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USE OF IMAGE ENHANCEMENT TECHNIQUES FOR IMPROVING REAL TIME FACE RECOGNITION EFFICIENCY ON WEARABLE GADGETS

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Abstract

The objective of this research is to study the effects of image enhancement techniques on face recognition performance of wearable gadgets with an emphasis on recognition rate.In this research, a number of image enhancement techniques are selected that include brightness normalization, contrast normalization, sharpening, smoothing, and various combinations of these. Subsequently test images are obtained from AT&T database and Yale Face Database B to investigate the effect of these image enhancement techniques under various conditions such as change of illumination and face orientation and expression.The evaluation of data, collected during this research, revealed that the effect of image pre-processing techniques on face recognition highly depends on the illumination condition under which these images are taken. It is revealed that the benefit of applying image enhancement techniques on face images is best seen when there is high variation of illumination among images. Results also indicate that highest recognition rate is achieved when images are taken under low light condition and image contrast is enhanced using histogram equalization technique and then image noise is reduced using median smoothing filter. Additionally combination of contrast normalization and mean smoothing filter shows good result in all scenarios. Results obtained from test cases illustrate up to 75% improvement in face recognition rate when image enhancement is applied to images in given scenarios.

Keywords: Face recognition, Image enhancement, Wearable gadgets.

Abbreviations	
2DLDA	Two-Dimensional Linear Discriminant Analysis
2DPCA	Two-Dimensional Principal Component Analysis
AT&T ORL Faces	AT&T Database of Faces
BMP	Bitmap
EX	Exponential Distribution
EX	Exponential Distribution
FAR	False Acceptance Rate
FRR	False Rejection Rate
HQ	Histogram Equalization
HQ	Histogram Equalization
HSI	Hue, Saturation, Intensity
JPEG	Joint Photographic Experts Group
KFA	Kernel Fisher Analysis
KPCA	Kernel Principal Component Analysis
LDA	Linear Discriminant Analysis
LN	Lognormal Distribution
LN	Lognormal Distribution
NM	Normal Distribution
NM	Normal Distribution
PCA	Principal Component Analysis
RGB	Red, Green, Blue
TER	Total Error Rate
UP	Unprocessed Image
UP	Unprocessed Image
XM2VTS	Multi-modal Face Database Project
YaleB	The Yale Face Database B

1. Introduction and Review of Existing Work

Image processing is one of the most active disciplines of Computer Science. There has been a lot of research going on in this area. Emergence of wearable gadgets, in particular Microsoft HoloLens and Google Glass, has opened up a new chapter and brought a lot of research opportunities in Computing specifically in image processing, as the core functionality offered by these devices involve analysis of digital images.

Face recognition is among those topics that has attracted maximum attention in the field of image processing. Aligned with the advancement of technology, face recognition algorithms have vastly evolved over the last few decades. Specifically the modern algorithms are less error prone to variation of light and orientation. However, the success rate of these algorithms heavily depends on the quality of initial images involved in the process. One of the commonly used methods of improving image quality is image pre-processing. Study by Abdul-Jabbar [1] and Amani [2] implies that adjusting images by applying some sort of image enhancement techniques can have positive effect on the final performance of face recognition by mitigating false positive results.

The ultimate aim of image enhancement techniques is to produce an image that is more suitable than the original image for specific use. This makes more sense when applied to Microsoft HoloLens or Google Glass. Contrary to the most visible benefits, wearable gadgets also carry some limitations which include lack of high quality image sensor and camera flash to capture objects in motion under low light conditions which usually results in blurry and noisy images. An example could be a situation where Microsoft HoloLens or Google Glass is used as a remote surveillance camera by police officers to detect and recognize criminal faces in real time. Obviously pictures taken under these circumstances would not have sufficient quality in their original form and some adjustments to pictures is required in order to improve their quality before the start of recognition process.

Image processing has a long history. Many image processing techniques were developed as part of NASA's project to improve moon's pictures at Jet Propulsion Laboratory in 1964 [3]. Currently image enhancement is used in vast spectrum of fields such as atmospheric sciences, digital forensics and oceanography [4]. Image normalization is one of the most significant parts of face recognition systems.

