Face Recognition Analysis Using 3D Model

Muhammad Sajid Khan[1,2](✉), Muhammad Jehanzeb[2], Muhammad Imran Babar[2], Shah Faisal[3], Zabeeh Ullah[4], and Siti Zulaikha Binti Mohamad Amin[5]

[1] College of Computer Science, Sichuan University, Chengdu 610065, People's Republic of China
sajidpk48@yahoo.com

[2] Department of Computer Science, Army Public College of Management & Sciences (APCOMS), Rawalpindi, Punjab, Pakistan

[3] Department of Computer Science, University of Haripur, Hattar Road Near Swat Chowk, Haripur 22620, Khyber Pakhtunkhwa, Pakistan

[4] Federation University Australia, Mt Helen, Ballarat, VIC 3350, Australia

[5] Western China Earthquake and Hazards Mitigation Research Centre, College of Architecture and Environment, Sichuan University, Chengdu 610065, People's Republic of China

Abstract. Facial Recognition is a commonly used technology in security-related applications. It has been thoroughly studied and scrutinized for its number of practical real-world applications. On the road ahead of understanding this technology, there remain several obstacles. In this paper, methods of 3D face recognition are examined by measuring quantifiable applications and results. In facial recognition, three Dimensional Morphable Model (3DMM) techniques have attracted more and more attention as effectiveness in use increases over time. 3DMM provides automation and more accurate image rendering when compared to other traditional techniques. The accuracy in image rendering comes at a cost; as 3DMM requires more focus on texture estimation, shape-controlling limits, and extrinsic variations, accurately matching fitting models, feature tracking and precision identification. We have underlined different issues in comparison based on these methods.

Keywords: Reconstruction · Recognition · Morphable model
3D model

1 Introduction

Human face modelling in three dimensions is a challenging topic for researchers in the field of graphic design and pattern recognition. In the last two decades, several techniques have been reported successful for recognitions such as identifications, using geometrical models for verification. Although some algorithms have performed well both in accuracy and speed, improvements are still needed. The development of 3DMM has its challenges but reconstructing according to this software will without a doubt show more accurate results. This issue is the fundamental problem in computer vision. It uses growth in software sectors like plastic surgery, face tracking, face

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morphing, animations and 3D games, fields that are not developed to the standard of 3DMM. Before this technology came along, facial reconstruction was limited to producing real faces, and it also faced the need to focus on algorithms to make them simpler, faster and more accurate [26]. In the 20th century, facial features, bone reconstructions and technical development began. The first attempt was made in the US and was considered remarkably successful [41]. In the same year, neck and nose were reformed where facial bones were finished professionally. Faces were reconstructed in two steps: the basic reconstruction and final modelling. The beginning of the 21st century marks the introduction of digital face; various software systems were developed to reconstruct digital faces. The first computerized technique was developed at University College London in Great Britain for forensic purposes; the system was developed for 3D surface data acquisition of the human face [34]. The 3D faces reconstruction examples and application given in Table 1. The algorithms used for 3D face reconstruction are divided into two main categories briefly described in Fig. 1.

Table 1. Example of 3D face reconstruction applications

Domain name	Application	Input data	Purpose
Recognition	Associate-predict model [32]	Identity data set	Intra personal variation
Synthesis	Partial Least Squares (PLS) method [63]	Pie data set	Multi-modal face recognition
Features detection	Conditional regression forests system [12]	Raw images	Processing images in real time
Resolution	3D variant of patch match approach [19]	Quantized depth map	Super resolution for colour
Image matching	Energy based multi-model [50]	Features pairs	Improves the accuracy of models

Table 2. Three-dimensional face reconstruction models

Approach	Representation	Function	Typical criterion
Deformable [31]	Corners, geometrical, photometrical images	Fitting, changes in shape	Classification error
Statistical [4]	Voxels, structure, type and position of data set	Detection and diagnosing	Classification error
Mesh model [68]	Texture, shape density of shape	Accurate and fast	Acceptance error
Morphable [18]	Regions or cells	Appearance	Classification error

