Review Article
pISSN 2383-5389 / eISSN 2383-8116
Journal of International Society for Simulation Surgery 2015;2(2):47-51
http://dx.doi.org/10.18204/JISSiS.2015.2.2.047

Personalized Face Modeling for Photorealistic Synthesis

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Faces play a key role in revealing the personalized attributes such as the identity, emotion, health condition, etc. Due to the importance of faces, computer-assisted face modeling and reconstruction have been actively studied both in computer vision and graphics community. Especially, face reconstruction and realistic face synthesis are well-grounded research problems and various approaches have been proposed during the last decade. In this paper, we discuss a wide range of existing work in face modeling by introducing their target applications, categorizing them upon their methodology and addressing their strength and weakness on performance. Finally, we introduce remaining research issues and suggest the future research direction in face modeling. We believe that this paper provides a high-level overview on face modeling techniques and helps understand the major research issues and the trends of methodology.

Key Words Faces · Appearance modeling · Virtual character.

Received: October 30, 2015 / **Revised:** November 6, 2015 / **Accepted:** November 12, 2015
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Introduction

Faces are one of the most important objects in our daily life. People heavily depend on a face to recognize the identity, gender, age, emotion of person and also perceive the attractiveness and other subjective properties of individual. Such a unique role of faces is associated with a wide range of applications such as forensics, game, movie special effects, virtual and augmented reality and many others. Accordingly, face modeling has received a great attention from research communities for decades and a huge amount of literature suggest the solution to this problem.

Existing work aims to either extract the intrinsic attributes of the face (e.g. identity, age, emotion, shape, skin reflectance) or to synthesize the realistic face. The first group develops the powerful parameterized face model and applies this model into the input to derive the personalized model parameter. The input can vary upon the application scenario and it is normally as few as a single face image with some extra information (e.g. a depth image, a collection of the same person's face, etc.) if available. The major challenge of this problem is to accomplish the robust estimation of model parameters. It is because the limited number of inputs leads the inference ill-posed unless incorporating the strong constrains. To implant the strong regularization power into the model, it is important to build a concise appearance model with a reduced number of parameters. In this way, the inference problem becomes feasible.

The other group focuses on constructing a highly realistic face model for the synthesis purpose. To achieve the realism in face model, they often increase a number of parameters for generating the complex illumination with details on skin (e.g. subsurface scattering and freckles). Especially, the subsurface scattering effects are the most challenging aspect of human skin. As a result, it is often required to capture up to few thousands of input images for constructing the personalized face model. This process requires not only many input images but also a specialized equipment under the studio-like environment because the scattering component is rarely factorized from regular images.

Therefore, the framework of realistic face modeling is often developed with its capturing system. Recent approaches in face modeling are further developed to achieve the both robustness and realism. For example, Shim (33) suggested the face specular map to accomplish the robust parameter estimation and also shows the improved performance in realistic facial synthesis. More recently, unstructured face images are utilized in 3D face reconstruction (16, 21, 32, 42). Unlike previous approaches, input faces can be drawn from completely unknown illumination, pose and expression conditions. Once the pose estimation and face registration are established, these images provide additional observations of faces, more informative than a single or several images under fixed conditions. This helps regularize the face reconstruction problem and estimate the accurate face model.

In the following section, we introduce important applications of face model, categorize them upon their methodology and address their strength and weakness on performance. Finally, we address remaining research issues and suggest the future research direction in face modeling.

Applications of Digital Faces

Face Recognition

Face recognition has a long history in computer vision research and is still one of the major research topics (18). Traditional applications include the security, surveillance system, forensics, missing children database, health monitoring system and many others.

In recent years, as the smart functionality is rapidly adopted to various electronic devices, the identification technique becomes a key technology to enable the smart feature for providing a user-specific services or recommendation (35). Since face recognition is a nonintrusive and passive solution for the identification, it is suitable to many industrial applications.

