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Ocular biometrics: A survey of modalities and fusion approaches

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ABSTRACT

Biometrics, an integral component of *Identity Science*, is widely used in several large-scale-county-wide projects to provide a meaningful way of recognizing individuals. Among existing modalities, ocular biometric traits such as iris, periocular, retina, and eye movement have received significant attention in the recent past. Iris recognition is used in Unique Identification Authority of India's Aadhaar Program and the United Arab Emirate's border security programs, whereas the periocular recognition is used to augment the performance of face or iris when only ocular region is present in the image. This paper reviews the research progression in these modalities. The paper discusses existing algorithms and the limitations of each of the biometric traits and information fusion approaches which combine ocular modalities with other modalities. We also propose a path forward to advance the research on ocular recognition by (i) improving the sensing technology, (ii) heterogeneous recognition for addressing interoperability, (iii) utilizing advanced machine learning algorithms for better representation and classification, (iv) developing algorithms for ocular recognition at a distance, (v) using multimodal ocular biometrics for recognition, and (vi) encouraging benchmarking standards and open-source software development.

1. Introduction

With the increasing requirement of establishing the identity of individuals, a number of identity programs are being instituted across the globe. Therefore, the design of accurate and robust methods for identity recognition has become a very important research challenge. Traditional approaches rely on the use of identification cards, passwords, or PINs to determine or verify one's identity. However, due to several challenges associated with traditional methods such as the ease to forge or forget, use of biometrics is gaining significant importance. Biometrics refers to the use of physiological and behavioral characteristics of humans for establishing their identity. Among physiological characteristics, several body parts have been studied that demonstrate biometric properties such as universality, uniqueness, permanence, and collectability. It has been observed that the ocular region, including iris, is one of the most stable ones and can be effectively used for recognition [1].

The field of ocular biometrics has undergone significant progress in the last decade. Researchers have developed a number of techniques to leverage the information present in the ocular region. Ocular region is an important and interrelated system (organ) that consists of several subsystems such as cornea, lens, optic nerve, retina, pupil, iris, and the periocular region. Out of these, iris, periocular, retina, and sclera have been well studied for being potential biometric modalities (Fig. 1). Related research started with iris recognition in 1987 [2], followed by sclera [3], retina [4], and then periocular recognition [5] in 2009. A number of noteworthy contributions have been made to improve the state-of-the-art in ocular related biometrics. Currently, there are several identification and verification systems in deployment that use one or more of these ocular biometric modalities. For instance, the United Arab Emirate's immigration program, deployed in 2001, uses iris recognition for frequent travelers [6]. Retina recognition is being used in high security military and nuclear instalments [7].

After decades of research in individual biometric modalities by the research community, it is observed that none of the individual modalities can satisfy every biometric characteristic at every point in time. For instance, fingerprint of laborers and farmers and iris patterns of individuals suffering from certain eye diseases can change over time. To address such instances, researchers and practitioners have proposed multi-modal fusion or selection of biometric modalities to improve the recognition performance [8]. The Aadhaar program in India is using iris and fingerprint for de-duplication and verification [10]. Office of Biometric Identity Management (OBIM), formerly US-VISIT, is using fingerprints and face for recognition [11]. Therefore, the current best practice is to combine or fuse multiple modalities for improved coverage and performance. Under the same principle, ocular modalities are also

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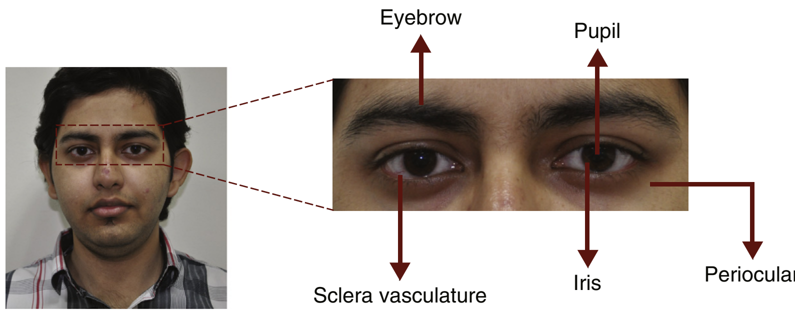

Fig. 1. Ocular biometric modalities.

combined with other ocular and non-ocular modalities for improved performance.

