Or/Ex, Il/Oc/hair, Br, Ms, Gl/Po: frontal, intermediate, profile, over-profile/ scene/Bg	Upright and rotated/variable/ present/yes/515, 390, 91, 29/ outdoor, indoor/ simple, cluttered	300×225	Visual, color
UCD color face image database/2003 (Ref. 19)	94	299	Oc/Br, Ms/Gl/Or: upright, rotated/ Po: frontal, intermediate, profile	39/18/26/242, 50/ 182, 91, 26	Variable	Visual, color
FG-NET aging database/2006 (Ref. 20)	1002	82	Ex, Il, Po/Br, Ms, Gl, Hats	Variable/yes	Variable (400×500 approximately)	Visual, color and gray
VADANA database/2011 (Ref. 21)	2998	43	Ex, Il, Po, Gl, facial hair	Variable	250×250	Visual, color

[a]Il, illumination; ex, expression; Po, pose; Gz, gaze; Gl, glasses; Or, orientation; Oc, occlusion; Br, beard; Ms, mustaches; Bg, background; and tm, time.

The Multimedia Understanding Group (MUG) facial expression database[16] consists of image sequences of 86 subjects in two parts. The first part contains six basic expressions (happiness, fear, anger, sadness, surprise, and disgust) and the second part contains laboratory induced emotions.

The Japanese Female Facial Expression (JAFFE) database[17] images were taken at Kyushu University, Japan. Tungsten lights were positioned to create even illumination on the face. Ten persons posed for three or four examples of each of the six basic facial expressions (happiness, sadness, surprise, anger, disgust, and fear) and a neutral face for a total of 219 images of facial expressions.

2.3 *Face Detection Databases*

The VT-AAST (jointly developed by Virginia Tech and the Arab Academy for Science, Technology, and Marine Transport) color face image database[18] is divided into four parts. The first part contains 286 color images (includes 1027 faces) in the original format with a wide range of variation in illumination, expression, orientation, pose, environment, and race. Part two contains the same set in a separate file format. Parts three and four provide a set of corresponding images with manually segmented human colored skin regions in color and gray scale, respectively.

The UCD color face image database has two parts.[19] Part one contains 94 color images (includes 299 faces) in GIF format, with a high degree of variability in facial expression, lighting conditions, scale, location, orientation, and pose. The second part contains manually segmented faces for each image in part one. A variety of sources (digital cameras, scanned pictures, and internet) were used to collect the images.

2.4 *Face Aging Databases*

The FG-NET aging database[20] is a face image database that contains the faces of subjects at different ages. The database was developed to assist in the investigation on the effects of aging on facial appearance. The database was developed as part of the European Union project Face and Gesture Recognition Research Network (FG-NET).

Vims Appearance Dataset for facial analysis (VADANA) [21] contains a large number of images for each subject within and across ages with the largest number of intrapersonal pairs and variations in illumination, expression, and pose. A parallel version with aligned faces was also provided along with the relationships between subjects.

3 DeitY-TU Face Database Design and Development

The DeitY-TU face database is a visual face image database of different tribes as well as nontribe people of five northeastern states of India.

3.1 *Equipment Setup for Image Acquisition/Capturing Using Multiple Cameras*

Images in the database are taken under strictly controlled conditions of lighting, pose, etc. A total of four Nikon D5100 cameras (Thailand) with Nikon 18 to 55 mm lens and one Canon EOS 1000D camera (Taiwan) with Canon EF-S 18 to 55 mm lens are used for capturing five different poses of the face. Three numbers of simplex photo light systems with 196 V to 100 W modeling bulbs are also used for controlling four illumination conditions. Five different images of a subject are captured from five different angles in a single shot using an infrared remote sensor called the Nikon ML-L3, which has the capability of working within a range of 16 ft from the camera.

Cameras are placed and fixed in front of the subject at a distance of 4.5 ft. The five cameras, named as Cam1, Cam2, Cam3, Cam4, and Cam5, are placed at $+50$, $+25$, 0, -25, and -50 deg, respectively, with respect to the subject. Heights of the cameras are adjusted according to the subject's head position. The three lights are named as L1, L2, and L3, among which L1 is placed right above the head of the subject, and L2 and L3 are placed at angles of $+60$ and -60 deg, respectively, with respect to the subject. The distance of the side lights (L2 and L3) from the subject is 4.5 ft, and the top light (L1) is 7 ft above the ground. All images are captured against a homogeneous black background of 8.7×6.5 ft dimensions to prevent light reflection. Depending on the various measurements required for the complete setup, the photographic room is required to have dimensions of at least 12 ft $\times$ 10 ft $\times$ 10 ft. Figure 1 shows a top view of the entire setup used for the various cameras and lights along with the subject's position.

3.2 *Imaging Conditions*

Four illumination conditions have been controlled in this database, which are full illumination, half illumination, left light on, and right light on. Each of the lights has the facility to illuminate at full (100%) and half (50%) power. The top light is set to illuminate at full power in all conditions. Various illumination conditions have been created by controlling the side lights only. In "full illumination," both left and right lights have been set to full power. For "half illumination," both the lights have been set to illuminate at half power. In the case of "left light on" the left light has been set at full power and the right light has been set off. Similarly, for "right light on," the right light has been turned on at full power and the left light is switched off. Figure 2 shows the different illumination conditions with samples of frontal face images with a neutral expression.

In the DeitY-TU database, a total of eight expressions have been captured that include the six basic expressions (i.e., anger, laughter, sad, surprise, fear, and disgust) and the other two expressions are neutral and closed eye. All the expressions are shown in Fig. 3. All expressions are captured in "full illumination," and "half illumination" conditions. Only the neutral expression is also captured in "left light on," "right light on," and with glasses in "full illumination," which results in the following 19 conditions: (i) neutral expression in full illumination, (ii) neutral expression in half illumination, (iii) neutral expression in left light on, (iv) neutral expression in right light on, (v) neutral expression wearing glasses in full illumination, (vi) anger expression in full illumination, (vii) anger expression in half illumination, (viii) laughter expression in full illumination, (ix) laughter expression in half illumination, (x) sad expression in full illumination, (xi) sad expression in half illumination, (xii) surprise expression in full illumination, (xiii) surprise expression in half illumination, (xiv) fear expression in full illumination, (xv) fear expression in half illumination, (xvi) disgust expression in full illumination,

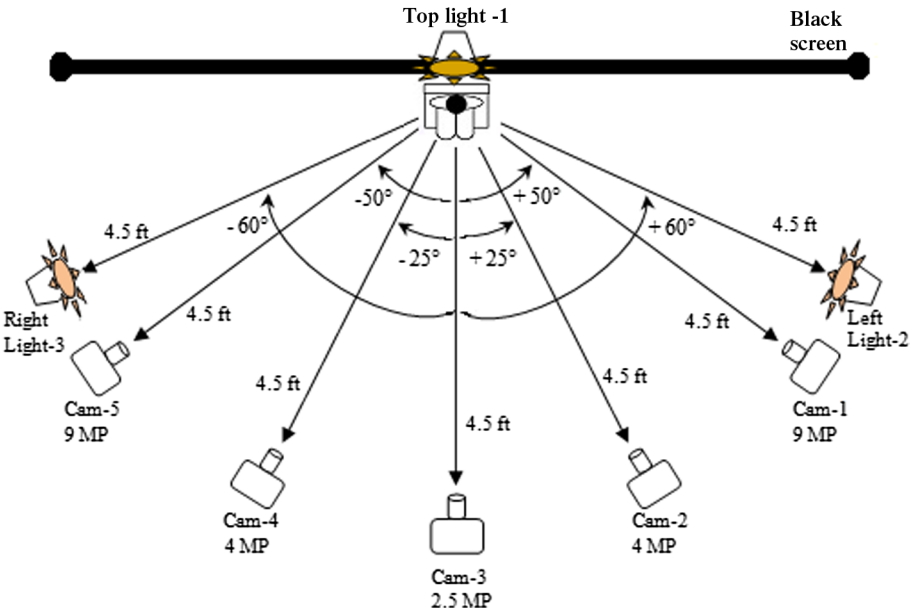


Fig. 1 Top view of camera and light setup in the photographic room.

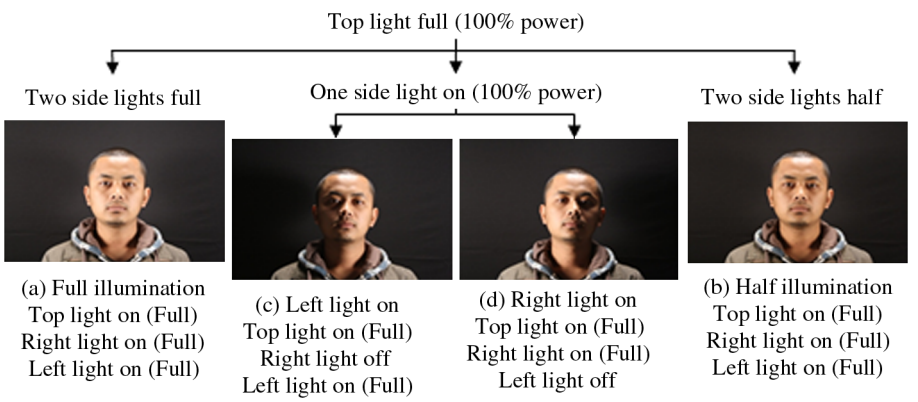


Fig. 2 Four illumination conditions applied on the neutral faces (example shows only frontal faces).