Despite vast improvement and advances in face recognition algorithms, the performance of these techniques heavily depends on the quality of initial images. It is commonly recognized that illumination conditions have great impact on recognition of unfamiliar faces. Studies by [5 - 7] and other scholars have shown that image quality and change of illumination in images drastically degrade recognition performance and describe variations in pose and illumination as the most problematic impediment affecting face recognition. This illumination can have detrimental effect in scenarios in which face recognition is used to identify a suspect based on photos acquired by low end cameras under dim street lightings.

Image processing is a well-established field of study with a strong research background. Image pre-processing techniques play an important role in face recognition systems and have major impact on robustness and efficiency of face recognition methods. The main objective of image pre-processing techniques is to ensure that environmental factors such as illumination should not influence facial feature extraction by enhancing images to maximize discriminative information [8].

According to research conducted by Heseltine et al. [9], image pre-processing falls under four main types namely color normalization, statistical methods, convolution filters and combinations of these techniques.

Color normalization, also known as histogram stretching, is the process of changing pixel intensity value range and gray color normalization to produce an image with enhanced contrast. Examples of this technique are gray world normalization, histogram equalization and comprehensive color normalization. Statistical methods deal with brightness and are utilized to normalize image brightness. Various statistical techniques are introduced over years trying to improve brightness normalization. Examples of such statistical techniques are vertical brightness, horizontal brightness and local brightness mean. Convolution or correlation is the method of applying filters to images. In this method one or two functions (2D filter matrix) move over every element of the other function (2D image) to take the sum of products. Examples of convolution methods are smoothing, blurring, sharpening, and contouring.

Study by [1] proves that adjusting images by applying some sort of image enhancement techniques can have positive effect on the final performance of face recognition by mitigating false positive results. In this research the impact of three image pre-processing techniques including image adjustment, histogram equalization and image conversion to JPEG and BMP on face images with low contrast, bad or dark lightning is examined. To evaluate results of illumination variations on AT&T ORL faces database, many face recognition techniques such as Principal Component Analysis (PCA), Linear Discriminant Analysis (LDA), Kernel Principal Component Analysis (KPCA) and Kernel Fisher Analysis (KFA) are used.

Results achieved by proposed face recognition method [1] show that applying image pre-processing and normalization techniques on different face recognition algorithms improve 10% to 30% accuracy as compared to original data set. During this research it is also found that JPG and BMP databases have higher recognition rate than original ORL image database with JPG format having slightly higher recognition rate (from 0.71% to 1.5% depending on recognition algorithm).

A research has been conducted by [10] on image enhancement techniques and the effect of some of these methods such as histogram equalization, local transformation, un-sharp masking and linear contrast stretching is reviewed separately. Although the research covers advantages of various image enhancement techniques and the areas in which each of these techniques is applied, it does not cover computational cost of enhancement techniques and the effect of these methods when combined together. Authors of this experiment suggested devising a combination of methods in order to achieve more effective results.

Empirical assessment performed by [11] on histogram remapping and results obtained on the XM2VTS (containing 2360 images corresponding to 295 subjects) and YaleB (containing 640 images for 10 subjects) databases for four target distributions (the uniform, the normal, the lognormal and the exponential distribution) shows that similar and sometimes even better recognition rates is achieved when considering other techniques than the uniform distribution for histogram remapping. The experiment is conducted using linear discriminant analysis as feature extraction and the cosine similarity measure as the scoring function for the nearest neighbor classifier. The reported result shows lower false rejection rate and false acceptance rate for XM2VTS database (Tables 1 and 2) is achieved when histogram remapping is applied on database images (where UP = Unprocessed, HQ = Histogram Equalization, NM = Normal Distribution, LN = Lognormal Distribution, EX = Exponential Distribution).

The final result on YaleB database is also showing significant improvement (up to 80%) in recognition rate (Table 3). The images database in this experiment is divided into 5 subsets based on illumination level. The first subset is used for training while remaining subsets are employed for testing.

From the result of this experiment, authors [11] conclude that lognormal distribution results in most consistent recognition performance at the cost of determining one or two parameters in advance.

Table 1. Error rate (%) for evaluation set [11].

