Journal of Applied Science and Engineering, Vol. 22, No. 1, pp. 163–170 (2019) *DOI: 10.6180/jase.201903_22(1).0016*

Three Dimension Face Recognition Based on Gabor Transformation and Support Vector Machine

Delong Zhang[1], Min Zhang[2] and Yongbo Liu[3]*

[1]*School of Electric Automation, Weifang University of Science and Technology, Weifang 262700, P.R. China*
[2]*Department of Mechanical and Electronic Engineering, Shandong Management University, Ji'nan 250357, P.R. China*
[3]*Department of City Management, Hunan City University, Yiyang, Hunan 413000, P.R. China*

Abstract

Face recognition based on 2D face images is still challenged by the large change of illumination, pose and expression after more than 10 years' research and its recognition rate is still far away from satisfaction under the change of the above three factors. Gabor wavelet and support vector machine (SVM) are studied. Gabor wavelet has good biological neurons function, and good adaptive change to illumination. Furthermore, SVM can provide good classification effect. Gabor wavelet and SVM are combined with PCA to improve recognition rate of human face. Besides, we put forward a kind of Gabor wavelet feature extraction method based on three-dimensional human face contour line. Five different types of human face recognition are used to verify the effectiveness of this algorithm. The experiment results show that the proposed scheme has higher recognition rate than several traditional schemes.

Key Words: Three Dimension Face Recognition, Gabor Wavelet, Support Vector Machine, Feature Extraction

1. Introduction

With the rapid development of economy and the popularity of the Internet, information security has gradually been valued by people. As one of the important means to protect information security, face recognition has gradually drawn attention from researchers. Moreover, face recognition is an important branch of computer vision technology and biometric identification technology, and it is also is an important field of pattern recognition and artificial intelligence [1]. The important task of face recognition is to identify the faces in the static image or video. How to recognize face quickly and correctly is still a difficult problem in face recognition task at present [2,3]. The selection of face recognition algorithm is directly related to the recognition rate.

Face recognition research beginning in the 1960s has gone through decades of development, and some encouraging results have been achieved for it. However, most of these traditional face recognition methods are aimed at 2D color or grayscale image, namely 2D face recognition [4]. In the practical application, they still face many serious problems. Illumination, expression and posture change affects the robustness and accuracy of identification results, which restricts the further development of 2D face recognition, making it be in a bottleneck stage in the mature technology application. The reason is that the human face is essentially a non rigid three-dimensional object with color texture information, which contains both color texture information of the human face and the shape structure information [5]. The two-dimensional face image is projection of 3 dimensional face color texture to two-dimensional plane, so it loses three-dimensional shape structure information describing the important features of human face. There dimension face information for authentication identity has greater potential in better recognition performance than two-dimensional face image, and it is now widely accepted in the field of face recognition.

*Corresponding author. E-mail: liiuyongbo@sina.com

The 3D data acquisition device obtains the three-dimensional depth data, after de-noise, normalization, registration and other pretreatment measures, and how to extract the important characteristics of strong ability to distinguish face from these data is the key problem of determining face recognition results [6,7]. Because the data of 3D face is different from that of 2D gray image, some feature extraction methods of 2D face recognition cannot be applied to 3D face data. Therefore, for the new model of 3D face, we need to study its particularity to extract the real expression of its essential identity [8–10]. In addition, the face is not an invariant three-dimensional rigid body, and it will produce irregular deformation, such as facial expression change. So when extracting features, we need to take into account the impact of three-dimensional deformation of the face, that is to extract the robust expression features.

The rest of the paper is organized as follows: in section 2, the current studies on human face recognition are briefly reviewed; the proposed scheme for three dimension human face recognition is described in detail in section 3; in section 4, the experimental results and corresponding analysis are shown; finally, the conclusion is given in section 5.