(xvii) disgust expression in half illumination, (xviii) closed eye in full illumination condition, and (xix) closed eye in half illumination condition.

For each of these 19 conditions, the face has been captured from five different viewpoints as shown in Fig. 4. Considering the middle camera (Cam3) as the one placed at 0 deg with respect to the subject, the other four poses have been defined by placing the cameras, named as Cam1, Cam2, Cam4, and Cam5, at +50, +25, −25, and −50 deg, respectively, with respect to the subject. The database face images may be captured from more different poses, but that will further increase the size of the database as the

Fig. 3 Sample faces with eight expressions in full illumination. Example shows only frontal faces.

Fig. 4 Sample faces of five poses with neutral expressions in full illumination.

Table 2 Detailed setup for each camera.

Camera No./angle (in degree) with respect to the subject	ISO sensitivity	Image resolution (pixels)	Camera expose	Lens (mm)	White balance
Cam 1/ + 50	800	3696 × 2448	S-15, F-5.6	55	Incandescent
Cam 2/ + 25	800	2464 × 1632	S-15, F-5.6	55	Incandescent
Cam 3/0	800	1936 × 1288	S-15, F-5.6	55	Incandescent
Cam 4/ – 25	800	2464 × 1632	S-15, F-5.6	55	Incandescent
Cam 5/ – 50	800	3696 × 2448	S-15, F-5.6	55	Incandescent

Table 3 Detailed setup for the three lights.

Light No.	Angle (with respect to object)	Height from ground (ft)	Distance from subject (approximately)	Simplex photo light (W)
L1	Over the head	7	2.5 ft from head (but varies according to height of the subject)	100
L2	+60 deg	4.5	4.5 ft	100
L3	–60 deg	4.5	4.5 ft	100

combination of different illuminations and expressions is the sum total of 19 images for each pose. All the other setups used for cameras and lights are listed in Tables 2 and 3, respectively. In Fig. 5, the different combinations of expressions, illumination conditions, poses, and glasses are shown, which have been used for capturing the images.

Moreover, the database images contain some natural occlusion for many persons, especially due to hair covering parts of the face. A few sample occluded images are shown in Fig. 6.

3.3 *Naming Convention*

After capturing, all the images have been renamed for ease of understanding. To make the naming convention meaningful, different codes have been used for different expressions, illumination conditions, presence or absence of glasses, and for different poses along with the state code and person number as follows:

State Code_Person Number_Expression Code_ Illumination Code_Glass Code_Pose Code.jpg

Using the above naming convention, every image in the database acquires a distinctive identity. In this database, separate state codes are given for each of the seven states from which the data has been collected. All the assigned state codes are shown in Table 4.

At least 100 persons' images are being collected from each state and the state code is followed by the person's number, which is coded using three numerical digits, such as 001, 002, 003, etc. After the person code, the eight expressions: "neutral," "anger," "laughter," "sad," "surprise," "fear," "disgust," and "closed eye" are coded using the notations E1, E2, E3, E4, E5, E6, E7, and E8, respectively.

The expression codes are followed by the illumination codes. These four illumination conditions "full illumination," "half illumination," "left light on," and "right light on" are coded using the notations I1, I2, I3, and I4, respectively.

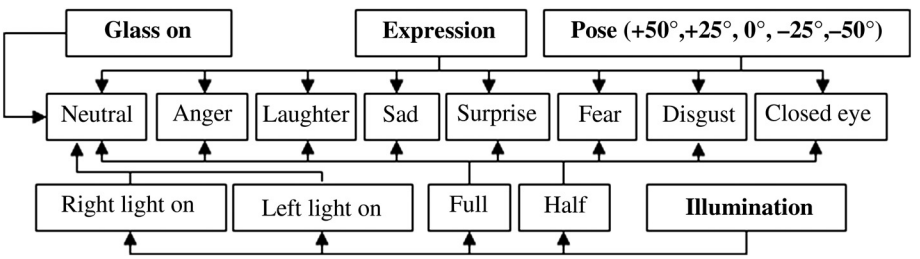


Fig. 5 Different combinations of expressions, illumination conditions, poses, and glasses for capturing the face images of each person.

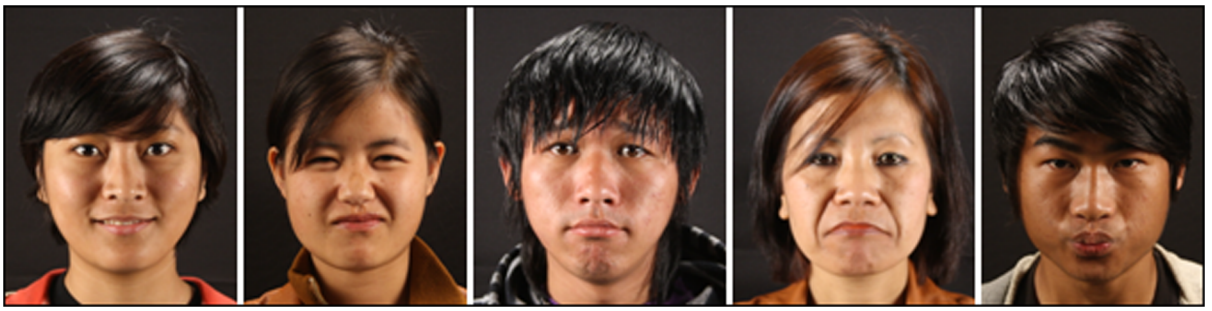


Fig. 6 Samples of occluded face images of DeitY-TU face database.

Table 4 Northeastern states of India and their corresponding codes used for naming the database images.

State name	State code
Arunachal Pradesh	AR
Assam	AS
Manipur	MN
Meghalaya	ML
Mizoram	MZ
Nagaland	NL
Tripura	TR

After that, numerical numbers such as "1" and "0" have been used to indicate the presence and absence of glasses, respectively. Then the five poses: pose 1 (+50 deg), pose 2 (+25 deg), pose 3 (0 deg), pose 4 (–25 deg), and pose 5 (–50 deg) are coded using P1, P2, P3, P4, and P5, respectively. For example, from the image name "TR_009_E4_I1_0_P3.jpg," it is clear that the image is of person number 9, taken from the state Tripura, the image is captured with "sad" expression in "full illumination," the person is not wearing any glasses, and finally, the image has been captured from a 0 deg angle, i.e., this image is a frontal image.

3.4 *Sample Face Images*

The DeitY-TU face database will cover the face images from seven states, namely, Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, and Tripura. Capturing has already been completed in five states: Assam, Mizoram, Nagaland, Tripura, and Manipur. A total of 49,780 face images of 524 individuals have been collected as of now, out of which, 100, 112, 107, 101, and 104 individuals are from Tripura, Mizoram, Assam, Nagaland, and Manipur, respectively. For each person, a total of 95 images are being captured. Some sample faces collected from the five states are shown in Fig. 7; and in Fig. 8, a complete collection of sample face images for a single person in the database are shown.

3.5 *Database Statistics*

The final DeitY-TU face database will contain face images of at least 700 individuals. Participants are the students, faculty members, and other staffs of various institutes, which include both tribes and nontribes of the different states ranging in age from 15 to 63. Table 5 lists the number of males/females and tribes/nontribes of all the five states. The distribution of ages is shown in Fig. 9, which reflects that a majority of people are between the ages of 18 to 25. Some other information, such as caste, subtribe, and age of each person, will also be released with the final database.

3.6 *Soft Biometric Features in DeitY-TU Face Database*

Classical biometry offers a natural and reliable solution for establishing the identity of an individual. Soft biometrics is a set of characteristics that provide some information about the individual, but is not able to authenticate the person individually, mainly due to lack of distinctiveness and permanence.[22] A number of studies are carried out to improve the face recognition performance by developing feature representation schemes. These features include the most important skin regions which appear on the human face, such as scars, moles, freckles, eye, mouth, nose, chin, lips, eyebrows, wrinkles, tattoos, etc.[23] Facial local features have a unique capability to investigate the face images in forensic applications by enhancing the image accuracy.[24] Some of the uses of these local facial features may be listed as follows:

i. Person identity can be checked using local facial features such as mole, scar, and freckle.
ii. These features are used in forensic science for criminal identification and for identifying missing children as well.
iii. These may also be very crucial in differentiating twins.
iv. In the Government Sector, a person's identity can be verified using the local facial features for security purposes.

In the DeitY-TU database, the presence of large numbers of the soft biometric traits, especially moles, scars, and freckles, has been noticed for several individuals.

3.6.1 *Moles*

Moles are typical pigmented spots, usually formed on different regions of the human skin. The size, shape, and color of moles varies a lot, but generally most of these are smooth and small; only some are irregularly raised and become large. These stained spots are formed due to the clustering of melanocytes cells, which are the cells responsible for skin coloration.

Fig. 7 Sample frontal neutral faces in full illumination condition collected from five different states.

