Towards the Development of a Novel Handheld Robotic Tool for the Expanded Endoscopic Endonasal Approach*

E Dimitrakakis[1], G Dwyer[1], HJ Marcus[2], NL Dorward[2], D Stoyanov[1]

[1] *Wellcome/EPSRC Centre for Surgical and Interventional Sciences (WEISS), University College London*

[2] *National Hospital for Neurology and Neurosurgery, London*

e.dimitrakakis@ucl.ac.uk

INTRODUCTION

The transphenoidal approach is one of the best examples of keyhole brain surgery. This surgical procedure is done through the nose and is used to treat tumours within the pituitary gland, which lies deep within the base of the brain. In recent years, surgeons have also described the use of an Expanded Endoscopic Endonasal Approach (EEEA) for treatment of other tumours around the base of the brain [1]. The benefits of this approach, however, are largely theoretical, and most surgeons still find operating in this way with non-articulated tools, very difficult.

In our study, we aim to develop a handheld tool with an articulated robotic instrument at the tip. General surgery has greatly benefited from advancements in precise robotic surgical platforms and tools that allow for smaller incisions, thus faster recovery time, shorter hospital stay, reduced pain and smaller risk of infection. Their application in neurosurgery, however, is limited because a complete redesign must take place to account for the minimal workspace in the human skull and the low forces applied. In [2], an extensive review of robotic systems used in neurosurgery is provided and potential problems that need to be solved before their wide adoption in surgical theatres are listed.

Despite the success of existing surgical robotic platforms, there is a shift towards developing handheld robotic tools that are completely ungrounded and are manipulated by surgeons in free space while being compact and requiring minimal setup time. Trends in handheld medical robotics are described in [3], while the famous handheld robotic tool for general surgery ‘FlexDex’ is developed in [4]. The ‘FlexDex’, although a handheld and easy to use tool, cannot be used in neurosurgery, due to its size and mechanical constraints.

The goal of this paper is to design a novel robotic handheld tool for Endonasal Approaches. The difference between our tool and the readily commercially available tools is the articulation ability that the robotic instrument at the tip of the tool will provide. Modern rigid instruments have just a gripper as an end-effector and operate under fulcrum, according to the studies conducted in [5]. The robotic end effector at the end of our tool will give the surgeon the ability to reach places on the surface of the brain that were not reachable with those pre-existing instruments.

In this abstract, we present a preliminary design of the tool, we solve the kinematic problems of the robot manipulator and we showcase its workspace.

*This work was supported by the Wellcome/EPSRC Centre for Interventional and Surgical Sciences (WEISS) at UCL (203145Z/16/Z)

MATERIALS AND METHODS

I. DESIGN OF THE HANDHELD TOOL

A 3D rendition of the design of the EEEA robotic tool is shown in Figure 1 (top), whereas a rendering of how the tool is going to be used in a surgical scenario is shown in Figure 1 (bottom). Since the work space inside the human skull, which is the hollow space behind the nasal passages and below the brain called sphenoid sinus, is limited and the nasal passages themselves are narrow, our end-effector must be exceptionally small.

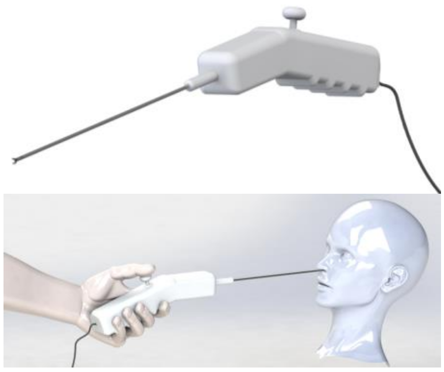

Figure 1. A rendering of the handheld robotic tool (top), a concept rendering of how the tool is going to be used in a EEEA surgical scenario (bottom).

The robot manipulator at the tip of the tool is approximately $1.37cm$ long and has an outer diameter of $3mm$. It consists of 2 Degrees of Freedom (DoF) giving the surgeon more articulation capabilities than commercially available tools. A shaft of $25cm$ in length is used for insertion of the instrument to the operating cavity, and a $1mm$ middle channel is utilized to allow for the tendons that control the gripper to pass through.

The tool is antagonistically controlled in a tendon-driven configuration. Four channels are created at a $0.9mm$ radius, from the centre of each joint, utilizing tendon passages. An antagonistic tendon pair passing opposite channels is used to actuate each DoF.

The actuation system will consist of three motors; one motor for each DoF in a pulley-driven antagonistic configuration, and a third one for the movement of the gripper. This system is located inside the handle of the tool as depicted in Figure 2 (right). Also on the handle, a 2 DoF joystick is placed that will move the motors and thus, the robot. Finally, a rerouting mechanism that will reroute the tendons from their starting point at the top of each motor, to the appropriate passage channels on the manipulator is implemented inside the handle, shown in Figure 2 (right) as well.

II. KINEMATIC ANALYSIS

The Denavit-Hartenberg (DH) kinematic parameters for the 2-DoF robotic manipulator at the tip of the tool, as depicted in Figure 2 (left), are shown in Table 1.

Table 1. The DH parameters of the articulated tool.

