PCA effect on the 3D face recognition system speed

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Abstract. In this paper, a system of three-dimensional (3D) face recognition is not done through 3D face reconstruction method but directly uses the data retrieved from Kinect Xbox camera system. From a previous study, there exists a possibility to increase the speed and accuracy of the system. In order to accelerate the recognition speed, a single step in the said study is eliminated, which is the reconstruction of 3D face data. The algorithms used in this research are Backpropagation Neural Network and PCA. Testing is done in two ways. The first test uses a combination of Backpropagation and PCA, while the second test uses Backpropagation only. PCA has the function of simplifying the amount of data, thereby reducing the amount of computing that can increase speed system. The results show that the system that uses a combination of Backpropagation and PCA achieved an increase in speed up to 34.2 times, but a reduced accuracy of 8.5%.

1. Introduction
Recent technologies such as the internet, digital television, mobile phones, household appliances, and smart electronics have entered mainstream use¹. This caused security concerns, which has become more difficult to maintain than it previously ever been. Authentication is therefore a crucial element of a computer security system. One of the available authentication methods is biometric authentication which has many advantages over traditional credential-based authentication mechanism. Among divers biometric authentication methods, face recognition is a one the most popular technique that is continuously improving over the past decade ². Each person face should have some differences, to make face recognition system work ³.

To date, most face recognition systems are based on the evaluation of 2D characteristic points or colour images, and still has weakness due to all kinds of adverse factors such as illumination variation, pose changes, makeup, or facial expressions ⁴ ⁵. In view of the mentioned shortcomings, 3D face recognition is used to solve them. There are many studies of 3D face recognition ⁶ and at research ⁷ ⁸, the data of the face was taken using depth camera such as ToF PMD Cam-Cube 3.0 and Kinect Xbox. It was then processed by reconstructing the data into a 3-dimensional model, before being inputted into the recognition algorithm i.e. Backpropagation, Eigen face, LBP, LDA, and CMA. In research ⁹ ¹⁰, it did not focus on increasing speed. However, it is possible to increase the recognition speed and accuracy of a 3D face recognition. In a study ⁷ the recognition speed is 2189 Ms and the accuracy is 95.12%, and in a research ⁸, four algorithms has been tested with recognition speed variation of 260.5 Ms to 623 M, and accuracy rate variation of 87.5% to 92.5%.

The basic difference of this research compared to the previous researches is in the number of steps in data process. By eliminating the reconstruction step, the recognition speed of the system thus can be increased. Another notable difference is in the recognition algorithm. This research utilizes a combination of PCA and Backpropagation algorithms. The benefit of Principal Component Analysis (PCA) is to cut down the dimension of the data. No data redundancy is found as the components are orthogonal. With PCA, the complexity of grouping the images can be reduced. PCA is a dimensionality reduction technique which is used in order to simplify the face identification and recognition process, thus increasing the speed of the system. PCA is also known as Eigen space projection or Karhunen-
Loeve transformation [11]. The implementation of both algorithms resulted in a high level of accuracy of the system [12].

In the experiment, we conducted two scenarios. The first test used a combination of PCA and Backpropagation, while the second test excluded the PCA and used only the Backpropagation algorithm. It gets the best results for without using a PCA with a speed of 58.49 Ms and an accuracy of 90%. When compared with previous studies, the increase in recognition speed was up to 34.2 times but failed to improve accuracy as it decreased by 8.5%. This research increased the speed of 3D face recognition. This is very useful in increasing the reliability of applications that use systems like this.

2. Method
The flowchart in Figure 1 describes the process of the system in this research:

![System flowchart](image)

**Figure 1.** System flowchart.

Our procedure of implementation for the face recognition process is divided into three main steps of process: (1) Image acquisition, (2) Image processing, and (3) Recognition.

2.1. Image Acquisition
The background is plainly colorad and does not contain any other objects to reduce the noise level or disturbance to the depth data obtained using ToF cameras [13]. The face is in a neutral facial expression, not wearing glasses, and facing straight to the camera to improve face recognized accuracy.

