Shape-contexts: automatic computation of 3D landmarks applied to the generation of an atlas of the knee

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Introduction

Spatial normalization of medical images has become essential to make meaningful comparisons between images from different subjects, and the normalization of brains to the Talaraich space is probably the most widely known example. In the process of generating a standard space as well as in the generation of statistical shape models, the establishment of corresponding landmarks is required. This task is usually performed manually by an expert although automatic approaches have also been explored for the brain.

Common manifestations of osteoarthritis (OA) of the knee are the morphological and molecular degenerations of articular cartilage, and magnetic resonance imaging (MRI) has become the imaging modality of choice to characterize these changes. As with brain pathologies, in addition to follow-up studies, the comparison of different subject populations is becoming a necessity. To accomplish this goal the generation of an atlas is required as well as proper algorithms to establish corresponding points between shapes, since difficulties arise when manually identifying suitable landmarks on rounded surfaces. The purpose of this work is twofold: 1. to present 3D scale-rotational-translational invariant *shape-contexts* [1] as a robust landmarking technique, and 2. to generate an atlas of the knee.

Materials and Methods

Sagittal MR images of 6 human subjects were acquired at 1.5 Tesla on a GE scanner (GE Medical Systems, Milwaukee, WI) with a 3D fat-suppressed SPGR sequence, in-plane resolution of 0.23 mm x 0.23 mm, and slice thickness of 2 mm. Femoral cartilage was segmented using a semi-automatic segmentation technique based on edge-detection and Bezier spline interpolation, and shape-based interpolation was performed for creating isotropic voxels to compute 3D cartilage thickness maps based on minimum Euclidean distances (ED). Femora were segmented with a similar technique and their surfaces were represented by discrete points. In order to find corresponding landmarks between different femora, normal vectors to the surfaces were computed (Fig. 1a). Points in the surfaces were then uniformly sampled and 3D *shape-contexts* (Fig. 1b) where used to represent their shapes as 3D polar histograms of neighboring points. The *x*-axis of each 3D *shape-context* was aligned to the corresponding normal vector. 3D *shape-contexts* are translational invariant; normalization by mean distances makes them scale invariant; and rotational invariance is fulfilled by using the normal vectors as the *x*-axis. The χ^2 test statistic, an effective and simple measure of histogram similarity, was then used as a landmark matching cost and point matching was computed based on the Hungarian method [2] to minimize this cost.

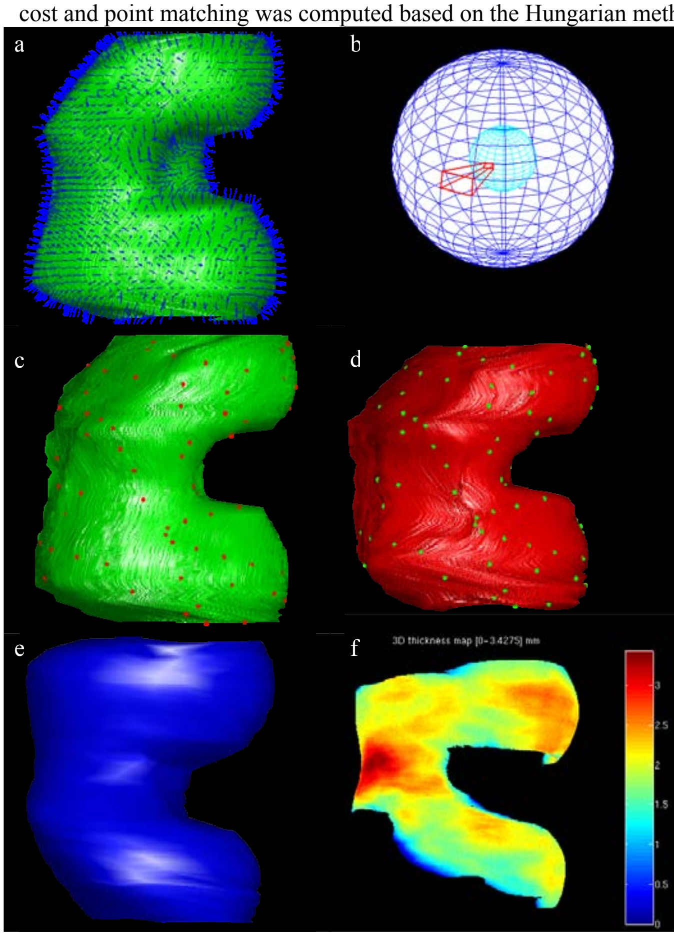

Fig. 1 (a) Femoral normal vectors. (b) Graphical representation of a bin in a 3D *shape-context*. (c) Target femur and landmarks. (d) Source femur and landmarks. (e) Mean femoral shape. (f) Mean cartilage thickness map.

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To register the femora, affine [3] as well as warping [4] transformations were performed based on the computed landmarks, and a larger set of bone landmarks was obtained based on minimum ED. The corresponding affine and warping transformations that were computed for the bone structures were applied to the cartilage surfaces (bone-cartilage and articular), and cartilage landmarks were computed based on minimum ED. The original femora were then iteratively aligned to create a mean femoral shape as suggested by Cootes et al. in [5], and Principal Component Analysis was performed to compute the modes of variation. The alignment of cartilage surfaces followed that of the femora and a mean cartilage thickness map was generated. For validation purposes of the scale, translational and rotational invariance properties of 3D *shape-contexts* additional experiments were performed. In these experiments rotations in the three axes, as well as scaling and translations were applied to the femora prior to computation of landmarks.

Results

3D scale-rotational-translational invariant *shape-contexts* were able to compute plausible landmarks in all the experiments as is depicted in the example of Fig. 1c and 1d where corresponding landmarks of two femora are shown. Fig. 1e shows the computed mean femoral shape and Fig. 1f the mean femoral cartilage thickness map. Examples of new shapes generated by the computed shape parameters (eigenvalues and eigenvectors) are not shown.

Discussion

If corresponding regions of interest are required for the comparison of different cartilage properties of different populations of patients with OA of the knee, then an atlas of the knee is required. In this work we have presented a 3D automatic scale-rotational-translational invariant technique to compute corresponding landmarks of 3D shapes, and we have applied it to generate a femoral statistical shape model and a mean femoral cartilage thickness map. However the same technique could be applied to generate other mean shapes, as well as mean maps of different cartilage properties such as MR T2 relaxation times. Future work requires a larger training set, and the generation of different atlases based on the Kellgren-Lawrence scale.

References

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