Causes of moles. When melanocyte cells are not evenly distributed, they cluster, which results in a visibly pigmented spot commonly known as a mole. These skin growths are usually benign and harmless because the cells grow normally. However, there are some cases wherein regular moles become cancerous. This could lead to skin cancer, such as melanoma. Figure 10 shows some of the mole faces.

Types of moles.

i. Compound mole: This type of mole is slightly raised and is tan to dark brown in color.
ii. Congenital Navi: Such moles appear at birth. Their appearance is estimated as one in every 100 people.
iii. Junctional moles: These types of moles are the slightly raised kind of moles that remain flat initially.
iv. Blue moles: They are slightly raised in appearance and are usually found on the neck, head, and arms. They are blue in color.
v. Sebaceous moles: These moles grow when the oil glands become over active. They are usually rough to feel and appear as a yellow color.
vi. Dermal moles: Such moles are commonly found on the upper body and they sometimes contain hair. They are elevated in nature and are brown to flesh-colored in appearance.

Moles in DeitY-TU face database. Moles that are present in northeastern Indian people's faces are compound moles and junctional moles. Moles may be circular or irregular in shape. Some of them are slightly raised and some are flat. The sizes of raised mole are so large that they become prominent. The shapes are circular in maximum cases.

The images in Fig. 10 are an example of face images having a prominent mole and flat mole. Figure 10(a) has a mole that is prominent enough and slightly raised and it is circular in shape. But Fig. 10(b) has a prominent mole that is not circular, it is irregular in shape. Figure 10(c) has a flat mole which is circular in shape. Prominent moles are compound moles whereas flat moles are junctional moles.

3.6.2 *Scars*

Scars are the marks left by the healing of damaged tissues. Scar formation is a natural part of the healing process after injury. Various factors influence how human skin scars. The depth and size of the wound or incision and location of the injury affect the scar characteristics.

Fig. 8 Samples of complete image set (95 images) for a single person: (a) Images in five poses with eight expressions captured in "full" and "half" illuminations, (b) images in five poses with neutral expression captured in "left light on" and "right light on" illumination conditions, and with "glasses on" in "full" illumination condition.

Table 5 DeitY-TU face database statistics.

State	Total images	No. of images per person	Total persons	Male	Female	Tribe	Nontribe
Mizoram	10,640	95	112	62	50	112	0
Assam	10,165		107	46	61	14	93
Tripura	9500		100	49	51	34	66
Nagaland	9595		101	57	44	101	0
Manipur	9880		104	80	24	29	75
Total	49,780	95	524	294	230	290	234

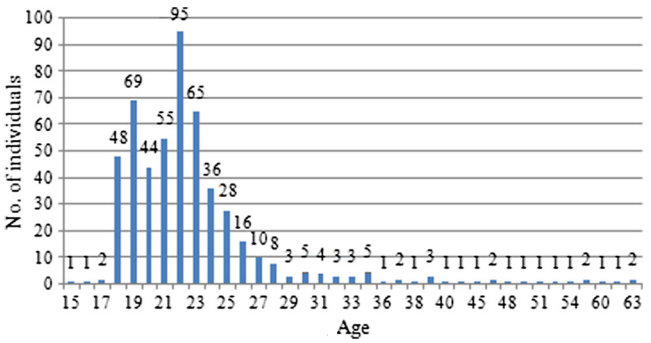


Fig. 9 Age distribution of the participants.

Causes of scars. If injury or any surgery takes place on skin, then the formation of scar tissue begins to start. Immediately after having an injury/surgery, three biological inflammatory responses start at the injury spot. They are inflammation, repair, and remodeling. Swelling, redness, heat, and pain occur during the acute inflammation stage which lasts for approximately 72 h. During the repair process rather than forming brand new tissue, the damaged tissue will heal with the formation of scar tissue. As a result, a mark is left at that spot.

Types of scars.

i. Keloids scar: These scars are the result of an overly aggressive healing process. These scars extend beyond the original injury.
ii. Contracture scar: Burning of skin may result in contracture scars. Comparably, this type of scar tissue is tighter and may impair the ability to move that part freely.
iii. Hypertrophic scar: Raised and red scars that are similar to keloids, but do not breach the boundaries of the injury site.
iv. Acne scar: Acne scars caused by skin conditions such as acne and chickenpox can have a sunken or pitted appearance.

Scars in DeitY-TU face database. Scars that are found in the DeitY-TU face database vary in sizes and are irregular in shapes. Some scars look linear whereas some are nonlinear. Linear-like scars are those that appear as a straight line, such as horizontal or vertical lines. The size of the scar depends on the injury that causes the scar.

The images in Fig. 11 are the examples of images of persons having scars on their face. The left two images have irregular shaped scars. Figures 11(a) and 11(b) have scars on the forehead and on the right eyebrow, respectively; whereas Fig. 11(c) has a linear-shaped scar on the right cheek. Faces with scars are available for all the states except Nagaland in the DeitY-TU face database.

3.6.3 *Freckles*

A small patch of light brown color on the skin is usually known as freckles.[25] Freckles are clusters of concentrated

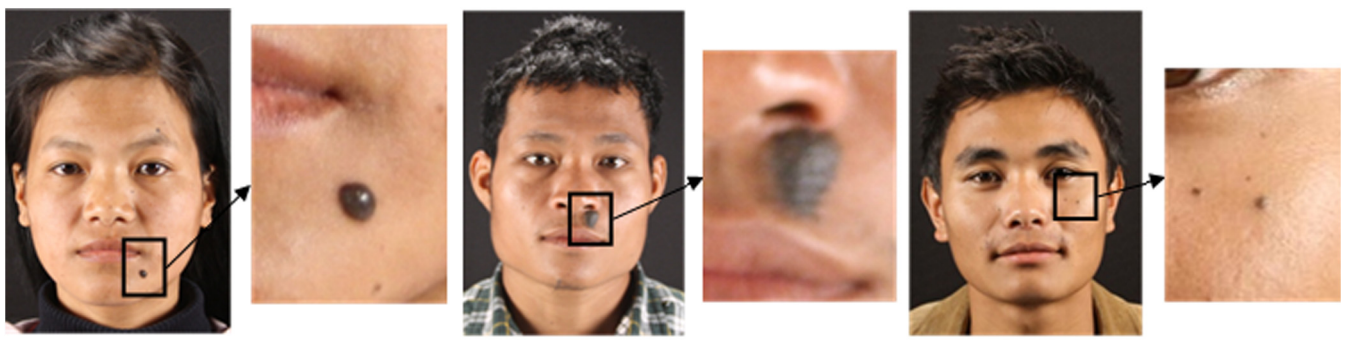


Fig. 10 Face images having prominent mole (a and b) and flat mole (c).

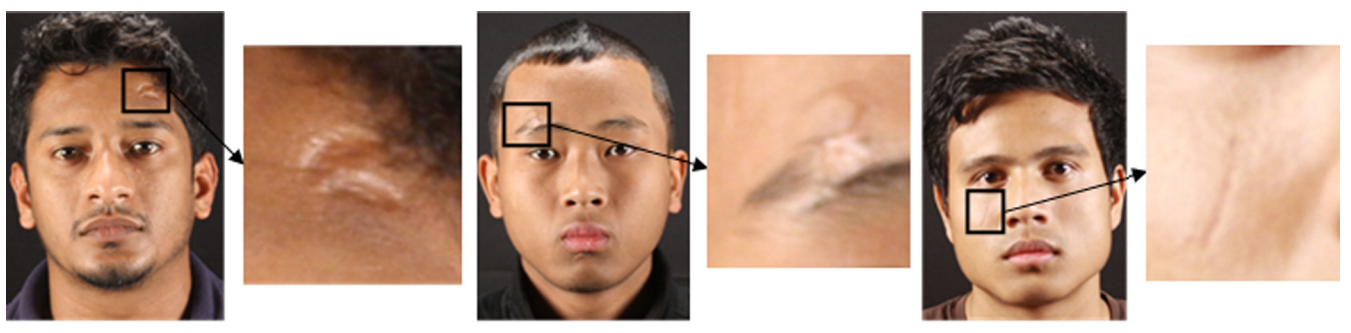


Fig. 11 Face images having irregular scars (a and b) and linear scar (c).

Fig. 12 Sample face images having simple freckles.

Table 6 Number of persons with moles, scars, and freckles of the DeitY-TU face database.

	No. of persons with moles			No. of persons with scars			No. of persons with freckles		
State	Total persons	Male	Female	Total persons	Male	Female	Total persons	Male	Female
Assam	21	12	9	6	3	3	2	2	0
Manipur	36	25	9	6	4	2	3	2	1
Mizoram	25	12	13	14	11	3	3	0	3
Nagaland	29	16	13	4	2	2	1	0	1
Tripura	15	10	5	9	6	3	8	7	1
Total	126	75	49	39	26	13	17	11	6

melanin that are most often visible on people with a fair complexion. Some people have freckles that fade away almost completely in the winter and return in the summer. Other people's freckles do not change much with or without the sun and can be seen year round. Freckles also tend to fade as people get older. The formation of freckles is triggered by exposure to sunlight.

Types of freckles.

i. Simple freckles: They are usually tan, round, and small—about the size of a common construction nail head.

ii. Sunburn freckles: They are often darker, have irregular jagged borders, and may be larger than a pencil eraser. Sunburn freckles are more common on the upper back and shoulders where people frequently get their most severe sunburns.

