A Novel Technique for Knee Kinematics Tracking Using A-Mode Ultrasound: Simulation and Feasibility Study

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INTRODUCTION
Kinematics tracking is the process by which the motion of the joints is studied. This motion consists of rotation and translation of the joint bones relative to each other. Joint motion analysis is used in diagnosis of joint pathology, as well as studying the normal joint function and forces acting on it. Currently, fluoroscopy is used in joint kinematics tracking [1] as shown in Figure 1. We are researching the use of pulse-echo A-mode ultrasound for the bone motion tracking instead of the fluoroscopy to avoid its radiation. In this work we performed feasibility study using simulation, and concluded that it is feasible to perform knee motion tracking with accuracy of 2 mm.

Figure 1. Current method for kinematics tracking using fluoroscopy [1], showing the fluoroscopic images (top), the 3D bones models fit to the fluoroscopic image (middle), and the 3D models at the different poses corresponding to the fluoroscopic images.

METHODS
The idea of the proposed system is to attach a number of single-element ultrasound transducers to a brace as shown in Figure 2. This brace will have any of the commercially available optical or electromagnetic tracking system’s probe attached to it in order to track the global motion of the brace. The ultrasound transducers will be responsible for transcutaneously detecting points over the surface of the bone. The bone’s echo extracted from each signal at each transducer will be registered in the optical or electromagnetic tracker’s coordinate frame to create a set of points acquired over the surface of the bone. These points represent the bone’s position at that point of time. A 3D model of the bone is then registered to these points using the iterative closest point method (ICP) to estimate the bone’s position. At each tracking step, the 3D model will be at a position close to the new position of the points set, because this process will be repeated at a rate of 100 Hz or more in order to ensure that the change in the bone’s position between every two successive tracking steps is small enough to guarantee high tracking accuracy.

Figure 2. A schematic for the proposed kinematics tracking system

In this work we simulated the mentioned process using real kinematics data obtained for a patient using fluoroscopy. 3D models of the proximal tibia and distal femur were segmented from CT scans of the patient’s knee. These models were then moved using the kinematic data in incremental steps. Simulated points over the surface of the bones (simulating the points on the bone’s surface to be acquired using ultrasound) were used to track the bones’ simulated motion using another set of the bones 3D models which move only according to the registration with the simulated points. In other words, the tracking models follow the simulated points’ motion. Simulation was performed using deep knee bend kinematics data.

RESULTS
The simulation performed using 24 simulated ultrasound transducers for the femur and 18 for the tibia with the configuration shown in Figure 3. Accumulated tracking error of 0.02, and 0.5 mm was obtained for the femur and tibia respectively. The tracking step error for the whole cycle is shown in Figure 4.

Figure 3. Four snapshots taken at different steps during the simulation of the knee bones’ motion tracking (b) showing the 3D models simulating the real bones motion (beige), the simulated ultrasound-acquired points on the bones’ surfaces (green), and the models used for tracking the motion of the distal femur (blue), and proximal tibia (red).

Figure 4. The step error curve for the simulation shown in Figure 3, for the distal femur (blue), and proximal tibia (red)

DISCUSSION
The tracking accuracy we obtained from the performed simulation proves the feasibility of tracking the knee kinematics using the proposed method. This motivated us to start the implementation of the system and to perform phantom experiments in order to assess the real accuracy and performance of the proposed method.

REFERENCES

Poster No. 0891 • ORS 2012 Annual Meeting