Haptic Milling Simulation in Six Degrees-of-Freedom

With Application to Surgery in Stiff Tissue

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Abstract

The research presented in this thesis describes a substantial part of the design of a prototypical surgical training simulator. The results are intended to be applied in future simulators used to educate and train surgeons for bone milling operations. In earlier work we have developed a haptic bone milling surgery simulator prototype based on three degrees-of-freedom force feedback. The contributions presented here constitute an extension to that work by further developing the haptic algorithms to enable six degrees-of-freedom (6-DOF) haptic feedback. Such feedback is crucial for a realistic haptic experience when interacting in a more complex virtual environment, particularly in milling applications. The main contributions of this thesis are:

The developed 6-DOF haptic algorithm is based on the work done by Barbic and James, but differs in that the algorithm is modified and optimized for milling applications. The new algorithm handles the challenging problem of real-time rendering of volume data changes due to material removal, while fulfilling the requirements on stability and smoothness of the kind of haptic applications that we approach. The material removal algorithm and the graphic rendering presented here are based on the earlier research. The new 6-DOF haptic milling algorithm is characterized by voxel-based collision detection, penalty-based and constraint-based haptic feedback, and by using a virtual coupling for stable interaction. Milling a hole in an object in the virtual environment or dragging the virtual tool along the surface of a virtual object shall generate realistic contact force and torque in the correct directions. These are important requirements for a bone milling simulator to be used as a future training tool in the curriculum of surgeons. The goal of this thesis is to present and state the quality of a newly developed 6-DOF haptic milling algorithm. The quality of the algorithm is confirmed through a verification test and a face validity study performed in collaboration with the Division of Orthopedics at the Karolinska University Hospital. In a simulator prototype, the haptic algorithm is implemented together with a new 6-DOF haptic device based on parallel kinematics. This device is developed with workspace, transparency and stiffness characteristics specifically adapted to the particular procedure. This thesis is focuses on the 6-DOF haptic algorithm.

Key Words

Surgical simulation, Virtual reality, Haptic feedback, Surgical training, Medical simulators, 3D visualization, Six degrees-of-freedom, Bone milling

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