Methods	UP	HQ	NM	LN	EX
FRR (%)	3.5	3	2.83	3	4.33
FAR (%)	3.55	2.97	2.84	3.02	4.08
TER (%)	7.05	5.97	5.67	6.02	8.41

Table 2. Error rate (%) for test set [11].

Methods	UP	HQ	NM	LN	EX
FRR (%)	3.25	2.5	2.5	2.5	3.25
FAR (%)	3.75	3.39	2.96	3.19	4.18
TER (%)	6.98	5.89	5.44	5.69	7.43

Table 3. Recognition rate (%) for YaleB database [11].

Methods	UP	HQ	NM	LN	EX
Subset 2	100	100	100	100	100
Subset 3	99.2	100	100	100	99.2
Subset 4	47.1	63.6	61.4	78.6	72.1
Subset 5	11.6	62.1	63.7	87.9	84.2

The proposed method in [2] takes the research a step further by using multiple image adjustment methods to achieve improvements. For feature extraction in this experiment, the 2DPCA algorithm is performed first and then 2DLDA algorithm is used for second feature extraction.

The experiment on high frequency emphasis is conducted using Butterworth filter and Gaussian filter and the result shows higher improvement when Butterworth filter is employed over Gaussian filter. It is also found that the variation between different faces might be smaller than variation of same face images under different illumination. Histogram equalization is recognized as an effective method for solving this issue by stretching the range of gray levels and enlarging image contrast. The author [2] employed Otsu's method for global thresholdingas the threshold is calculated for individual images. This method is employed to emphasis on regions with lower intensity level (darker areas) which hold important features while ignoring regions with greater intensity (brighter areas). This results in less memory requirement and smaller processing time.

To evaluate the proposed solution, the experiment is conducted on AT&T and Yale faces database using PCA, LDA, 2DPCA, 2DPCA + 2DLDA as feature extraction algorithms. The reported results of experiments as shown in Table 4 demonstrate the maximum recognition rate of 95.76% using 2DPCA + 2DLDA algorithm when 10 eigenvectors are selected for 2DLDA method and 20 eigenvectors are selected for 2DPCA method.

Table 4. Comparison of the top recognition accuracy (%) 2DPCA + 2DLDA for varying 2DLDA's eigenvectors and 20 2DPCA's eigenvectors [2].

Number of 2DLDA's selected eigenvectors	5	7	9	10
Top recognition %	93.94	93.33	93.94	95.76

2. Methods

The objective of this research is to introduce an approach in image enhancement that improves face recognition rate. Therefore a model is developed in order to produce optimum results while keeping high performance as the main factor for real time processing on low end devices. The artifact is built upon other researchers' work. One of the key steps was to find the relevant scholarly works and literature on the topic. Research papers on image enhancement for face recognition were carefully reviewed and studied to find out whether that particular paper has any contribution to this research.The objective was to find at least one image enhancement method in each category of image enhancement techniques defined by Heseltine et al. [9]. Final step comprises of the translation of these algorithms in a programming language and implement the artifact. Next section describes some of these algorithms. The new model is then evaluated on a virtual machine that simulates a low end device specification such as Microsoft HoloLens or Google Glass and profiling information is collected. Quantitative methods are used to analyze the proposed model in the final stage. In order to validate the model as an experimental research and to evaluate accuracy and efficiency of the model, a series of tests are performed using simulated environment.

In order to test the artifact, a collection of images is required to train face recognition system. For the purpose of this research the AT&T Database of Faces [12] and the cropped version of the Extended Yale Face Database B [13] are selected to train and test artifact.

To study the effect of artifact on AT&T database a smaller database consists of randomly chosen images from 26 subjects is formed. Out of these 26 subjects, 5 images are randomly picked to be used as sample images. Each of these 5 sample images has exactly 3 images from the same subject in database images. Rest of subjects has either 3 or 10 images. The test application is executed several times to collect data with different image enhancement techniques applied to images and different number of components used for face recognition algorithm. The numbers of principal components used are 3, 7, and 15 components.

