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3D face recognition using covariance based descriptors[☆]

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ABSTRACT

In this paper, we propose a new 3D face recognition method based on covariance descriptors. Unlike feature-based vectors, covariance-based descriptors enable the fusion and the encoding of different types of features and modalities into a compact representation. The covariance descriptors are symmetric positive definite matrices which can be viewed as an inner product on the tangent space of (Sym_d^+) the manifold of Symmetric Positive Definite (SPD) matrices. In this article, we study geodesic distances on the Sym_d^+ manifold and use them as metrics for 3D face matching and recognition. We evaluate the performance of the proposed method on the FRGCv2 and the GAVAB databases and demonstrate its superiority compared to other state of the art methods.

1. Introduction

Face recognition is one of the biometric techniques frequently used in security systems. It offers several advantages over other biometric methods as stated in [15]. Face recognition can be used in two different scenarios: verification and identification. In verification, the system compares an input face to the “enrolled” face of a specific user to determine whether they are from the same person (one to one match). In identification, the system compares an input face with all the enrolled users faces in the database to determine if the person is already known under a duplicate or false identity (one to all match).

Although research in automated 2D face recognition has been conducted long time ago, it has only recently caught the attention of the scientific community. Several methods and reviews on face recognition techniques have been published in the literature during the past ten years [1,5,15,41,43]. Besides these efforts, face recognition using 2D images is still not reliable enough, especially in the presence of variations in the pose and/or illumination of subjects. [4] constructed a 3D morphable model with a linear combination of the shape and texture of multiple exemplars. Their model was fitted to a single 2D image to obtain the individual parameters, which were used to characterize the personal features. Creating several synthetic faces could be an efficient solution to overcome the issue of pose invariance in 2D face recognition, but the important characteristics of a 3D model, such as shape details, can not be generated from one single 2D picture. The recent developments in 3D imaging systems have brought an important alternative to overcome unsolved problems in 2D face recognition.

The 3D facial data provide naturally more information on the characteristics of the human face which are likely to improve the performance of recognition systems. The main advantage of the 3D based approaches is that the 3D model retains all the information about the face geometry. The simplest 3D face representation is a 3D polygonal mesh, that consists of a set of points (vertices) connected by edges (polygons). There are many ways to build a 3D mesh, the most widely used being: (i) to combine several 2.5D images, where a 2.5D image is a simplified three-dimensional surface representation which contains one depth (z) value for every point in the (x, y) plane, (ii) to properly tune a 3D morphable model or (iii) to make use of a 3D acquisition system (3D scanner). Similarly to 2D face models, 3D face models experience variations in pose, illumination, facial expressions, and aging. The main challenge is then to propose methods using low dimensional feature representation, with enhanced discriminating capability.

1.1. Related works

3D face recognition techniques can be classified into three categories, depending on the type of features they use: global based, local based and hybrid methods.

The global based methods use the holistic face surface as an input to compute similarity measures between faces. Kamencay et al. [16] proposed a 2D-3D face-matching method based on a principal component analysis (PCA). They use a

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canonical correlation analysis to learn a mapping between 2D and 3D face images. Another 3D face recognition algorithm is proposed by Xu et al. [40] using 3D eigenfaces. First, they build a 3D mesh model from point cloud, and deduce the 3D eigenfaces from the mesh models using a PCA. Finally, they apply the k-nearest neighbor algorithm to perform recognition. Tsalakanidou et al. [33] proposed a face recognition technique based on the implementation of the principal component analysis algorithm and the extraction of depth and colour eigenfaces.

The local based methods firstly detect landmarks or representative facial regions and then use these landmarks/regions to compute similarity measures between faces. Gupta et al. [12] proposed a method based on anthropometric facial fiducial points. Using the points which are associated with discriminatory anthropometric features, they develop an automatic face recognition algorithm that employs facial 3D Euclidean and geodesic distances and a linear discriminant classifier. Mian et al. [20] presented a feature-based algorithm for the recognition of textured 3D faces. They proposed a keypoint detection algorithm which can repeatably identify locations on a face, and measure similarity between them through their graphs. Perakis et al. [24] proposed a method that treats the partial matching problem, using a 3D landmark detector to detect the pose of the facial scan and a deformable model framework which supports symmetric fitting.

Curve feature based methods belong also to the class of local based methods, and use discriminative surface curves extracted from facial representation as local features. For instance, Drira et al. [10] proposed a geometric framework for analyzing 3D faces. They proposed to represent facial surfaces by radial curves emanating from the nose tips and use elastic shape analysis of these curves to compare faces. Another framework proposed by Heseltine et al. [13] for 3D face matching allows profile and contour based face matching. In their approach, they evaluate profile and contour types, and select subsets of facial curves for face matching. The level curves of a depth function is proposed by Samir et al. [27] to represent 3D facial surfaces using a differential geometric approach which computes geodesic distances between these closed curves on a shape manifold.

