Influence of Facial Expression and Viewpoint Variations on Face Recognition Accuracy by Different Face Recognition Algorithms

Manop Phankokkruad, Phichaya Jaturawat
Faculty of Information Technology
King Mongkut's Institute of Technology Ladkrabang
Bangkok, Thailand 10520
Email: manop@it.kmitl.ac.th

***Abstract*—Face recognition is a personal identification method using biometrics that is gaining the attention in this research field. The face recognition process can be done without the human and devices interaction, so it can be applied in several applications. In additions, the face recognition systems are typically implemented at different places in unconstrained environments. Hence, the study of the factors that impact the face recognition accuracy is an interesting and challenging topic. In the class attendance checking system using face recognition, there are variations of three factors that possibly affect the accuracy of the system; facial expressions, and face viewpoints. This study intends to compare facial recognition accuracy of three well-known algorithms namely Eigenfaces, Fisherfaces, and LBPH. The experiments conducted in the respects of the variation of facial expressions, and face viewpoints in the actual classroom. The results of the experiment demonstrated that LBPH is the most precise algorithm which achieves 81.67% of accuracy in still-image-based testing. The facial expression that has the most impact on accuracy is the grin, and face viewpoints that affect accuracy are looking down and tilting left, and right respectively. Therefore, LBPH is the most suitable algorithm to apply in a class attendance checking system after considering the accuracy.**

***Keywords*—Face Recognition, Fisherfaces, Eigenfaces, LBPH, Class Attendance, Facial Expression, Face Viewpoint, Computer Vision**

I. Introduction

A face is a human physiological characteristic that different from each person and easy to be seen. Face recognition is popular and widely uses personal identification method. This method uses only one additional device that is a camera, so it can be applied in various systems. Also, the face recognition process can be done without device interaction from the person. Since a camera is the only addition device for face recognition system, face recognition system can provide an inexpensive and reliable personal identification,which has feasibility to apply in many purposes [1]. It is cheaper than the fingerprint scanner, so face recognition system can be installed in every classroom with smaller budgets.

Moreover, there are many factors that affected to the face recognition accuracy. Enviromental factors, algorithms and quality of image database are the commonly factors that affected recognition accuracy [2]. Sometimes the factors made images are non-ideal for face recognition, and then decreased face recognition accuracy. One example of those factors is age of people [3]. The other factors that impact on face recognition accuracy are face shape, face texture, glasses, hair, and also the factors that unstable such as lighting, etc. Thus, any controllable factors should be well controlled to have a minimal impact on the recognition system. As described in Jafri and Arabnia's work [4], they categorized the factors that cause variation of facial appearance into two groups: internal and external factor. Givens et al. [5] described many intrapersonal factors of face that have to be concerned while using the face recognition system. These factors can cause missed face recognition in case of individuals who have a similar face appearance [6]. Likewise, an external factors are due to the environments of face recognition system. This type of the factors can cause a few changes of face appearance in the image acquisition process. There are several external factors that are possibly uncontrolled and varied while using the system. Many publications of face recognition algorithms represented each algorithm has characteristics and provide high face recognition accuracy in different aspects. For these reasons, the face recognition becomes a good alternative method. Despite literature reveals that a lot of research work has been carried out on face recognition. From the prior work [7], the algorithm selection is a very challenging part of a class attendance checking system implementation because this is an automatic system that hard to control student's facial expressions, gestures, and some environmental factors. These factors are also highly affecting the face recognition accuracy.

This research studies three basic face recognition algorithms which have high and reliable accuracy. Eigenfaces [8], Fisherfaces [9], and Local Binary Pattern Histograms (LBPH) are chosen to study in the experiments with variation of the factors that have a chance to occur within a class attendance checking system. A variation of face expressions, and face viewpoints are the factors that were used in the experiments to study an effect to face recognition accuracy. This is the good way to study algorithms with their advantages and disadvantages when the variation of factors occurred. Consequently, this experiment will be helpful for the developers to choose the most appropriate face recognition algorithm for the face recognition

978-1-5090-5504-3/17/$31.00 ©2017 IEEE
SNPD 2017, June 26-28, 2017, Kanazawa, Japan

systems which have the similar conditions.

The rest of the paper is organized as follows. Section 2 provides the background, state of the problem, face recognition algorithms and the variation of factors. Section 3 gives an implementation and also its different conditions. In section 4, the results, evaluations, and and discussion are described. Finally, the summary, conclusions and future work of this paper are presented in Section 5.

