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On guided model-based analysis for ear biometrics

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ABSTRACT

Ears are a new biometric with a major advantage in that they appear to maintain their structure with increasing age. Current approaches have exploited 2D and 3D images of the ear in human identification. Contending that the ear is mainly a planar shape we use 2D images, which are consistent with deployment in surveillance and other planar-image scenarios. So far ear biometric approaches have mostly capitalized on general properties and overall appearance of ear images, and the details of the ear structure have been little discussed. Using the embryological studies of the ear development, which reveal a component-wise structure for the ear, we propose a new model-based approach. Our model is a part-wise description of the ear derived by a stochastic clustering on a set of scale invariant features of a training set. We further extend our model description, by a wavelet-based analysis with a specific aim of capturing information in the ear's boundary structures, which can augment discriminant variability.

In recognition, ears are automatically enroled and then recognized via the parts selected by the model. The incorporation of the wavelet-based analysis of the outer ear structures forms an extended or hybrid method. By results, both in modelling and recognition, our new model-based approach does indeed appear to be a promising new approach to ear biometrics. Recognizing the occlusion by hair as one of the main obstacles hindering the deployment of ear biometrics, we have specifically chosen our techniques to provide performance advantages in occlusion. We shall present a thorough evaluation of performance in occlusion, using a robust PCA for comparison purposes. Our new hybrid method does indeed appear to be a promising new approach to ear biometrics, by guiding a model-based analysis via anatomical knowledge.

1. Introduction

The French criminologist Alphonse Bertillon was the first to recognize the biometric potential of human ears in 1890 [5]. He incorporated features from the ear in his 'spoken portrait' method for forensic identification. Empirical evidence supporting the ear's uniqueness was later provided by Iannarelli, who examined over 10,000 ear samples and developed a manual system for ear identification [20]. Despite the longstanding evidence of uniqueness of ears, machine vision approaches to ear identification are relatively new. Burge and Burger [7] were amongst the first to introduce an automatic ear biometric method. Current approaches have exploited 2D and 3D images of the ear in human identification.

Ears have appealing properties for personal identification: they have a rich structure that appears to be consistent throughout life from a few months after birth; clearly, ears are not affected by changes in facial expression; images of ears can be acquired without the subject's participation, with no hygiene issues; and ear images can be captured from a distance. However there exists a big potential obstacle—the occlusion by hair and earrings, which is almost certain to happen in uncontrolled environments.

One of the first ear biometric systems was introduced by Burge and Burger [7]. They modelled each individual ear with an adjacency graph which was calculated from a Voronoi diagram of the ear curves. However, they did not provide an analysis of biometric potential. Hurley et al. [19] used force field feature extraction to map the ear to an energy field which highlights 'potential wells' and 'potential channels' as features. Achieving a recognition rate of 99.2% on a dataset of 252 images. Naseem et al. [28] have proposed the use of sparse representation, following its successful application in face recognition. The geometrical properties of ear curves have also been used for recognition [11,27]. The most prominent example of these, proposed by Iannarelli [20], was based on measurements between a number of landmark points, determined manually. These methods are primarily reliant on accurate segmentation and positioning of the landmarks. Bustard and Nixon [8] have recently proposed a robust registration technique for 2D ear images addressing problems such as pose variation and clutter.

The 3D structure of the ear has also been exploited, and good results have been obtained [10,30,39]. Yan and Bowyer [39] captured

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and segmented the 3D ear images and used Iterative Closest Point (ICP) registration to achieve a 97.8% recognition rate on a database of 415 individuals. Chen and Bhanu [10] proposed a 3D ear detection and recognition system. Using a local surface descriptor and ICP for recognition, they reported recognition rates of 96.8% and 96.4% on two different data sets. Although using 3D can improve the performance, using 2D images is consistent with deployment in surveillance or other planar image scenarios.

PCA has been used regularly in ear biometric research [9,38,19] and it obtains satisfactory results in controlled environments. Other statistical methods such a ICA and LDA have also been utilized [40,37]. However these methods have almost no invariance properties, thus they rely on the acquisition and pre-processing stages to window and align the data. In related studies Akkermans et al. [1] developed an ear biometric system based on the acoustic properties of the outer and middle ear. This introduces a unique opportunity for ear biometrics to combine the image-based information with acoustic data. A survey of ear biometrics has been recently provided by Hurley et al. [18].

Despite various approaches to ear biometric recognition, the structure of the ear has not been explicitly understood, and discriminant features have not been identified. Current approaches, which are mainly holistic, capitalize on general properties and overall appearance of the images. Since the ear is mainly a planar shape we use 2D images, which are consistent with deployment in surveillance and other planar-image scenarios. By evidence from the embryological development of the ear, we propose that the ear is better described as a composite structure of separate parts. We thereby propose a new model-based approach, in which our ear model is a constellation of various ear components. Ear embryology studies attribute individual growth centres to the development of the ear, apportioning various components to the ear's complex structure. Even though there is no direct evidence to sustain the link between ear development and automated recognition, it can guide our approach and provide a basis for explicit evaluation of the proposed method.