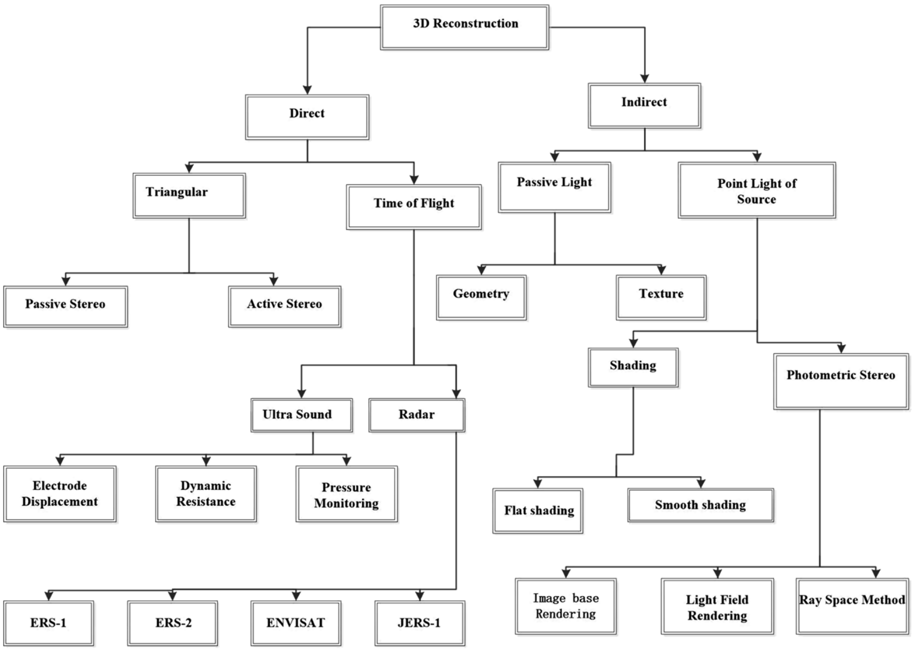

Fig. 1. Classification model of 3D face reconstruction, [36, 41, 42, 54, 57, 58]

Face image processing is commonly used in various practical life applications such as cosmetic planning surgery, security applications, and for machine interaction by human and robotic animation. But what is 3D facial reconstruction? 3D reconstruction is the phenomenon of capturing the shape and appearance of real objects. The procedure may be completed by active or passive methods. 3D Face terminologies are divided into two categories based on reconstruction and features. Active methods deal with reconstruction of radio metric and mechanical objects like laser and visible light, ultrasound, whereas the passive method concerns the measurement of radiation and emission of light in 3D structure such as image sensors [52]. Reconstruction of a 3D object requires, first, the gathering of 3D information about that object. This process is called data acquisition. It is the fundamental part of the reconstruction process and has a very important role in computer vision applications. After an accurate data acquisition, a registration is needed to fit and manipulate a generic face model with those results to complete reconstruction. Reconstruction of human faces is necessary to generate human face models looking as realistic as possible. This process requires a conversion from two-dimensional (2D) spaces to three-dimensional (3D) spaces. 3D face modelling is currently receiving a lot of attention in the computer industry developing computer graphic communities and is a thriving research field that can yield various applications such as virtual reality, animation, face recognition, facial synthesis, video meeting and games. 3D models have advanced along with the headway of PC applications, such as 3D films, on line amusements, security applications, restorative surgery, PC vision and mathematic rules. It's difficult to overcome the critical issues and enhance the development systems of displaying three-dimensional images. Several improvements of 3D-displaying frameworks have been achieved using 2D response efforts to create an advanced output of 3D images. Examples of this include the advancement of savvy cam and camcorders. Moreover, the easy adaptability and affordability for the use of these new outputs grant everyone access to advanced applications. Face reconstruction is briefly presented in this article, and we focus on the different strategies of 3D displaying, especially providing various approaches about fitting of three-dimensional face mode [14, 20].

