Towards the Development and Evaluation of a Handle Prototype for a Handheld Robotic Neurosurgical Instrument

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I. INTRODUCTION

The Expanded Endoscopic Endonasal Approach (EEEA) is a Minimally Invasive Surgery (MIS) technique that is performed through the sinus and aims at the removal of lesions from a number of areas at the base of the brain [1]. Although a promising alternative to transcranial approaches that require craniotomies and brain retraction, the EEEA comes with its limitations and 74% of surgeons identified the limited surgical manipulation that the standard non-articulated instruments offer as the biggest challenge [2]. This procedure could potentially be improved using robotic instrumentation that provides articulation at the tip.

The purpose of this preliminary study is to create an ergonomic handle for a handheld surgical robotic tool intended for the EEEA. A handheld tool was chosen rather than a tele-operated robotic platform, due to its compactness and its ability for easier integration into the surgical workflow. In previous work, a 3 degrees-of-freedom articulated robotic end-effector for this tool was developed, with the purpose of pairing it with the ergonomic handle in future work. This paper will present the design and development of an ergonomic handle for a robotic neurosurgical tool. The guidelines for developing ergonomic handles will be outlined followed by our proposed handle design and simulation environment.

II. MATERIALS AND METHODS

A. Ergonomic guidelines

Long-term use of incorrectly designed tools can cause conditions such as the carpal-tunnel syndrome and the hand-arm vibration syndrome [3], meaning that appropriate ergonomic tool design is essential. According to [4], it is difficult to define a clear and universal consensus on specific components or instructions that make a handle design ergonomic and comfortable to use. Despite this difficulty, however,there are still some characteristics that are found to be contributing towards an ergonomic design. These instructions and suggestions on ergonomic guidelines are summarized in table I.

TABLE I: Some of the ergonomic guidelines suggested from the current literature.

Instructions towards an ergonomic handle design
The surgeon's hand size should not hugely affect the design [5]
The handle type should be finger-operated [5]
The thumb actuates the robot joints (eg joystick or rotary switch) [6]
The index finger actuates the robot gripper (eg trigger) [6]
The tool geometry should include a large palmar grip surface [7]
The Handle - shaft angle should be 45^o [7]
A partially opened hand should hold the instrument at rest [7]

B. Handle implementation

Following these instructions, we developed a handle design that was inspired by most commercially available handheld robotic tools that are used in surgery. It is finger-operated, employing a thumb-controlled joystick that actuates the robot joints, mainly its pitch and yaw rotations, and an index finger-controlled standard trigger that actuates the robot gripper. The roll motion is carried out by the surgeon's hand. It contains a large handle surface that provides the surgeon with palmar grip and the handle-shaft angle is 45^o. To account for different hand sizes and to make sure that the instrument at rest is maintained by a hand that is also kept at rest, we introduced a 'rotating joystick body' that is modifiable and can be rotated into the position that each surgeon feels more comfortable with. Figure 1 shows the handle with its rotating body in 7 different discrete positions.

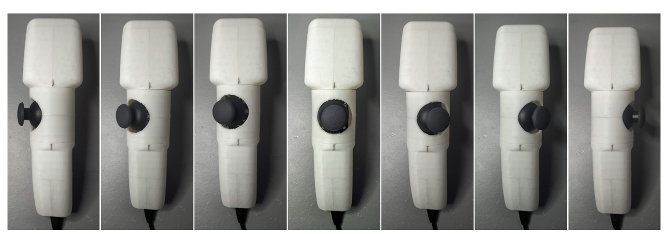

Fig. 1: Seven discrete joystick positions on a printed rotating-body handle prototype.

The level/resting position of the hand is shown in Figure 2A. In Figure 2B, the thumb is shown in 'adduction' (left) and 'abduction' (right). It is evident from this figure that the resting position of the hand requires the thumb to be in an 'abduction' position, not so close to the rest of the fingers.