Our model is the first model-based approach to ear biometrics. The deployment advantages of a model include robustness in noise and occlusion, which is particularly favourable since images of the ear are susceptible to occlusion, mostly by hair. Extending our model description, we also propose a new wavelet-based analysis which explores the fluctuations in the two parallel ridges of the ear boundary. We shall illustrate that the information residing in these curves has only been partially explored by the model. By localization, a wavelet can also offer performance advantage when handling occluded data. Results from both modelling and recognition indicate that our new hybrid method does indeed appear to be a promising new approach to ear biometrics.

We shall discuss the components and the variations of the ear structure in Section 2. The material discussed in this section is mainly derived from embryological and surgical accounts of the human ear, revisited from a new perspective, to be exploited in ear biometrics. In Section 3, we shall present our new parts-based model for ear biometrics. Our model is learned via a stochastic clustering algorithm on a set of scale invariant features detected on the training set. Extending our model description, in Section 4, we propose a new wavelet analysis. A specific aim of this analysis is to capture information in the ear's outer structures, which have been under-represented in the model. The variations between the boundary curves are explored using log-Gabor filters. In Section 5, starting with the description of the database, we shall present extensive performance analysis. We shall specifically focus our attention on assessing the effects of occlusion, where the performance is compared with PCA and a robust PCA. Finally, overall conclusions are reviewed and potential future work avenues are discussed.

2. Ear features – a biological insight

The formation of the ear in the human embryo is commonly discussed as the individual development of separate components. Identifying those components which compose the complex structure of the human ear has been the main concern of ear embryology studies. This is the reason for our interest in ear embryology – the premise of local and independent structures within the auricle is appealing to our classification purpose. Ear embryology has not been previously studied in this context. We start by reviewing the terminology of the ear's anatomy.

2.1. Ear terminology

Fig. 1 shows the common terminology of the external ear. The most prominent part is the ear's outer rim called the helix, which merges into the lobe at the bottom. The antihelix is the rounded brim of the concha, which runs almost parallel to the helix. It forks into two branches at the top, forming the superior and the inferior cruses of antihelix. The concha is a shell-shaped cavity, which merges into the incisura. The incisura has two small bumps on either side named the tragus and the antitragus. The concha is divided into two parts by the crus of helix which is the horizontal part of the helix.

2.2. Ear embryology

The initial appearance of the external ear in the human embryo is in the shape of six individual hillocks in the fifth week of the embryonic life [33]. These hillocks progress and coalescence give the final shape of the auricle. Fig. 2a shows a drawing of a six week old embryo with its auricular hillocks numbered. As illustrated in Fig. 2b, the external ear originates from the tissue of the mandibular and the hyoid arches, which are separated by a cleft, which gives rise to the external auditory canal.

Much of the literature regarding the ear formation is concerned with identifying the contributions from each of these six hillocks, and though they were first observed by His in 1882 [33], there is still disagreement as to the precise embryology of the external ear. Fig. 3 summarizes the suggested arrangements by different authors, apportioning different hillocks and combinations to ear formation.

The main disparities in these arrangements seem to be in Wood-Jones and Chuan [36] arrangement, where it assigns three

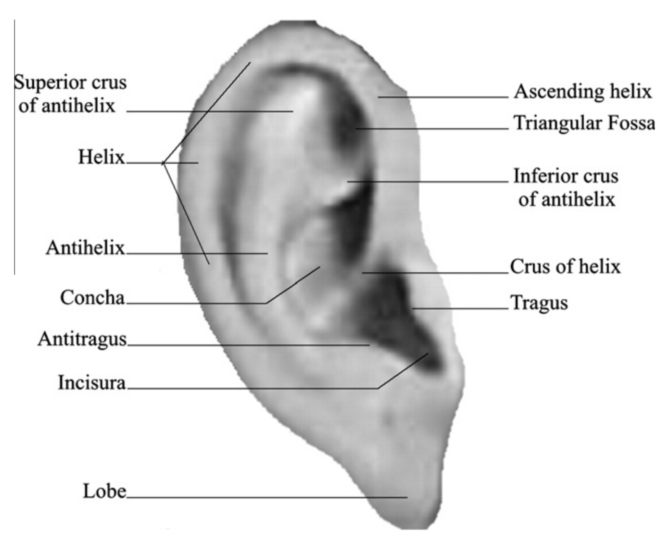

Fig. 1. The terminology of the ear.