A CT-less image model with bone cutting dynamics for safe bone cutting

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Introduction: The CT-less model generated intra-operatively is effective to navigate the cutting tool to the designated planes in right position and orientation for total knee replacement purpose. However, the image is not sufficiently accurate so that the generated boundary based on the model is not adequate in assisting the surgeon to prevent the cutter from cutting out of the bone boundary and may has the danger of harmming the nearby soft tissue. This paper is aimed at further enhancing the CT-less morphological model with bone cutting dynamics. The enhanced knee joint model is then able to not only provide navigation for accurate positioning of the cuter, but also assisting the surgeon to perform safe bone cutting.

Methods: Safe bone resection in computer assisted knee replacement is carried out by a handheld bone cutter and depends on the surgeon's skill. The skill includes sensitive sensing of the tactile change occurring at the cutting through of bone boundary together with correct judgment and responsive withdrawing reaction. The paper tries to model this process by a bone cutting dynamics and then supplement into the bone model for bone cutting assistance purpose.

Cutting impedance is defined related to the cutter moving speed, shape, thickness of cutter edge and bone material properties. As the cutter reaches the cutting boundary, the cutting impedances have significant change, which provides a reliable criterion for bone cutting boundary detection. The bone cutting dynamics is developed together with the intelligent cutting tool. The bone cutting force and the moving speed of the cutter are measured. Using the bone cutting dynamics within the CT-less model, protection actions can be activated to help stop the cutter going forward if the cutter is moved by a robot; or turn off the cutter if the cutter is held by free-hand.

Results & Discussion: Experiments have been performed on saw bones. We evaluate two cutting boundaries generated by two methods. One is the knee joint model from only knee joint morphology measurement. The other is with cutting dynamics. The surface of saw bone was also scanned by a laser scanner (ShapeGrabber, Canada). The cutting tool is held by a robot. As shown in Fig. 1(a) the errors between the cutting boundaries generated by the morphological model and the real sawbone are with average around 4mm, but the maximal error may up to 12mm. This big error is dangerous with

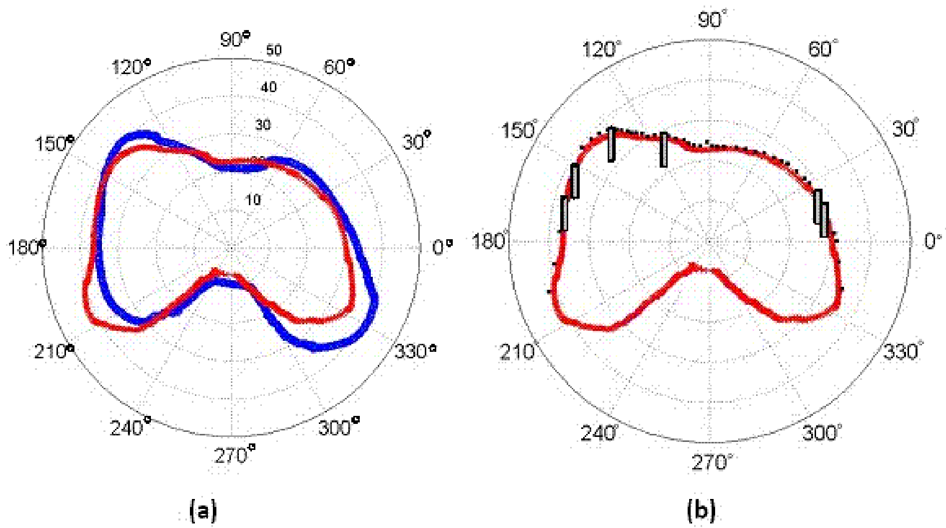

Fig. 1 Errors of Cutting Boundary Generating by (a) only Morphology (b) Morphology and Bone Cutting Dynamics

potential to harm surrounding soft tissue if the image is directly used to guide a robot-held cutting tool. The results shown in Fig. 1(b) are the positions detected by the model with cutting dynamics. The errors between the cutting boundaries generated by the saw bone and the model with cutting dynamics are much smaller than those results in Fig. 1(c). The cutting dynamics can effectively reflect the surgeon's skill in stopping the cutter at bone being cut through.

Conclusion: A model has been proposed with the information of bone morphology and cutting dynamics. This model has been applied to a robot-held bone cutting tool and successfully provide functions of not only navigating the cutter to the right position, but also stop cutter harming the surrounding soft tissue.