The hybrid methods combine global and local features. Among hybrid based approaches, Taghizadegan et al. [32] presented a 3D face recognition method which uses the nose tip as a reference point, and employs two dimensional PCA to obtain features matrix vectors. An Euclidean distance method is employed for classification. Huang et al. [14] presented a method for 3D face recognition using a multi-scale extended Local Binary Patterns as facial descriptors along with a local feature hybrid matching scheme. To combine local and holistic analysis, they used SIFT based matching.

1.2. Contributions of the paper

Recently the image analysis community has shown a growing interest in characterizing image patches with the covariance matrix of local descriptors rather than the descriptors themselves. Covariance methods have been successfully used for object detection and tracking [35], texture [34] and image classification [37]. Motivated by their success in image analysis, in this paper, we propose a 3D face recognition method based on covariance descriptors as an extension of covariance based descriptors presented in [31] for 3D shape retrieval. This article explores the usage of covariance matrices of features as discriminant representation for 3D face recognition problems. Our idea is to represent a 3D face with a set of *m* landmarks selected from its surface. Each landmark has a region of influence, which we characterize by the covariance of its geometric features instead of directly using the features themselves. These features, each of which captures some properties of the local geometry, can be of different type, dimension or scale. Covariance matrices provide a mean for their aggregation into a compact representation, which is then used for computing distances between 3D faces. Covariance matrices, however, lie on the manifold of Symmetric Positive Definite (SPD) tensors (Sym_d^+). Therefore, matching with covariance matrices requires the computation of geodesic distances on the manifold using proper metrics. Several geodesic distances on the Sym_d^+ manifold have been studied. Once we have chosen the appropriate metric, the next step is to establish covariance matches between 3D faces and compute a global similarity measure. Two different strategies are proposed. The first strategy is to compute optimal match using a Hungarian solution for matching unordered set of covariance matrices. The total cost of matching is used as a measure of dissimilarity between the pair of 3D faces. The second strategy is to compute a mean distance by integrating the chosen metric over the pairs of homologous regions, after spatial registration of the 3D faces. Our experiments conducted on two different 3D face datasets demonstrate the performance of the proposed method compared to state of the art approaches.

The remainder of the paper is organized as follows. In Section 2, the method is detailed. Then, in Section 3 the experiments are presented. Conclusions and future developments end the paper.

2. The proposed 3D face recognition system

Fig. 1 gives an overview of the proposed 3D face recognition method. After the acquisition step, the input face surface is preprocessed. The preprocessing helps improving the quality of the input face which may contain some imperfections as holes, spikes and includes some undesired parts (clothes, neck, ears, hair, etc.) and so on. It consists of applying successively a set of filters (Fig. 2). First, a smoothing filter is applied, which reduces spikes in the mesh surface, followed by a cropping filter which cuts and returns parts of the mesh inside an Euclidean sphere. Finally a filling holes filter is applied, which identifies and fills holes in input meshes. Note that spikes mainly occur in three regions: the eyes, the nose

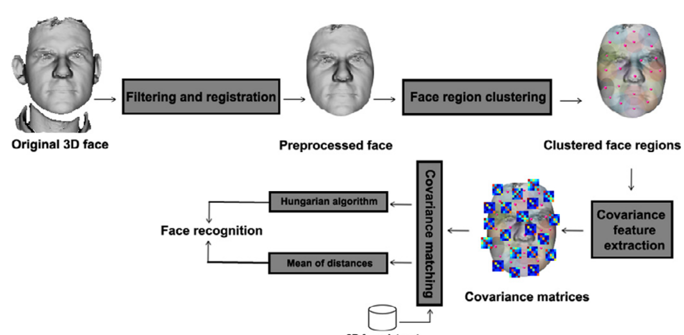

Fig. 1. Overview of the proposed framework.

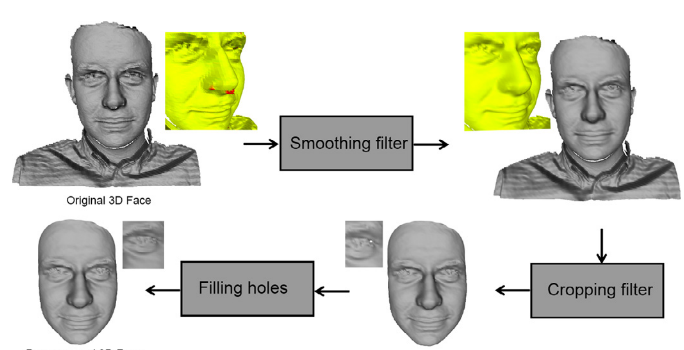

Fig. 2. Automatic 3D face preprocessing.