In this survey article, we review the advancements made in individual ocular biometric modalities and the research that has been conducted in combining multiple ocular modalities or ocular and other non-ocular modalities. The advancements and developments are measured in terms of the contributions provided to higher recognition performance, to higher computational efficiency, and to the collection of databases that help researchers in addressing interesting and important challenges which continue to emerge. Therefore, the paper summarizes the contributions in terms of both technologies and databases prepared. Section 2 provides a review of technical contributions made in individual ocular biometric modalities and Section 3 summarizes the contributions in terms of combining multiple ocular biometric modalities. Section 4 summarizes publicly available databases related to ocular biometric modalities. Section 5 discusses the authors' view of the path forward in ocular biometrics – where the technology should be heading to improve recognition performance.

2. Ocular biometrics

As discussed earlier, multiple biometric modalities have been established in the ocular region. This section presents a detailed summary of the research conducted in the field of ocular biometrics between 2010 and 2014.[1] Section 2.1 presents a comprehensive survey of iris biometrics, Section 2.2 explores the advances in periocular biometrics, Section 2.3 covers the work done in the field of retina biometrics, and Section 2.4 summarizes several emerging ocular modalities.

2.1. Iris

Ocular biometrics has become an established biometric trait, primarily due to the extensive efforts made by the biometrics community in the field of iris recognition. The possibility that the iris may be used as an optical fingerprint was first explored by Flom and Safir [2]. Since then, it has evolved into a reliable biometric trait and has been explored extensively by the biometric research community. The popularity of iris biometrics has resulted in the large-scale deployment of commercial and public iris recognition systems around the world. One of the foremost examples of such a system includes the Aadhaar Unique Identification Authority of India (UIDAI) Program [10], which performs approximately 100 trillion iris matches everyday.

Daugman's IrisCode algorithm [14] has served as the basis for a number of efforts made by researchers in the biometrics community. The feature descriptor consists of a compact sequence of multi-scale quadrature 2D Gabor wavelet coefficients. In [15], Daugman analyzes the statistical variability which forms the basis of iris recognition. The principle driving the algorithm is the failure of a test of statistical independence on the iris sample image encoded by multi-scale quadrature wavelets as discussed in [14]. The combinatorial complexity of this method of information description across individuals spans approximately 249 degrees-of-freedom. It generates a discrimination entropy of about 3.2 bits/mm^2 over the iris such that it enables real-time identification to support exhaustive searches through very large databases. In [16], Daugman presents (1) several advances towards the IrisCode algorithm for iris recognition: more accurate detection and modeling of iris boundaries with active contours, (2) statistical inference methods for detecting and excluding eyelashes, and (3) the possibility of employing score normalizations, depending on the amount of valid iris data available.

Kong et al. [17] also analyze the IrisCode algorithm. The study proves the equivalent relationship between bit-wise hamming distance and bit-wise phase distance and studies the role of the Gabor function as a phase-steerable filter. These studies lead up to the most significant contribution of the paper, which is the precise phase-representation algorithm for iris recognition. Experiments conducted on the WVU Iris database show precise phase representation is more accurate than IrisCode, though its computation time is considerably longer. The authors propose that the precise phase representation may be considered as a flexible representation for balancing the trade-off between matching speed and identification accuracy.

As shown in Fig. 2, the flow of information in an iris recognition system can be organized as acquisition, preprocessing, segmentation, feature extraction, and matching. Section 2.1.1 reviews iris acquisition in visible light and near infrared light. Section 2.1.2 presents the various preprocessing techniques developed for treating iris images and improving recognition performance. Section 2.1.3 examines the segmentation methodologies that have evolved to handle ideal as well as non-ideal iris images. A brief overview of feature selection techniques is provided in Section 2.1.4. Publications focusing on matching and indexing of iris templates are surveyed in Section 2.1.5. The emerging field of non-ideal iris recognition and associated methodologies are presented in Section 2.1.6.

2.1.1. Acquisition

Researchers have explored multiple kinds of acquisition techniques in iris recognition. These techniques vary in spectrums, devices, and also the distances at which the images are captured. Early research in iris recognition relied exclusively on the acquisition of high-resolution iris images. Daugman [14] proposed the use of the Near Infrared (NIR) spectrum in the wavelength range 750–950 nm for iris acquisition. The evolution of sensor technology has permitted greater flexibility in the development of acquisition modalities. Some recent advances in iris acquisition systems have

[1] For a literature review prior to 2010, readers are referred to [12,13].