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Advancing the state of the art in 3D human facial recognition

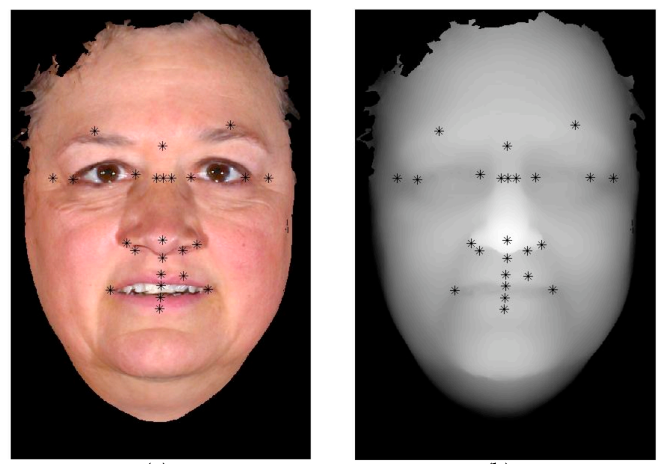
Shalini Gupta, Mia K Markey, and Alan C Bovik

We present novel approaches for three dimensional (3D) human facial recognition based on (a) discriminatory facial anthropometric measurements, and (b) rigid facial range image matching using the complex-wavelet structural similarity metric index, which significantly improve the performance of the existing state of the art.

Automated human face recognition is an important computer vision problem with numerous applications including security, surveillance, database retrieval, and human computer interaction. Over two decades of research in the area has resulted in a number of successful techniques for recognition of color/intensity two dimensional (2D) frontal facial images[1]. However, the performance of these algorithms degrades severely when variations in facial pose, ambient illumination, and facial expression are present[2]. Hence, achieving robust and accurate automatic face recognition remains a nontrivial open problem.

Recently, researchers have proposed using 3D facial models for recognition to resolve some of these issues[3]. Three dimensional facial models provide explicit information about the shape of the face, can be easily corrected for pose by rigid rotation in 3D space, and are scale and illumination invariant. Although 2D facial recognition techniques based on local facial features have been very successful[2], such techniques for 3D face recognition have been poorly studied due to a lack of understanding of the discriminatory structural characteristics of human faces. Other successful 3D facial recognition techniques based on rigid facial surface matching suffer from a very high computational cost which renders them inappropriate for realtime operation. The existing 3D facial recognition techniques are also unable to handle changes in facial expressions. We attempted to resolve some these open problems in the area of 3D facial recognition.

Discriminatory features for face recognition are numerical quantities that vary considerably between individuals, yet are constant for different instances of the same individual. However, none of the previous 3D face recognition algorithms based on local facial features, have been based on a sound understanding of discriminatory facial structural characteristics. In order to identify such characteristics we extensively investigated the existing literature on anthropometric facial proportions[4]. We identified facial anthropometric measurements reported to be highly diverse across different age, gender and ethnic groups of humans. We employed there to design effective novel 3D facial recognition algorithms[5].



(a) (b)

__Figure 1.__ Fig 1(a) shows the facial fiducial points associated with discriminatory facial anthropometric measurements on a color image; Fig. 1(b) shows them on a facial 3D depth map image (reproduced from Gupta et al.[5]).

Specifically, we employed 3D Euclidean and along-the-surface geodesic distances between 25 manually located facial fiducial points (Figure 1) associated with the highly variable anthropometric measurements as features for face recognition[5]. We investigated geodesic distances because a recent study[6] suggests that facial expression changes may be modeled as isometric deformations of the face, under which geodesic distances between pairs of the points on the facial surface remain constant. We em-

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ployed the stepwise linear discriminant (LDA) procedure to select a subset of the most discriminatory features and followed it with an LDA classifier. With a gallery set containing one image each of 105 subjects and a probe set containing 663 images of the same subjects, our algorithm produced an equal error rate of 1.4% and a rank one recognition rate of 98.6%. It significantly outperformed the existing baseline algorithms based on principal component analysis (PCA) and LDA applied to face range images (Figure 2). Our proposed technique was also robust to changes in facial expressions.

For rigid facial surface matching, the existing approaches rigidly align a pair of surfaces closely, using an optimization procedure, and compare them by means of a distance metric. These techniques suffer from a very high computation cost of (a) computing the point-to-closest-point mean squared error (MSE_{CP})/Hausdorff distance (HD) metrics that are popularly employed, and (b) of the iterative alignment procedure. We attempted to speed up such techniques by employing the recently developed complex-wavelet structural similarity metric (CW-SSIM)[7] to match coarsely aligned facial range images[8]. This index is computationally efficient than MSE_{CP} and HD, and is also robust to small alignment errors. Thus, it eliminates the need to finely align 3D faces before matching.