Freckles in DeitY-TU face database. Freckles appear as a group of dots. Generally, freckles are circular in shape and may be located on any part of the face. They appear on the cheek along with the nose and on the forehead.

The images in Fig. 12 are an example of face images having freckles. Figure 12(a) has freckles on both cheek and forehead; whereas Fig. 12(b) has freckles on nose only. Both the images are of simple freckles. No sunburn freckles have been found in this database.

Table 6 shows the number of individuals of the DeitY-TU face database who have moles, scars, and freckles on their facial region. The distribution of soft biometric features among different states is shown in Fig. 13, which indicates that among all three types of soft biometric features (mole, scar, and freckles), mole is the most common feature in people from all of the five states. People from Manipur are found to have maximum moles among the other states. It also specifies that people from Tripura are more prone to freckles, compared to the people belonging to other four states.

The number and locations of significant soft biometric features such as moles and scars are calculated particularly from a face region of neutral expression in full illumination images. The size and shape of the scars are not fixed and regular, for which the position of scars is measured by taking

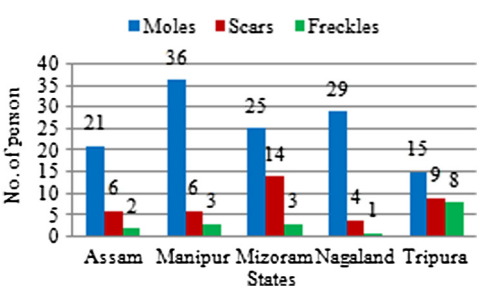


Fig. 13 Distribution of soft biometric features in the DeitY-TU face database.

Table 7 Number and location of moles and scars of a few persons from different states.

State	Person number (gender)	Moles		Scars	
		Number of moles (prominent)	Locations	Number of scars	End point locations
Assam	004 (M)	2	X:1077, Y:811; X:875, Y:877	1	X:1058, Y:512 and X:1054, Y:539
Manipur	006 (M)	2	X:734, Y:674; X:845, Y:1059	1	X:954, Y:599 and X:981, Y:612
Nagaland	067 (M)	3	X:1087, Y:765; X:1113, Y:774; X:1097, Y:832	0	—
Tripura	009 (M)	2	X:843, Y:694; X:891, Y:796	1	X:975, Y:393 and X:961, Y:422
Mizoram	040 (M)	2	X:891, Y:776; X:1098, Y:790	1	X:1177, Y:704 and X:1199, Y:780

the estimated right most and left most endpoints of the scar with respect to the subject. A few samples of these estimations are listed in Table 7. It provides the number of moles/scars and their location in terms of x- and y-coordinates. Freckles appear as clusters in skin and generally occupy a wide region in the face.

3.7 *Ground Truth Data and Anthropometric Variations in the Database*

In the field of face recognition, detection of primary facial feature points and measurements of the distance among all those primary facial features is a crucial task and is being developed by the application of anthropometric

Table 8 Ground truth coordinates of different facial feature points for face images of four persons from Tripura state (neutral expression in full illumination).

Person No. (gender)			001 (M)	002 (M)	003 (M)	005 (F)
Right eyebrow	End	Right	X:733, Y:572	X:792, Y:554	X:824, Y:597	X:874, Y:541
		Left	X:894, Y:513	X:931, Y:544	X:963, Y:593	X:1010, Y:532
Right eye	Corner	Right	X:778, Y:601	X:815, Y:596	X:843, Y:638	X:900, Y:580
		Left	X:877, Y:594	X:909, Y:610	X:937, Y:653	X:992, Y:590
	Midpoint	Upper	X:816, Y:583	X:861, Y:584	X:893, Y:629	X:948, Y:564
		Lower	X:814, Y:611	X:862, Y:615	X:887, Y:656	X:947, Y:595
Left eyebrow	End	Right	X:959, Y:497	X:1024, Y:548	X:1043, Y:595	X:1078, Y:530
		Left	X:1138, Y:517	X:1167, Y:570	X:1190, Y:618	X:1221, Y:533
Left eye	Corner	Right	X:993, Y:581	X:1034, Y:613	X:1057, Y:661	X:1100, Y:596
		Left	X:1094, Y:581	X:1127, Y:609	X:1143, Y:657	X:1193, Y:589
	Midpoint	Upper	X:1044, Y:565	X:1082, Y:592	X:1104, Y:644	X:1148, Y:568
		Lower	X:1049, Y:591	X:1085, Y:624	X:1103, Y:670	X:1149, Y:602
Nose	Corner	Right	X:891, Y:742	X:913, Y:744	X:936, Y:786	X:996, Y:723
		Left	X:1005, Y:738	X:1023, Y:750	X:1052, Y:790	X:1084, Y:729
	Midpoint		X:959, Y:761	X:968, Y:754	X:996, Y:786	X:1037, Y:719
Lip	Corner	Right	X:863, Y:835	X:872, Y:829	X:907, Y:866	X:961, Y:797
		Left	X:1046, Y:829	X:1051, Y:838	X:1080, Y:871	X:1119, Y:800
	Midpoint	Upper	X:946, Y:803	X:966, Y:807	X:998, Y:835	X:1038, Y:763
		Lower	X:947, Y:859	X:965, Y:858	X:992, Y:898	X:1039, Y:825
Chin			X:953, Y:973	X:956, Y:975	X:984, Y:1016	X:1039, Y:940

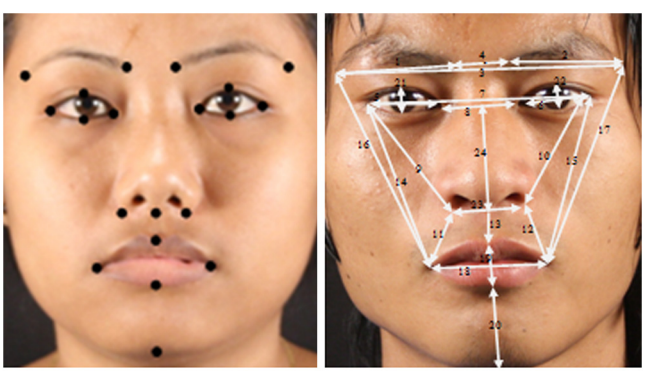
Table 9 Anthropometric measurements employed in this study.

Sl. No.	Distances	Codes used for the distances
1	Right eyebrow right corner to right eyebrow left corner	REbR-REbL
2	Left eyebrow right corner to left eyebrow left corner	LEbR-LEbL
3	Left eyebrow right corner to right eyebrow left corner	LEbR-REbL
4	Left eyebrow left corner to right eyebrow right corner	LEbL-REbR
5	Right eye right corner to right eye left corner	RER-REL
6	Left eye right corner to left eye left corner	LER-LEL
7	Left eye right corner to right eye left corner	LER-REL
8	Left eye left corner to right eye right corner	LEL-RER
9	Right nose corner to right eye right corner	RN-RER
10	Left nose corner to left eye left corner	LN-LEL
11	Right nose corner to right mouth corner	RN-RM
12	Left nose corner to left mouth corner	LN-LM
13	Subnasal point to upper lip outer middle	SN-ULOM
14	Right eye right corner to right mouth corner	RER-RM
15	Left eye left corner to left mouth corner	LEL-LM
16	Right eyebrow right corner to right mouth corner	REbR-RM
17	Left eyebrow left corner to left mouth corner	LEbL-LM
18	Right mouth corner to left mouth corner	RM-LM
19	Upper lip outer middle to lower lip outer middle	ULOM-LLOM
20	Lower lip outer middle to chin middle	LLOM-CM
21	Left eye upper lid midpoint to left eye lower lid midpoint	LEUM-LELM
22	Right eye upper lid midpoint to right eye lower lid midpoint	REUM-RELM
23	Left end point to right end point of nose	LN-RN
24	Nose height	NH

study. Anthropometry is a hallmark technique that deals with the study of body proportion and absolute dimensions that vary widely with age and sex within and between ethnic groups. It was first introduced to the forensics field for identifying criminals by physical characteristics. The basis of anthropometric analysis is to explore the variation of human physical characteristics, and to find out the differences and similarities among numerous races.

The DeitY-TU face database contains images of the different tribe and nontribe people of various races, especially people belonging to Mongolian origin.[26,27] This region has been occupied by different streams of the Mongoloid people who came from the north and the east at different periods, and gradually, the biological scenery of this region shaped up into separate entities, which are referred to as tribes today.[28,29]

Differences between the tribes and nontribes of this region may be investigated and analyzed by employing



(a) (b)

Fig. 14 Sample images of DeitY-TU face database showing (a) 20 different landmark points and (b) 24 anthropometric distances between these landmark points.

Table 10 Number of persons from different states for which anthropometric measurements have been conducted.

State	Male tribe	Female tribe	Male nontribe	Female nontribe
Mizoram	20	20	0	0
Assam	6	7	14	13
Tripura	10	10	10	10
Nagaland	20	20	0	0
Manipur	10	5	10	15
Total	66	62	34	38

anthropometric measurements on the face images. For this, it is required to detect the various landmark points and their ground truth coordinates to measure the anthropometric distances between these points. Comparing these distances, it may be possible to find out the structural differences between the tribes and nontribes of this region. The measurements of the ground truth data (i.e., position of right/left eyebrow corners, right/left eye corners, nasal endpoints, mouth corners, and chin) have already been done in terms of (x, y) coordinates and will be provided along with the final database release. For greater correct identification, the upper and lower midpoints of both the right/left eyes and mouth are also considered. Positions of the different feature points for some sample images are listed in Table 8.