II. Background and Proposed Algorithms

In this section, the state of the problem, face recognition algorithms, and related theoretical of face recognition are described. This work uses the Eigenface and Fisherfaces, and LBPH in the face recognition process. These algorithms available in the computer vision library (OpenCV), which contains several functions of computer vision and images processing. There are many researches and publications about these algorithms and demonstrated the acceptable high face recognition accuracy. Besides, the OpenCV library is the open source that convenient for using without cost, easier, and good for long-term practical usage.

A. State of the Problem

From the prior work [7], face recognition method was implemented in a class attendance checking system. Although the face recognition works well for this purpose, but the accuracy of this system was lower than an expectation. It is only 48.18% of the accuracy by testing with 148 students in actual classroom environment. The class attendance checking system was done by manual capturing student's images and proceeds the face recognition. There are many problems while conducting the face recognition experiments in actual classroom. First is a variation of student's facial expressions that hard to control. Second is a light level in classroom that has been changed every week. The last one is an inconvenience of the image capturing process that takes a little bit of time for each person. These problems demonstrated this system still is inefficient for using in realistic conditions. The facial expressions and the face viewpoints are the challenges to this kind of system. While the students walking passed the camera, it is the nature of human behavior to have different facial expressions. The moving people is cause of the different face viewpoint that sometimes not a straight face. The motion of people sometimes causes blurred images and decreases the quality of input image. Besides the system features, the reference images of students are the important factor that effects to the face recognition accuracy. In prior work, the reference database was created by using the images that the students took for themselves via the web application. There are eight to fifteen images per students that were collected uncontrolled the face expressions with different light levels. These factors cause the database quality is not good enough. Thus, this research creates a new reference database with prescribed face expressions and viewpoints that accorded to the possible face in the automatic face recognition system. This reference database will be used to create a training model and test the accuracy of three face recognition algorithms that are Eigenfaces, Fisherfaces, and LBPH.

B. Eigenfaces Algorithm

Eigenfaces [8] refers to an appearance-based approach to face recognition that seeks to capture the variation in a collection of face images. Eigenfaces is based on the principal components analysis (PCA) of a distribution of faces [10]. The approach of using eigenfaces for recognition was developed by Turk and Pentland [11]. Furthermore, Eigenfaces is a traditional approach for face recognition which has the advantage of simplicity of the implementation. The method of face recognition have been s-dimensional vector faces in the training set of each PCA may be a T-dimensional vector space based on compatible with the direction of maximum variance in the original image. To identify unknown images, the images were projected onto the surface to find the weight. This method is the same way to find a set of weights from well-known face images. By comparison, a set of weights for the unknown faces with the known faces of the weight of both types of faces can be identified. If the image is a vector of random variables are defined as PCA eigenvectors of the diffusion matrix S_T defined as:

$$S_T = \sum_{i=1}^{M} (x_i - \mu)(x_i - \mu)^T \tag{1}$$

where μ is means of all images in the training set and is the image with its columns concatenated in a vector. The projection matrix is comprised of T eigenvectors according to T largest eigenvalues, also creating a T-dimensional face space. Since these eigenvectors (PCA basis vectors) look like some ghostly faces named Eigenfaces [12].

C. Fisherfaces

Fisherfaces [9] is a strong algorithm with an argument in favor of using linear methods for dimensionality reduction in the face recognition problem at least when one seeks insensitivity to lighting conditions. Since the learning set is labeled, it makes sense to use this information to build a more reliable method for decreasing the dimensionality of the feature space. The using class specific linear methods for dimensionality reduction and simple classifiers in the reduced feature space, one may get better recognition rates. However, results of many researches reveal both algorithms have an effective processing time and storage usage. Fisher's Linear Discriminant (FLD) is an example of a class specific method, in the sense that it tries to "*shape*" the scatter in order to make it more reliable for a classification. This method selects w in [11] in such a way that the ratio of the between-class scatter and the within class scatter is maximized. Let the between-class scatter matrix be defined as:

$$S_w = \sum_{j=1}^{C} \sum_{i=1}^{nj} (x_{ij} - \mu_i)(x_{ij} - \mu_i)^T \tag{2}$$

where x_{ij} is the i^{th} sample of class j, μ_j is the mean of class j , and nj the number of samples in class j. Likewise, the

between class differences are computed using the between-class scatter matrix,

$$S_b = \sum_{j=1}^{C} (\mu_j - \mu)(\mu_j - \mu)^T, \quad (3)$$

where μ_i is the mean image of the class X_i, and μ is the mean image of all classes. N_i is the number of sample images in class X_i, and C is the number of the classes. S_w is the maximized value of between-class scatter matrix while w is the minimized of within-class scatter matrix for using in a classification process [13]. To illustrate the benefits of class specific linear projection, we constructed a low dimensional analogue to the classification problem in which the samples from each class lie near a linear subspace.

