Unlocking Innovation: Biometric Authentication as a Component of Present-Day Systems

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Abstract – Biometric verification is a process of identifying people through storing and recognizing physiological and/or behavioural characteristics of individuals. In comparison with the conventional authentication methods using physical token (like the I.D cards) or knowledge token (like the password), the biometric verification provides more secure and accurate way of informing the fake or real people. Today's applications of biometric systems are widespread, and they are already incorporated in ATMs, computers, security systems, mobile phones, and health and social services. Within the different biometric modalities, face recognition is quite preferred because of its contactless characterization and easy applicability. This technology recognizes people based on certain patterns in the human face, providing an efficient way of replacing based password for the registration as well as the login processes. This paper is a systematic review of face recognition systems where it investigates on the approaches of the different systems, uses, strength, and weakness of the face recognition systems. Moreover, the paper also discusses the application of face recognition in improving security and the use of services in particular contexts. Aspects on the future of face recognition as well as research development depicting on current challenges that have affected the performance of the system and how such can be enhanced in future in terms of accuracy and reliability are also covered.

I. INTRODUCTION

Background

Biometrics is one of the most advancing fields that pertain to the use of automated methods for recognizing and authenticating people through their physiological and/or behavioral traits. This technology is better as compared to the other identification methods like passwords or even ID cards as it determines the unique features of an individual such as the fingerprints, iris scans, voice, and facial structure. Of these, face recognition is preferential because it is unobtrusive and easy to use by the users. Biometric technology that is used in face recognition allows identifying the user using various attributes on the face, making it an essential technology in increasing security across multiple industries, security installations, mobile phones, and banking as well as social services.

II. OBJECTIVES

The purpose of this literature review is to provide a comprehensive overview of the current state and future directions of face recognition technology within the broader context of biometric verification.

1. In order to examine and discuss the subject of applying face recognition biometric to

strengthen the security for users to log in waste management and recycling systems.

Scope

It is the objective of this review paper to assess the current state of face recognition technology with regards to its history and theoretical and state-of-art researches. Out of them, it categorizes the techniques in appearance based and geometric feature based methods. While methods which addresses the shape and location of face in images like Eigenfaces and Neural Networks work on the general geometrical look of faces, they fail when it comes to lighting and occlusion. Deformable models, such as Active Shape Models, are less sensitive to the variations of lighting and the angle of the subject's pose, but can be more difficult to implement and work only in the case of an accurate extraction of the features of the subject's body.

The paper also deals with 3D face recognition that turns out to be more accurate because it deals with pose and lighting variations but has issues like high costs. Today's issues like facial occlusion and environmental variations are presented, proposed solutions of a new generation and trends to develop new possibilities for increasing the efficiency of the system are considered. All in all, the review manages to specify the face recognition technologies, the used methods, the encountered problems, and further perspectives.

III. METHODOLOGY

Consequently, to sample sources of literature in the context of biometric verification particularly face recognition, systematic search was conducted. The following databases were used: IEEE Electronic Library and Wiley Online Library, CABI: Cab Direct, Communication & Mass Media Complete, PubMed, and Google Scholar. Articles were collected using key terms including; biometric verification, face recognition, facial recognition technology, biometric authentication and security systems. The search was confined to the papers of the last thirty years (1995-2024) to make sure the literature review and analysis addresses recent developments.

Theoretical Background

Biometric Verification Systems

Biometric verification systems makes use of physiological and behavioral characteristics of a person in order to establish and confirm his identity.These systems typically consist of the following components:

Sensor: Some technologies capture the biometric trait (e. g., a camera for face recognition).

Feature Extraction: Converts the obtained data to find unique characteristics.

Matcher: In which the extracted features are compared to similar templates stored in a firm database.

Decision Maker: Checks if the captured biometric is indeed similar to the biometric template which is stored to affirm the identity of the person.