Face Analysis for Medical Applications

A number of medical applications actively adopt 3D face models to analyze the individual or pathological characteristics. The study of teratology utilizes the 3D face modeling approach to understanding the dysmorphology (15). Also, in the area of biomedical engineering and medical system, several techniques were introduced for predicting the possible outcome of plastic face surgery (22, 24) or even suggesting the aesthetically harmonic matches of facial features for the plastic surgery (6). Kovacs et al. (23) used 3D face model to design the surgical reconstruction of severely burned faces. Lately, the virtual face model was used to simulate the surgical operation for training purpose (45).

Realistic Synthesis

The film and game industries have been working vigorously for generating realistic virtual object although it is challenging due to the phenomenon known as the uncanny valley (31). Among

Table 1. Summary of popular face database

2D Face Database	No. of Subjects	No. of Poses	No. of Illuminations	No. of Expressions	Others
PIE (2002) [34]	68	13	43	4	
Multi-PIE (2010) [13]	337	15	19	1	
Yale (1992) [3]	15	1	3	6	2 occlusions
Yale B (2001) [11]	10	9	64	1	
FERET (2000) [30]	1199	9-20	2	2	
AR (1998) [26]	126	1	4	4	2 sessions
CAS-PEAL (2008) [10]	1040	18	15	6	6 occlusions
UMIST (1998) [12]	20	Multiple	1	Multiple	
Univ. of Oulu (2010) [25]	125	1	16	1	
BioID (2001) [19]	23	1	Multiple	Multiple	
XM2VTSDB (1999) [28]	295	Multiple	1	Multiple	4 sessions
CVL (2003) [29]	114	5	1	2	
KFDV (2004) [17]	1000	21	21	10	
3D Face Database	**No. of Subjects**	**No. of Poses**	**No. of Illuminations**	**No. of Expressions**	**Others**
BU-3DFE [44]	100	1	1	25	
3DMAD [8]	17	1	1	1	3 sessions
Texas 3DFRD [14]	105	1	1	Multiple	
Face Video Database	**No. of Subjects**	**No. of Poses**	**No. of Illuminations**	**No. of Expressions**	**Others**
BU-4DFE [43]	101	1	1	6	
Cohn-Kanade [20]	97	1	1	23	
DISFA [27]	27	1	1	Multiple	

the natural beings, the human brain is particularly sensitive to facial appearance. This is because the complicated light transport caused by skins, which are composed of bumps, pores, blemishes, flecks, winkles and multilayered structure of skin anatomy. In order to encapsulate this complexity, Alexander et al. (2) suggested a special capture framework that records high resolution images of human skins under variable lighting and obtains the multi-layered textures to represent the skin appearance. In fact, they contributed to develop the NVIDIA FaceWorks (1), which is the state-of-the-art real-time face renderer.

Problem Formulation for Face Modeling

Data-driven Face Modeling

Data-driven approaches generally formulate the face modeling problem by learning the underlying statistics of the face. All of existing work use a well-structured database to obtain the statistical model for facial appearance and evaluate the performance of their model on it. Face database can be roughly divided into three groups: 1) static face images under variable conditions, 2) 3D face models with or without color images, and 3) face videos to capture the temporal variation. In this paper, we provide a brief summary of various face database in Table 1.

Previous work considers face images as high dimensional vectors and applies various data analysis techniques. Turk and Pentland (36) introduced the eigenfaces, which derives the most representative linear subspaces using the principle component analysis (PCA). Blanz and Vetter (5) developed the Morphable face by applying PCA on both 3D scans and 2D images of faces. (5) is the first, pioneer work of modeling 3D facial shape from 2D image while it is not effective to extract the accurate texture component from input image. FisherFaces (4) used the Fisher linear discriminant (FLD) to subdivide face database into similar groups and learn the corresponding subspace. In order to simultaneously learn multiple variations of faces (e.g. expressions, illumination, pose, age, etc.), Tensorfaces (37) employed a higher order tensor and extract the model by extended singular value decomposition (SVD). Although tensor-based approaches are advantageous to cope multiple variations in facial appearance, their results produce rather blurry faces so that they are less effective to retain the skin details of individual. Later, Spherical Harmonics Basis Morphable Model (46) and its extensions (38) employed the Spherical Harmonics for effectively handling the illumination variations. (46) and (38) developed extremely powerful face model so that they are robust against the harsh lighting and shadows. At the same time, however, their robustness sacrifices the realism in face synthesis.

