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DISCLAIMER

AUTOMATED VOLUMETRIC GRID GENERATION FOR FINITE ELEMENT MODELING OF HUMAN HAND JOINTS

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ABSTRACT

We are developing techniques for finite element analysis of human joints. These techniques need to provide high quality results rapidly in order to be useful to a physician. The research presented here increases model quality and decreases user input time by automating the volumetric mesh generation step.

INTRODUCTION

We are developing techniques for finite element analysis of human joints. In particular, we aim to provide the tools for modeling the structural dynamics of joints, based on patient-specific imaged data and on material models for biological tissues. Motivation for this research lies in the areas of computational medicine and biology as well as in computer science: Future generations of the types of tools developed here will be useful in clinical diagnosis and treatment planning and evaluation, and in modeling general orthopedic systems. In addition, we face research issues relating to automating processes and parallelizing code to run in "reasonable" time, so that the tools may become useful in the clinical as well as the research setting. A number of other researchers share our general objectives in pursuing these research goals [1, 2, 3].

Tools that are developed here need to provide high quality results rapidly in order to be useful to a physician. Two main issues are run time and user input time. We focus here on user input time, which can be minimized by automating as much of the data processing as possible. In the model, the data are generated and used in the following progression: data acquisition (e.g., MRI or other scanning modalities), segmentation, surface generation, volumetric mesh generation, finite element modeling, visualization of results. Each of these steps, when completed fully manually, is time consuming (and frequently inaccurate). The research presented here increases model quality and decreases user input time by automating the volumetric mesh generation step.

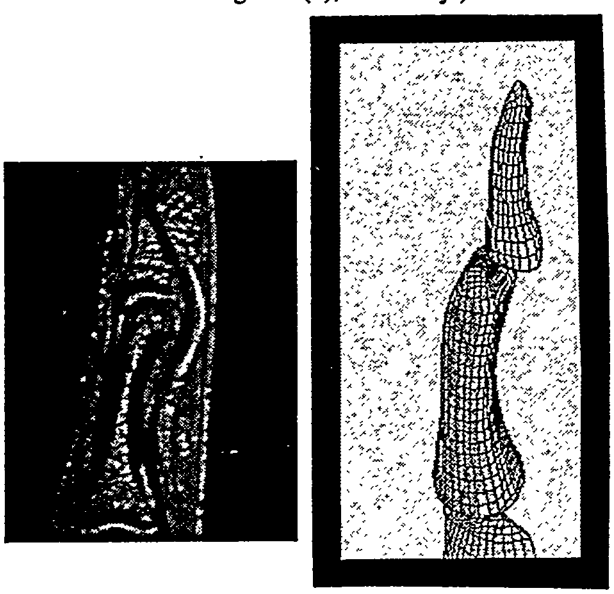
RESULTS

Due to normal and sometimes pathological variations in anatomy, each person's finger bones are of a slightly different shape and size. However, since similarities usually outweigh differences, the problem of generating a mesh for each bone in all fingers of different people is greatly diminished by the development of one or more templates, each of which can be used to mesh more than one bone. In the method used to automate mesh generation, one template out of a library of templates is chosen, based on the geometry of the surface to be gridded, and then deformed to fit that geometry. A particular pre-defined (for the chosen template) sequence of steps to compute the volumetric grid is then performed.

We are making a library of structures that are included in the hand finite element model. At the present time, we have made a library of meshing templates for all bones. We demonstrate the validity of the library by using it on all finger bones (within a particular hand data set), thereby producing a high-quality mesh for each bone. We use 3D pattern matching to determine whether a given template can, indeed, be used successfully in this particular instance. For example, if the bone is pathologically deformed, it may need to be handled as a special case, even though its location and function may dictate the use of a specific template. This evaluation occurs before a mesh is generated and evaluated.

The gridding algorithm that is used begins with determining a series of centroids, where each centroid is calculated in a plane that is perpendicular to the long axis of the bone. The centroids are then connected in a line that forms the "spine" of the long bone. A number of planes are cut through the bone, each plane perpendicular to the spine at the centroid. The spine is then copied multiple times, and each copy is translated radially. Finally, a set of radial planar surfaces is added; all radial surfaces meet at the spine. The outer edge of each surface is defined by the original surface grid. To form the actual volumetric mesh, the computational (originally block shaped) mesh is placed inside the bone, and its vertices and faces are projected in a multi-step process in such a way that each vertex lies at the intersection of the perpendicular cut plane and the outer edge of the closest radial surface, and each face approximates the original surface grid. With all vertices and faces in place, the internal nodes are then arranged to optimize the grid quality.

The final result obtained (Fig. 1 b) is a high quality mesh that is suitable for finite element modeling. Diagnostic measures, such as orthogonality of the elements, may be applied to confirm the mesh quality. Finger movement about the joint axes, using our finite element software, NIKE3D, provides further evidence of meshing success. Other tissues obtained from an MRI input data set (Fig. 1 a) may be meshed with similar results. (Only the index finger is shown in (a) and the bones of the index finger in (b), for clarity.)



(a) **(b)**

Figure 1: Finger bones (a) MRI input data (b) volumetric grids generated from templates.

In extending this work, we are developing generalized techniques to handle (1) long bones in any orientation, (2) bones in the wrist and other bones that do not have a long axis, (3) surfaces with a greater degree of detail, (4) local deviations from the smooth bony surface, by starting with more complex templates, and (5) other, non-bony structures. With these improvements, we will be able to handle the more biologically realistic surfaces that we obtain from our own segmentation of scanned images. In the longer term, we are developing algorithms to match each bone's shape to a template, i.e., to automatically choose that template from the library that is most relevant for the given bone. In this case, there is no a priori knowledge of which template to use for which bone, except that the bone is expected to fit one of the library of templates that is presented. Since it is difficult for the human user of the mesh generation software to evaluate the match of the bone to the entire library of bone templates, this is a critical step that benefits greatly from an automatic determination of the best match of bone to template.

The research presented here represents the first step in automating the tedious process of generating high quality, volumetric grids of bones and other, even more complex biological structures in the hand. The algorithms developed in this research will continue to be extended and may eventually be applied to any surface definitions of tissues in the human body.

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