A Two-level Method for Building a Statistical Shape Atlas

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INTRODUCTION

A statistical anatomic atlas has many applications, such as visualizing and analyzing the inner anatomic structures, 2D-3D and 3D-3D registration, registration-based segmentation, surgical planning and navigation. Due to genetic, sex and life-style factors, there are inherent non-pathological differences in the appearance and location of anatomic structures between individuals. Surface mapping, i.e., registration of one mesh topology to multiple shape variations, is fundamental to the building of an atlas.

One important challenge in the creation of statistical anatomic atlases is dealing with the size and geometrical complexity of anatomical shapes such as the femur and pelvis, and hence the associated computational requirements for speed and memory. We present a two-level method for the construction of a statistical atlas. The problem is broken into two parts: a low-resolution solution to the correspondence and mapping of surface models, followed by a high-resolution interpolation and alignment to return to a full-featured shape-space. The most difficult step is determining the correspondence and mapping. We use Chui and Rangarajan's[1] non-rigid registration based on fuzzy correspondence and thin-plate splines (TPS-RPM) to parameterize the non-rigid transformation problem. This two-level method is utilized in the building of a statistical atlas of the femur.

METHODS

The data for atlas creation are comprised of surface models of triangular meshes derived from volumetric CT scans. The starting femur surface models have roughly 60,000 vertices (100,000 triangles). We first generate low-resolution surface models for all our data using Garland's mesh simplification technique[2]. Next, we register each study surface model with respect to a reference surface model using Chui and Rangarajan's TPS-RPM method. TPS-RPM warps the reference model to each study model to get a corresponding point set on the study surface by minimizing the residual sum of squares of the distances. The resulting surface model has the same dimension and topology as the reference model and the approximate shape of the study model. After that we refine the correspondence between study surface and the reference surface by locating more precisely the vertices on the warped reference surface with respect to the vertices of the study surface. Then we use radial basis functions[3] (RBF) to migrate from low to high-resolution. RBF allows us to interpolate the low-resolution models to a higher resolution from the correspondence solution of the low-resolution model. Finally, we refine the correspondence for the high-resolution models as we did the low-resolution models. This sequence is repeated independently for each dataset in the atlas population.

Once we align the topology of all the high-resolution surface models, we define the atlas as a three-dimensional cloud of points and apply principal component analysis (PCA) to solve for the eigenvectors of the atlas.

RESULTS

The atlas population consists of 87 femur surface models. The surfaces are from 53 male and 34 females; 43 are left femurs and 44 are right femurs. The original CT images do not include the whole femur but only the mid-to-proximal femur and the distal femur containing the condyles. In the pre-processing step, we distribute the triangles into the two parts based on relative height of the femur and its parts. To improve the performance, we applied the registration to the femoral head and condylar surfaces separately. In our experiments, the low-resolution condylar surfaces have, on average, 120 vertices (230 triangles), and the femoral head surfaces have 320 vertices (640 triangles). The high-resolution condylar surfaces have 22,000 vertices (45,000 triangles); the femoral heads have 40,000 vertices (78,000) triangles. Thus we can handle more than 60,000 vertices and 100,000 triangles for each femur model.

The TPS-RPM step takes about 2 minutes and the RBF step takes 8 seconds running in Microsoft Visual Studio 6.0 on an Intel Pentium 4 CPU, 2.40 GHz, with 1.00 GB of RAM.

DISCUSSION

Our work focuses on a new methodology for building a statistical atlas from the huge dimension data using a hierarchic approach. Our two-level approach decreases the computational complexity and improves the speed while using less memory.

REFERENCES

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