**Facial Recognition: A Survey**

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**Abstract**

With the increase in datasets thank to the internet and the recent popularity of deep learning some facial recognition systems have progressed to an almost human like accuracy. Although these systems have matured limitations due to real world factors such size of datasets or image conditions such as pose.

The importance of a more accurate and robust facial recognition system in current society is continuously increasing due to its wide application areas. The motivation to write this paper is to first and foremost provide an up-to-date review of the current research and applications, second to offer insights into the emerging approaches of larger companies. This paper will supply an overall survey in which an existing recognition techniques will be categorized and descriptions of the representative methods. Finally related topics such as the problems concerning a robust system are covered and how these systems can impact current society.

**1. Introduction**

The potential value shown by facial recognition systems being seamlessly integrating into society to perform automated detection and recognition for more accurate biometric systems. As a result it is a vividly researched area of image analysis, pattern recognition and more precise biometrics [1, 2, 3, 4], as well as already being used as one of the identification methods to be used in e-passports [5, 6]. These systems require the capabilities able to recognize and distinguish between facial features in both constrained and unconstrained environmental conditions.

As a consequence research in this field has shifted from basic detection and recognition of a person facing forward in a constrained environment and proceeding towards the recognition of one or more persons from both still images and videos in various environments. Due to these factors of facial expression, various levels of illumination and image quality, as well as occlusion and low resolution.

**2. Scope and Objectives**

This paper will introduce the facial recognition techniques [Section 3] and give an overview of the literature over the past 25 years [Section 4]. The paper will then carry out the primary objective of presenting the current and emerging facial recognition research and applications as well as the issues encounter for both research and real world application [Section 5]. Furthermore a critical analysis of the benefits and limitations of the current systems and future work is presented in [Section 6].

**3.Theoretical and Technical Foundation**

**3.1 Introduction**

The current research or applications for facial recognition systems can fall into the three following methods, Feature-based, Holistic Matching, and Hybrid.

**3.2 Feature-based**

This method uses local features of the face for instance the mouth which are obtained along with local statistics such as geometric values and input to a classifier.

One large difficulty for this method is feature recovery, which occurs during the recovery of unseen facial features as a consequence of variations, for instance illumination or poses [1].

This method determines which category a face fits into based on the extraction method used: first is either *Structural Matching* and/or *Feature-Template-Based* which consider the geometrical constraints on the featuressecond is *Generic* which are based on curves and lines,

**3.3 Holistic**

This method involves taking the complete face region into consideration when inputting the data into the system. A popular holistic method is Eigenfaces [7] which are the most method for face recognition; two other popular methods are Principal Component Analysis (PCA) used mostly for data analysis and Linear Discriminant Analysis (LDA) used in pattern recognition and machine learning [8].

In 1992 Turk and Pentland made the first successful demonstration of Eigenfaces [9]. They investigated a face recognition two dimensionally.

Illustrated in Figure 1 is each of the processes that an Eigenface system will go through starting with inserting a dataset of faces named “TrainingSet”, which will compare the faces and to construct the desired Eigenface.

Next Eigenfaces are created through the extraction of feature characteristics from the input face. The faces are normalized so that features such as the eyes, nose and mouth are in the same positions and then resized to ensure the same size. Finally using Principal Component Analysis these Eigenfaces will be extracted.

Once the Eigenfaces have finished being constructed, it is defined as a vector of weights able to accept entering queries i.e. new face datasets. Finally the weight of the new face is established, a comparison is made with the known weights. If the input image's weight exceeds the threshold it is believed unidentified. Next a classification of the face is created by locating the matching or closest weights from the database and returns the assumed correct image [9].

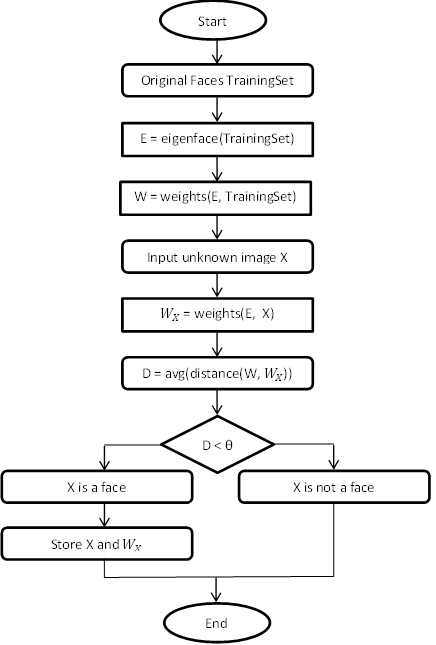


Figure Algorithm Flow Chart For Eigenface

**3.4 Hybrid**

This is a method that combines the previous two methods to create a new one. One advantage of Hybrid methods over Holistic and Feature-based is that generally three dimensional faces are used allowing for recognition to a greater detail. The image of the face captured in 3D, meaning that certain aspects of the face such as curvature of the chin or forehead can be recognized. As a result any position of the face whether in profile or at an angle would be acceptable due to the software, which using depth as a measurement, is able to gain sufficient data to reconstruct the face that lacks is lacking.

The processes of such as system are the following:

*Detection*: Acquiring, either from video or image a face.