The AT&T database is considered a fairly simple database for testing face recognition algorithms due to lack of high illumination variation. The benefit of image enhancement techniques is known best when applied to images taken under low light conditions, therefore the final test is involved dark images for both training set and sample set. For this purpose YaleB database provides better images with wider range of illumination variation. Therefore Yale B database is selected to cover more complex scenarios and test the effect of image enhancement techniques under wide range of illumination variation. In order to achieve this, 28 subjects are randomly chosen to form training set database with 6 subjects selected as sample images. Each of these subjects have 4 bright images in the database with little or no shadow on the face and one dark image with shadow while rest of subjects have 8 images each ranging from too bright to too dark images. On the other hand, the selected test images are taken under low light with lots of shadows in the face. The number of principal components used for face recognition is 3, 7, 15 and 30 components.

For each database of images, face recognition is first performed on pure training images and sample image without applying any image pre-processing using different number of eigenvectors. Next each image enhancement technique is individually applied to images and the result is collected. In the last stage, various combinations of image enhancement techniques are applied to images and the result for each combination is recorded.

Each of the above mentioned tests is rehearsed for a set of selected images. For example one round of tests involved only dark images while another round involved only light images. Lately, to show the benefit of image enhancement, another test is performed that involved both light and dark images. Tests are also repeated with different number of training sets for each person. For example one test involved only 3 images for each person while in another test 5 images per person is used to train algorithms.

To evaluate the effect of proposed image enhancement techniques on face recognition, two face recognition techniques namely PCA and LDA are implemented as part of this research.

For each face recognition algorithm, several tests are performed to find appropriate value for a number of components that will result in high false recognitions. Finally image enhancement is applied to the same set of images and configuration to evaluate the effect of those techniques. Figures 1 (a) and (b) elaborate major processes and high level flow chart of experimental evaluation undertaken for this research.

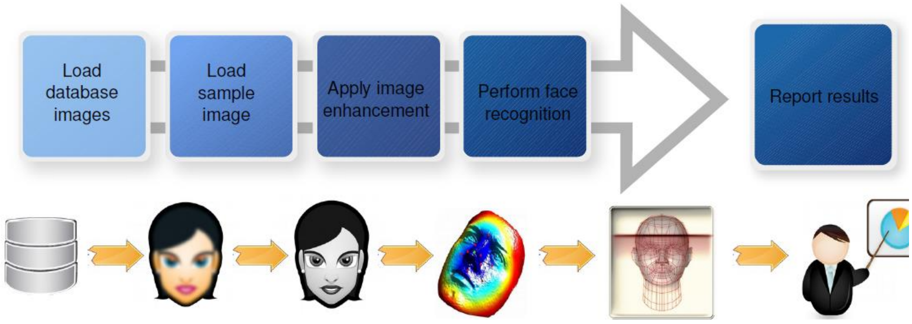

Fig. 1. (a) System process diagram.

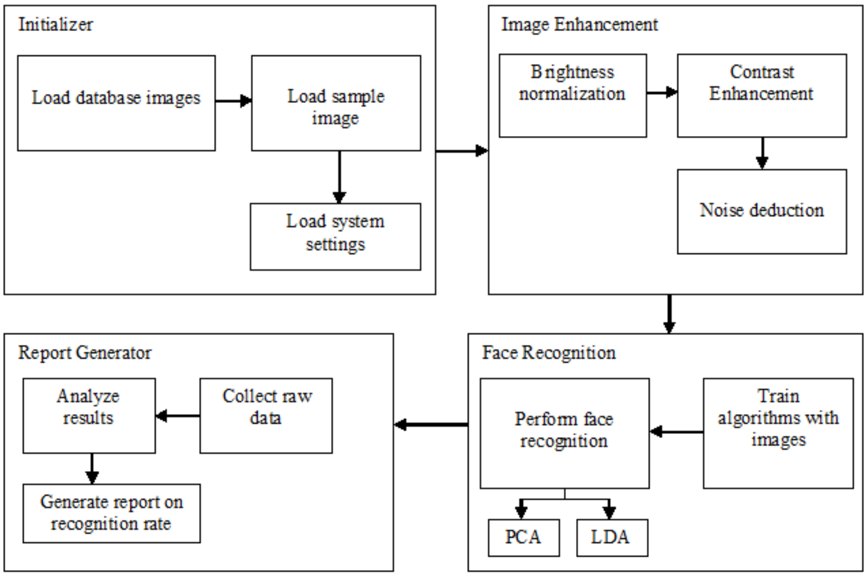

Fig. 1. (b) System flow chart.