2. Related Work

At present, the commonly used face recognition algorithms include knowledge-based method, template matching based method, appearance based method, and feature invariance based method. The knowledge based recognition method requires a high degree of experience knowledge, and the rules which are transformed by experience should not be too strict or too simple. This method requires a large amount of calculation, and recognition time is longer. At the same time, the pose of human face has a great influence on it. Feature invariance based method leads to features being easily destroyed and is difficult to identify in complex environments. The method based on template matching is easy to implement, but it also has disadvantages. The adaptively of this method is poor. The appearance based methods mainly rely on statistical analysis and machine learning theory, and compared with the definition of face model of template matching method, this method usually learn samples, so as to obtain the face template model to be as training classifier for identification of the testing sample. These methods mainly include feature space, artificial neural network, support vector machine (SVM) and AdaBoost based method.

Support vector machine (SVM) has good learning ability, especially generalization ability, it has good generalization performance and good classification accuracy, and has high recognition rate in face recognition [11]. A kind of dimensionality reduction technique based on diagonal locality preserving projection was applied to face recognition [12]. Multi feature face identification based on Hash table and binary tree classifier was put forward by Nair [13]. Huang et al. constructed a kind of face recognition based on pyramid histogram and SVM [14]. A new local low-level features was presented to improve performance of 3D face recognition [15]. Zeng et al. put forward a kind of face recognition method using linear discriminant regression classification based on fisher criterion [16]. An efficient 3D face recognition method using geometric features was proposed by Li [17]. 2DPCA-Euclidean distance classification was used in 3D face recognition by Yashar [18]. Lei et al. put forward an efficient 3D face recognition approach using local geometrical signatures [19]. Three-dimensional statistical facial feature model was used in accurate land-marking of three-dimensional facial data [20]. Jin et al. proposed a novel method for 3D Face Recognition Based on 2D Gabor Wavelet Transform and LBP [21]. Torkhani et al. proposed a 3D–2D face recognition approach via extended Gabor wavelet combining curvature and edge detection [22]. Vinay et al. study on how to solve the face recognition problem utilizing Gabor Wavelet Features with PCA and KPCA [23]. Arindam et al. used the Gabor based Kernel Entropy Component Analysis to handle the Human Face Recognition problem [24].

3. Three Dimension Face Recognition Based on Gabor Transformation and Support Vector Machine

3.1 Gabor Wavelet Feature Extraction Based on 3D Human Face Contour

3D face data acquired by three-dimensional data acquisition equipment is not completely in the same coordinate system due to face location tilt in the acquisition process, so we need to place all kinds of face data in a unified coordinate. We take the Frankfurt coordinate system in forensic anthropology, the center line of the ears is X axis, and the midpoint of the wire is the coordinate origin. Through the origin of coordinates, Y axis is vertical upward to the face. Z axis is vertical to XOY plane, and the direction is toward the tip of the nose.

Because the distance of each point on the contour line is not uniform, it is necessary to unify the step size of the contour line. Resampling points operation should be carried out for the contour line and the sampling point is used to describe the curve. Based on the established 3D coordinate system and grid control points, we find the vertical point set of the highest depth point to determine the contour line in the halve human face. Point with larger data depth value can only be the most protruding forehead point, nasal tip point, mouth and chin raised most protuberant point, and the key points are in the halve face contour line.

After extracting the face halve contour line, we further find out valuable reference point. We firstly work out the curvature of contour point set, then analyze its curvature change again, and then find out the point with local maximum curvature. These valuable reference points are the point with the largest concave and convex change on the contour line, including the high forehead, the nose bridge point, nasal tip and nasal root point, upper and lower lip sharp point, and chin concave point, etc. For crosscutting outline of nasal tip, first of all, according to the curvature change of the profile and the location of the nasal tip point, we identify two nosewing points. Set the distance between the two nosewing points, then according to the characters of facial structure, namely three stop five eye rule, we determine crosscutting outline of nasal tip.

