Needle Bending in a VR-Puncture Training System Using a 6DOF Haptic Device

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Abstract. The use of virtual reality techniques opens up new perspectives to support and improve the puncture training in medical education. In this work a 3D VR-Simulator for the training of lumbar and ascites punctures has been extended to support the bending of the puncture needle. For this purpose the needle is designed as an angular spring model. The forces that restrict the user from bending the needle are calculated using a multiproxy technique and given to the user via a 6DOF haptic device (Sensable Phantom Premium 1.5). Proxy based haptic volume rendering is used to calculate the proxy movement. This way it is possible to integrate original CT-patient data into the rendering process and generate forces from structures that have not been segmented. The bending technique has been integrated in a VR-training system for puncture interventions and shows good results concerning update rate and user acceptance.

Keywords. Needle Bending, Procedure simulation, Surgical Simulation, Visualization, Virtual Reality, Haptic feedback, Lumbar puncture

1. Background

The approaches presented are used in a VR-training system for puncture interventions that enables the training and evaluation of lumbar [1] and ascites punctures. Usually, these puncturing techniques are trained directly on the patient. The motivation for the development of a virtual reality training system for these puncture interventions is to gain experience on a cheap system without risking the patient's health. The trainee can also get new insights into the human anatomy. During a real puncture it is sometimes difficult to reach the target following a straight line. However the physician can try to reach the target by bending the needle. To enable this modus operandi for the simulation our puncturing system has been extended by a 3D needle bending algorithm that makes use of a 6DOF haptic device. The use of a 6DOF haptic device, the extension to a 3D bending algorithm that is coupled to a multiproxy based haptic volume rendering and the recently implemented application to ascites puncture distinguishes from the work presented in [2] and from other approaches working on puncture or anaesthetic simulation [3,4,5].

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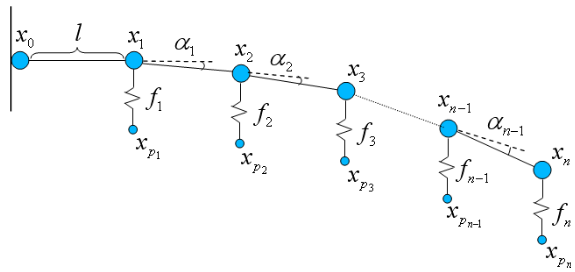

Figure 1. Angular spring model connected to multiple proxies.

2. Tools and Methods

In the following the realization of the needle bending simulation is described. The virtual reality puncture training framework is based on a haptic, a visual and an evaluation component. The haptic component renders the forces that affect the needle during the insertion. A force feedback device with six degrees of freedom (Sensable Phantom Premium 1.5) is used for the haptic I/O. As a 3D extension of the work of Dehghan et al. [2] the needle is modeled as a set of rods connected by angular springs (fig. 1). The bending of the needle is given by the angles $\vec{\alpha}_i$ at the rod connections. The iterative computation scheme

$$\vec{\alpha}_i^{t+1} = \sum_{j>i}^{n} \vec{M}_{ij}^t / k \tag{1}$$

computes the angles. k is the angular spring constant and

$$\vec{M}_{ij}^t / k = \vec{L}_{ij} \times \vec{f}_j \tag{2}$$

is the torque induced on the spring $\vec{x}_i$ by the lever arm $\vec{L}_{ij}$ and the force $\vec{f}_j$. The forces acting on the needle are generated using a multiproxy approach where each rod connection $\vec{x}_j$ is linked to a proxy $\vec{x}_{pj}$ (fig. 1). The forces $\vec{f}_j$ that sum up to the force passed to the user are defined as

$$\vec{f}_j = -k|\vec{x}_j - \vec{x}_{pj}| \tag{3}$$

The restriction of the proxy movement depends on the position of the proxy. The proxies $\vec{x}_{p1}$ to $\vec{x}_{pn-1}$ are restricted to move on a line given by the insertion point and angle of insertion at the moment the needle pierced the skin. Furthermore a viscosity effect that is generated depending on the current tissue they lie in is applied. The proxy $\vec{x}_{pn}$ is restricted according to a proxy-based haptic volume rendering approach that has been extended to combine structure information extracted from original CT data with segmented label data [1]. This way the haptic rendering of small unsegmented structures is enabled and extends the haptic impression calculated from the skin, bone, muscle or fat label data. The visual component (fig. 2) is built of a 3D view with optional stereo view showing the puncture scene. Additional assistance visualizations enable insights into the human anatomy by showing 2D slices of the virtual body or 3D visualizations with transparent organs or special perspectives like a needle cam. The evaluation component rates the success of the needle insertion and gives the user a feedback. This is done by comparing the user's needle paths to expert defined optimal paths for the puncture intervention.

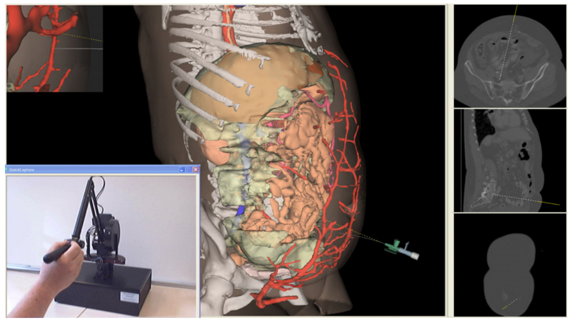

Figure 2. Graphical user interface and webcam snapshot of the haptic device. Orthogonal slices of the CT–dataset are shown on the right. An assistance needle cam view shows the tip of the needle from a side view. The virtual body is shown with transparent skin. The bending of a needle with a very weak spring constant is illustrated by the comparison to a yellow line showing the original needle direction.

3. Results

The proposed algorithms are used in a training system for lumbar and ascites punctures (fig. 2). This training system has proved to have a high user acceptance. Together with the recently developed bending extension the haptic component is able to serve a sufficient force update rate of about $1500Hz$ on a dual Xeon machine with the number of needle segments (rods) set to 19.

4. Discussion

The use of virtual reality techniques opens up new perspectives for supporting and improving the puncture training in medical education. We integrated a needle bending approach using a multiproxy technique for enhancing the realism of a puncture simulator.

References

[1] Matthias Färber, Erik Hoeborn, David Dalek, Friedhelm Hummel, Christian Gerloff, Christian A Bohn, and Heinz Handels. Training and evaluation of lumbar punctures in a VR-environment using a 6DOF haptic device. *Stud Health Technol Inform*, 132:112–114, 2008.

[2] Ehsan Dehghan, Orcun Goksel, and Septimiu E Salcudean. A comparison of needle bending models. *Med Image Comput Comput Assist Interv Int Conf Med Image Comput Comput Assist Interv*, 9(Pt 1):305–312, 2006.

[3] P. Gorman, T. Krummel, R. Webster, M. Smith, and D. Hutchens. A prototype haptic lumbar puncture simulator. *Stud Health Technol Inform*, 70:106–109, 2000.

[4] Ulrika Dreifaldt, Zsuzsanna Kulcsar, and Paul Gallagher. Exploring haptics as a tool to improve training of medical doctors in the procedure of spinal anaesthetics. In *Eurohaptics*, Paris, July 2006.

[5] T. Dang, T. M. Annaswamy, and M. A. Srinivasan. Development and evaluation of an epidural injection simulator with force feedback for medical training. *Stud Health Technol Inform*, 81:97–102, 2001.