If we were to place the joystick at the exact centre of the handle, the thumb would be at an 'adduction' position and the surgeon would feel uncomfortable and easily tired. By placing the joystick on a rotating body, the surgeon can

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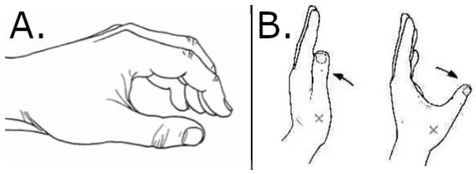

Fig. 2: A. The hand at its resting position, and B. thumb adduction (left), thumb abduction (right) [8].

rotate the joystick to the left if they are to use it with their right hand and to the right, if they are to use it with their left hand. The angle of rotation, namely the angle by which the surgeon needs to rotate the joystick body to feel comfortable, depends on the surgeon's hand size.

In Figure 3 it is shown how this handle can cater to different hand sizes and can be used independently of right- or left-handedness. It is worth mentioning that in Figures 3.A and 3.B the rotating body has been rotated by approximately 15^o, whereas in Figures 3C. and 3.D by approximately 35^o

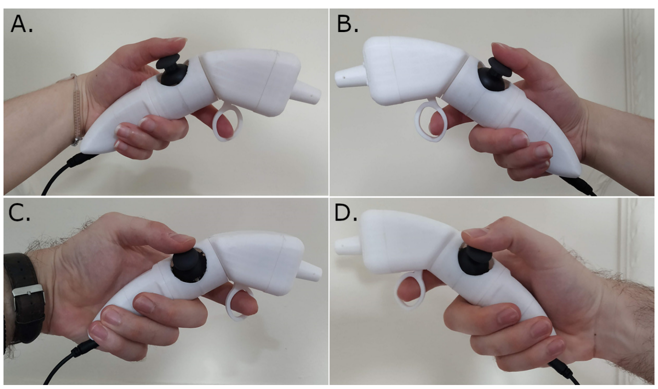

Fig. 3: The handle held by A. a small left hand, B. a small right hand, C. a large left hand, and D. a large right hand.

C. Simulator implementation

For the simulator, we decided to use CoppeliaSim (formerly V-REP), a versatile and powerful robot simulation platform [9]. Objects inside the CoppeliaSim simulator are controlled remotely by Robot Operating System (ROS) nodes and other custom solutions. The simulation task we decided to develop in this environment is a ring-transfer task, with the developed handle controlling a surgical forceps. An endoscope-resembling camera was also implemented inside the simulation that is user-controlled through a 3D-printed endoscope. Both the shafts of the developed handle and the endoscope were physically constrained in space in accordance to the EEEA workspace constraints.

To evaluate the efficacy and comfort of the device, we performed the ring transfer task using the handle to move the robotic end-effector, and using keyboard inputs to move the robot shaft in space. This will be substituted by an optical tracking system in the future that maps the surgeon's handle movements in 3D space to the simulation environment. All six rings could be transferred from the one set of spikes to the next, with comfort and ease. This, however, will be extensively tested in future work when a number of evaluation and comparison tests will be carried out to investigate the efficacy of the tool. A series of pictures of the simulated task moving the first two of the six rings can be seen in Figure 4.

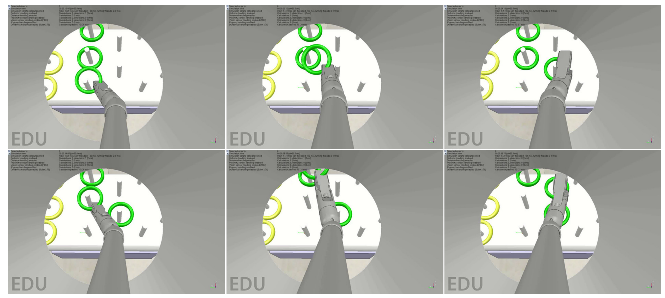

Fig. 4: The ring transfer task inside the CoppeliaSim simulation environment using the handle prototype.

III. Conclusion and Discussions

In this preliminary study we developed an ergonomic handle prototype for a handheld robotic neurosurgical instrument. Alongside the handle, a simulation in the CoppeliaSim environment was developed to evaluate the prototype. The end-goal of the study is to evaluate the efficacy of the handle, before the implementation of the final robotic instrument prototype. This is why as a continuation of this abstract, we plan on developing additional handles with different design strategies, and additional simulation tasks, and conduct a clinician user-study where experts are going to decide which handle design is the most appropriate for the EEEA.

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