*Determining*: Deciding what region, proportions and pose a face has.

*Analysis*: Attaching a template of measurements with focus on the position and dimensions of the eyes and nose.

*Description:* Translating the template of measurements of the facial features to a numeric dataset.

*Comparing*: Taking the numerical representation of a new face and comparing with those already in the dataset.

When a comparison of a new 3D face and one in the dataset there should be no alterations to either image whereas if the face is 2D then 3D image to make few changes resulting in one of the biggest challenges to this method.

**4. Literature Review**

In the 1960s research of facial recognition began with Woody Bledsoe, Charles Bisson and Helen Chan Wolf who either alone or together created systems for basic face recognition [10, 11, 12]. As shown in these papers and [1] early research was primarily focused on the feasibility of whether machine recognition of faces was possible or not. The investigations and experiments that would be carried out used datasets containing as little as 10 images and as they were not fully automated in the beginning, a technician or administrator needed to locate features such as the ears, and mouth on the input image. The programs calculated distances and ratio to common reference point which was then compared to set reference data.

By the 1970s Goldstein, Harmon, and Lesk [13] successfully automated the recognition process by using 21 markers, for example the thickness of the lips and the color of the hair.

Kirby and Sirovich’s research in the late 1980s [14] gave another leap forward to nascent technology, by concluding that less than one hundred values were needed to accurately represent a face that has the correct alignment and normalization.

Since this many researcher have examined various aspect of facial detection and recognition. Significant advances were made during the mid-1990s [1], with several methods proposed and tested on datasets that could contain up to 100 images.

Over the past 25 years, research [1] focused on making face recognition systems fully automatic in real-time by tackling problems such as localization of a face from either image or video and the extraction of features such as eyes, nose and mouth. Meanwhile, significant advances have been made while constructing new classifiers for accurate face recognition systems. Among the appearance-based holistic approaches, Eigenfaces [7, 14] and Fisherfaces [15, 16, 17] have proven to be effective in experiments with large databases. Whereas another approach Feature-based graph matching approaches [18] although successful when compared to holistic approaches are less precise to different levels in illumination and viewpoints.

On the topic of illumination recent advances on 3D face recognition means that range data that is acquired through structured light can still be matched reliably [19] however, the extraction techniques needed for this approach are not yet reliable or accurate enough [20]. For example, if a the systems needed to extract features from a face that had the eyes close most eye localization techniques will not be able to work.

In more recent comprehensive FERET evaluations [22, 23, 24], aimed towards evaluating all of the various systems with identical datasets of images, the systems described in [1, 7, 17, 19, 25, 26] and more were evaluated. Of these systems the Elastic Bunch Graph Matching system (EBGM) [18], the subspace LDA system [17], and the Probabilistic Eigenface system [26] were judged to be among the top three, with each method displaying different performances on different subsets of sequestered images.

**5. Innovations and Applications**

In section 5.1 will discuss the research into improving the current research and method for the current systems, solving the problems of unconstrained variation and the cutting edge research being made by large companies.

In section 5.2 the current real world applications and systems that are being created using these new methods and approaches.

**5.1 Advances in research**

**5.1.1 Pose**

One of the research areas that is desired for real-world application facial recognition systems is how to deal with the pose of a person. The ability to recognize faces regardless of the varied poses is something human can easily do but difficult to computer vision systems. Frontal face recognition has been studied for numerous decades from the very start [10, 11, 12] and currently implemented systems are trained with faces front forward having the same face but at a slightly different direction can result a lower accuracy of matching the correct face if at all.

Studies [27, 28] reveal the best Near Frontal Face Recognition (NFFR) algorithms [29, 30, 31, 32] when given the Labeled Faces in the Wild (LFW) dataset perform poorly at recognizing faces that have varied poses. This means that challenges for face recognition caused by pose variations are as follows:

*Self-Occlusion*: where a marked area in the frontal face is invisible in the non-frontal face and *Nonlinear warping* *of facial textures*: where features, such as an eye, from frontal pose will warp when the face has a different pose. Attempts to solve the both of these problems are discussed in [33, 34] which proposed to only extract features from the less-occluded half of the face and that engineered features cannot mitigate the problem that arouse due to nonlinear warping to the facial textures as a result of variations. Hence the engineered features can only handle moderate variations of pose.

*Loss of semantic correspondence*: occurs when the position of facial textures alters nonlinearly following the pose change. One way of approaching this problem is patch-wise warping however as argued in [35] this strategy has varied results but performs more poorly if the pose difference is large.

*Accompanied variation in resolution, illumination and expression:* as discussed in 5.1.2 and 5.1.3.

**5.1.2 Illumination**

Illumination is an unconstrained variable with images that has persistently challenged facial recognition systems therefore studies into different methods to process variations of illumination effectively. In [36] a Diagonal Relative Gradient (DRG) is developed to reduce the influence of illumination as an improvement to a normal Relative Gradient (RG). The experimental results demonstrated that the new proposed DRG surpassed the RG when extracting features.

