Hexapod Intervention Planning for a Robotic Skull-Base Surgery System

Charlie Sim¹, Ming-Yeong Teo¹, Wan-Sing Ng¹, Carl Yap¹, Yong-Chong Loh¹,
Tseng-Tsai Yeo², Shao-Ping Bai¹, Charles Lo¹

¹School of Mechanical & Production Engineering, Nanyang Technological University,
Computer Integrated Medical Intervention Lab, 50, Nanyang Avenue, Singapore 639798

²National Neuroscience Institute, Jalan Tan Tock Seng, Singapore 308433

Abstract. This paper introduces a novel intervention planning methodology facilitating the use of a parallel manipulator (Hexapod) in a robotic skull-base surgery (“**SBS**”) system. This safety intensive procedure requires a cavity to be created in the skull-base so as to allow access to deep-seated brain areas that are inaccessible by other routes. An image-guided system (presenting 3-D information) allows the surgeon to pre-operatively define the features that are to be avoided. Although the Hexapod used has good positioning accuracy and high stiffness, its workspace suffers from some undesirable characteristics. A novel technique has been developed to alleviate this problem by means of segregating the task-envelope (i.e. the cavity in the skull-base) and Hexapod workspace generation process. The placement of the task-envelope within the reachable workspace of the Hexapod is planned in a virtual world. This “placement” is then replicated in the physical world by the use of a dexterous base robot supporting the Hexapod. This ensures that the region encapsulated by the task-envelope encapsulated is fully reachable by the Hexapod.

1. Introduction

A novel robotic system “*NeuroRobot*” for Skull-Base Surgery (“**SBS**”) is currently being developed at the *Computer Integrated Medical Intervention Laboratory*. **SBS** is a procedure with stringent accuracy and safety requirements. This procedure requires a bone removal tool to be used to create a cavity (i.e. a Task-Envelope) in the skull-base so that a lesion (e.g. tumor) can be removed by allowing for access to deep-seated brain areas that are inaccessible by other routes. Critical features (e.g. vein, blood vessel) have to be avoided in the process. Due to the thick bone ridge of the skull-base, a conventional **SBS** procedure spans an 8 to 9 hours duration. The main reason why this system was envisaged is due to the fact that commercially available systems are lacking in the degrees-of-freedom required. Eminently, the robotic manipulator used in other systems possess a large workspace leading to unconstrained motion that pose danger to both the patient and surgeon alike. One of the main challenges in developing this system is the use of a parallel manipulator (i.e. the Hexapod) over a conventional serial robot. The Hexapod has good positioning accuracy, high stiffness and small workspace acting as a mechanical limit to constrain the motion available to the end-effector. On the contrary, it suffers not only from a

small and oddly distributed workspace, but also a change in the workspace's shape, size and distribution when its orientation is varied. A novel technique has been developed to alleviate this problem by means of segregating the task-envelope (i.e. the cavity in the skull-base) and Hexapod workspace generation process.

2. Method

Initially, the required image modalities (e.g. CT, MRI) are obtained. The images are fed into an image-guided surgical planning system that will present the images in both 2-D and 3-D to the surgeon, allowing for the topographical assessment of the tumor, skull-base bony structure and the features to be avoided. On each 2-D slice, the surgeon identifies the regions to be avoided. These are called the “no-go” sites (**Fig. 1a.**). Given the “no-go” sites (or a group of sites identifying a “no-go” region) on any given image slice, the largest “go” cavity on each slice is generated by the use of a Voronoi Map. A projection line based algorithm “smooths” the cavities from one slice to another, so as to produce a task-envelope (**Fig. 1b.**) achievable by a surgical bone-removal tool with a straight shank. The algorithm further takes into account the geometrical limitations of the Hexapod.

Next, the workspace is generated in accordance to the end-effector orientation range required by the Hexapod to produce the pre-generated task-envelope (**Fig. 1c.**). This is achieved by the use of a workspace discretisation method. Essentially in robotic *SBS*, the cavity to be created is volume-based, and not just a straight line requiring only a single end-effector orientation. It will be an impossible task for “path-planning” to be performed using the current “state-of-the-art” as most methodologies strictly advocate pure trajectory verification without rectification.

With both the task-envelope and the workspace obtained, the virtual task of placing the task-envelope within the workspace can be easily achieved. This ensures the whole region within the generated task-envelope can be fully reached by the Hexapod carrying the bone removal tool.

Fig. 1. (a.) Identifying “No-Go” Sites on 2-D Slices; (b.) Cavity Produced after “Virtual” Bone-Removal; (inset) Generated Path; (c.) Workspace Generated by Discretisation (-5° to 5° orientation range for all axes); (inset) The Hexapod (from Physik Instrumente)