D. Local Binary Pattern Histrogram

Local Binary Pattern Histrogram (LBPH) is the local feature based for face representation proposed by Ahonen et al. [14], [15]. This method is based on local binary patterns(LBP), which is firstly proposed as a texture description method. In the approach for texture classification, the occurrences of the LBP codes in an image are collected into a histogram. The classification is then performed by computing simple histogram similarities. However, considering a similar approach for facial image representation results in a loss of spatial information and therefore, one should codify the texture information while retaining also their locations. LBPH has the advantage of invariant to the light intensity, but it takes more processing time rather than the holistic approach [16].

A histogram of the labeled image $f_l(x, y)$ can be defined as:

$$H_i = \sum_{x,y} I\{f_i(x, y)\} \, i = 0, ..., n-1 \quad (4)$$

In which n is the number of different labels produced by the LBP operator and

$$I\{A\} = \begin{cases} 1 & A \text{ is true} \\ 0 & A \text{ is false} \end{cases} \quad (5)$$

The histogram that was obtained from the images containing information about local facial micro patterns including face's edges, eyes location, and other flat areas for adequate facial representations.

In the case of class attendance checking system using face recognition, the student face expression and face viewpoints are the factors that variant and hard to control. These factors are the challenge for the three selected algorithms. Therefore, the comparative study will be conducted in the initial phase in order to specify the type of face recognition algorithm that suitable for the system.

E. Variation of Testing factors

From the prior study, there are many factors that affect to the face recognition accuracy and some factors have a chance to emerge while using the practical system. First is the database quality, there are many factors that have to control in image acquisition process, such as the image quality, image size, noise levels, light levels, facial expressions, face viewpoints, glasses, etc. So, the image database have to obtain the sufficient images to avoid the factors that directly affected by the quality of the training model. Second is the input image quality, this factor is totally unexpected and hard to control when deployed the face recognition system. Although, the image pre-processing phase can improve the input images quality, there are some surrounding factors that cannot eliminate it such as face expressions and face viewpoints. Consequently, this research studies the disturbing factors: facial expression and viewpoint, that might occur when using the face recognition system. Also, this work conducts the comparative testing of face recognition algorithms accuracy in order to find the most suitable algorithms to apply in face recognition system.

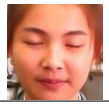
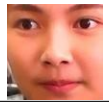
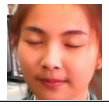
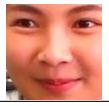
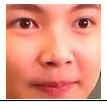
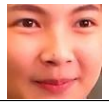
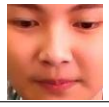
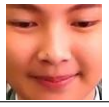
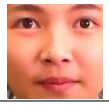
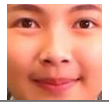
III. Implementation

This section presents the implementation steps including the face image database creation, the study of three face recognition algorithms that are Eigenfaces, Fisherfaces, and LBPH.

A. Image database creation

In order to create the database, the images of students were collected from two cameras. First is the webcam on a desktop computer, it used for manual capturing images of volunteers by controlled their face expressions, viewpoints, and gesture. Thus, this process can obtain one set of still images per student. Moreover, the image was captured at the same places in the light controlled environments.

TABLE I: The example images of the face in controlled database

Face Position	Expressions			
	Normal	Close eyelids	Smile	Grin
Frontal				
45 degree left				
45 degree right				
45 degree lower				
45 degree upper				

Each student had forty images in a reference database, twenty images from manual capturing and twenty images from video extraction. There were twenty characteristics of images that combined four types of facial expression and five facial viewpoints. All the images were collected in the same environment with the lighting controlled. Most of the images that were collected from thirty students were similar to those images in Table I. In the frontal face position, the images were collected with four expressions; a normal face, closed eyelids, smiling and grinning. The other positions were collected in the same way. This database was expected to provide an efficient database for a class attendance checking system because it contains many facial appearances that frequently occur when using the system. However, this method takes time to collect images from each student and it is inconvenient for students to come at a specific time to take the photos. Thus, this method is inappropriate for a classroom that has many students.