One-dimensional Gabor function is defined as follows.

$$g(x) = \frac{\|k\|^2}{\sigma^2}\exp\left(\frac{\|k\|^2\|x\|^2}{2\sigma^2}\right)\exp(j\cdot k'\cdot x) \tag{1}$$

$$k = k_v \cdot e^{i\phi_u},\ k_v = 2^{-\frac{v+2}{2}\pi},\ \phi_u = u\frac{\pi}{n},\ k' = \|k\|$$

where k represents central frequency of the filter, k_v represents different kernel function of the wavelet, which controls the width of the Gaussian window, oscillation wavelength and direction, j represents complex operator, σ represents bandwidth of wavelet filter, ϕ_u represents direction selectivity of the filter, u and v represent direction and scale of the filter, and n represents the total number of direction. Suppose that the face halve contour line includes k number of points, the point coordinate sequence along the counterclockwise direction is represented as $\{(y_0, z_0), (y_1, z_1), \ldots, (y_{k-1}, z_{k-1})\}$. $y, z \in R^d$, $y(x) = y_x$, $z(x) = z_x$, the contour line can be expressed as coordinate sequence $s(x) = [y(x), z(x)]$, $x = 0, 1, \ldots, k-1$. Each point can be expresses as a complex number

$$s(x) = y(x) + j\cdot z(x) \tag{2}$$

The convolution between contour line and Gabor filter is

$$o_{u,v}(x) = s(x) * g(x) \tag{3}$$

$\{o_{u,v}(x); x = 0, 1, \ldots, k-1\}$ represents Gabor wavelet transformation characteristics of contour line.

3.2 Proposed Three Dimension Face Recognition Scheme

Support vector machine (SVM) is a classifier with very strong learning ability and generalization ability. In solving the problem of small sample, nonlinear and high dimension recognition problem, it has many unique advantages. SVM and neural network are similar, but different. Therefore, some researchers consider that the SVM is becoming a new research hotspot after neural network. By nonlinear transformation, input vector is mapped to a high dimensional space, and the optimal line classification plane is established in the high dimensional space, and by choosing the appropriate inner product function, it realizes the nonlinear transformation. The linear separable sample set is $\{(x_i, y_i), i = 1, 2, \ldots, n\}$, $x_i \in R^d$, $y_i \in \{-1, 1\}$. We should find out weight vector and optimal to make them meet the following constraints.

$$y((w, x_j) + b) \ge 1,\ \Phi(w) = \frac{1}{2}w^T w$$

After introducing Lagrange multiplier,

$$L(w,b,\alpha)=\frac{1}{2}\|w\|^2-\sum_{j=1}^{l}\alpha_j(y_j((w\cdot x_j)+b)-1)$$

The maximum objective function is

$$Q(\alpha)=\sum_{j=1}^{l}\alpha_j-\frac{1}{2}\sum_{i=1}^{l}\sum_{j=1}^{l}\alpha_i\alpha_j y_i y_j x_i^T x_j$$

The dual program of the original problem is

$$\min -\sum_{j=1}^{l}\alpha_j+\frac{1}{2}\sum_{i=1}^{l}\sum_{j=1}^{l}\alpha_i\alpha_j y_i y_j x_i^T x_j$$
$$s.t. \sum_{j=1}^{l}\alpha_j y_j=0$$
$$\alpha_j\ge 0, j=1,2,\ldots,l$$

The solution of the above problem is $\alpha^*=(\alpha_1^*, \alpha_2^*, \ldots, \alpha_l^*)$. Weight vector is $w^*=\sum_{j=1}^{l}\alpha_j^* y_j x_j$ and the optimal $b^*=y_1-\sum_{j=1}^{l}y_j\alpha_j^*(x_j-x_i)$, $i\in\{i \mid \alpha^*>0\}$. Then we can obtain $(w^*\cdot x)+b^*=0$. At this time, the optimal function is

$$f(x)=\operatorname{sgn}\{(w^*\cdot x)+b\}=\operatorname{sgn}\left\{\left(\sum_{i=1}^{l}\alpha_j^* y_j(x_j\cdot x)\right)+b\right\}$$

The original SVM method is adopted to implement two kinds of classification, but it cannot be directly adopted in classification of multiple types. So how to effectively use it for the classification of multiple types is a problem to be investigated. As multiple class classification of face classification and recognition, we need to construct SVM multiple class classifier. We use classification method of two classes to construct a type of n class classifier. Given m number of training sample belonging to k categories, (x_1, y_1), (x_2, y_2),…, (x_m, y_k). $x_i\in R^n$, $i=1, 2, \ldots, m$, $y_i\in\{1,\ldots,k\}$. We use the above training sample to construct one classification function $f_k(x)$. If vector x_i belongs to the k-th class, $sign[f_k(x)]=1$. Otherwise, $sign[f_k(x)]=-1$. Here, one to one algorithm proposed by KreBel is adopted. The classification problem of k categories is transformed into $\frac{k(k-1)}{2}$ number of classification problem of two categories. The i-th class and j-th class construct SVM sub-classifier. In the training sample, we choose the i-th and j-th training sample, the i-th class is labeled to be positive class and the j-th class is labeled to be positive. Then the following equation is established.