![Image samples](image)

**Figure 2.** Image samples acquired by application: (a) RGB image, (b) infrared image, and (c) depth map image.

Under these conditions, RGB and depth images can be captured using the application for Kinect. Figure 2 shows a sample of RGB and depth images captured using Xbox One Kinect system. For
experimentation, 10 faces are used, and each face is captured 10 times. 80 faces are used as learning data, and 20 faces are used as training data.

2.2. Image Processing
We only used 3D images within our face recognition system. An image data is solely an image with depth information as shown in Figure 5. In other words, an image data is an array of numbers where the numbers quantify the distances between the focal plane of the sensor to the surface of objects within the field of view along the rays emanating from a regularly spaced grid. The image data/depth maps have a resolution of 512 x 424 pixels with each pixel containing the decimal number from eleven binary number. These numbers can vary from 0 to 2^{11} or 2048. The depth maps are normalized to 80 x 120 pixels, represented as 9600 vectors. Next, the mean image is calculated using equation (2) by summing the entire database ID vectors together and then dividing it with the number of faces in the database. Each face is then centred by subtracting the mean image from each image applying equation (1) [11].

\[ x^{-i} = x^i - m \]  
\[ m = \frac{1}{p} \sum_{i=1}^{p} x^i \]

Next, the data matrix is created by merging the centred database image side-by-side. The covariance matrix is then calculated by multiplying the data matrix with its transpose, using equation (3).

\[ \Omega = \bar{X} \bar{X}^T \]

This is continued by the calculation of the Eigenvalues and Eigenvectors for covariance matrix using equation (4).

\[ \Omega V = \lambda V \]

Where V is the Eigenvectors set and \( \lambda \) is corresponding Eigenvalues.

By calculating the eigenvalues and eigenvectors of the covariance matrix, we able to get that the eigenvectors with the largest eigenvalues related the dimensions that have the strongest correlation in the dataset, this is namely the principal component. PCA is a beneficial statistical technique that has been implemented in fields application such as face recognition, image compression and finding patterns in data of high dimension [14] [15].

2.3. Recognition
In the recognition step, we used Backpropagation Neural Network, is the most foundational classic establishing block in a neural network [16]. The algorithm can efficiently train a neural network, after each forward undergo through a network, backpropagation carry out a backward pass while adjusting the model’s parameters (weights and biases). This algorithm has been effectively applied in a lot of fields with excellent results such as in these studies [17] [18] [19] [20].

The scheme has two major steps, which are training and testing. During the training step, Backpropagation algorithm will try to discover the right weight by modifying the weight between neurons with speed according to the learning rate and momentum rate predetermined to gain an appropriate outcome, i.e. a network that could recognize the expected data input. The next step is testing the algorithm to recognize the input data, where the weight is coming from the training phase. Both aforementioned stages needed the data from the camera. Below is the condition in designing an artificial neural network used in the system:
1. The neural network is designed in three layers: the input layer, hidden layer, and output layer. The input layer is passive, which means that it did not modify the data (Figure 3).
2. Number of output node is 1 for each recognized person.
3. Tolerance number is 0.01.
4. Threshold number is 0.04.
5. Number of hidden layer is 1.
6. Nguyen and Widrow optimization [21] will use a layer between the input layer and hidden layer.
7. Momentum factor.
8. The initial weights range between -0.5 to 0.5

There isn’t any similar architecture for each different research object. Neural network can have any number of layers and any number of nodes per layer. Most application uses three-layer structure with a maximum of a few hundred input nodes. This explains why an experiment is required to discover an optimal design.

![Neural network architecture design.](image-url)  
Figure 3. Neural network architecture design.