With a database of 360 3D facial images of 12 subject (30 images per subject), our proposed technique achieved a rank one recognition rate of 98.6%. It significantly outperformed facial surface matching based on MSE_{CP} and HD, both in terms of accuracy and computational cost (Figure 3). This study also extended the scope of application of CW-SSIM to 3D range images.

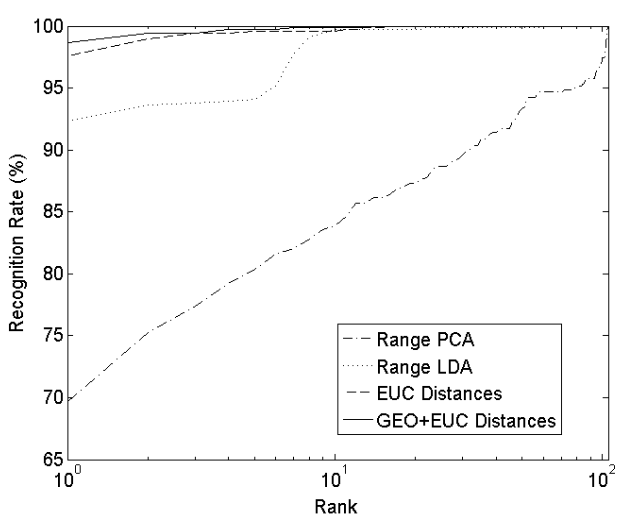

Figure 2. Cumulative match characteristic curves for 3D face recognition algorithms based on distances between anthropometric facial fiducial points, and PCA and LDA applied to range images.

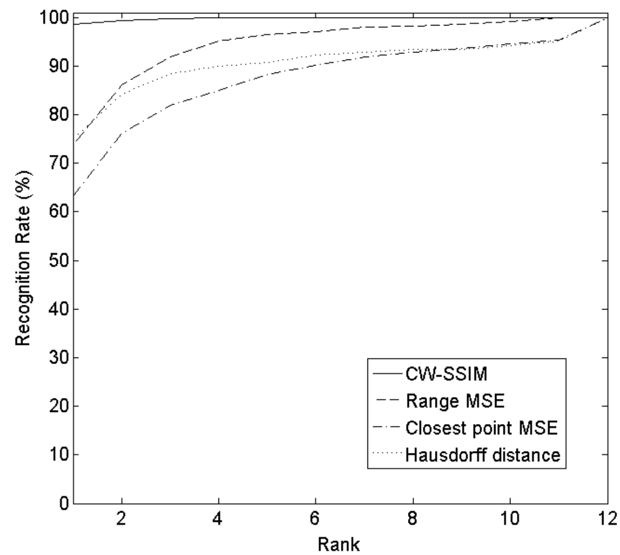

Figure 3. Cumulative match characteristic curves for rigid facial surface matching algorithms based on different distance metrics.

To summarize, we systematically identified discriminatory facial structural information from other areas of science and employed it to design effective 3D facial recognition algorithms. In future we will also investigate techniques to automatically locate the associated facial fiducial points. We have also developed novel techniques for rigid facial surface matching using the CW-SSIM similarity index, which are more accurate and computationally efficient than the existing techniques for the task.

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Author Information

Shalini Gupta and Alan C Bovik
The Laboratory for Image and Video Engineering
(http://live.ece.utexas.edu/)
The University of Texas at Austin
Austin, TX 78712

Shalini Gupta is a doctoral student in the department of Electrical and Computer Engineering at the University of Texas at Austin since August 2004. She is currently developing novel techniques for 3D human facial recognition. She received a master's degree from the same institution during the course of which

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she developed novel algorithms for computer aided diagnosis of breast cancer. She received her bachelor's degree in Electronics and Electrical Communication Engineering from Punjab Engineering College, India.

Alan C Bovik is Professor and holds the Curry/Cullen Trust Endowed Chair in the Department of Electrical and Computer Engineering at The University of Texas at Austin, where he is the Director of the Laboratory for Image and Video Engineering (LIVE). He has published over 450 papers and holds two U.S. patents. He is also the author of The Handbook of Image and Video Processing, Second Edition (Elsevier Academic Press, 2005) and Modern Image Quality Assessment (Morgan & Claypool, 2006). Dr. Bovik received the Technical Achievement Award of the IEEE Signal Processing Society in 2005.

Mia K Markey
The Biomedical Informatics Laboratory
(http://bmil.bme.utexas.edu/)
The University of Texas Department of Biomedical Engineering
Austin, TX 78712

Mia K. Markey earned her B.S. in Computational Biology from Carnegie Mellon and her Ph.D. in Biomedical Engineering from Duke. Dr. Markey is an Assistant Professor in The University of Texas Department of Biomedical Engineering. Her primary research interests are biomedical informatics and biomedical signal processing.

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