IV. Results, Evaluations and Discussion

A. Factors variations

As described, the selected factors including facial expressions, facial viewpoints and light exposure were tested in the experiments. Every factor was varied in the possible range that had a chance to occur in the practical class attendance checking system. The results of facial expressions, viewpoints and light exposure variations including their challenges will be described as follows. Face expression is the factors that hard to control in the automatic face recognition system because the student gesture will always change while walking pass the camera. The results of the class attendance checking system observation demonstrated four types of face expressions that frequently seen while recorded the video that are normal faces, close eyelids, smile, and grin as depicted in Figure 1.

In addition, the face viewpoints are the factor related to the student gesture. The movement of the student body causes the unstable of face viewpoints, so it sometimes not the frontal faces while using the system. The viewpoint can affect the details of the vectors that represent the faces, and it can cause the error in face recognition. The results of the observation show there are five faces viewpoints that possible to occur while using the class attendance recording system. The viewpoints that depicted in Figure 2 are frontal faces, tilted left, tilted right, looked up, and looked down.

(a) normal (b) close eyelids (c) smile (d) grin

Fig. 1: The example of images with face expressions variations (a) normal (b) close eyelids (c) smile, and (d) grin respectively

B. Face recognition accuracy

The results of still-image-based face recognition testing with variation factors will be described. The first experiment is the still-image-based face recognition in case of without confounding factors. This is the testing with the non-adjustment image of the students in the test set. This testing conducted by using a closed test set of thirty students which have ten images per students. The student faces in the test set belong to the students that exist in the reference database, but not the same image. These images were tested by three algorithms, Eigenfaces, Fisherfaces, and LBPH. The result of this experiment is shown in Table II. The accuracy of the results is calculated from the ratio of the number of correct recognition to the total faces.

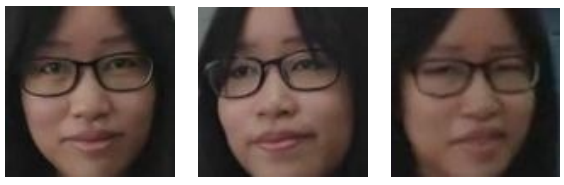
TABLE II: Result of accuracy without confounding factors

Algorithms	Total faces	Correct	Accuracy (%)
Eigenfaces	300	140	46.67
Fisherfaces		208	69.33
LBPH		245	81.67

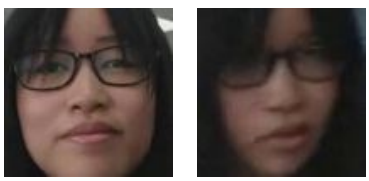
TABLE III: Result of face recognition accuracy with variation of facial expression

Algorithms	Accuracy(%)		
	Normal	Smile	Grin
Eigenfaces	46.88	51.52	38.10
Fisherfaces	71.88	66.67	57.14
LBPH	79.69	80.30	80.95

From Figure 3, LBPH got the highest face recognition accuracy at 81.67%, Fisherfaces got 69.93%, and Eigenfaces got the lowest accuracy at 46.67%. These are satisfied results



(a) frontal (b) tilted right (c) tilted left



(d) looked up (e) looked down

Fig. 2: The example of images with face viewpoints variations (a) frontal (b) tilted right (c) tilted left, (d) looked up, and (d) looked down respectively

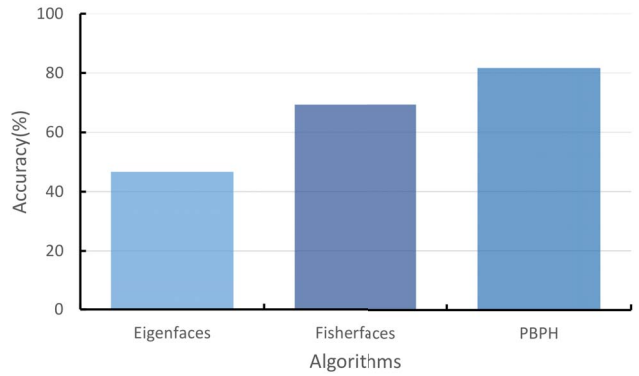


Fig. 3: A comparative of still image face recognition accuracy without confounding factors

