Interactive Modeling and Simulation of Peripheral Nerve Cords in Virtual Environments

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ABSTRACT

This paper contributes to the modeling, simulation and visualization of peripheral nerve cords. Until now, only sparse data sets of nerve cords can be found. In addition this data has not been used in simulators yet, because it is only static. To recreate the anatomical structure of peripheral nerve cords we propose a hierarchical tree data structure where each node represents a nerve branch. The shape of nerve segments itself is approximated by spline curves. Interactive modeling allows for the creation and editing of control points which are used for branching nerve sections, calculating spline curves and editing spline representations via cross sections. Furthermore the control points can be attached to different anatomic structures. Through this approach nerve cords deform in accordance to the movement of the connected structures, e.g., muscles or bones. As a result we have developed an intuitive modeling system that runs on desktop computers and in immersive environments. It allows anatomical experts to create movable peripheral nerve cords for articulated virtual humanoids. Direct feedback of changes induced by movement or deformation is achieved by visualization in real-time. The techniques and the resulting data are already used for medical simulators.

Keywords: Modeling, Surgical Simulation, Visualization

1. PURPOSE

There are only few data sets of peripheral nerves. Furthermore, most of these models are static and can only be found in proprietary formats within multimedia anatomy atlases. One reason for the lack of more data is the difficulty to detect nerves in medical imaging (such as CT and MRT). In spite of that, it is still possible to create new data by time consuming manual segmentation which is usually supported by semi-automatic aids. However, the resulting data is still static geometry. In order to enable movable and deformable peripheral nerve cords, data structures and algorithms must be designed and implemented. In addition, for a plausible anatomical simulation of an articulated virtual humanoid, the nerve cords have to interact with other anatomical structures, i.e., move together in accordance and allow for functional simulations. To achieve this goal nerves and other structures must be linked together. Defining these links in situ and performing docking tasks requires a modeling environment which is presented in this paper.

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2. METHODS

To model and simulate peripheral nerve cords we use a hierarchical tree data structure in combination with splines. Thus, each nerve section is represented by a spline curve and a node that can have several children. The spline curves are composed of control points. The control points are attached to movable virtual anatomical structures (Fig. 1).

The modeling can be performed at a desktop system or in an immersive environment. The major feature of the system is the interactive placement of control points for different anatomical structures with a real-time update of the involved data structures. First an articulated virtual humanoid model with a skeleton geometry is loaded into the modeling environment. Then additional geometric 3D representations of anatomical systems and structures like musculature, fat tissue and skin are loaded. To supply additional patient-specific information, DICOM datasets can be loaded and positioned interactively to be co-located with the geometry (Fig. 2). Some of the most important operations of the modeling system are the creation and manipulation of *control points*, setup *branches*, *grouping* and setting *names*. In order to set the name of a nerve segment, we make use of a functional anatomical ontology.[1] Thereby the user can select the name at each branch from a limited amount of valid candidates.

The simulation and deformation of the nerve cords is achieved by spline interpolation. The control points are transformed accordingly to related anatomical structures. E.g., movement of the limbs induces deformation of the particular peripheral nerve cords. The deformation is done by readjusting the splines through interpolation during each update cycle. To save computation time, this is constrained to updates of segments that contain changed control points. Although, several interpolation schemes are possible,[2] we chose Kochanek-Bartels splines due to their properties and intuitive parameters for modeling.[3] Functional simulation (e.g., tracing a nerve impulse to a motor response) is supported by the hierarchical structure and the linking of leaf nodes to musculature (innervation).

For collision detection and visualization we have also implemented several geometric representations. Polygonal lines are the fastest visualization technique and well suited for fine nerve cords. Thicker cords are represented either by tessellated cylindrical tubes or by geometries with arbitrary cross sections that are defined per control point and are interpolated accordingly.

3. RESULTS

The developed algorithms for simulation and visualization of peripheral nerve cords are already utilized by a regional anesthesia simulator.[4] The modeling tool is especially useful to add and adjust control points for segmented geometry to enable movable structures. The usability of a predecessor of the interactive modeling system that was focused on musculature has already been proven.[5] First datasets are currently being created with this system by experts in the field of anatomy.

4. NEW OR BREAKTHROUGH WORK

Until now, peripheral nerve cords have been mostly neglected in surgical simulation. With our approach the creation of new and permutation of existing data sets is possible. In addition, the data is not static, but movable and deformable and thus can be integrated into surgical simulation.

5. CONCLUSION

We proposed a hierarchical data structure to represent peripheral nerve cords in a virtual humanoid model. Simulation, deformation and visualization techniques have been implemented and allow for real-time interaction. An intuitive modeling system has been developed to create new data sets from scratch, to add control points to existing static data (e.g, data from segmentation) or to define inter-individual anatomical variations to create new subject-specific data sets. Future work includes the simulation of external electric stimulation of nerves as conducted during regional anesthesia procedures.

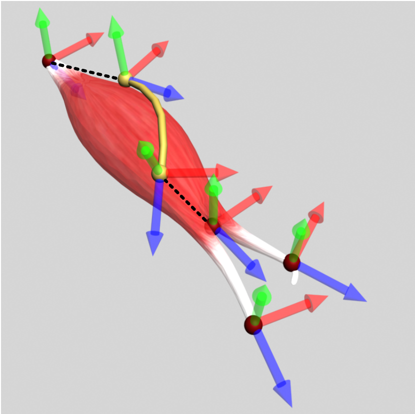

Figure 1. Example of the attachment of a nerve segment to an anatomical structure. The dotted lines shows which control points and coordinate systems are linked together.

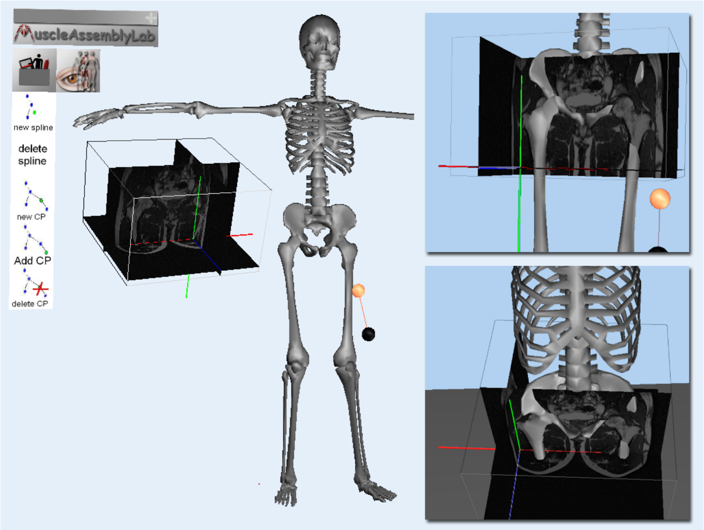

Figure 2. The modeling system allows the interactive editing of control points. DICOM data sets can be co-located to verify the local anatomical setup.

SUBMISSION STATEMENT

This paper has not been submitted anywhere else.

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