Clustering of deformation modes for quantitative evaluation of statistical shape models

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Introduction: Factor Analysis (FA) techniques used in statistical shape modelling have proven to be useful to improve efficacy and accuracy in computer-assisted orthopaedic surgery applications (e.g., [1, 2]).
One aspect that currently prevents full exploitation of these techniques is their evaluation, with current analyses being based in more or less intuitive aspects (e.g., visual inspection), the outcome is dependent on the observer. Furthermore, the 3D characteristic of the data makes difficult the analysis of results, which is important when one wants to compare results from different FA-based techniques [3].
In this work we present a technique to segment regions that present homogeneous or similar direction of deformation, in an effort to characterize and quantify results from factor analysis techniques. The clusterization technique is based on the minimization of an energy composed by two terms: a first term based on the colinearity between point directions and the preferred direction of a given cluster (a concept similar to the average direction across the cluster), and a second term that considers the area gain when adding a candidate point to a cluster. A weighting parameter allows to adjust the trade-off between the amount of colinearity one searches across a cluster and its area growth. The method is inspired in the work presented in [4], which was built for vector field segmentation of moving objects. In addition, following some key ideas presented in [5] the method is adapted to an unstructured 3D displacement vector field across a surface.

Methods: Computerized Tomography (CT) images of 33 human left femurs were used to build a statistical shape model based on a Principal Component Analysis (PCA) and a Principal Factor Analysis (PFA). For each case, and for each mode i of deformation, a vector field was obtained as the point differences $v^j_a-v^j_b$, with $v^j_a=\overline{v^j}-K\Phi_i$, $v_b=\overline{v^j}+K\Phi_i$, with $\overline{v^j}$ the mean position of point j, Φ_i the corresponding i-th eigenvector or principal factor (see [3] for more details), and K a positive constant.
Then, the clusterization technique was applied to each vector field describing each preferred mode of deformation. Initially, a seed point is chosen arbitrarily to start the algorithm. Later, this seed was changed within the cluster in order to check the sensitivity of the method to this parameter. Once the algorithm stops (i.e., all cells in the mesh have been inspected) the clusters are sorted by size and for each the preferred deformation direction is saved for further visualization .

Results: For both PCA and PFA-based statistical shape models, the first mode of deformation presents one main cluster describing the deformation of the bone in its longitudinal direction. More interesting were the second and third modes. For the second mode, both PCA and PFA describe a deformation of the femoral head. However, PFA clusters are bigger, meaning that the PFA decomposition is more homogeneous than the one obtained with PCA. The same homogeneity behaviour was observed after clusterization of the third mode. However, the interpretation of this mode is harder, with

smaller and more spread clusters, giving indication of more local deformations than the second mode. This result was expected and agreed with previous studies [3].
Sensitivity of the algorithm under variation of the position of the seed was tested as well. After varying the seed point position no noticeable change of area and/or position of the clusters was detected.

Discussion: The proposed method presents itself as a tool to quantify and to better determine the extent to which a given mode of deformation acts. This is very important in applications where one wants to parameterize the magnitude and location of shape variability of a certain area within a structure. This is the case for image-free surgery based on statistical shape models, where being able to precise the extent where a certain shape deformation takes place helps to improve the application of these technologies. Finally, it was remarked the ability of the proposed method to ease the evaluation of different FA techniques, in a scenario where the three-dimensionality of the data hinders an evaluation based only on qualitative analyses.

References

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