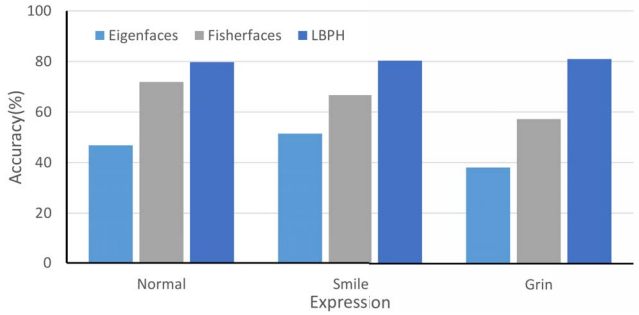


Fig. 4: A comparative of still image face recognition accuracy with face expressions variations

comparing to the previous work of class attendance checking system, which got accuracy at 48.18% in case of LBPH. The results of this testing demonstrated that the image database is the important factor that affects the accuracy. The reference database which contains covered possible face expressions and viewpoints can improve the LBPH accuracy.

The second experiment of this section is face recognition accuracy testing with a variation of face expressions. Because the students capture their images by themselves, the face viewpoint in the test set is only the frontal face and not has the close eyelids images. There are three types of face expressions were tested in this experiment that is normal faces, smile, and grin.

As depicted in Table III, LBPH can deal with the variation of face expression with stable and high accuracy that are 79.69% in the normal case, 80.30% in smile case, and 80.95% in grin case. Fisherfaces has a good accuracy at 71.88% in normal case and slightly dropped in case of smile and grin. Eigenfaces is the algorithm that has the lowest accuracy in every case, especially in the grin expression that has a bit lower accuracy than the other cases. The trends of the accuracy of each algorithm are displayed in Figure 4.

The results showed that LBPH achieved the highest accuracy in every experiment. The results of this research relate to zdils study [13] that reveals LBPH is the most successful face recognition method followed by the Fisherfaces and Eigenfaces in the case of a small number of training images. The results of the process time in this research related to the Ahmed and Amin's work [17] show that the Fisherfaces is the fastest algorithms followed by Eigenfaces and LBPH.

C. Evaluations

In the case of evaluation, it was done by manual checking. The reason for this is that in the video many students were walking past the camera at the same time with different facial expressions and facial viewpoints. Although it is possible to estimate the moment when the students passed the camera and create labels there can be overlap causing a dislocation of the solution when verifying the results in the preliminary phase. Humans have the ability to recognize and classify the face with a robust attitude to the variation of facial viewpoints [18]. Thus, the manual checking is very useful to check and verify the face detection and recognition results, with greater efficiency in small experiments. Manual checking also allows us to consider the appearance of the image and classifies any problems that may result in false detection and recognition.

D. Discussion

The image database is an important part of the face recognition system. In this research, The selected method is manually capturing the student images and recording the video simultaneously. This process was done in a controlled environment with specific facial expressions and viewpoints. The advantage of this method is that every factor dependent on the face recognition system requirements can be strictly controlled. However, this method has a disadvantage because it takes so much time to collect the images of all the students.

As the results, facial expression is a factor that can affect face recognition accuracy. Grinning is an expression that has the most impact that decreased about 27% of accuracy in the case of LBPH because this expression changes the appearance of faces more than closed eyelids and smiling. In the case of closed eyelids, face recognition accuracy is likely to be higher than the normal case. This may be because the number of closed eyelids images is much fewer than the other cases, so a proportion of the correct face recognition is high. Face viewpoint is the factor that relates to student body movement. The greatest impact of face viewpoint on face recognition accuracy is the looking down face. However, tilting left and right faces also affect face recognition accuracy, the reason

(a) Input image (b) False image (c) Input image (d) False image

Fig. 5: Examples of the false recognition of Eigenfaces (a)(b), and Fisherfaces (c)(d)