3. Implementation and Results
Table 1 shows the results of architecture experiments on various combinations of hidden node number and learning rate value. The training is continuously repeated until the smallest MSE values are obtained and stopped when the MSE values started to increase. The termination of training equals with the maximum number of epoch. Two tests have been done. In the first test, the system used a combination of PCA and Backpropagation. In the second test, the system used Backpropagation without using PCA. In Table 1, if a number passes the maximum value that the system can calculate (in this case, the number is too small), it will appear as NaN [22]. It appears in systems that has hidden nodes below 50 and is using PCA. This meant that the measurement of speed and accuracy is impossible in such architecture. Measurement of the accuracy level is based on the tolerance number. If the difference between the output and the target is outside of the tolerated number, no accuracy number is displayed, which means that the architecture cannot recognize the image data. These combinations of architecture are therefore ignored.
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In this study, if we compare the average time of training speeds between the systems that used PCA and the systems that excluded PCA, an increase in training speed by 125.18 times is achieved by the systems that used PCA, while also increased the recognition time by 5.49 times. This is caused by the smaller amount of data [23]. For the recognition speed compared to the previous study [4], the system in this study is faster by 34.21 times and 7 times respectively for the systems that used PCA. This is due to a smaller number of processes the system had to go through. Maximum speed increases if the system used a combination of PCA and Backpropagation. This is very useful if the system is applied to a device with low-end specifications.

However, while the recognition speed increases, the accuracy rate attained is the opposite for the systems that used a combination of PCA and Backpropagation. Figure 4 illustrates the different rate of accuracy between the previous research and the system in this study.

![Figure 4. Comparison of accuracy results.](image-url)
The accuracy rate of is lower compared to the previous research [5]. This is caused by the elimination of 3D model reconstruction process, which can be described as the data normalization process. Accuracy decreases further by 8.5% after the inclusion of PCA, which can be attributed to the amount of data depth reduced by PCA process. This is probably because a way to distinguish a human face from another is through texture/number of the depth of data. However, this theory requires further research.

4. Conclusion
This paper puts forward a new 3D face recognition technique to improve its recognition speed. Backpropagation and PCA can be implemented together for a 3-dimensional face recognition without going through model reconstruction process. 3D face image is taken by Kinect Xbox One time-of-flight depth camera. In order to accelerate the speed of recognition, one data-processing step in the previous research is eliminated. The eliminated process is the reconstruction of 3D face data from Kinect. Instead, the data is directly used as the data input into PCA before being processed using Backpropagation algorithm. It resulted in an increase of recognition speed. Two tests are done. The first test used a combination of PCA and Backpropagation, while the second test excludes the PCA and used only the Backpropagation algorithm. The result from the tests shows that the system with PCA yielded an increase in recognition speed up to 34.2 times but failed to improve accuracy as it decreased by 8.5%.

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References
[1] Apăvăloaie E-I. The Impact of the Internet on the Business Environment. *Procedia Economics and Finance*. Elsevier BV; 2014;15:951–8. doi.org/10.1016/s2212-5671(14)00654-6.
[2] Chen S, Pande A, Mohapatra P. Sensor-assisted facial recognition. *MobiSys*. ACM Press; 2014. doi.org/10.1145/2594368.2594373.
[3] Erwin, Saparudin, Fachrurrozi M, Tamaarsa A, Zhang A. Facial Recognition Technique with Combination Method of Local Binary Pattern Histogram and Image Euclidean Distance. *JPCS*. IOP Publishing; 2019 Mar;1196:012009. doi.org/10.1088/1742-6596/1196/1/012009.
[4] Zhang L, Ding Z, Li H, Shen Y, Lu J. 3D Face Recognition Based on Multiple Keypoint Descriptors and Sparse Representation. Zhang Y, editor. PLoS ONE. *PLoS*. 2014 Jun 18;9(6):e100120. doi.org/10.1371/journal.pone.0100120.
[5] Zhou S, Xiao S. 3D face recognition: a survey. *hum-cent comput info*. Springer Science and Business Media LLC; 2018 Nov 24;8(1). doi.org/10.1186/s13673-018-0157-2.
[6] Alexander L, Kusnadi A, Wella W, Winantyo R, Pane IZ. Authentication System Using 3D Face With Algorithm DLT and Neural Network. *SCIS and ISIS*. IEEE; 2018 Dec. doi.org/10.1109/scis-isis.2018.00039.
[7] Zhang D, Lu G, *3D biometrics: Systems and applications*. New York: Springer New York Heidelberg Dordrecht London, 2013. doi: 10.1007/978-1-4614-7400-5_2.
[8] Cheng Z, Shi T, Cui W, Dong Y, Fang X. 3D face recognition based on kinect depth data. *ICSAI*. IEEE; 2017 Nov; doi.org/10.1109/icsai.2017.8248353.
[9] Nagat A-A, Caleanu C-D. Face identification using kinect technology. 2013 *IEEE 8th SACI*. IEEE; 2013 May. doi.org/10.1109/saci.2013.6608961.
[10] Jonathan, Kusnadi A, Julio D. Security system with 3 dimensional face recognition using PCA method and neural networks algorithm. *CONMEDIA*. IEEE; 2017 Nov. doi.org/10.1109/conmedia.2017.8266048.
[11] Turk MA, Pentland AP. Face recognition using eigenfaces. Proceedings 1991 *IEEE Comput. Sco.CVPR*. IEEE Comput. Sco. Press. doi.org/10.1109/cvpr.1991.139758.
[12] Zhao X, Wang K, Yang K, Hu W. Unconstrained face detection and recognition based on RGB-D camera for the visually impaired. Wang Y, Pham TD, Vozenilek V, Zhang D, Xie Y, editors. *ICGIP* 2016. SPIE; 2017 Feb 8. doi.org/10.1117/12.2266122.