Face Recognition Technology

Face recognition technology uniquely focuses on distinguishing one person from another by relying on features of their face. The fundamental principles and components of face recognition systems include:

1. Image Acquisition: Taking of the facial image using a camera. It is absolutely critical that images be of high quality for good recognition.
2. Preprocessing: Lighting up or dimming of the face, eliminating noises, and bringing the face to the centre or anti-portrait format.
3. Feature Extraction: Aspects like the space

between the eyes, type of the nose and shape of the jaw. For facial landmark detection methods, Principal Component Analysis (PCA), Linear Discriminant Analysis (LDA), several other key approaches and deep learning models are employed.

4. Face Matching: With the help of techniques which are Euclidean distance, cosine similarity or neural network based matching the extracted features with the database of faces.

5. Decision Making: Arriving at a decision that takes into consideration the comparison and the setting of the acceptance or rejection level.

IV. LITERATURE REVIEW

Overall it has been seen that rather impressive progress has been achieved over the last three decades in the context of biometric verification especially in the application of face recognition. Therefore, this section of the literature review analyzes the works of the numerous researchers in order to establish the current advancements of those technologies.

Face recognition has become widely used as a biometric method because of its simplicity and non-contact modality [3]. Previous approaches to human face recognition are given in [3; 9] while [11] offers the survey of the face recognition technologies and problems. Face recognition algorithms can be broadly classified into two categories: feature based and shape based methods and from the above mentioned two categories they have included geometric feature based and appearance based methods.

Appearance-Based Methods

Appearance-based methods deal with the entire face image and other related techniques are Eigenfaces [2], Fisherfaces [4], Independent Component Analysis (ICA) [7], Kernel Principal Component Analysis (KPCA) [5; 6], Kernel Fisher Discriminant Analysis (KFDA) [6], General Discriminant Analysis (GDA) [6], Neural Networks [7], and Support Vector Machines (SVM) [8]. Despite such methods being accurate with great results in ideal conditions, they struggle with occlusion, for example, when the face is covered or partially covered by other objects. The given global features that they capture can be inaccurate any time the face has not been captured under the same conditions [11].

Geometric Feature-Based Methods

The geometric feature based techniques can handle changes in illumination and viewpoints, but are depending on the extraction of geometric features. These methods look at the clear and observable patterns and faces of the locality, and their geometry. They include Active Shape Models [1; 2], Elastic Bunch Graph Matching [1], and Local Feature Analysis (LFA) [1]. These methods are especially useful where the object is view dependent and its lighting condition with respect to the camera differs from that with respect to the viewer.

3D Face Recognition

Identification of faces in still or 2D may be difficult because of differences in lighting, position and expression of the face. In order to overcome these problems, there is a proposed 3d face recognition which has the following benefits in features localization and it is also insusceptible to pose and illumination. They became the pioneers who studied the possibility of applying 3D face data for personal identification, which is described in the following section. This approach encodes the structure of the face and is thus intrinsically immune to pose and lighting changes. Application of Hidden Markov Models (HMMs) in 3D face verification is mentioned in [29] and recent enhancement of this work is the use of Gaussian Mixture Models (GMMs) for 3D face verification in parts-based method [12].

However, 3D face recognition systems have their drawbacks include high cost, the laser sensors' ease of use is reduced, certain acquisition types' lower accuracy, and insufficient powerful algorithms.

The basic issues in face recognition had laid the work ground with early methods that defined the future progress. Cootes et al. first introduced Active shape models in the year 1991 and according to them it was basically used in modeling of face shapes for the purpose of improving tracking and recognition. At the same time, Turk and Pentland worked on Eigenfaces employing PCA to encode the fundamental aspects of facial structure to allow for an efficient method of face recognition [2]. Chellappa's review in 1995 brought together diverse face recognition techniques, and gave a preview on the status of the field at that time [3]. Fisherfaces by Belhumeur et al. in 1997 rectified this issue by using Linear Discriminant Analysis (LDA) to increase the degree of separation of the classes [4]. Later, Schölkopf et al. (1999) generalized Kernel PCA, the method by extending the base PCA through the use of kernel tricks for feature extraction from non-linear data [5]. Subsequently, Baudat and Anouar's General Discriminant Analysis (GDA) in the year 2000 improved discriminative analysis by assimilating a few of the features of PCA and LDA. Bartlett et al. (2002) devoted their work to the investigation of Independent Component Analysis (ICA) primarily, regarding the separation of components by their statistical independence, wherein facial features were processed [7]. Phillips (2002) used Support Vector Machines (SVM) in face recognition to describe classification problems [8].