1.1 Deformable Model Approach

The recovery and segmentation of shapes, 3D cases, corners, geometrical and photometric images, parameterizations of models and representation of shapes are based on simple deformable model techniques of 3D face reconstruction. Deformable models can be cited as changes made in shape of any object as per set of instruction or parameters [40]. All deformable models are independent in a wide range of applications and the conversion of these models in any shape of objects may increase the intention of researches in that area. These models are utilized in many applications such as morphing and texturing, pose performance and illumination in face recognition (Table 2).

Additionally, they can be applied in the deformation of boarder-converging models, twisting and taper bending, functions of local deformation and shearing. These applications are available in (human soft surface model, tracking model, animations and surgery simulation) a variety of shapes and structures. These variables, represent compactness, linearity and other convergence theorems have been used to acquire the different requirements of 3D modelling from 3D deformable lines. Powerful and high-resolution specification techniques are usually required for better performance of 3D deformable models, and it is computationally expensive when combining many operations for one model.

1.2 Morph Able Model Approach

In the 3D Morphable approach, the spatial reconstruction of face is briefly mentioned in the geometrical part of vector space representation. Shape, texture and density of natural faces in space were addressable issues of morphing models. We may be able to introduce new arbitrary faces by controlling the parameters of texture and shape. In many cases linear transformation is adopted to simplify the mapping between morphing model and 3D images. Fitting methods reduce the computational time and improve the fitting performance. The diversity of the human face (shape, texture, appearance) makes the analysis of facial imaging more critical and complex. Appearance and variation can be categorized into four basic sources: (1) pose changes (2) lighting sources (3) facial expression (4) aging. A large amount of approaches, algorithms, analyses and techniques have been cited for fitting models, computational time and mapping purposes. Blaz and Vetter reported the issues of 3D morphable model including texture and estimation of 3D, data sets from human faces and facial comparison for recognition purposes. This system can be further implicated for facial automation, feature detection and faster-fitting production. Examples are mentioned in Table 3.

Table 3. Applications of three morphable models

Models	Property	Purpose
Patel [47]	Shape and texture	Face shape recovery
Heo [25]	Features derivation from input images	Improving the accuracy and efficiency of fitting models
Moghaddam [48]	Silhouettes computing from input images	Edges and specular highlights
Knothe Model [22]	Local dominance and model feature analysis	Fitting improvement
Volker and Vetter [65]	Texture extraction	Matching of various morphable models
Vetter [35]	Synthesis approach	Extraction human face from single image
Cootes [9]	Aligning model to image	Optimize parameters, illumination and rotation of rigid body

1.3 Statistical Model Approach

In the biomedical era, statistical shape models act as a catalyst for interpreting and segmented images. Variation in voxels and shape structure information are obtained from probabilistic atlases and landmarks in most of the algorithms required for same place. The main concept of statistical model shape has derived from training sets and how variation, structure, type and position of data sets can be changed with statistical analysis. Currently, analysts take more interest in statistical shape models because these models are used in detecting and diagnosing diseases. Shape and landmark based correspondence are both challenging problems (non-linear description and non-rigid shape) in constructing models and are considered time consuming as well as leaving room for error [29, 39]. Prior research demonstrates that a small error in shape correspondences affects the accuracy and structure of final statistical shape model.

Minimum description length approach (MDL) defines how bit length is used to measure the correspondence error and how it arranges the training set to build this model. The Bayesian approach makes an improvement in face tracking such as through translation, rotational, positional movement of face. It is impossible to ensure a one hundred per cent Error-Free model, however. The verification process is important to specify all the aspects of the model's validity. Both factors are very essential for proposing the new statistical shape model.

1.4 Mesh Model Approach

Mesh models can be applied in many complex cases of representation. Mesh is a geometrical representation assigning the smaller region or cell over which the flow is solved. It is more precise in tracking and compressing images. Meshing models lay on optimization process to reduce the error occurrences between actual images and mesh model images [56]. Neighbourhoods are an important concept in mesh applications as it shows faster and more accurately the non-uniformed samples of images consisting of irregular patches. Mesh models are divided into three categories, depending on the skewness and smoothness: (1) structure grids (2) unstructured grids (3) hybrid grids. The quality depends on the convergence rate, accuracy, required time and shapes. The main problem in mesh modelling is the determination of an accurate shape for the desired images. Image derivative of the first and second degree evaluate the performances of models. Content-based methods provide fast and efficient mesh modelling without high computational costs and other optimization processes. Multiple features of 3D models were (uniform scaling, robust, rotational, and translational, re-meshing simplification) scientists considered as a perfect mesh geometrical model approach among other models [56].