$$\min_{w^{ij},b^{ij},\xi^{ij}}\frac{1}{2}(w^{ij})^T w^{ij}+C\sum_l\xi^{ij} \tag{4}$$

$$s.t.(w^{ij})^T\phi(x_l)+b^{ij}\ge 1-\xi_l^{ij},\ \text{if}\ y_l=i \tag{5}$$

$$(w^{ij})^T\phi(x_l)+b^{ij}\le -1+\xi_l^{ij},\ \text{if}\ y_l=j \tag{6}$$

$$\xi_l^{ij}\ge 0 \tag{7}$$

$\frac{k(k-1)}{2}$ number of SVM sub-classifier is tested.

$$sign((w^{ij})^T\phi(x_l)+b^{ij}) \tag{8}$$

According to equation (6), if x belongs to the i-th class, the votes of the i-th class is 1. If x belongs to the j-th class, the votes of the j-th class is 1. The accumulated votes are calculated, and we choose the sample with the highest votes as the training sample.

PCA face recognition algorithm is a kind of traditional, effective method of face recognition, but there are many shortcomings such as recognition rate is not high and is greatly affected by environment and facial expression. In order to more effectively recognize human face, PCA algorithm is optimized by Gabor wavelet and SVM classifier, so as to achieve the purpose of increasing the recognition rate. The proposed 3D face recognition algorithm is described as follows and its flowchart is shown in Figure 1. Based on Gabor wavelets and SVM optimization of PCA face recognition algorithm steps are as follows.

Step 1. The image normalization processing is carried out to make the size of the picture consistent. The original face recognition library is divided into training and identification library of human faces.

Step 2. Gabor wavelet based on contour line is used to extract face feature for training face library and recognition face library. The extracted Gabor wavelet feature vector forms one Gabor face feature matrix.

Step 3. The method of uniform sampling is used in fu-

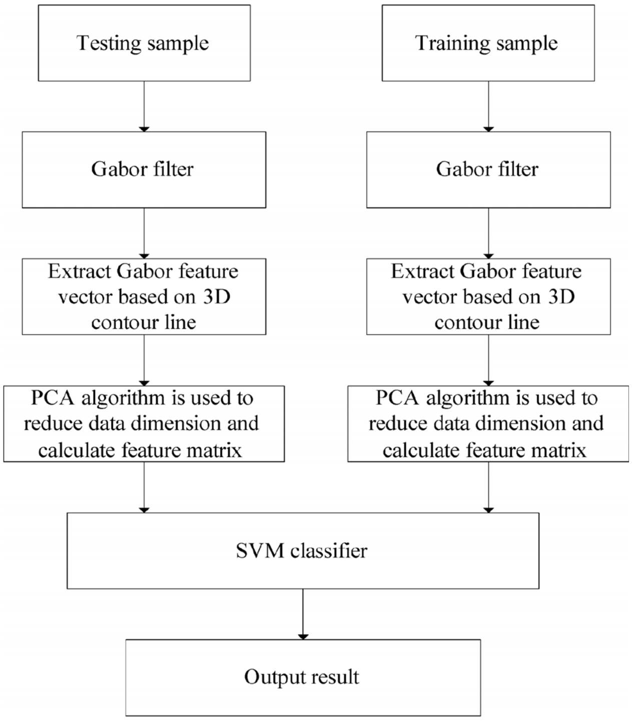

Figure 1. The proposed 3D face recognition.

sion of Gabor face characteristic matrix to reduce the amount of calculation and redundant information.

Step 4. PCA algorithm is used to reduce dimension of Gabor face feature matrix, and then calculate the covariance matrix and the characteristic matrix.