We have selected a total of 20 landmark points, which will be used for further anthropometric measurements.

Table 11 Average distances calculated for the male tribes of the five different states.

Sl. No.	Distances	Assam	Manipur	Mizoram	Nagaland	Tripura
1	REbR-REbL	166.5983	168.686	165.7736	**180.5791**	*148.8273*
2	LEbR-LEbL	162.7067	166.35	165.3036	**181.4762**	*148.8613*
3	LEbR-REbL	408.9767	411.046	399.9295	**440.418**	*376.3247*
4	LEbL-REbR	**83.32667**	80.901	*71.63727*	83.208	81.08333
5	RER-REL	74.58333	**91.107**	89.83636	82.398	*68.39267*
6	LER-LEL	74.34167	**90.372**	89.41182	82.454	*68.11*
7	LER-REL	304.4383	**323.209**	313.1591	320.993	*282.1187*
8	LEL-RER	155.9567	138.702	*134.51*	**156.966**	145.868
9	RN-RER	184.8867	196.785	189.7627	**204.093**	*174.1513*
10	LN-LEL	185.8267	193.993	188.6182	**206.268**	*173.8733*
11	RN-RM	*90.84833*	98.498	96.84318	**105.297**	97.356
12	LN-LM	*90.31667*	98.696	96.41545	**104.418**	97.68133
13	SN-ULOM	*47.15833*	**60.34**	50.89	54.9699	51.06
14	RER-RM	249.0083	259.556	251.8714	**271.9422**	*239.9767*
15	LEL-LM	247.5717	257.462	249.5945	**271.8606**	*238.798*
16	REbR-RM	300.6833	314.285	307.89	**326.993**	*287.7393*
17	LEbL-LM	292.545	310.796	306.9427	**325.0388**	*285.7513*
18	RM-LM	172.3917	175.682	172.3805	**182.427**	*164.2893*
19	ULOM-LLOM	68.155	*65.702*	66.53182	**69.9725**	68.59333
20	LLOM-CM	118.6967	117.824	114.9709	**125.3249**	*103.5507*
21	LEUM-LELM	30.12667	30.227	29.36773	**32. 8001**	*26.70067*
22	REUM-RELM	29.705	29.903	29.01636	**32.7034**	*26.11533*
23	LN-RN	**104.7717**	100.89	104.5186	102.9178	*98.1*
24	NH	153.1683	147.439	147.4314	**162.988**	*143.35*

Note: Bold represents highest value; italics represents lowest value.

From these landmarks, a total of 24 linear measurements have been selected for the comparison of images, which are listed in Table 9. All the 20 landmark points and the 24 distances to be measured are shown in Fig. 14.

3.7.1 *Selection of image data*

Here, facial anthropometric analysis of the different races including the Mongolian people have been done using the visual face image database being collected from seven northeastern states of India. However, the faces have been captured with multiple variations of illumination, expression, and pose. For anthropometric measurements, we have considered only the neutral frontal face images of 1936×1288 pixels' dimension, captured in full illumination condition. To have an apparent perception of the facial differences between the tribe and nontribe males as well as females, we tried to select at least 10 male tribes, 10 female tribes, 10 male nontribes, and 10 female nontribes from each of the five states. Due to unavailability of sufficient image data in all the states, we have adjusted our selection over a small set of images as shown in Table 10. After careful review, photographs of 200 subjects were considered for manual distance measurement and analysis.

3.7.2 *Measurement of distances*

The obtained manual measurements for all the 24 distances of the 200 individuals are subdivided into four groups: male tribes, male nontribes, female tribes, and female nontribes, as shown in Table 10. All the distances measured are Euclidian distances in terms of pixels. Average values of these distances have been separately measured for the four groups for each of the five states (three states for the nontribes) and are shown in Tables 11–14, respectively. All the highest and lowest values for each distance are shown in bold and italic, respectively.

3.7.3 *Analysis and observations*

According to the observations of the data values of anthropometric measurements of the tribe and nontribe faces of NE India, shown in Tables 11–14, we find that there are huge differences between the distances of the fiducial points of tribes and nontribes. All these data shows how the tribe faces differ from the nontribe faces within the same states, as well as the differences between the tribes or nontribes of different states.

Comparison between the intrastate male tribes and nontribes. If we compare the different distances obtained for the male tribes and male nontribes as shown in Tables 11 and 12, we can see that length of the eyebrows (distance nos. 1 and 2) of the male tribes is relatively shorter than the male nontribes for the three states: Assam, Manipur, and Tripura, though for Manipur, the difference is not that major. Moreover, the distances between the outer endpoints of the eyebrows (distance no. 3) are almost similar for the male tribes and nontribes of each of the three states separately, but the distance between the inner endpoints of the eyebrows (distance no. 4) is significantly larger for the male tribes in comparison to the nontribes of the three states: Assam, Manipur, and Tripura. So, this indicates that the eyebrows of the male tribes are shorter in length and are a bit farther away from each other compared to that of the male nontribes.

The length of the eyes (distance nos. 5 and 6) is also shorter for the male tribes than the male nontribes for the people of Assam and Tripura, but there is no significant difference for the Manipuri tribe and nontribe males. Similar to the eyebrows, the distances between the outer endpoints of the eyes (distance no. 7) also does not differ much for the male tribes and nontribes of the three states, and the distance between the inner endpoints of the eyes (distance no. 8) is also larger for the male tribes in the cases of Assam and Tripura, but for Manipur, it is almost same. Again, the thickness of the eyes denoted by the distance nos. 21 and 22 are similar for the tribe and nontribe males of Assam and Manipur, but for Tripura, the eyes of the male tribes are thinner than the male nontribes.

Table 12 Average distances calculated for the male nontribes of the three different states.

Sl. No.	Distances	Assam	Manipur	Tripura
1	REbR-REbL	168.1693	**172.3871**	*155.2753*
2	LEbR-LEbL	167.0171	**172.8293**	*153.1347*
3	LEbR-REbL	407.2993	**413.7254**	*378.8153*
4	LEbL-REbR	**75.60857**	*70.34429*	73.11933
5	RER-REL	83.69	**94.04429**	*75.894*
6	LER-LEL	82.91286	**94.07179**	*75.558*
7	LER-REL	300.81	**324.6482**	*284.476*
8	LEL-RER	**142.2286**	136.8936	*135.5773*
9	RN-RER	182.5879	**204.0354**	*167.294*
10	LN-LEL	181.1593	**204.2686**	*166.0933*
11	RN-RM	96.79143	**100.52**	*90.624*
12	LN-LM	96.48929	**100.5175**	*90.60467*
13	SN-ULOM	55.23714	**58.64143**	*46.30467*
14	RER-RM	247.5514	**269.1932**	*224.73*
15	LEL-LM	243.0786	**268.2468**	*222.9647*
16	REbR-RM	300.235	**331.9137**	*269.274*
17	LEbL-LM	298.3529	**329.6093**	*267.1453*
18	RM-LM	173.7964	**176.2614**	*164.918*
19	ULOM-LLOM	68.345	**68.37679**	*60.444*
20	LLOM-CM	**117.3807**	112.2532	*111.502*
21	LEUM-LELM	31.44357	**33.73714**	*31.34867*
22	REUM-RELM	31.04857	**33.13036**	*30.75133*
23	LN-RN	100.8214	**133.5311**	*91.03067*
24	NH	149.2029	**158.9457**	*137.8753*

Note: Bold represents highest value; italics represents lowest value.

Table 13 Average distances calculated for the female tribes of the five different states.

Sl. No.	Distances	Assam	Manipur	Mizoram	Nagaland	Tripura
1	REbR-REbL	154.9843	156.106	152.5923	**167.5572**	*136.5762*
2	LEbR-LEbL	155.1571	156.986	151.8659	**167.2911**	*138.8562*
3	LEbR-REbL	389.0586	387.39	378.9532	**419.6009**	*349.9323*
4	LEbL-REbR	81.52571	*73.386*	76.50773	**84.0473**	76.51
5	RER-REL	75.17143	**87.448**	86.125	79.3188	*67.44769*
6	LER-LEL	74.45714	**87.102**	85.48636	79.1528	*67.57385*
7	LER-REL	292.0943	303.486	300.4777	**315.6656**	*266.8977*
8	LEL-RER	143.2	130.458	*129.9445*	**157.8811**	132.4977
9	RN-RER	177.5357	189.236	182.55	**198.2087**	*166.5392*
10	LN-LEL	180.6029	187.23	180.9836	**198.5761**	*166.7777*
11	RN-RM	93.30286	**99.68**	91.76364	97.6943	*85.59385*
12	LN-LM	93.42	**98.44**	91.065	97.9060	*85.40077*
13	SN-ULOM	48.05714	50.315	47.19455	**51.4861**	*42.88077*
14	RER-RM	237.8471	245.535	239.5614	**256.8499**	*220.8631*
15	LEL-LM	239.1886	242.2725	237.3	**255.1904**	*218.9992*
16	REbR-RM	290.4929	295.815	294.4673	**314.8386**	*268.0831*
17	LEbL-LM	295.4829	296.2525	292.7682	**313.4929**	*268.4215*
18	RM-LM	167.7729	171.565	160.7286	**174.4018**	*147.4692*
19	ULOM-LLOM	**75.90143**	62.1475	60.96409	66.0724	*58.13769*
20	LLOM-CM	104.2643	104.52	106.7527	**112.1954**	*97.5*
21	LEUM-LELM	31.43857	29.285	28.93773	**33.5458**	*28.50462*
22	REUM-RELM	31.03286	28.5975	28.64864	**33.5693**	*28.15923*
23	LN-RN	90.87143	88.7975	94.25409	**94.9848**	*81.69923*
24	NH	142.0129	137.435	139.6314	**153.2471**	*133.3392*

Note: Bold represents highest value; italics represents lowest value.