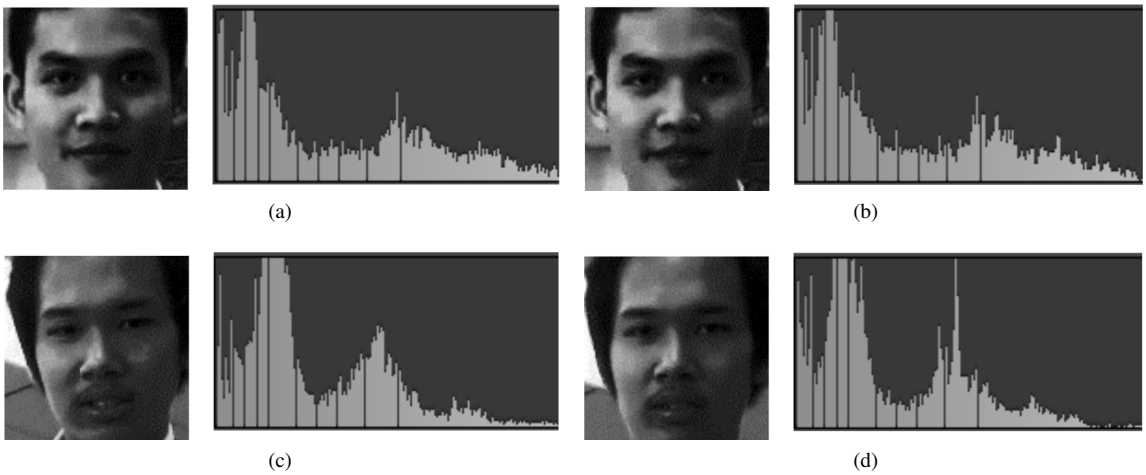


Fig. 6: Examples of the false recognition results of LBPH

being these face viewpoints make it difficult to see the whole face and cause a loss of some face detail. The looking up face is the only one where the accuracy is similar to the normal case because this viewpoint can visualize the whole face clearly with full face details. Because of this, the position of the camera in a class attendance checking system should be adjusted to 1.6 meters or little higher to decrease the looking down face from tall students.

LBPH is the algorithm that achieved the highest accuracy in every experiment, followed by Fisherfaces and Eigenfaces. The reason for this is LBPH considers the regions of images and converts them into a binary code to represent each image, so the representation of the same person with a different facial appearance might reduce some face details such as a difference of facial expression. Moreover, this method compares input image to each image in the training set and analyzes them independently, so an image database that contains all of the possible face expressions and viewpoints is able to improve LBPH accuracy. Eigenfaces and Fisherfaces transform facial features into a vector with high image details and consider the image of each subject as a whole set. The recognition process compares the input images to the mean of each subject, so a variation of facial appearance can increase the chance of face mismatch.

In the case of Eigenfaces and Fisherfaces, false face recognition usually occurred with students who have a similar facial appearance. The students who were misidentified had some part of the face similar to others in the reference database. The examples of false recognition results are shown in Figure 5(a) in the input image and Figure 5(b) are recognition results of Figure 5(a). Figure 5(c) is the input image and Figure 5(d) is the recognition result of Figure 5(c). The features that are similar and affect the face recognition results are the nose, expressions and glasses. The quality of the image also has little effect while some of the input images have a similar facial appearance but the blurred image received false recognition.

For LBPH which uses a different approach from Eigenfaces and Fisherfaces, false recognition occurred through mismatch of the image histogram because of the methodology that has been mentioned before. Examples of the histogram of images are shown in Figure 6.

V. Conclusion

Face recognition is a personal identification method using biometrics that the process can be done without the human and devices interaction. For this reason, face recognition has been selected for application in a class attendance checking system in order to improve the precision of student checking. Since, the face recognition systems are typically implemented at different places in unconstrained environments, the work have studied the factors that impact the face recognition accuracy. There are two factors that possibly affect the accuracy of the system; facial expressions, and face viewpoints. Furthermore, this study intends to compare facial recognition accuracy of three well-known algorithms namely Eigenfaces, Fisherfaces, and LBPH. The experiments conducted in the respects of the variation of facial expressions, and face viewpoints in the actual classroom. The results of the experiment demonstrated that LBPH is the most precise algorithm which achieves 81.67% of accuracy in still-image-based testing. A face expression that has the most impact on the accuracy is the grin, and face viewpoints that affect the accuracy are looked down, tilted left and right respectively. Therefore, LBPH is the most suitable algorithm to apply in a class attendance checking system after considering the accuracy.

This research can serve as a guideline for people who are interested in applying face recognition into the real-world system, especially in terms of the class attendance checking system. Even though the face recognition algorithms in this testing have a reliable accuracy, the results of class attendance checking system evaluation demonstrated the comparison of three algorithms are still not robust for a real-world system, and the processing speed are still low in the typical computer. Thus, it is a challenge to improve the face recognition accuracy

for basic face recognition algorithms such as Eigenfaces, Fisherfaces and LBPH in real-time video operations. Since these algorithms are easy to implement with the library that is provided in OpenCV, they are very useful for beginners who want to study and implement an effective face recognition system for their purposes.