3. Image Pre-processing Techniques for Face Recognition

Following is a brief description of some of the common pre-processing techniques used for face recognition.

3.1. Histogram equalization

Histogram equalization is among the most common image pre-processing techniques in the field of face recognition. It is the core of all histogram remapping techniques. This technique is fundamentally used for contrast enhancement [14]. Histogram remapping techniques are classified under color normalization category of image pre-processing. The first common step in all histogram remapping techniques is to render histogram of any given image into a histogram that approximates the uniform distribution [11].

Histogram equalization is utilized to equalize image intensity by better distribution of intensity values of an image on the histogram and compensate illumination added to image during image acquisition stage. Histogram equalization tends to improve the contrast of an image by increasing image global contrast. This method is useful when input images have too bright or too dark foregrounds and backgrounds like medical X-ray images [15]. Histogram equalization will have best results when applied to images with higher color depth than image palette size.

Histogram equalization can be used on both grayscale images as well as on color images in which the method is separately applied on each component of RGB color space. However color images are usually converted into HSI color space. In this case the method can directly be applied to the intensity space of the image and the hue and saturation of the image will not be impacted.

There are modified versions of histogram equalization such as adaptive histogram equalization aiming at equalizing local contrast as compared to global contrast which improve image contrast without producing brightness mean shifting.

Histogram equalization transforms an image with intensity value range into an image with new intensity value range. For example if image intensity is ranged from 70 to 210 and the desired range is 0 to 255 then 70 is deducted from each intensity pixel resulting intensity range of 0 to 140. Next each intensity pixel is multiplied by 255/140 converting the range to 0 to 255.

3.2. Linear least squares

Linear least squares is one of the most popular linear algebra methods in computer vision. One common usage of linear least squares is to automatically normalize image brightness; hence it falls under statistical category of image pre-processing techniques.

In statistics, least squares are used to fit statistical models into data for summarizing and understanding underlying system mechanism. The simplest form of least squares is linear least squares which tries to fit data into a linear regression model.

The idea of linear least squares is to find a line that represents an average relationship between variables while minimizing the sum of squared difference between data values and corresponding projected model values.Similar approach can be adopted in image processing by defining a line that has minimal distance from sum of square difference of each pixel of the image to the defined line. Then the image can be reconstructed by adjusting each pixel value in such a way that pixels are fitted on the linear least squares line.

3.3. Unsharpmasking

Unsharp masking as opposed to its name is a sharpening technique utilized to increase sharpness of digital images and falls under convolution filters category of image pre-processing techniques. The reason that digital images need sharpening is from the fact that digital images are stored as a fixed grid of pixels and each pixel is capable of storing only one color or shade at a time. For example a sharp edge between black and white colors that looks like half black and half white is rendered as gray pixel due to the fact that only one color can be recorded by a pixel.

In order to create an unsharp mask, first a slightly blurred version of the original image is created. Then the blurred image is subtracted away from the original image to form the unsharp mask. The unsharp mask is utilized to detect edges in the picture. Combination of unsharp mask with the negative image and increasing contrast on the detected images using the mask, results in sharper final image.

4. Results and Discussion

4.1. Results obtained from AT&T database

As shown in Fig. 2(a), highest face recognition rate on the AT&T database, using sample images chosen for these tests, is achieved when combination of contrast normalization and mean smoothing filter or a combination of brightness and contrast normalization and mean smoothing filter are applied. For these tests images were enhanced with pure contrast normalization, combination of brightness and sharpening, contrast and median, and combination of brightness and contrast normalization and sharpness had lowest recognition rate among other tests.