Step 5. The SVM classifier is used to classify it. Firstly, the characteristic matrix is input to the SVM trainer, and a model is set up. The kernel function type, value between each parameter, the value of the discriminant function is compared with each data after training, so as to output classification and recognition rate.

4. Experiments and Analysis

The adopted face libraries include 1) ORL face database, 2) Yale face library, 3) self-built face library, 4) PIE database, and 5) Multi-PIE database. Face library after normalization processing is divided into the training sample and testing sample library. The number of training samples in ORL face database is 200, the number of each type of face is 5, and the number of the testing sample is 200. The number of training sample in Yale face library is 75, the number of each type of face is 5, and the number of the testing sample is 75. Images of seven persons are chosen from the self-built face library, 5 pictures of each person are taken as the training sample and there are a total of 35 pictures. The kernel function of SVM is RBF kernel function, penalty factor is 1, g is 0.01. ORL face database, Yale face database and self-built face library are recognized respectively. Performance of several commonly used algorithms is compared. PIE Database is generated by CMU, which is a database of 41,368 images of 68 people, each person under 13 different poses, 43 different illumination conditions, and with 4 different expressions. In addition, the Multi-PIE face database is also proposed by CMU, which contains more than 750,000 images of 337 people recorded in up to four sessions over the span of five months. Subjects were imaged under 15 view points and 19 illumination conditions while displaying a range of facial expressions.

From Table 1 to Table 5, we can see that recognition rate of proposed scheme based on Gabor wavelet and SVM is superior to the conventional face recognition algorithm. Face recognition based on PCA optimized by contour line Gabor wavelet and SVM provides the highest recognition rate. The recognition rate of proposed

Table 1. Recognition results on ORL face library

Recognition algorithm	Recognition rate	Running time (s)
PCA	0.770	9.084
2DPCA	0.905	8.875
PCA+LDA	0.92	10.375
PCA+SVM	0.92	10.733
Gabor+PCA+SVM	0.98	21.234
GIST+LBP	0.95	18.547
Contour line Gabor+PCA+SVM	0.99	20.15

Table 2. Recognition results on Yale face library

Recognition algorithm	Recognition rate	Running time (s)
PCA	0.733	3.469
2DPCA	0.88	3.469
PCA+LDA	0.88	3.765
PCA+SVM	0.91	3.65
Gabor+PCA+SVM	0.97	10.376
GIST+LBP	0.96	10.574
Contour line Gabor+PCA+SVM	0.98	9.127

Table 3. Recognition result on self-built facial library

Recognition algorithm	Recognition rate	Running time (s)
PCA	0.8	1.546
2DPCA	0.915	0.985
PCA+LDA	0.901	1.876
PCA+SVM	0.94	3.108
Gabor+PCA+SVM	0.95	5.46
GIST+LBP	0.96	5.52
Contour line Gabor+PCA+SVM	0.97	4.79

Table 4. Recognition results on PIE database

Recognition algorithm	Recognition rate	Running time (s)
PCA	0.754	3.113
2DPCA	0.82	3.234
PCA+LDA	0.83	3.657
PCA+SVM	0.85	3.24
Gabor+PCA+SVM	0.96	9.657
GIST+LBP	0.96	9.652
Contour line Gabor+PCA+SVM	0.97	8.524

Table 5. Recognition result on multi-PIE database

Recognition algorithm	Recognition rate	Running time (s)
PCA	0.81	1.257
2DPCA	0.941	0.974
PCA+LDA	0.955	1.824
PCA+SVM	0.933	3.236
Gabor+PCA+SVM	0.949	5.357
GIST+LBP	0.958	5.581
Contour line Gabor+PCA+SVM	0.96	5.247

scheme can reach 99% on ORL face database, human face recognition rate for Yale human face library is as high as 98%, and recognition rate of self-built facial library is 97%. It fully shows that face recognition PCA algorithm optimized by contour line Gabor wavelet and SVM algorithm is effective. But it also has drawbacks. In time of face recognition, PCA algorithm optimized by traditional Gabor wavelet and SVM costs longer running time than the general algorithm. But PCA algorithm optimized by contour line Gabor wavelet and SVM costs shorter running time than PCA algorithm optimized by traditional Gabor wavelet and SVM.