REFERENCES

[1] S. Z. Li and A. K. Jain, *Handbook of Face Recognition*, 2nd ed. Springer Publishing Company, Incorporated, 2011.

[2] K. Shi, S. Pang, and F. Yu, "A real-time face detection and recognition system," in *2012 2nd International Conference on Consumer Electronics, Communications and Networks (CECNet)*, April 2012, pp. 3074–3077.

[3] H. Ling, S. Soatto, N. Ramanathan, and D. W. Jacobs, "A study of face recognition as people age," in *2007 IEEE 11th International Conference on Computer Vision*, Oct 2007, pp. 1–8.

[4] R. Jafri and H. R. Arabnia, "A survey of face recognition techniques," *Information Processing Systems*, vol. 5, no. 2, pp. 41–68, 2009.

[5] G. Givens, J. R. Beveridge, B. A. Draper, P. Grother, and P. J. Phillips, "How features of the human face affect recognition: a statistical comparison of three face recognition algorithms," in *Proceedings of the 2004 IEEE Computer Society Conference on Computer Vision and Pattern Recognition, 2004. CVPR 2004.*, vol. 2, June 2004, pp. II–381–II–388 Vol.2.

[6] P. Kocjan and K. Saeed, *Face Recognition in Unconstrained Environment*. New York, NY: Springer New York, 2012, pp. 21–42.

[7] M. Phankokkruad, P. Jaturawat, and P. Pongmanawut, "A real-time face recognition for class participation enrollment system over webrtc," in *Proceedings of SPIE - The International Society for Optical Engineering*, vol. 10033, 2016.

[8] M. Turk and A. Pentland, "Eigenfaces for recognition," *J. Cognitive Neuroscience*, vol. 3, no. 1, pp. 71–86, Jan 1991.

[9] P. N. Belhumeur, J. a. P. Hespanha, and D. J. Kriegman, "Eigenfaces vs. fisherfaces: Recognition using class specific linear projection," *IEEE Trans. Pattern Anal. Mach. Intell.*, vol. 19, no. 7, pp. 711–720, Jul 1997.

[10] S. Zhang and M. Turk, "Eigenfaces," *Scholarpedia*, vol. 3, no. 9, p. 4244, 2008.

[11] M. A. Turk and A. P. Pentland, "Face recognition using eigenfaces," in *Computer Vision and Pattern Recognition, 1991. Proceedings CVPR '91., IEEE Computer Society Conference on*, Jun 1991, pp. 586–591.

[12] K. Delac, M. Grgic, and S. Grgic, "Independent comparative study of pca, ica, and lda on the feret data set," *International Journal of Imaging Systems and Technology*, vol. 15, no. 5, pp. 252–260, 2005.

[13] A. zdil and M. M. zbilen, "A survey on comparison of face recognition algorithms," in *2014 IEEE 8th International Conference on Application of Information and Communication Technologies (AICT)*, Oct 2014, pp. 1–3.

[14] T. Ahonen, A. Hadid, and M. Pietikainen, "Face description with local binary patterns: Application to face recognition," *IEEE Trans. Pattern Anal. Mach. Intell.*, vol. 28, no. 12, pp. 2037–2041, Dec 2006.

[15] T. Ahonen, A. Hadid, and M. Pietikinen, "Face recognition with local binary patterns," in *Computer Vision - ECCV 2004: 8th European Conference on Computer Vision, Prague, Czech Republic, May 11-14, 2004. Proceedings, Part I*, 2004, pp. 469–481.

[16] M. Pietikainen, "Local binary patterns," *Scholarpedia*, vol. 5, no. 3, p. 9775, Sep. 2010.

[17] M. T. Ahmed and S. Mohd. Amin, "Comparison of face recognition algorithms for human-robot interactions," *Jurnal Teknologi*, vol. 72, pp. 73–78, Jan 2015.

[18] A. J. O'Toole, P. J. Phillips, and A. Narvekar, "Humans versus algorithms: Comparisons from the face recognition vendor test 2006," in *2008 8th IEEE International Conference on Automatic Face Gesture Recognition*, Sept 2008, pp. 1–6.