1.5 Texture Mapping and Classification Approach

Texture mapping has become a well-known method in computer vision and graphics. It is a straightforward method to bring realism into imaginary images (Fig. 2).

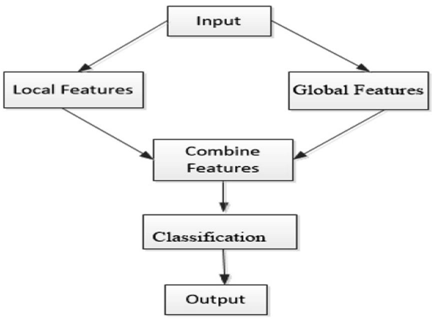

Fig. 2. The overview of texture process [21]

A various number of changes in transparency, colour, security, displacement and surface normality, motion blur and lens refocus known as texturing and are divided into sub categories, deterministic texture and s-stochastic texture. Texture mapping is defined as the low-cost method for faking the surface, or it is the transformation process (array or algebraic form) of a three-dimensional object and is considered as one the most important and valuable process of image processing and computer graphics. The actual applications of texture classification are applicable in pattern recognition, medical imaging and industrial investigation. In many cases the texture is relative to the arrangement of surrounding environmental images. Currently, texture-mapping methods are primarily used to make variations in images and movies. Texture mapping might be more commonly known as Image Perspective Transformation (IPT). The real applications of texture classification are applicable in pattern recognition, medical imaging and industrial investigation. Three main issues appear in texture classification, the use of wide ranging features to characterize the texture and the statement of variations as well as the measured distances of two of the same textures. In the early stages, features are limited to autoregressive models, Markov random fields and co-occurrences matrices. The extraction of local and global features can be assembled into many techniques to do texture classification and is considered one of the simplest and easiest methodologies. Local and global features can be jointly called as fusion features. Fusion features are classified by different classifiers; it has provides a high level of accuracy, improvement and efficiency in classification to process [23, 24].

1.6 Scope and Organization

In remaining part of the paper, we primarily review morphable models for 3D face reconstruction and classification, focusing on recent developments. In other sections we describe the different algorithms and techniques in table form for the ease of the reader. The point of which is to define those methods that have been briefly mentioned and permitting their application along with new amendments and ideas. Face reconstruction is a very dispersive field, and various topics are covered in many journals in (face detection, recognition, alignment and texture) several fields. In Sect. 2 we provide a detailed introduction of 3D reconstructed methodologies and briefly explain the classification diagram of techniques. In Sect. 3 we discuss 3DMM and survey the reconstruction issues based on face recognition with other methods. The articles available in area of face models are divided into sub topics: Correspondence Estimation, robustness, representation power, albeit with parameters, PCA for appearance Compositional Image Alignment (ICIA) algorithm and texture shape error. The initial focus on our review is the basic concept of 3D for face reconstruction. Section 4 describes the classification of face recognition methods and provides the evaluation performances of many algorithms.

2 Three Dimensional Morphable Model

Many applications involved in generating real human faces emphasize other characteristics such as changes in age, physical appearance, body weight and other facial features. The morphable model is a multitasking function that consists of large number of 3D scans using linear combinations. Simply models were developed in three stages process: pre-processing, model building and user interaction. To understand different algorithms that are used for fitting cover shape, it is important to get basic idea of morphable 3D faces. A morphable 3D face model is a vector space of 3D shapes and textures spanned by set examples (Sattar and Kang, 2006) [33]. The morphable model arises from cyberspace layer scan and captures any variations and common properties found in the set. Shape and texture can be defined by the following linear combinations of standard deviations [46].