In the real life, the collected face image background is complex, and the light intensity is also different. In the process of face recognition, environment is an important influence factor. In order to verify face recognition based on Gabor wavelet and SVM optimization algorithm,we collecte 70 images, each type of 10. The PCA algorithm optimized by contour Gabor wavelet and SVM is used in the face recognition system. Recognition results on ORL and Yale face library are shown in Figure 2 and 3 respectively. Recognition results on self-built library are shown in Figure 4, 5, 6 and 7.

5. Conclusion

With the recent progress in 3D sensors, more and more organizations have committed to using the three-dimensional data-aided face recognition and achieved good results. 3D face recognition has potential to overcome the

Figure 2. Recognition result on ORL face library.

Figure 3. Recognition result on Yale face library.

Figure 4. Recognition result of face 1 in self-built library.

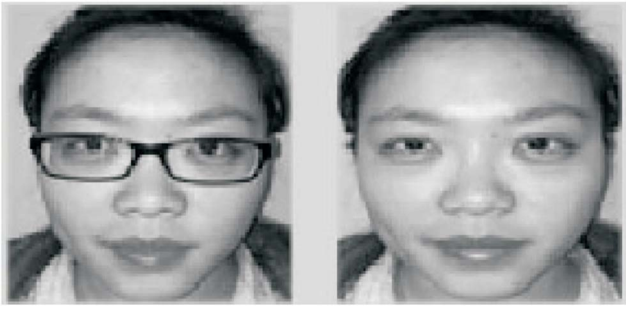

Figure 5. Recognition result of face 2 in self-built library.

Figure 6. Recognition result of face 3 in self-built library.

Figure 7. Recognition result of Multi-PIE database.

difficulties of the image-based face recognition caused by the variations of illumination, facial posture and expression etc. Effective feature extraction of 3D facial surface is one of the core technologies for 3D face recognition. We put forward a kind of Gabor wavelet feature extraction method based on three-dimensional human face contour line. Then, contour line Gabor wavelet and SVM are combined with PCA to improve recognition rate of human face. The experiment results show that face recognition algorithm based on PCA optimized by contour line Gabor wavelet and SVM classifier is reliable and can provide high recognition rate.

References

[1] Ahonen, T., A. Hadid, and M. Pietikainen (2006) Face description with local binary patterns: Application to face recognition, *IEEE Trans. Pattern Anal. Mach. Intell.* 28(12), 2037–2041. doi: 10.1109/TPAMI.2006.244

[2] Choi, J. Y., W. D. Neve, K. N. Plataniotis, and Y. M. Ro (2011) Collaborative face recognition for improved face annotation in personal photo collections shared on online social networks, *IEEE Trans. Multimedia* 13(1), 14–28. doi: 10.1109/TMM.2010.2087320

[3] Sun, Y., Y. Chen, X. Wang, and X. Tang (2014) Deep learning face representation by joint identification-verification, *Proc. Adv. Neural Inf. Process. Syst.* 1988–1996.

[4] Arashloo, S. R., and J. Kittler (2014) Dynamic texture recognition using multiscale binarised statistical image features, *IEEE Trans. Multimedia* 16(8), 2099–2109. doi: 10.1109/TMM.2014.2362855

[5] Ding, C., C. Xu, and D. Tao (2015) Multi-task pose-invariant face recognition, *IEEE Trans. Image Process* 24(3), 980–993. doi: 10.1109/TIP.2015.2390959

[6] Hsieh, C. K., S. H. Lai, and Y. C. Chen (2009) Expression-invariant face recognition with constrained optical flow warping, *IEEE Trans. Multimedia* 11(4), 600–610. doi: 10.1109/TMM.2009.2017606

[7] Paysan, P., R. Knothe, B. Amberg, S. Romdhani, and T. Vetter (2009) A 3D face model for pose and illumination invariant face recognition, *Proc. IEEE Int. Conf. Adv. Video Signal Based Surveillance*, 296–301. doi: 10.1109/AVSS.2009.58

[8] Li, K. S., K. Li, and W. S. Zhang (2014) PCA face recognition algorithm based on improved BP neural network, *Computer Applications and Software* 31(1), 158–161.

