number of pixels which is the primary requirement of applying principal components analysis (PCA) for feature extraction. The cropped facial region of aligned and resampled two transparent facial scans that are overlaid one over the other is shown in Figure 3(c).

3. Experiments

3.1 Database

The accuracy of the proposed registration method has been tested on the Bosphorus 3D face database [15]. The Bosphorus database consists of 4652 3D facial scans of 105 persons with as many as 31 to 54 scans are available per subject. The database includes scans of 60 men and 45 women, in various poses, expressions and occlusions. The majority of the subjects are aged between 25 and 35. The 3D facial data are acquired using Inspeck Mega Capturer II 3D – a commercial Structured-Light based 3D digitizer device. The 3D shape data consists of approximately 35000 point coordinates. After the various operations of alignment, resampling and cropping in Section 2, the original point cloud representation of 3D facial scan with varying number of points, are reduced to a fixed number of densely aligned 100 X 100 =10000 correspondent points which makes the computation much faster.

For our experiments on registration, a subset of the original database has been used. The subjects have been divided into two groups- the gallery set and the probe set. The gallery set comprises of the neutral scans of 105 subjects that are known to the system. The probe set contains 367 facial scans with slight variations in upper and lower facial regions of each subject contained in the gallery set.

3.2 Evaluation based on Face Recognition

In order to assess the quality of the proposed registration method, face recognition system has been employed using Bosphorus 3D face database. After the registration step, the statistical analysis technique has been employed for distinct feature extraction and Principal Component Analysis (PCA), the most popular statistical method has been utilized in this paper. The extracted features from the probe face are then matched to that of the features from each of the gallery faces using the nearest neighbor classification (N-N). The accuracy of the proposed method has been calculated in terms of rank-1 identification rate.

3.3 Experimental Results and Discussion

To comprehensively evaluate the proposed approach and highlight its various aspects, three experiments (E1, E2 and E3) have been designed and a comparative performance analysis has been provided. Experiment E1 implements the idea of the individual reference face shape using ICP based registration technique whereas experiments E2 and E3 implement the average face model (AFM) based approaches as adopted in [2 and 7].

Experiment E1 follows the same procedure as given in section 2.2 and 2.3 for calculating the MLPs and the individual reference face shape. The ICP based registration method is used for iteratively registering each face scan to its corresponding reference face shape. The PCA is then applied to extract the distinct features from the resampled and cropped aligned face scans.Rank-1 identification rate is calculated using N-N classification that validates the accuracy of the proposed registration method.

Experiments E2 and E3 is based on the average face model (AFM) as proposed by Gokberk et al. [7] and Salah et al.[2].In E2 the MLPs are first calculated using GPA and the landmark points of all the gallery faces are transformed to it. The final average landmark locations are obtained by averaging the transformed landmarks. Each training face is then transformed to these landmarks with the help of Procrustes analysis followed by resampling at regular x-y grid. Consequently, the average face model can be computed by averaging the z-depth values of the training faces at regular (x,y) positions. Once the AFM is computed, the gallery and probe faces are registered to AFM in two phases-coarse and fine which can be seen in detail in [7].The accuracy of registration is then evaluated using PCA and the identification process.

In E3, the AFM is generated by first calculating the MLPs using the GPA. TPS deformation is computed for the training faces, which warps the landmarks of each face to the MLPs perfectly and interpolates the rest of the points. The AFM is then computed by averaging the z-depth values of the training faces at regular (x,y) positions, and the gallery and probe faces are registered to AFM similar to E2.

Table 1 illustrates the rank-1 identification rates achieved by the three experiments (E1 to E3) on the subset of Bosphorus 3D face database, thereby comparing the registration based on the individual reference face shape and AFM based methods.

Table 1 Comparison of Rank-1 Identification Performances

Experiments	*Methods*	*Rank-1 Accuracy (%)*
E1	Proposed Reg.(using ICP)	**98.36**
E2	AFM based Reg.(using Procrustes + ICP)	86.37
E3	AFM based Reg.(using TPS+ICP)	87.46

E1 employing the MLPs and individual reference face shape for registration using ICP performs best, yielding a higher rank-1 identification accuracy of 98.36%, is denoted by the boldface figure. On the other hand, E2 and E3 implementing the AFM based registration shows lesser identification rates. The proposed registration method is efficient since the reference face is more similar to the probe face which ensures a better registration whereas in AFM based registration, alignment is done using less similar mean face. Thus, individual reference face shape approach ensures that the dense correspondence will be established between points that have better structural correspondence. Besides, the probe face will be deformed less, and discriminatory information will not be lost in case of much similar reference face. Also, a single registration is enough for comparing a probe face to the entire pre-registered gallery faces which greatly reduces the computation time.

4. Conclusion

The proposed registration method has been evaluated under manual landmarking. For real time 3D face recognition, the computational requirements of the algorithms must be taken into consideration. The much slower ICP method is viable only if the registration is speeded up through the use of much similar individual reference face shape. The accuracy of the proposed registration method is demonstrated through the face recognition system. The experimental results show that the proposed method using ICP is superior to the AFM based registration methods in identification accuracy. However, the AFM based registration method shows similar processing time as the proposed method for the same experimental protocol. Thus by examining the results obtained on the subset of Bosphorus 3D face database, it could be concluded that the rigid registration using individual reference face shape outperforms the other methods since the deformation of each face will be minimized in case of rigid registration and much similar individual reference face.

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Author Profile

M. Judith Leo received her BE degree from Dr. SACOE, MS University, India in 2004.She had her ME degree in National Engineering College, Anna University, India in 2006. She is currently pursuing her PhD degree at MS University in the field of Biometrics. She has published six papers at Inter-National and National level Conferences. Her research interest includes computer vision and pattern recognition.

Dr. D. Manimegalai received her BE & ME degree from GCT, Coimbatore, India in1984 & 1991 and PhD from MS University, India in 2006. Her research articles have appeared in various National and International Conferences and in journals such as IJCSI, IJCA, AMSE and Pattern Recognition letter. Her current area of research interests includes Medical Image Processing, Data Mining and Image Retrieval. She is the principal investigator for a project funded by ICMR. She is a life member of Computer Society of India, System Society of India, Indian Society for Technical Education and a fellow member in Institution of Engineers.