The distance between the subnasal point to the upper lip outer middle (distance no. 13), i.e., the space between the nose and mouth for the male tribes are larger, similar, and shorter for Assam, Manipur, and Tripura, respectively, in comparison to the male nontribes.

No significant difference is observed between the male tribes and nontribes for the width of the mouth (distance no. 18) and thickness of the lips (distance no. 19). Still, the lips seem to be thicker for the male tribes compared to the male nontribes of Tripura.

The distance from the lower lip outer midpoint to the chin (distance no. 20) is observed to be same for the tribe and nontribe males of Assam, but it is slightly higher for the Manipuri male tribes and radically lower for the Tripura male tribes in comparison to the male nontribes of the particular states.

Width and height of the nose (distance nos. 23 and 24, respectively) for the Assamese tribe and nontribe males are similar. A substantial difference is noticed for the Manipuri males, as the width of the nose of the tribes is less to a greater extent than the nontribes, and the height is also less for the male tribes. For the Tripura males, both the nose width and height are higher for the tribes compared to the nontribes.

Comparison between the intrastate female tribes and nontribes. From Tables 13 and 14, we have constructed a comparison between the structural differences of the female tribes and nontribes. The length of the eyebrows (distance nos. 1 and 2) of the female tribes and nontribes is similar for Assam and Manipur, but the Tripura female tribes have smaller eyebrows compared to the nontribes. Again, the

Table 14 Average distances calculated for the female nontribes of the three different states.

Sl. No.	Distances	Assam	Manipur	Tripura
1	REbR-REbL	152.25	**159.43**	*147.0588*
2	LEbR-LEbL	150.1369	**158.698**	*148.1494*
3	LEbR-REbL	386.5238	**389.2773**	*366.5118*
4	LEbL-REbR	**85.74462**	*72.56133*	73.48529
5	RER-REL	78.42462	**85.42733**	*73.13941*
6	LER-LEL	77.82538	**85.61333**	73.41588
7	LER-REL	297.0415	**303.664**	*280.49*
8	LEL-RER	**141.1908**	*134.0133*	134.3394
9	RN-RER	181.7023	**189.7347**	*165.71*
10	LN-LEL	181.8238	**189.7547**	*169.6365*
11	RN-RM	*87.00692*	**93.72467**	87.32
12	LN-LM	*87.45769*	**92.96133**	87.47118
13	SN-ULOM	45.60692	**48.68933**	*43.96765*
14	RER-RM	234.1054	**246.5713**	*221.0918*
15	LEL-LM	234.3115	**244.542**	*221.0241*
16	REbR-RM	286.4254	**300.7587**	*266.3388*
17	LEbL-LM	286.5523	**299.5113**	*269.7194*
18	RM-LM	**166.03**	165.974	*155.0988*
19	ULOM-LLOM	**65.27692**	*64.034*	64.28882
20	LLOM-CM	*97.73231*	**106.996**	101.9
21	LEUM-LELM	**34.20154**	32.15667	*31.35647*
22	REUM-RELM	**33.88231**	31.82533	*30.91824*
23	LN-RN	87.30538	**91.52067**	*84.38765*
24	NH	**150.38**	141.6693	*134.3594*

Note: Bold represents highest value; italics represents lowest value.

distances between the outer endpoints of the eyebrows (distance no. 3) of the female tribes and nontribes of Assam and Manipur are similar, and for Tripura, it is much less for the female tribes than the nontribes. The distances between the inner endpoints of the eyebrows (distance no. 4) are similar for the three states: Assam, Manipur, and Tripura. So, it is seen that, unlike the male tribes, the eyebrows of the female tribes are not far away from each, but are not that much stretched out toward the outer ends as compared to the female nontribes.

Slight variations are noticed for the length of the eyes (distance nos. 5 and 6) between the female tribes and nontribes of Tripura, as the female tribes have eyes with a shorter length than the female nontribes. The distances between the outer endpoints of the eyes (distance no. 7), too, are similar for Assam and Manipur, but are significantly shorter for the female tribes than the nontribes of Tripura; and the distances between the inner endpoints of the eyes (distance no. 8) are similar for these three states. Again, the thickness of the eyes (distance nos. 21 and 22) are similar, yet are a bit less for the female tribes than the nontribes of the three states.

The distance from the subnasal point to the upper lip outer midpoint (distance no. 13) is similar for both the female tribes and nontribes of all the three states. The width of the mouth (distance no. 18) is similar for the female tribes and nontribes of Assam, but it is slightly higher for the Manipuri female tribes and less for the Tripura female tribes compared to the female nontribes of the corresponding states. The thicknesses of the lips (distance no. 19) are similar for the Manipuri female tribes and nontribes, but the lips are thicker for the Assamese female tribes and thinner for the Tripura female tribes than the female nontribes of those particular states.

For the Manipuri female tribes and nontribes, the distance between the lower lip outer midpoint and chin (distance no. 20) is similar, but it is found that for Assam it is higher and for Tripura it is lower for the female tribes compared to the nontribes.

The width of the nose (distance no. 23) is similar for all the female tribes and nontribes of the three states, but the nose height (distance no. 24) for the Assamese female tribes is significantly less than the nontribes, though it is similar for the female tribes and nontribes of other two states: Manipur and Tripura.

So, in the case of interstate comparison, it can be noticed from these average distances that the Nagaland people (both the tribe males and females) have eyebrows with greater length and for the Tripura people it is comparatively less than all the other states. Again, for eyes, it can be seen that it is higher for the Manipur people and lower for the Tripura people. Similarly, the other structural differences in facial construction are also easily observable for the interstate tribe and nontribe males and females, as all the highest and lowest values for each of these 24 distances are marked with bold and italic, respectively, in Tables 11–14.

4 Database Evaluation

4.1 *Preprocessing*

The preprocessing of face images is divided into two steps: registration and cropping. Registration has been performed in order to provide proper alignment of two images, which are captured in two different illumination conditions, i.e., full and half. For registration, the five pose images in full illumination have been used as the base images for each person, and all the other images of the same person have been registered.[30] Registration has been done using the affine transformation. Affine transformation has six degrees of freedom and is equivalent to the combined effect of translation, rotation, isotropic scaling, and shear (nonuniform scaling in some direction). Properties such as parallelism, ratio of lengths of collinear or parallel segments, ratio of areas, and linear combination of vectors are invariant under affine transformation. For performing registration for a particular expression, a minimum of 20 control point pairs are selected from the base image (full illumination image) and unregistered image (half illumination image). A number of control points may vary with different expressions and angles. A selection of control point pairs for neutral expression in

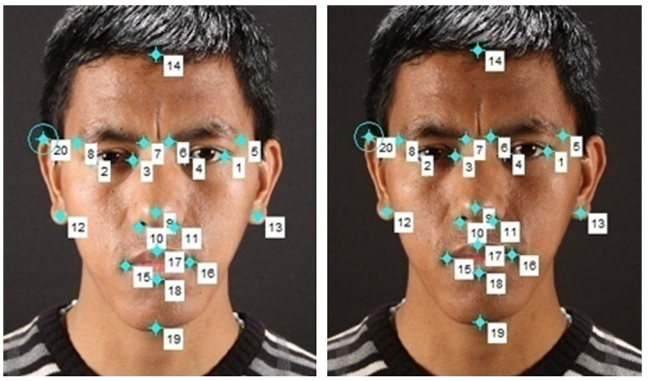


Fig. 15 Selection of control points in (a) base image (full illumination) and (b) target image (half illumination).

full and half illuminations has been shown in Fig. 15. A sequence of selecting control points is not fixed, but it must be same for both base image and unregistered image. The selected control points taken in the neutral expression image are as follows: (i) right eyebrow's right end point, (ii) right eyebrow's left end point, (iii) left eyebrow's right end point, (iv) left eyebrow's left end point, (v) right eye's right end point, (vi) right eye's left end point, (vii) left eye's left end point, (viii) left eye's right end point, (ix) nose tip point, (x) right nose point, (xi) left nose point, (xii) midpoint of forehead, (xiii) left lip corner, (xiv) right lip corner, (xv) upper lip middle point, (xvi) lower lip middle point, (xvii) upper left ear point, (xviii) lower left ear point, (xix) lower right ear point, and (xx) chin point.