Rather than creating new methods some researcher approach the problem by trying to create a more robust system. The approach in [37] attempted to solve the problem of illumination by using an Original Pixel Preservation Model (OPPM) for the sake of increasing the recognition rate. As basic recognition methods such as PCA and LDA both work on global features and depend on pixel values illumination problems become more complex when trying to use PCA or LDA to solve whereas OPPM is used to transform pixels from non-illumination to illumination that can then be normalized.

**5.1.3 Facial Expression**

As a part of face recognition and of equal importance facial expression has had a lot of research applied to it with the aim to create a system that can automatically recognize emotions so that it can be applied to many fields, such as emotion detection and analysis [74], image analysis and applications including, but not limited to, detecting behavior and emotions [75], detection of synthetic expression and detection of mental disorders.

With such a large focus there has been a lot of research with various approaches to improve on the detection and recognition. Study [38] uses appearance features of selected salient facial patterns whereas [39] proposes a design for a more robust and accurate system using an approach based on a confusion-crossed support vector machine tree. This method extracts Pseudo-Zernike moment features for training.

A third approach recently taken in [40] chose to use Histogram Variances Faces (HVF) which is the integration of expression dynamic features into a static image.

A difficult challenge of computer vision is real world recognition where there can be multiple factors. With the aim of real world applications research has approach methods to counter these factors by combining two fields, for example in [41] both pose and illumination are discussed to an invariant 2D to 3D facial recognition system where the 2D images is an input and the 3D data as a database. Another paper [42] proposes a real world and rapid face recognition for pose and expression via a feature library matrix.

**5.1.4 Convolution Neural Networks**

Convolution Neural Networks (CNN) have become extremely popular within the computer vision community, significantly improving the systems for many applications. A CNN is a type of feed-forward artificial neural network [43] where the individual neurons are tiled so that they respond to overlapping regions in the visual field [44]. Essentially these deep learning models will function by recognizing the many small features that make up a face and then combining them as a map of the whole face. Once the system has been trained on the labeled training data they will be able to identify the object or face they are seeing.

One of the most fundamental factors for the success of such methods is the availability of large amounts of data for training. The ImageNet Large Scale Visual Recognition Challenge [45] was instrumental in providing this data for the general image classification task. More recently, researchers have made datasets available for segmentation, scene classification and image segmentation [46, 47].

In the world of face recognition, however, public datasets have considerably few images and as a result most of the recent progress in the community remains lagging behind Internet giants such as Facebook and Google who has an abundance of images to use.

**5.1.5 Google FaceNet**

For instance, the most recent system by Google, FaceNet [48] which claims almost perfect recognition with accuracy of 99.96% was trained using 200 million images and 8 million unique identities. Given the size of this dataset is almost three times larger than any publicly available face dataset. Recently, Google researchers used the same dataset of 200 million face identities but instead used 800 million image face pairs to train a Convolution Neural Network similar to [49] and [50]. This method currently achieves the best performance on LFW with 99.63% accuracy and YouTube Faces Database (YTF) with 95.12% accuracy. The defining characteristic of such methods is the uses of a CNN feature extractor, which a learnable function is obtained by composing several linear and non-linear operators.

**5.1.6 Facebook DeepFace**

A representative system of this class of methods is DeepFace [51], another deep learning facial recognition system designed by Facebook’s research group claims 97% accuracy was trained on 4 million images. This method reaches an accuracy of 97.35% on the LFW dataset [51].

The DeepFace architecture is essentially a single convolution filtering the input faces, which are then processed by the three locally connected layers and two fully connected layers. The network consists of over 120 million parameters with more than 95% of them occurring in the local and fully connected layers.

The DeepFace project further progressed appearing in the DeepID series of papers by Sun et al. [52, 53, 54, 55], A number of new ideas were incorporated throughout this series of papers, including but not limited to: using multiple CNNs [53], a Bayesian learning framework [49] to train a metric, multi-task learning over classification and verification [52], different Convolution Neural Network architectures that branch fully connected layers following each convolution layer [54], and very deep networks inspired by [56, 57] in [55]. Compared to DeepFace, DeepID does not use 3D face alignment, but a simpler 2D affine alignment and trains on a combination of CelebFaces [53] and WDRef [49]. However, the final model in [55] is quite complicated involving around 200 CNNs.

**5.1.7 Apple**

Following Facebook’s to automate the tagging of photographs Apple has begun researching systems to automatically detect, recognize and share the photographs with the people within them. They also aim to implement facial recognition for the unlocking of mobile devices rather than passwords.

**5.1.7 MasterCard’s ‘Selfie’ Authentication**

The system developed by MasterCard for use on their mobile application targets the millennial generation, that when purchasing with their card will request the user to take a selfie (taking a photo of one’s self), to authorize it. With the increasing amount of selfies companies such as MasterCard have approached the technology similar to Apple as a form of authentication.

This method of online payments will aid to prevent any purchases that are not form the user and to further secure this system it requires the user to blink during the photo which prevents another user simply holding up a photo. The application, similar to Apple Pay, will allow users to scan their fingerprints to confirm transaction.

**5.2 Current Applications**

With the software becoming more popular and the systems less expensive facial recognition is becoming more widespread with better compatibility with cameras and computers that are used in banks and airports. Current applications can be split into two different approaches static, using images or video and real time, using live feed from CCTV camera.