$$S = \sum_{i=1}^{m} a_i s_i \tag{1}$$

where $i = 1$ and $T = \sum b_i T_i$

When the laser scans are converted into S and T vectors of shape and texture, there should be point-to-point correspondence of all scans with reference to the face. The vector S is usually stored in terms of x, y and z coordinates of all the vertices of a 3D mesh. Therefore, we have the following vector:

$$S_i = (X_1; Y_2; z_1; X_2;\ X_2; ::::: Zn)^T \quad (2)$$

In the same way, we can texture vectors form red, blue and green of all vertices colours as shown below:

$$T = (R_i; G_i; B_i; :::: Rn; B_n)^T \quad (3)$$

Having covered the basic morphable 3D shapes, we can now look at the various types of methods. Based on morphable models and the understanding 3D, the available information and its comparisons from different statistical algorithms were applicable. Generally, the reconstruction process is accomplished by establishing a detailed analysis in shape alignment and finally is statistically approached. The well-known models of 3DMM are described in Table 4. In face recognition, faces from images are not solely based on similarity, but there are many factors involved in tracking faces from images i.e. poses, illumination, expression, various parameters, aging and different sources. The major aim of recognition algorithms is to categorize the properties of faces that are demonstrated by texture and intrinsic shape of facial surface. Face recognition is divided into models based on appearance; many statistical techniques in appearance are based on methods used in different applications. These image-based techniques are then sub-divided into 2D images and 3D images. 3DMM is a type of 3D image-based technique, details form different issues related to the recognition of 3D face models and mention survey reports on fitting of models limited around shape and texture. All these methods will be published in sequence and describes the shape of table of contents, which summarizes work of different researchers. Image identification given in Fig. 3.

Table 4. Summary of research on 3DMM based on recognition

Models	Property	Purpose
Ganar A N, Gode C S [16]	Recover texture and shape parameters in term of model represents the identity of face from single image	High score of fitting and identification performance useful for measuring
Wang L Y, Liu B, Su S et al. [61]	Introducing multidimensional models in 3DMM for face recognition	Fast and efficient for matching
Chu, Baptiste, Sami Romdhani [11]	Using 3DMM to recognize faces in videos	Improve the accuracy of fr sdks in video dealing the face images

(*continued*)

Table 4. (*continued*)

Models	Property	Purpose
Huber [30]	Newton optimization and newton multi stage method used to accurate the shape and texture	Recognize the facial expression of human face in real scenario
I. Choi, and D. Kim et al. [10]	Better performance with extrinsic variation	Fully automatic algorithm and better accuracy for matching
Papazov C, Marks T K [45]	Model used large database of Korean faces	Show real changes and controlling of parameters for comparison of similarities
C. Mayer, M. Wimmer et al. [34]	Fitting algorithm is automatic and properly for facial expression	Fast and most applicable for real time application in recognition of face
Yongli Hu, Baocai Yin et al. [49]	Mesh resampling method is used to avoid the errors in model reconstruction	Multi lighting model is performed on different images to match facial image
B. Amberg, R. Knothe et al. [3]	Fully automatic and accurate, bit slower	Consider for high level of recognition
Rekik, Ahmed et al. [53]	Morphable expression model that demonstrates emotions of face by different parameters	Detection and verification of human face
Nathan Faggian, Andrew P. Paplinski [15]	Labelling the key features in automatic models of morph able models	Suitable for real time applications

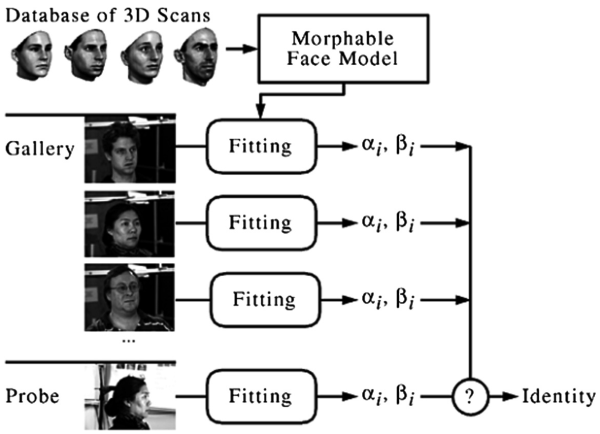

Fig. 3. Tracking model of 3DMM [46]