Most of the error rates are caused by LDA algorithm due to low number of training images for the subjects studied compared to other subjects, as Fisherfaces algorithm is based on classification of subject category. The results of image enhancement on PCA and LDA algorithms are separately shown in Fig. 2(b). For PCA, brightness normalization, combination of brightness normalization and sharpening, and combination of brightness and contrast normalization and median smoothing improved the result while other enhancement techniques either achieved same recognition rate as original images or performed less efficient with combination of contrast normalization and median filter being worst. On the other hand, for LDA algorithm, combination of contrast and median filter achieved highest recognition rate while combination of brightness and contrast normalization, and mean filter, and combination of brightness and contrast normalization and median filter had slight improvement compared to original database. All other image enhancement algorithms had negative impact on the results.

In this test the subjects being tested had only 3 images in the training database while other subjects had 10 images each, which degrade the accuracy of face recognition algorithm. Obviously the results can be tweaked by increasing number of principal components and training images for the intended subjects.

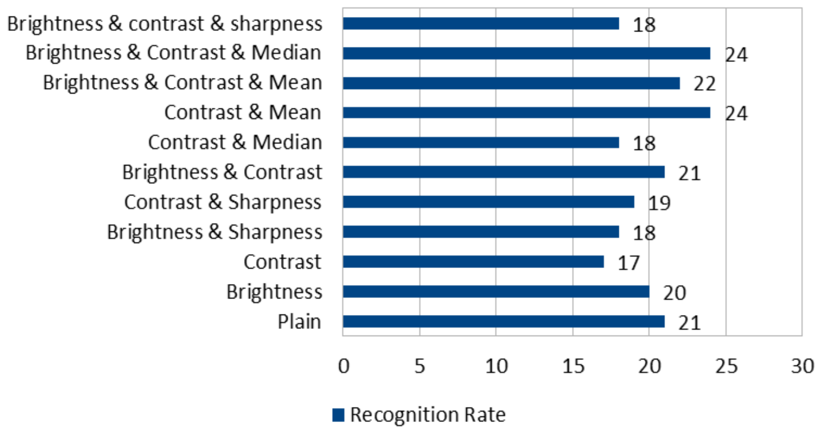

Fig. 2. (a) Comparison of recognition rate (30 test images) with various enhancement techniques on AT&T database.

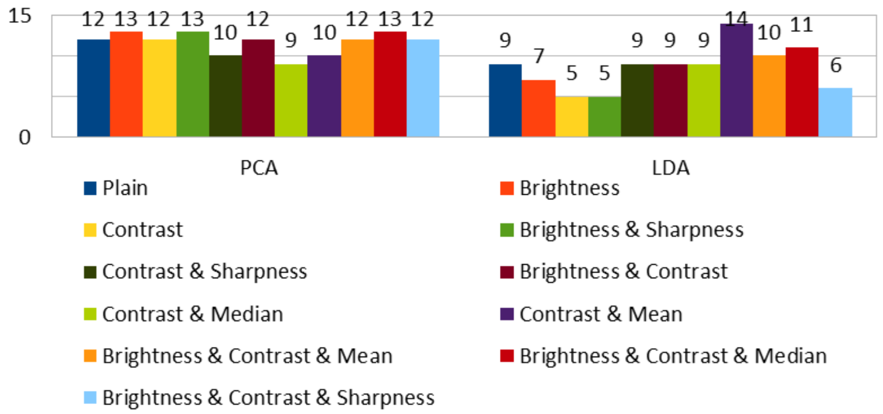

Fig. 2. (b) Success rate (30 test images) of PCA and LDA with various enhancement techniques on AT&T database.

4.2. Results obtained from Yale B database

As shown in Fig. 3(a), in this round of tests, all applied image enhancement techniques show improvement over normal images with highest face recognition rate achieved by application of histogram equalization and median filter technique.

The result of image enhancement on PCA and LDA algorithms is shown separately in Fig. 3 (b). It can be seen that by increasing number of training set images (5 images for Yale B test compared to 3 images for AT&T), LDA face recognition algorithm outperforms PCA by 50% to 75% margin. For PCA algorithm, all image pre-processing techniques improved face recognition with combination of contrast equalization and mean filter having highest recognition rate. Contrast normalization, and combination of contrast normalization and sharpening, and also combination of contrast normalization and mean smoothing filter results are also showing good improvement in recognition rate.