**5.2.1 Approaches**

The first approach is a system for finding a specific face from a large database of faces and returning a list of possible faces. This approach would be used mainly for law enforcement which could input a surveillance video of an individual or a crowd and having the system returning personal identification: driver’s license or mug shots matching are examples of this type [58, 58]

The second approach is about real time recognition where the system is used to identify a person on the spot. This type of approach is more favored for security systems in which a face is recognized and the system grants access to a building avoiding security hassles from a human base system. In this approach the face is compared against multiple samples of that person [60, 61].

**5.2.3 Law Enforcement**

In law enforcement one application is comparing school surveillance camera images to know child molesters [62] however there are mixed view on whether this proves useful with some claiming that these systems have not ever spotted a desired target.

**5.2.4 Banking**

In banking facial recognition systems have been applied to ATMs. The software is able to quickly verify a customer’s face whilst accessing the ATM [62, 64]; with the aim to catch any known fraud or to detect if the person who owns the card is the one using it.

**5.2.5 Security**

With facial recognition gaining higher accuracy recently and with it being more secure than some of the other biometric systems such as fingerprint or retina, facial recognition has been applied many security environments for general access control to buildings [37] which would be an authentication application where the clients are already known. This way of controlling who enters it can also speed up the process than a human counterpart.

One study [65] presents an automated gender classification system that can be applied to access control, for areas allowed to certain gender, or business intelligence, for advertising or better customer service, as it will detect biometric data such as age or gender.

**5.2.6 Counter Terrorism**

Over the past 15 years prevention of terrorism has become important especially within airports systems which with facial recognition compare surveillance to known terrorists and for immigration software for rapid progression through Customs [66].

Within certain countries facial recognition has been applied to political voting verification where eligible politicians and voters are required to verify their identities during a voting process to prevent one person voting multiple times [67].

**5.3 Advances in Application**

**5.3.1 Facebook DeepFace**

Facebook’s DeepFace has been applied to their tagging software to identify faces in photos that are posted on their site. Due to their technology being so advanced that is can recognize a person in an image with the same accuracy as an actual human being the tagging of photographs is almost automatic. Furthermore the more pictures of a person it has the more accurate the database.

**5.3.2 Facebook Moments**

As well as the applying the technology to their website they have also created “Facebook Moments” which accesses the images or photographs stored on the phone, automatically detect and recognize faces of friends on Facebook, then asks if the owner of the phone would like to upload the photos to their Facebook account.

**5.4 Conclusion**

This section has covered the current and emerging trends in research and applications. The change in research shown in Section 4 which had focus on improving the systems for automation in real-time and making advances in the design of classifiers however issues with unconstrained variations such as illumination and pose. In response the research shown in Section 5 focus on improving these issues as well as detection and recognition of emotions. Internet giants, Google and Facebook began research into Deep Learning, or more specifically CNNs, to create a system that can recognize with accuracy equal to a human.

In 5.2 the change in the focus from implementing systems around preventing crimes and increasing the security of building into recent application from larger companies applying their own face recognition systems into their own technologies. Due to interest by government deployment and the increased surveillance the market for these systems have resulted in a lower cost to infrastructure when deploying. The increasing amount of smartphone that can process the facial recognition systems provides new opportunities to the larger brand name such as Apple.

**6. Critical Reflection**

This paper has investigated face recognition systems, discussing the essential requirements of the system and the goals that have driven the research over the past few decades have been presented. Face recognition research as a result has been able to achieve a lot in the past two decades compared to other technologies as one of the main factors in training these systems was data sets that researchers either created themselves or used the public data sets which had only a few thousand images. With the popularity of social media and the amount of images uploaded on them new data sets could be created with various environmental conditions in each image. With how many users’ uploaded images are usually affected by the unconstrained variations, such as expression, a lot of research has been applied to solving them creating new approaches and methods that could benefit face recognition overall. Additionally with the commercial interest with some of the larger companies who have vast quantities of data and images and no current use for it, will soon be able to collect, analyze and sell of the data to third parties.

With the gaining interest with using Deep Learning to face recognition systems, different approaches have been successfully applied such as the current most popular, CNN, which provides higher accuracy results compared with other approaches as well as having a greater robustness allowing for a quick integration onto devices to automatically detect and recognize automatically.

**6.1 Benefits**

From the decades of research many improvement that can affect home and businesses have been shown in following subsections.

**6.1.1 High Accuracy**

Facial recognition has reached a high accuracy due to CNNs systems and the large datasets some of them are being trained on. These systems are accurate enough to distinguish between identical twins [76].

**6.1.2 Automated Facial System**

Many companies like the fact that these systems can automated as they will not need to have employees monitoring the system 24 hours a day saving time, reducing errors and having a higher efficiency in some applications. Automated systems such as [38, 70] that a robust enough to hand expression and guests also will be useful to this.

**6.1.3** **Better Security**

Better security can be applied to both home [37] and businesses. By having an authentication system only the faces in the database will be granted access but anyone that is not in the system will not be given access [68, 69].

**6.1.4 Easy Integration**

Integrated facial systems are also easy to program into the companies computer system, usually they will work with existing software and hardware that they have in place [70] and requires little or no involvement of the face being detected.