After registration, the face images are cropped manually to remove background and they have been resized to a dimension of 50×50 pixels to maintain a fixed size for all images and to save processing time.

Some samples of base, unregistered, registered, and cropped-resized images are shown in Fig. 16. The first row shows the base, registered, and unregistered face images. The second row shows the neutral expression full illumination images at $+50$, $+25$, 0, -25, and -50 deg as base images. The third row shows the neutral expression half illumination unregistered images at $+50$, $+25$, 0, -25, and -50 deg, and the fourth row shows their corresponding registered images. The cropped and resized images of the corresponding registered images are shown in the fifth row.

4.2 *Experimental Data Setup*

An evaluation has been conducted on 420 subjects' faces collected from the four north-east Indian states: Assam, Mizoram, Nagaland, and Tripura. The whole experimentation has been designed in three ways: pose-, illumination-, and expression-based experiments.

4.2.1 *Pose-based experiment*

Experiments based on pose are further subdivided into four categories. The training images are frontal face images for all experiments. The four test sets contain -50, -25, $+25$ and $+50$ deg posed face images. A total of 600 face images have been taken for the experiment, i.e., 300 for training and 300 for testing purposes. Training and test sets are all in full illumination with different expressions.

4.2.2 *Illumination-based experiment*

These experiments consider frontal face images with different expressions for both training and testing. Here, training and testing face images possess full illumination and half illumination, respectively. A total of 240 and 396 face images have been taken for training and testing purposes, respectively.

4.2.3 *Expression-based experiment*

In this experiment, only frontal face images with full illumination containing all the six basic expressions have been taken into consideration. As the Tripura dataset contains fewer subjects, in this experiment, only the face images of Tripura have been considered. The number of training and testing face images is 180 and 240, respectively.

4.3 *Baseline Algorithms for Face Recognition*

Two baseline algorithms, namely PCA and LDA, have been used here. A brief introduction of these algorithms has been depicted below.

4.3.1 *Principal component analysis*

In PCA, eigenfaces are comprised eigenvectors of the covariance matrix of the face images. Only the eigenvectors that possesses significantly large eigenvalues are selected to be used in the dimension reduction process. The principal component w_1 of a dataset X can be defined as

$$w_1 = \arg \max_{\|w\|=1} E\{(W^{\mathrm{T}}X)^2\}, \tag{1}$$

where $W = \{W[p, q]\}$ is the matrix of basis vectors with one vector per column where each basis vector is one of the eigenvectors of the covariance matrix and where vectors in W are a subset of those in V. V is the matrix consisting of the set of all eigenvectors of the covariance matrix.[31]

4.3.2 *Linear discriminant analysis*

LDA discovers a linear combination of features which divides into two or more classes of objects. This method maximizes the ratio of between-class variance compared to the within-class variance in any particular dataset, which guarantees maximal separability. For multiclass LDA, the intraclass matrix of multivariate observations x is defined as

$$\hat{\sum}_w = \sum_{i=1}^{n} \sum_{x \in c_i} (x - \bar{x}_i)(x - \bar{x}_i)'. \tag{2}$$

The interclass scatter matrices are given as

$$\hat{\sum}_b = \sum_{i=1}^{n} m_i(\bar{x}_i - \bar{x})(x_i - \bar{x})', \tag{3}$$

where m_i is the number of training samples for each class, $\bar{x}_i$ is the mean for each class, and $\bar{x}$ is the total mean vector given by $\bar{x} = 1/m \sum_{i=1}^{n} m_i \bar{x}_i$. The transformation ϕ can be obtained by solving a generalized eigenvalue problem

$$\hat{\sum}_b \phi = \lambda \hat{\sum}_w \phi. \tag{4}$$

Fig. 16 Sample base, unregistered, registered, and cropped-resized images of five poses.

After obtaining the transformation function ϕ, the classification is performed in the transformed space based on some distance metrics. When a new instance z will arrive, it is classified to

$$\arg \min_k d(z\phi, \bar{x}_k\phi), \tag{5}$$

where $\bar{x}_k$ is the centroid of the k'th class.[32]

4.4 *Evaluation Results*

The two baseline algorithms are trained and tested on DeitY-TU experimental datasets as discussed in the previous section. Before training and testing, all the images have been preprocessed. From the experimental results, it is observed that the performance of LDA is better than PCA for all three types of experiments. It is observed from Table 15 that, in most of the cases, PCA performs 5% to 6% less well than LDA. The maximum accuracy has been generated by LDA in the −25 deg test pose case experiment applied on the Assam face dataset. It is clearly observed that state-wise recognition accuracy differs for the same number of training and test sets. Now, considering the illumination-based experiment, the range of recognition accuracy generated by PCA is extremely poor. The highest and lowest recognition rates are 66.41% and 15.91%, respectively, in the illumination-based experiment. State-wise recognition rates are listed in Table 16. In the expression-based experiment,

Table 15 Recognition rates of the pose-based experiments.

LDA				PCA			
	Recognition rates				Recognition rates		
Test pose (deg)	Nagaland (%)	Mizoram (%)	Assam (%)	Test pose (deg)	Nagaland (%)	Mizoram (%)	Assam (%)
−50	22.67	19	22.66	−50	14.67	19	19
−25	27	22	26.33	−25	22.67	22	12
+25	21	22.33	22.33	+25	20	14.33	17.33
+50	18.33	16.67	19	+50	18.33	15.67	24

Table 16 Recognition rates of the illumination-based experiments.

LDA			PCA		
Recognition rates			Recognition rates		
Nagaland (%)	Mizoram (%)	Assam (%)	Nagaland (%)	Mizoram (%)	Assam (%)
57.32	54.54	66.41	22.22	14.14	15.91

the recognition rates of different expressions are summed up in Table 17. The expressions are recognized mostly by LDA. The recognition rate of the surprise expression is 90%, which is the highest among all the other expressions. In this case also, PCA performs poorly compared to LDA. The maximum accuracy is 40%, which is achieved with the happy expression. Considering the average recognition rates of different expressions for four states, the recognition rate of surprise expression is 76.25% using LDA, which is the highest among all the six expressions. The happy expression is recognized 3.13% less often than surprise. PCA generates the highest average recognition rate of 26.88% for the sad expression.

Figure 17 shows the graphical representation of the recognition rates of LDA and PCA for the pose-based experiments. LDA and PCA recognition rates for images of different states at different angles are presented here. It reflects that the performance of PCA is 5% to 6% less than LDA

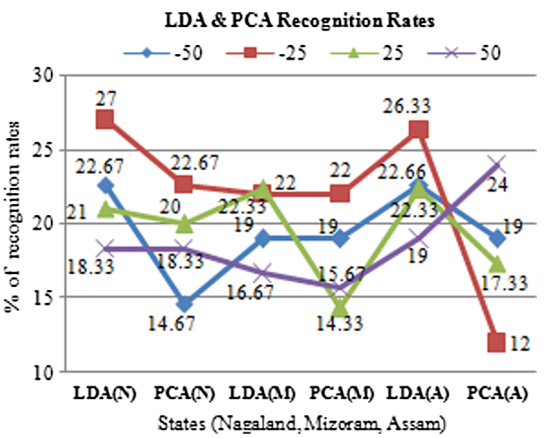


Fig. 17 Recognition rates of LDA and PCA for pose-based experiments.

for all the three states. LDA obtains the highest accuracy with the −25-deg test pose case experiment applied on the Assam face dataset. Figure 18 shows the recognition rates of LDA and PCA for illumination-based experiments. It shows that the recognition rates of LDA are much higher than PCA. The highest and lowest recognition rates for LDA are 66.41% for Assam and 57.32% for Nagaland, respectively. Again, the highest and lowest recognition rates of PCA are 22.22% for Nagaland and 15.91% for Assam, respectively. Recognition rates of LDA and PCA

Table 17 Recognition rates of the expression-based experiments.

	LDA				PCA			
	Recognition rates				Recognition rates			
Expressions	Nagaland (%)	Mizoram (%)	Assam (%)	Tripura (%)	Nagaland (%)	Mizoram (%)	Assam (%)	Tripura (%)
Anger	62.5	57.5	42.5	35	17.5	32.5	17.5	22.5
Happy	72.5	72.5	77.5	70	7.5	25	40	5
Sad	75	32	80	50	37.5	20	27.5	22.5
Surprise	90	82.5	72.5	60	7.5	12.5	10	7.5
Fear	67.5	45	67.5	30	15	25	15	12.5
Disgust	57.5	67.5	85	42.5	10	25	17.5	20

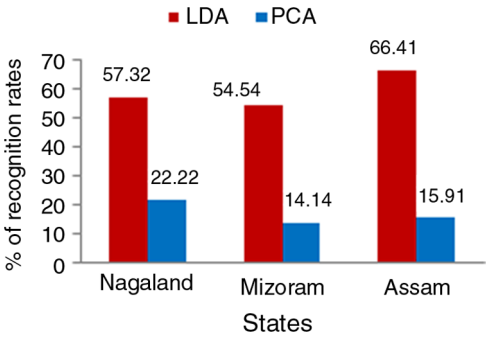


Fig. 18 Recognition rates of LDA and PCA for illumination-based experiments.

for expression-based experiments are shown in Fig. 19 for four different states (Nagaland, Mizoram, Assam, and Tripura). It reflects that the recognition rates of LDA for all the six expressions (anger, happy, sad, surprise, fear, and disgust) are much higher than the recognition rates of PCA. Also, this is true for all the four states.