[13] Fuchs S, Hirzinger G. Extrinsic and depth calibration of ToF-cameras. 2008 *IEEE CVPR*. IEEE; 2008 Jun. doi.org/10.1109/cvpr.2008.4587828.

[14] Alahmadi A, Hussain M, Aboalsamh HA, Zuair M. PCAPooL: unsupervised feature learning for face recognition using PCA, LBP, and pyramid pooling. *Pattern Anal Appl*. Springer Science and Business Media LLC; 2019 May 10; 23(2):673–82. doi.org/10.1007/s10044-019-00818-y.

[15] Zhang Y, Xiao X, Yang L-X, Xiang Y, Zhong S. Secure and Efficient Outsourcing of PCA-Based Face Recognition. *IEEE*. Institute of Electrical and Electronics Engineers (IEEE); 2020; 15:1683–95. doi.org/10.1109/tifs.2019.2947872.

[16] Brunel A, Mazza D, Pagani M. Backpropagation in the simply typed lambda-calculus with linear negation. *PACMPL*. Association for Computing Machinery (ACM); 2020 Jan;4(POPL):1–27. doi.org/10.1145/3371132.

[17] Whittington JCR, Bogacz R. Theories of Error Back-Propagation in the Brain. *Trends Cogn. Sci*. Elsevier BV; 2019 Mar; 23(3):235–50. doi.org/10.1016/j.tics.2018.12.005.

[18] Ramesh VP, Baskaran P, Krishnamoorthly A, Damodaran D, Sadasivam P. Back propagation neural network based big data analytics for a stock market challenge. *Commun. Stat. Theory Methods*. Informa UK Limited; 2018 Nov 17; 48(14):3622–42. doi.org/10.1080/03610926.2018.1478103.

[19] Lillicrap TP, Santoro A, Marris L, Akerman CJ, Hinton G. Backpropagation and the brain. *Nat. Rev. Neurosci*. Springer Science and Business Media LLC; 2020 Apr 17; 21(6):335–46. doi.org/10.1038/s41583-020-0277-3.

[20] PAOLA JD, SCHOWENGERDT RA. A review and analysis of backpropagation neural networks for classification of remotely-sensed multi-spectral imagery. *Int J Remote Sens*. Informa UK Limited; 1995 Nov 10; 16(16):3033–58. doi.org/10.1080/01431169508954607.

[21] Nguyen D, Widrow B. Improving the learning speed of 2-layer neural networks by choosing initial values of the adaptive weights. *IJCNN*. IEEE; 1990. doi.org/10.1109/ijcnn.1990.137819.

[22] Works M. *NaN (MATLAB Functions)* 205AD. 2020 Retrieved from http://matlab.izmiran.ru/help/techdoc/ref/nan.html.

[23] Zhang G, Tang B, Chen Z. Operational modal parameter identification based on PCA-CWT. *Meas*. Elsevier BV; 2019 Jun; 139:334–45. doi.org/10.1016/j.measurement.2019.02.078.