[9] Wu, D. (2015) *Multiple Information Fusion Face Recognition Research Based on Key Feature Points*, Harbin: Harbin University of Science and Technology.

[10] Imtiaz, H., and S. A. Fattah (2012) A curvelet domain face recognition scheme based on local dominant feature extraction, *ISRN Signal Process* 12, 1–13. doi: 10.5402/2012/386505

[11] Luan, F., L. Lin, and Y. Wang (2010) 4-step face authentication algorithm based on SVM, *2010 Third Int. Symp. Intell. Inf. Technol. Secure. Informatics* 1(2), 534–538. doi: 10.1109/IITSI.2010.99

[12] Veerabhadrappa, L. Rangarajan (2010) Diagonal lo-

cality preserving projection as dimensionality reduction technique with application to face recognition, Image (Rochester N.Y.), 135–140.

[13] Nair, A. R., B. C. Pilla, and E. George (2014) Multi feature face identification using hash table & binary tree classifier, *International Journal of Advance Research in Computer Science and Management Studies* 261–272.

[14] Huang, H., H. Liu, and G. Liu (2012) Face recognition using pyramid histogram of oriented gradients and SVM, *Int. J. Adv. Inf. Sci. Serv. Sci.* 4(18), 1–8. doi: 10.4156/aiss.vol4.issue18.1

[15] Lei, Y. J., B. Mohammed, and A. E. S. Amar (2013) An efficient 3D face recognition approach based on the fusion of novel local low-level features, *Pattern Recognition* 46(1), 24–37. doi: 10.1016/j.patcog.2012.06.023

[16] Zeng, X. H., and X. W. Li (2014) Improving face recognition with linear discriminant regression classification based on fisher criterion, *Computer Applications and Software* 31(9), 184–186.

[17] Li, Y. A., Y. J. Shen, G. D. Zhang, T. H. Yuan, X. J. Xiao, and H. L. Xu (2010) An efficient 3D face recognition method using geometric features, IEEE 2nd International Workshop on Intelligent Systems and Applications (ISA), 1–4. doi: 10.1109/IWISA.2010.5473292

[18] Yashar, T., H. Ghassemian, and N. M. Mohammad (2012) 3D face recognition method using 2DPCA-Euclidean distance classification, *ACEEE International Journal on Control System and Instrumentation* 3(1), 1–5.

[19] Lei, Y., M. Bennamoun, M. Hayat, and Y. Guo (2014) An efficient 3D face recognition approach using local geometrical signatures, *Pattern Recognition* 46(2), 509–524. doi: 10.1016/j.patcog.2013.07.018

[20] Zhao, X., E. Dellandrea, L. Chen, and I. Kakadiaris (2011) Accurate land-marking of three-dimensional facial data in the presence of facial expressions and occlusions using a three-dimensional statistical facial feature model, *IEEE Transactions on Systems Man and Cybernetics Part B: Cybernetics* 41(5), 1417–1428. doi: 10.1109/TSMCB.2011.2148711

[21] Jin, Y., Y. Z. Wang, Q. Q. Ruan, and X. Q. Wang (2011) A new scheme for 3D face recognition based on 2D gabor wavelet transform plus LBP, International Conference on Computer Science & Education, 860–865. doi: 10.1109/ICCSE.2011.6028773

[22] Torkhani, G., A. Ladgham, A. Sakly, and M. N. Mansouri (2017) A 3D–2D face recognition method based on extended gabor wavelet combining curvature and edge detection, *Signal Image & Video Processing* 11(5), 1–8. doi: 10.1007/s11760-016-1046-7

[23] Vinay, A., V. S. Shekhar, K. N. Balasubramanya Murthy, and S. Natarajan (2015) Face recognition using gabor wavelet features with PCA and KPCA - a comparative study," *Procedia Computer Science* 57, 650– 659. doi: 10.1016/j.procs.2015.07.434

[24] Kar, A., D. Bhattacharjee, D. K. Basu, M. Nasipuri, and M. Kundu (2013) Human face recognition using gabor based kernel entropy component analysis, *International Journal of Computer Vision and Image Processing* 2(3), 167–174.

Manuscript Received: Dec. 30, 2016
Accepted: Oct. 28, 2018