**6.1.5 Exact Work Hours**

One of the big benefits of using facial recognition in companies is that employees could use face identification to store the exact work hours and prevent other employees doing it for them [71].

**6.2 Limitations**

In spite of these important advances there are still issues that need to be solved which are reviews in the following subsections.

**6.2.1 No Standard Dataset**

Although there are a few standardized datasets for faces that can be used for benchmarking purposes, the proportions and types of 3D face datasets vary across different publications. With some researchers creating their or companies using the vast data saved on their servers, the training of some systems can be lacking compared to others.

**6.2.2 No Standard Evaluation**

With previous systems in past decades there was a way to evaluate the performance or accuracy of face recognition techniques, in terms of which datasets and/or algorithms have been used and their recognition performance could be reported [72]. Even though 3D face recognition is still a new emerging area, there is a need to compare the performance of techniques in a controlled setting where they can be conducted on a large dataset to the same evaluation protocols. This need for evaluation prompted the design of the evaluation studies [26, 60].

**6.2.3 Global Laws**

One of the new issues with the advancement of facial recognition created by companies like Google or Facebook is that there is a lack of global laws. With a technology that previously was limited to government and law enforcement and would only be used for security the laws currently in place do not affect the new systems, such as the Facebook Moment, which are invasive or the companies themselves who use the images uploaded on their website for training the systems without asking permission to the owner of the image.

When the flood of biometric data available from voice command software, facial recognition and finger print data is combined with other Meta data from a person’s electron life, for example GPS, call data, shopping receipts, medical records, etc., a person's privacy is destroyed. They will be able to be identified nearly anywhere at any time with only the weakest of consent. This lack of laws means there is the potential for privacy abuse and as a result government of each country must decide the actions to take until such laws are created. One example of this is that Canada and the countries in the European Union have blocked all access to the Facebook Moment to prevent such invasiveness and as this issue has become more pressing the US Government Accountability Office to give a report [73].

**6.3 Conclusion**

Facial recognition although highly accuracy is problematic as a person’s permission or involvement is not necessarily needed, compared to other biometrics. Simply walking down a street in a big city or entering a shop guarantees being captured on a camera, and in the future automatically identified, if not already.

However even with all these issues, the convenience for a person’s security as well as the data mining potential for big businesses with servers filled with data and images and potential consumers, are too compelling in comparison to the limitations and risk of privacy abuse. Furthermore with facial recognition achieving near 100% accuracy there are many applications that these system can be implemented into.

**6.4 Future Work**

Illumination and pose have always been a challenge to face recognition and even with the newly emerging systems from Google [48] or Facebook [51] which boast near human recognition these variations are the last factors that cause issues. Google in particular stated that for further work they will focus on two areas; better understanding the current errors in order to improve the current model and attempt to reduce the model size, training and processing time. Facebook is working on further improving their system’s accuracy to handle pose variations by straightening out angular shot in order to acquire a straight view of the face.

Facial recognition on large number of faces or of crowds either in photographs or video is one of the long running interests for primarily government or security installations. Systems that can accurately and quickly identify a group simultaneously would be more beneficial than of a single person.

**8. References**

[1] W. Zhao, R. Chellappa, A. Rosenfeld, and P.J. Phillips, “Face Recognition: A Literature Survey”, ACM Computing Surveys, vol. 35, Issue 4, pp. 399-458, 2003.

[2] K. Delac, and M. Grgic, “A Survey of Biometric Recognition Methods”, Proc. of the 46th International Symposium Electronics in Marine, ELMAR-2004, Zadar, Croatia, pp. 184-193, 2004.

[3] S.Z. Li, and A.K. Jain, “Handbook of Face Recognition”, eds., Springer, New York, USA, 2005.

[4] K. Delac, M. Grgic, “Face Recognition”, eds., I-Tech Education and Publishing, ISBN 978-3- 902613-03-5, pp. 558, Vienna, 2007.

[5] Biometric Data Interchange Formats - Part 5: Face Image Data, ISO/IEC JTC1/SC37 N506, ISO/IEC IS 19794-5, 2004.

[6] Face Recognition Format for Data Interchange, ANSI INCITS 385-2004, American National Standard for Information Technology, New York, 2004.

[7] M.A. Turk and A.P. Pentland, "Face Recognition Using Eigenfaces", 1991.

[8] S. Suhas, A. Kurhe, and P. Khanale, “Face Recognition Using Principal Component Analysis and Linear Discriminant Analysis on Holistic Approach in Facial Images Database”, IOSR Journal of Engineering e-ISSN: 2250-3021, p-ISSN: 2278-8719, Vol. 2, Issue 12, pp. 15-23, 2012.

[9] C.A. Hansen, “Face Recognition”, Institute for Computer Science University of Tromso, Norway.

[10] W.W. Bledsoe, “Man-Machine Facial Recognition: Report on a Large-Scale Experiment”, Technical Report PRI 22, Panoramic Research, Inc., Palo Alto, California, 1966a.

[11] W.W. Bledsoe, “Some Results on Multicategory Patten Recognition”, Journal of the Association for Computing Machinery vol. 13, Issue 2, pp. 304-316, 1966b.