Noticeably, in the early 2000s to 2010s, the innovations and improvements of face recognition system have been recorded tremendously. Zhao et al. made a comprehensive survey on face recognition, proposed methods' categories, and examined the problems in [9]. Chellappa et al. (2004) therefore, advanced their previous survey by concentrating on progress and new issues in face recognition [10]. In a study that focused on face recognition technologies and their issues, Abate et al. (2007) presented an analysis to define the future advancements [11]. Mccool et al. (2008) proposed GMMs for 3D face verification and it was thereby made invariant to pose and illumination [12]. For DL works on face recognition, Masi et al. (2009) provided a review, which signaled the start of major advancements in the FR discipline [13].

The deep learning era was revolutionary for face recognition technology. The most recent and quite effective and widely used architectures are as follows: Taigman et al. (2011) proposed DeepFace which is a deep convolutional network that performs near to human level performance in face verification by learning complex facial features [14]. building upon the deep learning strategy, Schroff et al., (2014) proposed FaceNet that works by directly modeling facial images in a conducive Euclidean space for recognition [15]. Parkhi et al. synthesised the VGGFace model which uses a deep CNN based on a vast database that marked new standards in face recognition [16]. Sun et al. (2016) thus canvassed generative models for face recognition while emphasizing on the possibilities of improving model stability [17]. The approach of contrastive learning was proposed by Chen et al. (2017) to enhance face recognition with less amount of supervision than before [18]. In the same year, He et al. brought out Momentum Contrast, a way of learning visual representations without labels and that extended deep learning [19]. Zhang et al. (2018) highlighted the issues and research agenda for bringing explainability to face recognition AI by emphasizing the model's open nature [20]. Nandakumar et al. (2019) made a study on multimodal biometrics, suggested ways on improving the reliability of the system through several biometric modalities [21].

This innovation has seen new developments continue to be made in the face recognition technology. Liu et al. (2020) proposed Swin Transformer to better exploit the features by using hierarchical vision transformers [22]. Chen et al. (2020) looked at self-supervised learning for face recognition and specifically on how they help to address the dependency on labeled data [23]. Goodfellow et al. (2021) used the GANs that improve the resistance of face recognition systems to adversarial perturbations [24]. In their article published in 2022, Zhang et al. included a discussion on their work and review the role of deep convolutional neural networks in face recognition [25]. Li et al. (2023) investigated the future of surveillance with the focus on the face recognition technologies in the efforts to improve public security [26]. In the explanation of the current situation and possible future developments concerning explainable AI in face recognition systems, Zhang et al. (2024) resumed the discussion [27].

V. IMPLEMENTATION AND SOFTWARE TOOLS

There is need to develop reliable and effective software tools and frameworks for the deployment of face recognition systems. There is a list of tools and libraries that brought support for full-face recognition system development and deployment. For instance, OpenCV is used for image analysis and computer vision with classical approaches such as the Haar cascades and deep learning integrated [30]. Another important tool is Dlib, a library that is designed for machine learning and image processing and which possess the so important for face alignment 68-point facial landmark detection algorithm [31]. The deep learning-based frameworks are TensorFlow and Keras: FaceNet [32] works well with TensorFlow-Keras; the PyTorch is flexible to support models like VGGFace2 and ArcFace [33].

VI. CONCLUSION

Face recognition as a technology has come a long way from over the past few decades starting from only geometric models to the advanced models based on deep learning. Its uses are versatile they can be used to carry out security and surveillance, social media, consumer electronics among others. Nevertheless, problems persist, for example, privacy, potential biases in the accuracy of recognition, and sensitivity to adversarial interference. The development of these techniques is expected to be future research directions in the improvement of the reliability, fairness, and the interpretability of these systems [32][33]. Due to the advancement of biometric authentication, physical authentication will be integrated into the present day complex technological systems, enhancing the advancement of many industries.

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