3 Classification and Performance Evolution of 3DMM

In this section we prefer many choices during the development of 3D morphable algorithms, like fitting of shape, representation, dissimilarity and correspondence between points. All these together affect the performance, speed, efficiency, applicability and accuracy of algorithm. In this section we discuss the basic issues in 3DMM techniques, which influence the performance. The results of many algorithms mentioned in form of tabular as given in Tables 5, 6 and 7. The region-based methods are applied above in this section the algorithms applied to use databases consist of data training sets, range images, galleries and points. The calculated performances of various algorithms depend on dissimilarities are measured by many measurement methods. The results are considered the best in [40, 42, 43]. The region-based methods are used to calculate the similarities for matching purposes. Some different cases are measured by using Hausdorff, which features vectors, Euclidean distance and Iterative closet (ICP). These algorithms worked to the managed missing data for the processing.

Table 5. Evolution of 3DMM database

Database	Type	Approach	References
FRGC	M-s	Gabor	Hsu [26]
USF3D	PCA-ST	PCA	Abiantun [1]
USF3D	PCA-S	LBP	Niinuma [44]
USF3D	M-s	LBP	Hassner [23]
BJUT3D	PCA-S	Gabor	Li [37]
USF3D	PCA-S	Pixel	Prabhu [51]

Table 6. Evolution of 3DMM with other models based on recognition

Approach	Models	Members	Data type	Error ratio	Algorithms	References
3D morphable models techniques						
Frame work	3D	05	Training data set	6.8849	Fitting algorithm learning-based	Zhu et al. [69]
Local features	3D	05	Real images	0.86	Cascaded regression	Huber et al. [30]
Bilinear programming	3D	03	Multi-dimensional model	0.8	BMMMs	Wang et al. [61]
Surface mesh	3D +2D	02	Training sets	0.5	Iterative Closet Point (ICP)	Tsalakanidou et al. [20]
View-based AAM	3D	04	Feature points	3.76	Particle swarm optimization	Lin et al. [38]
Image formation	3D	03	Spare set	0.524	Multi-linear equation	Aldrian et al. [2]

(*continued*)

Table 6. (*continued*)

Approach	Models	Members	Data type	Error ratio	Algorithms	References
Shape models	3D	06	Silhouette facial landmarks	0.82	Active shape model	Lale [59]
Albedo	2D +3D	05	Texture mapping images	0.5	AB3DMM	Hu [28]
Dense registration	3D	01	Internet photos	0.5	IBMM	Kemel [32]
Deformable models						
Template	2D +3D	04	Blend-shaped models	7.05	Template based	Rui [66]
3D shape template	3D	02	Variational frame work	3.1–5.8	Template based isometric	Adrien [5]
3D volumetric observations	3D +4D	04	Non-rigid moving object	2.12 to 12.35	On line algorithm	Xu [64]
3D scanning system	3D	05	Aligning input sequence	0.94 to 1.21	Bundle adjustment	Zhu [70]
3D variability	3D +4D	04	Frame work	43.2	Mean pose inference model	Zhu [70]

Table 7. Evolution of 3DMM with other models based on recognition

Approach	Models	Members	Data type	Error ratio	Algorithms	References
Statistical models						
Landmark localization	3D	04	Frontal images	0.0817 to 0.1025	RSF	Sagonas [55]
Laplace-Beltrami operator	3D	02	Deformable shapes	96.3 precision	Riemannian metric isometric	Gasparetto A [17]
Minimum Description Length (MdL)	3D	02	3d scan faces	0.43 to 1.26	Quasi-Newton method	Bolkart [8]
Wavelet transform	3D	03	3D Surfaces	0.189 to 4.896	Multilinear wavelet	Bolkart [7]
Mesh models						
FAUST	3D	04	Partial Scan	3 mm	Benchmarking	Bogo [6]
LBP	3D	02	Frame work	99.0% Accuracy	Descriptor	Werghi [62]

(*continued*)