[12] W.W Bledsoe, and H. Chan, “A Man-Machine Facial Recognition System-Some Preliminary Results”, Technical Report PRI 19A, Panoramic Research, Inc., Palo Alto, California, 1965.

[13] A.J. Goldstein, L.D. Harmon, and A.B. Lesk, “Identification of Human Faces”, Proceedings of the IEEE, vol. 59, Issue 5, pp. 748-760, 1971.

[14] M. Kirby and L. Sirovich, "Application of the Karhunen-Loeve procedure for the characterization of human faces", IEEE Transactions on Pattern analysis and Machine Intelligence, vol. 12, Issue 1, pp. 103–108, 1990. doi:10.1109/34.41390

[15] P.N. Belhumeur, J.P. Hespanha, and D.J. Kriegman, “Eigenfaces vs. fisherfaces: Recognition using class specific linear projection”, IEEE Transactions on Pattern Analysis and Machine Intelligence, vol. 19, Issue 7, pp. 711-720, 1997.

[16] K. Etemad, and R. Chellappa, “Discriminant analysis for recognition of human face images”, JOSA A, vol. 14, Issue 8, pp. 1724-1733, 1997.

[17] W. Zhao, A. Krishnaswamy, R. Chellappa, D.L. Swets, and J. Weng, “Discriminant analysis of principal components for face recognition”, In Face Recognition, Springer Berlin Heidelberg, pp. 73-85, 1998.

[18] L. Wiskott, J.M. Fellous, N. Kuiger, and C. Von Der Malsburg, “Face recognition by elastic bunch graph matching”, IEEE Transactions on Pattern Analysis and Machine Intelligence, vol. 19, Issue 7, pp. 775-779, 1997.  doi:10.1109/34.598235

[19] A.M. Bronstein, M.M Bronstein, and R. Kimmel, “Expression-invariant 3D face recognition”, In Audio-and Video-Based Biometric Person Authentication, Springer Berlin Heidelberg pp. 62-70, 2003.

[20] I.J. Cox, J. Ghosn, and P.N. Yianilos, “Feature-based face recognition using mixture-distance”. IEEE Computer Society Conference in Computer Vision and Pattern Recognition, 1996. Proceedings CVPR'96, 1996, pp. 209-216, 1996. IEEE.

[21] P.J. Phillips, H. Moon, S. Rizvi, and P. Rauss, “The FERET evaluation methodology for face-recognition algorithms”. IEEE Transactions on Pattern Analysis and Machine Intelligence, vol. 22, Issue 10, pp. 1090-1104, 2000.

[22] P.J. Phillips, H. Moon, S. Rizvi, and P. Rauss, “The feret evaluation”. In Face Recognition, Springer Berlin Heidelberg, pp. 244-261, 1998.

[23] S. Rizvi, J. Phillips, and H. Moon, “The FERET verification testing protocol for face recognition algorithms”, In Automatic Face and Gesture Recognition, 1998. Proceedings. Third IEEE International Conference on, pp. 48-53, IEEE.

[24] C. Nastar, B. Moghaddam, and A. Pentland, “Flexible images: matching and recognition using learned deformations”, Computer Vision and Image Understanding, vol. 65, Issue 2, pp. 179-191

, 1997.

[25] D.L. Swets, and J.J. Weng, “Using discriminant eigenfeatures for image retrieval”, IEEE Transactions on Pattern Analysis & Machine Intelligence, vol. 8, pp. 831-836, 1996.

[26] B. Moghaddam, and A. Pentland, “Probabilistic visual learning for object representation”, Pattern Analysis and Machine Intelligence, IEEE Transactions on, vol. 19, Issue 7, pp. 696-710, 1997.

[27] S. Li, X. Liu, X. Chai, H. Zhang, S. Lao, and S. Shan “Maximal likelihood correspondence estimation for face recognition across pose”, IEEE Trans Image Process vol. 23, Issue 10, pp. 4587–4600 2014.

[28] Z. Zhu, P. Luo, X. Wang, and X. Tang, “Multi-view perceptron: A deep model for learning face identity and view representations. In: Proc. Adv. Neural Inf. Process. Syst., pp. 217–225, 2014.

[29] D. Chen, X. Cao, F. Wen, and J. Sun, “Blessing of dimensionality: High-dimensional feature and its efficient compression for face verification”, In: Proc. IEEE Conf. Comput. Vis. Pattern Recognit., pp. 3025–3032, 2013.

[30] Y. Taigman, L. Wolf, T. Hassner, “Multiple one-shots for utilizing class label information”, In: Proc. Brit. Mach. Vis. Conf., pp. 1–12, 2009.

[31] K. Simonyan, O.M. Parkhi, A. Vedaldi, and A. Zisserman, “Fisher vector faces in the wild”, In: Proc. Brit. Mach. Vis. Conf., vol. 1, pp. 1–12, 2013.

[32] H. Li, G. Hua, Z. Lin, J. Brandt, and J. Yang “Probabilistic elastic matching for pose variant face verification”, In: Proc. IEEE Conf. Comput. Vis. Pattern Recognit., pp. 3499–3506, 2013.