Measurement based Face Modeling

As mentioned earlier, the skin produces complicated illumination effects due to its surface properties as well as face anatomy. To cope the complex behavior of faces, many researchers developed their own capture system. They are carefully designed to effectively separate the illumination components such as the mirror specular reflection, off-specular reflection, shadows, occlusions, skin texture and subsurface scattering from measurements.

The first pioneer work in capturing the facial reflectance was proposed by Debevec et al. (7). They introduced the Light Stage, which captures the face under 2048 different lighting directions and scans the 3D facial geometry at two different viewpoints. Then, the same face under novel lighting and viewing conditions could be successfully generated by a linear combination of two thousands of images. Although they did not explicitly model the subsurface scattering, synthesized faces appear realistic if the target lighting condition is well approximated by a linear combination of pre-recorded 2048 lighting directions. In early version of Light Stage, they focused on static face. The latest version of the Light Stage covers the emotion and expression variations by employing high speed cameras and lighting controllers (39), (9). Their system has been utilized in various movie special effects like a Spiderman 2/3, King Kong, Superman Returns, Hancock and Avatar. The greatest advantage of Light Stage framework is that they achieve the realtime rendering. It is because all the computational complexities are absorbed in the measurement and face rendering is simply the linear combination of measurement. On the other hand, the drawback is that the individual must be presence at and recorded by the Light Stage. In fact, this significantly limits their applications.

Weyrich et al. (40) proposed the skin reflectance model, which is developed from 149 individuals of varying age, gender and race. Their skin reflectance model explicitly decouples the subsurface scattering from texture and specular component and other visual elements as well. Consequently, (40) allows the user to interactively edit the overall appearance of a face, by modifying the skin type, freckles or age.

Unstructured Face Modeling

Unstructured approaches is a new trend in face modeling and refer to a class of face modeling techniques that deal with unstructured (i.e. unlabeled), a collection of face images of single person (16, 21, 32, 42). Handling the unstructured face images is challenging because they present various pose, illumination or expression conditions. Kemelmacher-Shlizerman and Seitz (21) solved this problem with the following three-step approach. First, they estimate the pose of each input by matching facial landmarks. Once the pose is determined, the unstructured images are registered geometrically such that pixels from the same facial region can be clustered. Secondly, given multiple pixels corresponding to the same facial region, it is possible to apply the generalized photometric stereo (PS) techniques (3, 41). Consequently, they recover the lighting and normals of input face based on the analysis by synthesis scheme. After some postprocessing such as iterative refinement, they can finally obtain the 3D shape of input face. More recently, Joseph et al. (32) use a generalized 3D shape model for further utilizing the profile faces. While the previous work (21) is effective to roughly frontal faces, (32) employ the 3D face model to roughly register even the profile faces. As a result, they improve the accuracy of estimating the depth of face, particularly the height of nose or forehead.

Discussion

Despite of a huge progress of the current face modeling, face reconstruction from the single image or unstructured images are still an open and interesting research issue. Recent research trends gradually pay attention to unstructured face modeling. This is because the unstructured image collections fit well with the scenario of consumer photo collection and it is also implementable with the common face search engines.

Conclusion

A face is a challenging object for modeling and synthesis because human brain is particularly sensitive to its appearance (i.e. uncanny valley). In this paper, we summarize various applications for face modeling research and introduce important studies as well as practical systems in this research domain. Based on vigorous studies in past decades, face modeling have reached a certain degree of maturity for the real-time, realistic face rendering if the facial measurement is recorded by the appropriate, specialized equipment. However, synthesizing facial motions are still unsolved even with the dense MOCAP (Motion Capture) data. Also, face modeling approaches using the unstructured dataset become a new research trend and their performance is expected to improve rapidly due to the rapid increase of online data and search engine.

Acknowledgements

This research was supported by the MSIP(Ministry of Science, ICT and Future Planning), Korea, under the IT Consilience Creative Program (IITP-2015-R0346-15-1008) supervised by the NIPA (National IT Industry Promotion Agency) and also the Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Science, ICT and Future Planning (NRF-2013R1A1A1062644).

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