Link	θ_i	a_i	α_i	d_i
$i = 1$	θ_1	$0\ mm$	90^o	$0\ mm$
$i = 2$	θ_2	$11\ mm$	-90^o	$0\ mm$

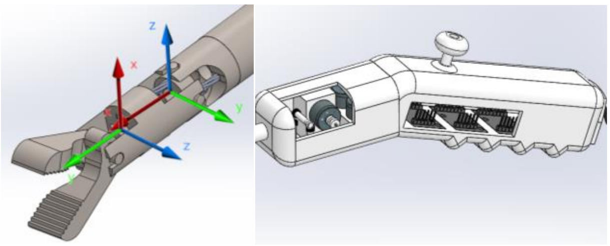

Figure 2. The articulated instrument (left) and a semi-cross section of the body and handle of the tool (right).

The inverse kinematics position problem was solved using a numerical approach algorithm for a more generic and easily expandable solution, in case we need to expand the number of DoF of the robot in the future.

A numerical approach was implemented for the calculation of the angle-vector $\theta(t^+) = [\theta_1^+, \dots, \theta_N^+]$ at time t^+. Given the current angles $\theta(t^-) = [\theta_1^-, \dots, \theta_N^-]$ at time t^- and the desired position vector of the end-effector $P_0^{N,d}(t^+) = \left[P_x^d(t^+), P_y^d(t^+), P_z^d(t^+)\right]^T$ at time t^+, the computation is cast as an Eucledian distance optimisation problem [6] defined as:

$$\min_{\theta} \|\theta(t^+) - \theta(t^-)\|\,,$$
$$subject\ to\ \left\|P_0^{N,d}(t^+) - P_0^N\right\| = 0$$

where P_0^N is the resulting end-effector's position. In a typical experiment $t^+ - t^-$ corresponds to the sampling period T_s.

Assuming the computed joint space angle-vector, the tendon stroke of each antagonistic pair must be computed. For each rotational DoF there are two tendons running from the robot's base, passing through holes at each joint, and ending at the counter-diameter holes at the corresponding joint to be rotated. To compute the tendons' lengths, it is crucial to compute the length of the path of each tendon, which necessitates the computation of the locations of the passing-through holes in 3D space.

For an N DoF robotic tool, each link has 2N symmetrically positioned channels at a radius r from its centre of symmetry. The computation of the tendon's path length is computed by expressing each hole in 3D space and then using the resulting homogeneous transformation matrix of each hole alongside with Euclidean geometric calculations.

RESULTS

Shown in Figure 3, is the resulting work space of our tool based on the kinematic analysis presented in the previous section with angle limits at $[-45^o\ 45^o]$. It is evident that the surgeon's abilities could be widely enhanced with the tool we propose, due to the expanded work space it provides compared to that of the traditional tool. A much larger area can be covered by manipulating the robotic instrument without having to constantly reposition the shaft.

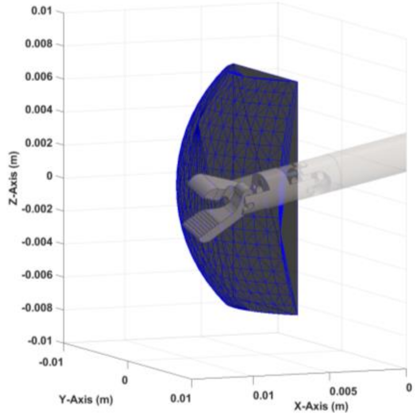

Figure 3. The workspace of the end-effector of the tool

CONCLUSION AND DISCUSSION

In this abstract, we presented our design and the kinematic analysis for a novel handheld robotic tool for EEEA surgical procedures. Our goal is to take advantage of its articulation ability to remove tumors from the surface of the brain that traditional tools struggle to remove. The immediate next step of our study is to 3D print the body and the manipulator of the tool and assemble it, in order to prove our concept and perfect our design before progressing to clinical studies.

REFERENCES

[1] A. B. Kassam, C. Snyderman, P. Gardner, R. Carrau, and R. Spiro, "The expanded endonasal approach: a fully endoscopic transnasal approach and resection of the odontoid process: technical case report," *Oper. Neurosurg.*, vol. 57, no. suppl_1, pp. E213–E213, 2005.

[2] J. J. Doulgeris, S. A. Gonzalez-Blohm, A. K. Filis, T. M. Shea, K. Aghayev, and F. D. Vrionis, "Robotics in neurosurgery: evolution, current challenges, and compromises," *Cancer Control*, vol. 22, no. 3, pp. 352–359, 2015.

[3] C. J. Payne and G.-Z. Yang, "Handheld medical robots," *Ann. Biomed. Eng.*, vol. 42, no. 8, pp. 1594–1605, 2014.

[4] S. Awtar, T. T. Trutna, J. M. Nielsen, R. Abani, and J. Geiger, "FlexDex™: a minimally invasive surgical tool with enhanced dexterity and intuitive control," *J. Med. Device.*, vol. 4, no. 3, p. 35003, 2010.

[5] H. J. Marcus, T. P. Cundy, A. Hughes-Hallett, G.-Z. Yang, A. Darzi, and D. Nandi, "Endoscopic and keyhole endoscope-assisted neurosurgical approaches: a qualitative survey on technical challenges and technological solutions," *Br. J. Neurosurg.*, vol. 28, no. 5, pp. 606–610, 2014.

[6] J. J. Moré and D. C. Sorensen, "Computing a trust region step," *SIAM J. Sci. Stat. Comput.*, vol. 4, no. 3, pp. 553–572, 1983.