[33] S.R. Arashloo, and J. Kittler, “Energy normalization for pose-invariant face recognition based on mrf model image matching”, IEEE Trans Pattern Anal Mach Intell vol. 33, Issue 6 pp. 1274–1280, 2011.

[34] D. Yi, Z. Lei, S.Z. Li, “Towards pose robust face recognition”, In: Proc. IEEE Conf. Comput. Vis. Pattern Recognit., pp. 3539–3545, 2013.

[35] A. Li, S. Shan, X. Chen, and W. Gao, “Maximizing intra-individual correlations for face recognition across pose differences”, In: Proc. IEEE Conf. Comput. Vis. Pattern Recognit., pp. 605–611, 2009.

[36] D.Y. Huang, C.J. Lin, and S.H. Dai, “Face recognition using the diagonal relative gradient method in a low illumination Environment”, Journal of Information Hiding and Multimedia Signal Processing, vol. 5, Issue 2, pp. 310-323, 2014.

[37] M. Sahani, C. Nanda, A.K. Sahu, and B. Pattnaik, “Web-based online embedded door access control and home security system based on face recognition”, In Circuit, Power and Computing Technologies (ICCPCT), 2015 International Conference on pp. 1-6, 2015. IEEE.

[38] S.L. Happy, and A. Routray, “Automatic Facial Expression Recognition Using Features of Salient Facial Patches” Affective Computing, IEEE Transactions on, vol. 6, Issue 1, pp. 1-12, 2015.

[39] Q. Xu, Z. Pinzheng, P. Wenjiang, Y. Luxi, and H. Zhenya, "An Automatic Facial Expression Recognition Approach Based on Confusion-Crossed Support Vector Machine Tree." In Acoustics, Speech and Signal Processing, 2007. ICASSP 2007. IEEE International Conference on, vol. 1, pp. I-625. IEEE, 2007.

[40] R. Du, W. Qiang, H. Xiangjian, J. Wenjing, and W. Daming, "Facial expression recognition using histogram variances faces." In Applications of Computer Vision (WACV), 2009 Workshop on, pp. 1-7. IEEE, 2009.

[41] U. Yang, S. Hyoungchul, and S. Kwanghoon, "Pose and illumination invariant 2D to 3D facial recognition system." In Industrial Electronics and Applications, 2008. ICIEA 2008. 3rd IEEE Conference on, pp. 2121-2126. IEEE, 2008.

[42] A. Moeini, and M. Hossein, "Real-World and Rapid Face Recognition Toward Pose and Expression Variations via Feature Library Matrix." Information Forensics and Security, IEEE Transactions on 10, no. 5, pp. 969-984, 2015.

[43] M. Matsugu, K. Mori, Y. Mitari, and Y. Kaneda, “Subject independent facial expression recognition with robust face detection using a convolutional neural network”, Neural Networks, vol. 16, Issue 5, pp. 555-559, 2003.

[44] Convolutional Neural Networks (LeNet) - DeepLearning 0.1 documentation. DeepLearning 0.1. LISA Lab. Retrieved 11 December 2015. website: http://deeplearning.net/tutorial/lenet.html

[45] O. Russakovsky, J. Deng, H. Su, J. Krause, S. Satheesh, S. Ma, S. Huang, A. Karpathy, A. Khosla, M. Bernstein, A.C. Berg, and F.F. Li. “Imagenet large scale visual recognition challenge”, IJCV, 2015

[46] T.Y. Lin, M. Maire, S. Belongie, J. Hays, P. Perona, D. Ramanan, P. Dollár, and C.L. Zitnick, “Microsoft COCO: common objects in context”, CoRR, abs/1405.0312, 2014.

[47] B. Zhou, A. Lapedriza, J. Xiao, A. Torralba, and A. Oliva, “Learning deep features for scene recognition using places database”, in NIPS, 2014.

[48] F. Schroff, D. Kalenichenko, and J. Philbin, “Facenet: A unified embedding for face recognition and clustering”, arXiv preprint arXiv:1503.03832, 2015.

[49] D. Chen, X. Cao, L. Wang, F. Wen, and J. Sun, “Bayesian face revisited: A joint formulation”, In Proc. ECCV, pp. 566–579, 2012.

[50] P. Sermanet, D. Eigen, X. Zhang, M. Mathieu, R. Fergus, and Y. LeCun, “Overfeat: Integrated recognition, localization and detection using convolutional networks”, arXiv preprint arXiv:1312.6229, 2013.

[51] Y. Taigman, M. Yang, M.A. Ranzato, and L. Wolf, “Deepface: Closing the gap to human-level performance in face verification”, In Computer Vision and Pattern Recognition (CVPR), 2014 IEEE Conference on, pp. 1701-1708. IEEE.

[52] Y. Sun, Y. Chen, X. Wang, and X. Tang, “Deep learning face representation by joint identification verification”, in NIPS, 2014.

[53] Y. Sun, X. Wang, and X. Tang. “Deep learning face representation from predicting 10,000 classes”, In Proc. CVPR, 2014.

[54] Y. Sun, X. Wang, and X. Tang, “Deeply learned face representations are sparse, selective, and robust”, CoRR, abs/1412.1265, 2014.

[55] Y. Sun, L. Ding, X. Wang, and X. Tang, “Deepid3: Face recognition with very deep neural networks”, CoRR, abs/1502.00873, 2015.