On the other hand for LDA algorithm, contrast normalization, and also combination of contrast normalization with mean filter and median filter have highest recognition rate and combination of image brightness and sharpening has slightly lower recognition rate than normal images. Overall image enhancement techniques improved face recognition accuracy by average of 60%.

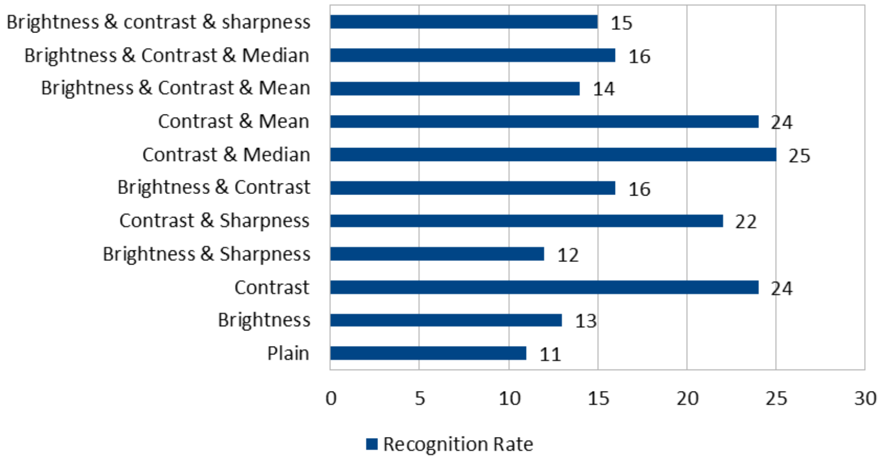

Fig. 3. (a) Comparison of recognition rate (30 test images) with various enhancement techniques on Yale B database.

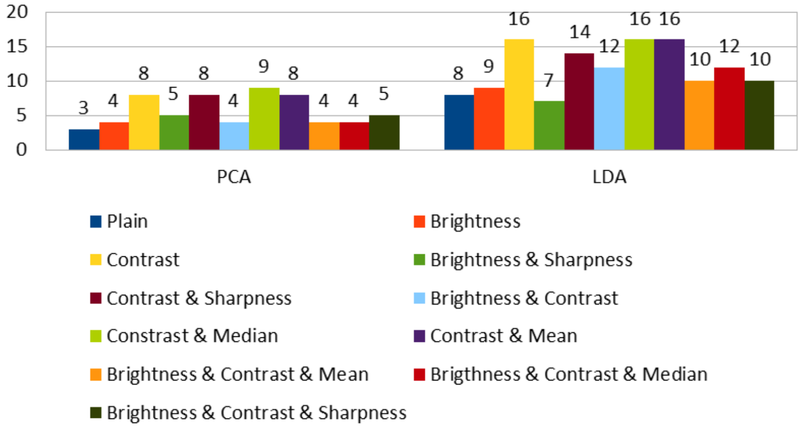

Fig. 3. (b) Success rate (30 test images) of PCA and LDA with various enhancement techniques on Yale B database.

5. Conclusion

The evaluation of data, collected during this research, revealed that the effect of image pre-processing techniques on face recognition dependshighly on the illumination condition under which these images are taken. The benefit of applying image enhancement techniques on face images is best seen when there is high variation of illumination among images. While applying same techniques on images that are taken under different orientation, rather different lighting, does not improve recognition rate and also in some cases has negative impact on the results. This can be seen by comparing results from Figs. 2(a) and 3(a). The results also show that LDA face recognition algorithm performs best when there is sufficient number of images available during training stage. This is revealed by comparing results achieved from execution of test cases on AT&T database and Yale B database. For Yale B database tests, 6 images are used for intended subjects to train algorithm while for AT&T database tests, only 3 images were used to train algorithm. This is in accordance with the findings published by[8]. The results are shown in Figs. 2(b) and 3(b). Results also show that highest recognition rate is achieved when images are taken under low light condition and image contrast is enhanced using histogram equalization technique and then image noise is reduced using median smoothing filter. On the other hand combination of contrast normalization and mean smoothing filter shows good result in all scenarios. This is the case of using wearable gadgets under low dim street lights and applying contrast normalization and mean or median filter can improve results by 50% to 75%.

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