The below conclusions can be drawn from the baseline evaluation results:

- The performance of LDA is better than PCA.
- In the pose-based experiment, baseline algorithms generate a very low recognition rate.
- The performance of baseline algorithms differs from one state to another.
- The surprise expression is mostly recognized through LDA for all four states.
- The sad expression is mostly recognized through PCA for all four states.

4.5 *Comparative Study Using Baseline Algorithms*

Some of the database developers have performed training and testing operations on their own datasets using various baseline algorithms to deliver a performance score, which may be used by the other researchers for evaluating their own algorithms. In Table 18, a few of these performances are listed along with the algorithms and databases used.

In Ref. 5, Gross et al. experimented on both CMU-PIE and CMU multi-PIE database images. They used three image sets: 68 subjects of PIE, 68 subjects of multi-PIE, and all subjects of multi-PIE database, and named them PIE 68, M-PIE 68, and M-PIE Full. In the illumination experiments, they used images recorded without flashes as a gallery and all flash images in turn as probes. Accuracies obtained for PIE 68 and M-PIE 68 using PCA are nearly identical, whereas, LDA performance degrades for M-PIE Full compared to PIE 68 dataset. For recognition across expression and illumination, they used the multi-PIE database only. The combined influence of illumination and expression reduced the accuracies drastically, with LDA acquiring higher accuracies (41.4%) compared to PCA rates (18.5%). For both PCA and LDA, they obtained higher accuracies for the squint expression. However, the illumination-based experiments, which also contain all the different expressions conducted on the DeitY-TU face database, give almost similar results using PCA (17.42%), but higher accuracy is achieved using LDA (59.42%) when compared with the multi-PIE database.

In Ref. 33, Cao et al. evaluated the CAS-PEAL database using three baseline algorithms: (i) PCA, also known as the eigenfaces, (ii) combined PCA and LDA (PCA + LDA), and (iii) PCA + LDA algorithms based on Gabor features (G-PCA + LDA). They evaluated four illumination normalization methods: histogram equalization (HE), gamma intensity correction (GIC), region-based HE, and region-based GIC (RGIC).[34] The three baseline face recognition algorithms (PCA, PCA + LDA, and G-PCA + LDA) were used to evaluate six frontal probe sets (expression, lighting, accessory, background, distance, and aging). Before training and testing, all the images were preprocessed using the four illumination normalization methods or no illumination normalization, respectively. Using Gabor features of the original

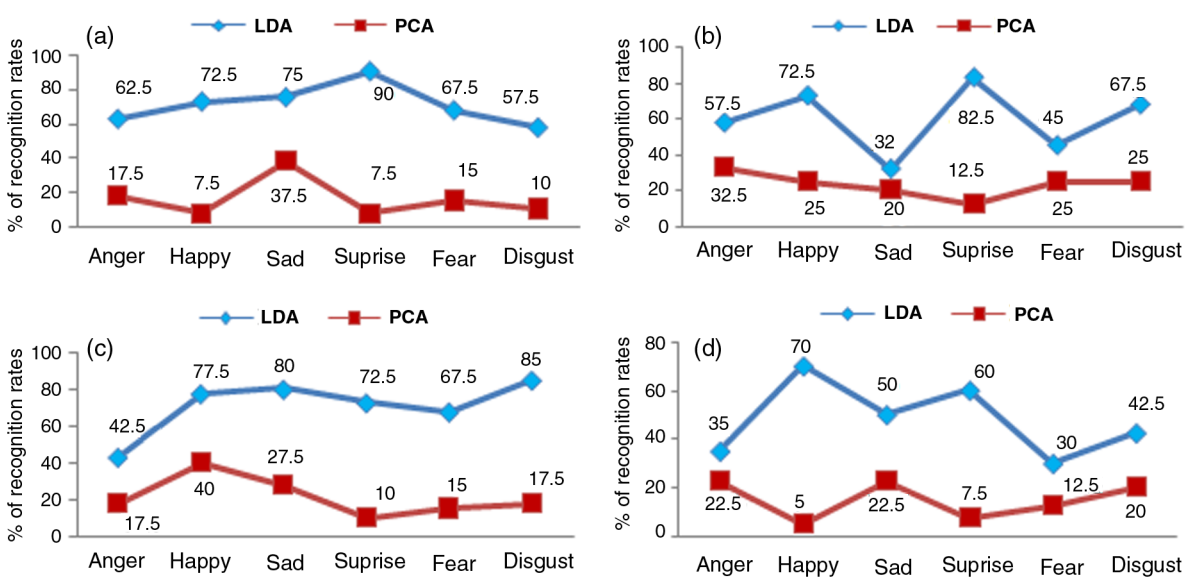


Fig. 19 Recognition rates of LDA and PCA for expression-based experiments for different states. (a) LDA and PCA recognition rates for Nagaland, (b) LDA and PCA recognition rates for Mizoram, (c) LDA and PCA recognition rates for Assam, and (d) LDA and PCA recognition rates for Tripura.

Table 18 A comparative study of different databases based on baseline algorithms.

Database	Algorithm used			Reported performance (%)
CMU PIE (Ref. 5)	Experiment across illumination		PCA	36.6
			LDA	95.0
CMU multi-PIE (Ref. 5)	Experiment across illumination		PCA	35.4
			LDA	71.3
	Experiment across expression and illumination		PCA	18.5
			LDA	41.4
CAS-PEAL database (Ref. 33)	Using frontal probe sets	PCA		28.2
		PCA + LDA		42.2
		PCA + LDA (HE)		48.4
		PCA + LDA (GIC)		45.4
		PCA + LDA (RHE)		47.8
		PCA + LDA (RGIC)		45.5
		G PCA + LDA		57.4
		G PCA + LDA (HE)		58.3
		G PCA + LDA (GIC)		57.8
		G PCA + LDA (RHE)		53.7
		G PCA + LDA (RGIC)		56.8
	Using pose probe sets	PCA + LDA		19.0
		PCA + LDA (RGIC)		23.3
		G PCA + LDA		28.7
		G PCA + LDA (RGIC)		32.8
JAFFE database (Ref. 17)	Gabor coding and semantic similarity			56.8
	Geometric and semantic similarity			36.6
DeitY-TU face database	Illumination-based experiments		PCA	17.42
			LDA	59.42
	Pose-based experiments		PCA (−50 deg)	17.56
			PCA (−25 deg)	18.89
			PCA (+25 deg)	17.22
			PCA (+50 deg)	19.33
			LDA (−50 deg)	21.44
			LDA (−25 deg)	25.11
			LDA (+25 deg)	21.89
			LDA (+50 deg)	18.00

Table 18 (*Continued*).

Database	Algorithm used			Reported performance (%)
	Expression-based experiments	PCA	Anger	22.50
			Happy	19.38
			Sad	26.88
			Surprise	9.38
			Fear	16.88
			Disgust	18.13
		LDA	Anger	49.38
			Happy	73.13
			Sad	59.25
			Surprise	76.25
			Fear	52.50
			Disgust	63.13

images evidently improved the performance of the algorithms based on PCA + LDA, although the RGIC method applied to the G-PCA + LDA algorithm achieved the best average identification rate. Two baseline face recognition algorithms (PCA + LDA and G-PCA + LDA) were used to evaluate the three pose probe sets (looking upward, looking right into the camera, and looking downward). Results proved that the "looking downward" pose was the most difficult one. However, the four pose-based experiments (−50, −25, +25, and +50 deg) conducted for the DeitY-TU face database achieved 17% to 19% accuracy using PCA and 18% to 25% accuracy using LDA.

Lyons et al.[17] used images labeled with five or six component vectors with ratings averaged over all subjects of the JAFFE database. Similarities between these semantic vectors were calculated using the Euclidean distance. Facial expression image similarity computed using the Gabor coding and semantic similarity computed from human ratings were compared by rank correlation. Geometric similarity was also rank correlated with the semantic ratings similarity values as a control. For the experiments with all facial expressions included, the rank correlation between the Gabor model and human data ranged from 0.42 to 0.725, and for the geometry-based control, rank correlation between the model and data ranged from 0.074 to 0.527. The expression-based experiments conducted on the DeitY-TU face database gives 9.38% to 26.88% accuracy using PCA and 49.38% to 76.25% accuracy using LDA for the six basic facial expressions.

5 Conclusion and Future Work

Along with all the details of image capturing equipment and different imaging conditions used for the DeitY-TU face database, this paper also provides a comprehensive study of the available 2-D face image databases. This paper analyzes the different features of the DeitY-TU face database, such as combined challenges on every face, accessories, anthropometric variations, soft biometrics, etc., along with a detailed analysis of the similarities and differences found between the tribe and nontribe males and females based on the facial anthropometric distance comparison. To assess the difficulty of the database, baseline algorithms have been employed in three different types of experiments. The experimental results have been compared with the performance scores of other 2-D face databases. In the future, the aim is to complete the capturing of at least 700 individuals' face images for the DeitY-TU face database and test other algorithms on them.

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