[56] K. Simonyan and A. Zisserman, “Very deep convolutional networks for large-scale image recognition” In International Conference on Learning Representations, 2015.

[57] C. Szegedy, W. Liu, Y. Jia, P. Sermanet, S. Reed, D. Anguelov, D. Erhan, V. Vanhoucke, and A. Rabinovich, “Going deeper with convolutions” CoRR, abs/1409.4842, 2014.

[58] D. Zhang and Y. Wang, “Gender Recognition Based on Fusion of Face and Multi-view Gait”, In LNCS, vol. 5558, pp. 1010-1018. Springer, 2009.

[59] P. Whaite, and P. Ferrie, "From uncertainty to visual exploration", IEEE T-PAMI, vol. 13, Issue 10, pp. 1038 -1049, 1991.

[60] A. Bartoli, "Groupwise Geometric and Photometric Direct Image Registration," Proc. 17th British Machine Vision Conf., 2006.

[61] J. Wright, A.Y. Yang, A. Ganesh, S.S. Sastry, M. Yi, "Robust Face Recognition via Sparse Representation," Pattern Analysis and Machine Intelligence, IEEE Transactions on , vol.31, Issue 2, pp. 210-227, 2009.

[62] A. Albiol, A. Albiol, J. Oliver, and J.M. Mossi, “Who is who at different cameras: people re-identification using depth camera” Computer Vision, IET, vol. 6, Issue 5, pp. 378-387, 2012.

[63] M. Karovaliya, S. Karedia, S. Oza, and D.R. Kalbande, “Enhanced Security for ATM Machine with OTP and Facial Recognition Features”, Procedia Computer Science, vol. 45, pp. 390-396, 2015.

[64] J. Feng, X. Fang, S. Li, and Y. Wang, “High-emulation mask recognition with high-resolution hyperspectral video capture system”, InSPIE/COS Photonics Asia pp. 92733H-92733H. International Society for Optics and Photonics, 2014.

[65] X. Xu and T.S. Huang, “SODA-Boosting and its application to gender recognition”, In IEEE International Workshop on Analysis and Modeling of Faces and Gestures, vol. 4778, pp. 193-204, 2007.

[66] P. Chaurasia, P. Yogarajah, J. Condell, G. Prasad, D. McIlhatton, and R. Monaghan, “Biometrics and counter-terrorism: the case of gait recognition”. Behavioral Sciences of Terrorism and Political Aggression, vol. 7, Issue 3, pp. 210-226, 2015.

[67] S. Gold, “Preventing electoral fraud using biometrics”, Biometric Technology Today, vol. 9, pp. 5-6, 2012.

[68] B. Gao, S. Cao, X. Shan, D. Chen, X. Zhou, Zhang and D. Zhao, "The CAS-PEAL large-scale Chinese face database and baseline evaluations", IEEE Trans. Syst., Man., Cybern. A, Syst. Humans, vol. 38, no. 1, pp. 149 -161, 2008.

[69] J. Zhu, M. R. Lyu, and T. S. Huang, (2009) “A Fast 2D Shape Recovery Approach by Fusing Features and Appearance Pattern” Int. J. Advanced Networking and Applications Volume: 6 Issue: 4 pp. 2393-2397, 2015. ISSN: 0975-0290 2397 Analysis and Machine Intelligence, IEEE Transactions on, vol. 31, Issue 7.

[70] L. Wiskott, J. Fellous, N. Kruger, and C. von der Malsburg, “Face recognition and gender determination”, In IEEE International Workshop on Automatic Face and Gesture Recognition, 1995.

[71] F. Yun “Age Synthesis and Estimation via Faces: IEEE CONFERENCE PUBLICATIONS A Survey”, pp. 2590 – 2597, 2010.

[72] Y. sheng Gao, S. Zhao, J. Liu, “Local Derivative Pattern Versus Local Binary Pattern: Face Recognition With High-Order Local Pattern Descriptor”, Image Processing, Biometrics Compendium, IEEE Transactions on vol.19, Issue: 2, 2010.

[73] United States Government Accountability Office, “FACIAL RECOGNITION TECHNOLOGY: Commercial Uses, Privacy Issues, and Applicable Federal Law”, July 2015. Retrieved 14 December 2015. website: http://www.gao.gov/assets/680/671764.pdf

[74] M. Valstar, J. Girard, T. Almaey, G. McKeown, M. Mehu, L. Yin, M. Pantic, and J. Cohn “Fera 2015- Second Facial Expression Recogntion and Analysis Challenge”, Proc. IEEE ICFG, 2015.

[75] E.B. McClure, K. Pope, J. Andrea, D.S Hoberman, A.J. Pine, and E. Leibenluft. "Facial expression recognition in adolescents with mood and anxiety disorders", 2014.

[76] J.R. Paone, P.J. Flynn, P.J. Philips, K.W. Bowyer, R.W.V. Bruegge, P.J. Grother, G.W. Quinn, M.T. Pruitt, and J.M. Grant, “Double trouble: Differentiating identical twins by face recognition”, *Information Forensics and Security, IEEE Transactions on*, *9*(2), pp.285-295, 2014.