Table 7. (*continued*)

Approach	Models	Members	Data type	Error ratio	Algorithms	References
Texture mapping						
Template matching	3D	04	Monocular images	0.1 to 10	Descriptor	Ngo [43]
Examples based	3D	04	Deficient images	3	Face texture	Dessein [13]
Super resolution	2D +3D	04	View points	2.1 to 2.55	Bayesian framework	Tsiminaki [60]
Co-segmentation	3D	03	Texture shapes	0.2	Bayesian spare annotation	Yumer [67]

4 Classification of 3DMM

In Fig. 4, the complete tree diagram of facial recognition, approaches image-based terminology. The theme driving this model combines the existing and new methods to show the sub-types and updates exposing strengths and weaknesses of our current understanding. The proposed figure is used to summarize the specific methods of face recognition. It will show reasonable results when applying on texture, shape, extrinsic

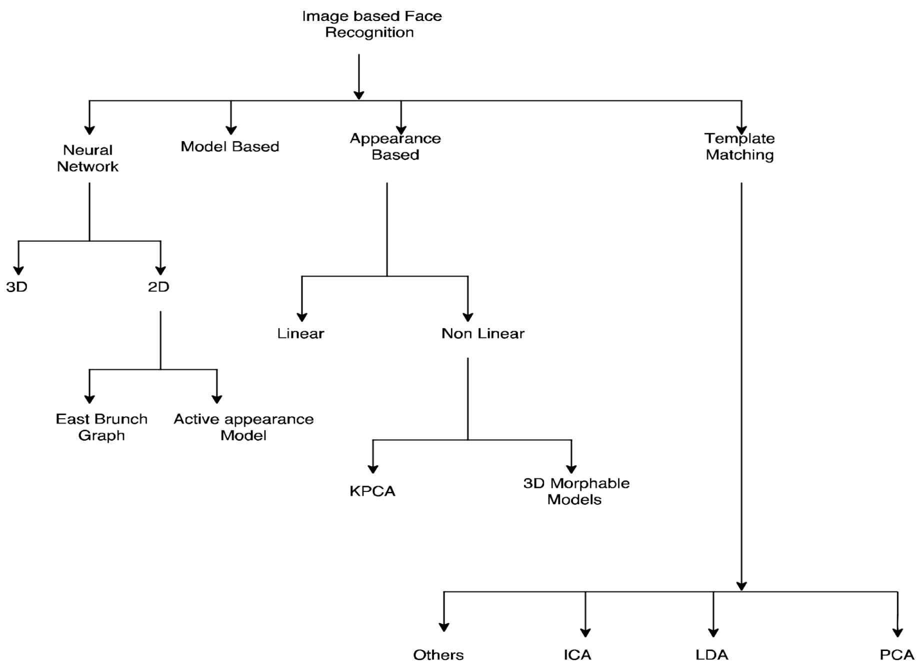

Fig. 4. Tree diagram of 3D face image-based face recognition [27].

and intrinsic variation in three-dimensional rendering. This model is used for 3D face analysis and reconstruction based on geometric recognition. The idea essentially classifies the methodologies in a visual layout to aid the understanding various techniques and easily decided which method is more suitable for face recognition. On the other hand, we provide the analysis of different techniques proposed by researchers for better performance and high improvements in different areas of face reconstruction for comparison and various purposes.

5 Conclusion

This article has provided an overview of three-dimensional face reconstruction based on recognition to construct and understanding of our current stage of development. The analysis of the methods of 3D face reconstruction combined with a list of 3D morphable face models helps highlight current success as well as problems in the industry. Many sectors ranging from graphic design, medical reconstruction, and facial identification software are well suited for the advancement in this technology. With the growing demand to take safety precautions whether they are cyber or physical, the emergence of facial recognition biometrics has, and will grow to supply safety measures to consumers. A key challenge in adequate methods has been shown through face-fitting issues in 3DMM models. There is a balance we must strike with the current state of our software development as well as the computational processing power of today's hardware. The types of facial recognition and specifically listed algorithmic complexities show efficiency discrepancies through multiple data types used in each approach.

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