Development of a New 5 DoF Robotic Assistant System for Neurosurgery

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Abstract— Craniotomy and Brain Tumor Biopsy are sorts of neurosurgeries related to the brain. A craniotomy is a bone flap removal from the skull surface which is an essential procedure in open skull surgeries. A craniotomy can be a time-consuming process, and the large forces needed for the cutting process make surgeons exhausted before operating the critical brain tissue. As a result, the probability of further errors increases. On the other hand, Brain Tumor Biopsy is a high accuracy surgery that involves a needle insertion to the tumor through a specific pre-planned trajectory. Surgeons still use a stereotactic frame as needle guidance. This frame is a half-century technology that can involve human errors during measurement and mounting processes. Nowadays, High stiffness robotic systems can achieve precise positioning and guidance without frames, save time and effort, and enhance safety.

This paper presents a new 5 DoF robotic-assistant system that can be used in both Surgeries. This system can reach any point on the surface of the patient's skull with different orientation angles within the proposed system workspace. Based on motion requirements and skull shape, decoupled remote center-of-motion (RCM) mechanisms are selected for this system. The proposed system illustrates a high stiffness under the maximum bone drilling forces with a position error below 230 µm.

Keywords— Craniotomy, Stereotactic, Neurosurgery, Remote Center-of-Motion, Surgical Robot.

I. Introduction

Stereotactic neurosurgeries require probe or needle insertion to a specific target inside the brain along a specific path as exposed in Fig. 1 [1]. In traditional stereotactic neurosurgery, the path is planned earlier by surgeons based on computerized tomography (CT) scan or magnetic resonance imaging (MRI) scan using a planning software to avoid critical tissues and vessels. Then surgeons prepare the stereotactic frame and mount it to the patient's head. According to the insertion point on the surface of the skull, a cranial open is performed. Cranial open is a small hole in the skull surface. More details about stereotactic neurosurgery specifically for deep brain stimulation (DBS) is given elsewhere [2]. But when a hematoma or a big brain tumor exists, craniotomy is required. A craniotomy involves bone flap removal from the surface of the skull. First, some holes called "burr holes" are performed by a surgical drill. Then, the holes are connected with a milling tool and the bone flap is removed to give surgeons the ability to access the brain [3].

For over three decades now, surgeons have used robotic systems in neurosurgeries for many purposes including precise positioning, speed, and Reliability. In 1985, Y.S.Kwoh, et la. used PUMA 200 industrial robot as probe guidance with a CT scan in stereotactic neurosurgery [4]. Since then, many challenges have faced neurosurgical robots such as safety, size, compactness, tactile feedback, and time consumption. Many robotic systems have been proposed for these surgeries and currently, some of them are employed in human clinical applications. The most successful Surgical robots specialized in stereotactic neurosurgery and craniotomy will be presented in this section. ISIS Robotics, France introduced A ceiling-mounted delta-type parallel manipulator with 7 DoF ("SurgiScope") [5]. "Renaissance" was developed with a parallel structure. Renaissance is a small portable hexapod (Stewart Platform) with 6 DoF and can be mounted to the skull [6]. A serial manipulator with 5 DoF and 0.7 mm accuracy called "NeuroMate" was introduced in [7]. Another serial manipulator with 6 DoF ("Pathfinder") was proposed in [8]. "Rosa" which is an open-chain manipulator with 6 DoF and shared control between surgeon and robot was developed in [9]. A hybrid manipulator with a combination of the serial structure robot of Pathfinder followed by a parallel structure robot of the Renaissance and the end effector has a linear actuator was proposed under the name of "Robocast" [10]. Robocast has 13 DoF with master and slave control. More robotic systems for stereotactic neurosurgery are discussed elsewhere [11]. On the other hand, researchers proposed robotic systems for craniotomy such as PUMA 260 industrial robot by Karlsruhe University, Germany [12], and Kuka light-weight manipulator using CO2 laser cutting technology [13].

As noticed, most of the robotic systems proposed for these surgeries are serial or parallel structure manipulators with complex control that can lead to low safety criteria. As known serial manipulators have large workspace and flexibility, but have low stiffness and its big size makes it more challenging for surgeons to complete their work. On the contrary, parallel manipulators have high stiffness criteria, but with limited flexibility and workspace. As the sphere is the nearest uniform shape to the human skull, the RCM mechanism architecture with easy controlled decoupled characteristics can be used as a solution for these surgeries. In 2016, Gao-Kuei Li et la. have proposed a novel 3 DoF robotic system for craniotomy based on two perpendicular decoupled RCM mechanisms that can

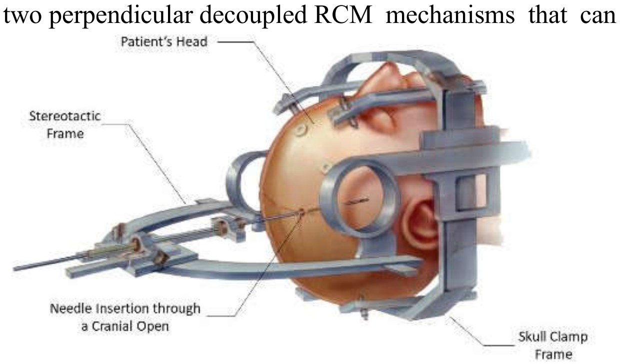

Fig. 1. Brain tumor biopsy surgery using stereotactic frame. [1]