Towards a Handheld Robotic Instrument for Minimally Invasive Neurosurgery

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INTRODUCTION

Due to its delicate subject matter and challenging operations, neurosurgery has always been in need for adapting new techniques and technologies. A procedure that could widely benefit from robotic technology is the Endoscopic Endonasal Transsphenoidal Surgery (EETS). The EETS approach is a minimally invasive neurosurgical technique that is performed via an anterior sphenoidotomy and aims at the removal of sellar and parasellar lesions with the use of an endoscope and standard rigid instruments [1].

In recent years, there has been an increased interest in the Expanded Endoscopic Endonasal Approach (EEEA) that expands the EETS areas of interest [2]. Although a promising alternative to transcranial approaches that require craniotomies and brain retraction, the EEEA comes with its limitations. In [3], a number of surgeons were asked about these technical challenges, with 74% of them identifying the limited surgical manipulation that the standard non-articulated instruments offer as the biggest challenge of this procedure.

In this paper, current development of an ergonomically designed handheld robotic instrument for the EEEA is presented. The instrument employs a three degrees-of-freedom (DoF) robotic end-effector that provides access to targets on the surface of the brain that were previously unattainable with rigid tools. It also incorporates a rotating joystick-body mechanism that can be placed at the optimal position for the surgeon's postural ergonomics, aiming to increase the efficacy of keyhole neurosurgery without burdening the surgeon with physiological problems.

MATERIALS AND METHODS

A. Development of the robotic end-effector

The robotic end-effector aimed to be located at the distal tip of this instrument is a 3-DoF, tendon-driven, spherical joint manipulator, with a diameter of 4mm and 17.5mm length. A preliminary prototype of this miniature manipulator was fabricated and evaluated for its extended workspace and force capabilities in [4]. Based on the encouraging results from that preliminary design, the end-effector showcased in Fig. 1 was developed. This prototype was 3D printed both in resin and metal, and is currently undergoing experimental evaluation.

B. Development of the ergonomic handle

1) Handle designs: Long-term use of tools that have not been ergonomically designed can cause conditions such as carpal-tunnel syndrome [5]. Thus, appropriate ergonomic tool design is essential. To avoid such complications, the handle incorporated in the robotic instrument should be ergonomically designed, and ideally have a fast adoption rate, so that it can be easily integrated in the surgical workflow. To cater to a large set of ergonomic literature guidelines, two different handle concept prototypes were developed shown in Fig. 2.

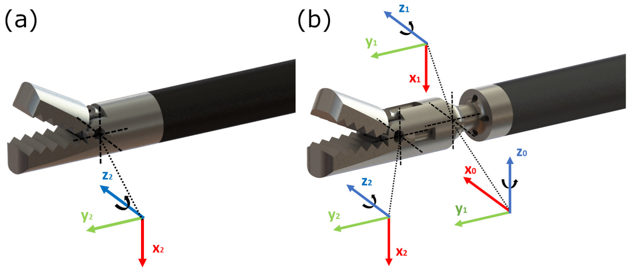

Fig. 1: (a) DoF of a conventional tool, and (b). DoF of the miniature end-effector.

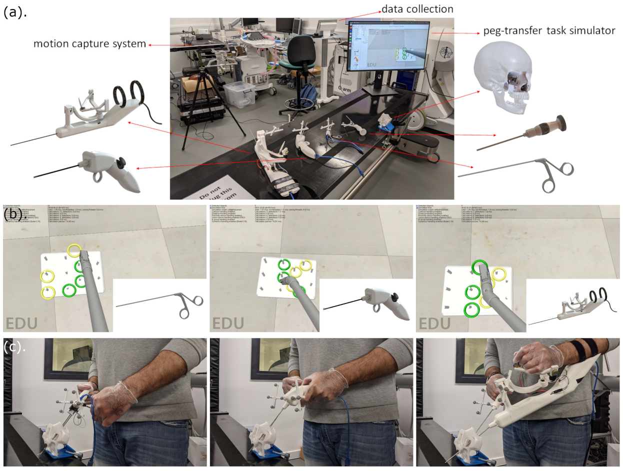

Fig. 2: (a) Experimental setup with renderings matched to their respective prototypes. (b). The simulated environment when a researcher is carrying out the peg-transfer task, and (c). The researcher holding the prototypes when carrying out the peg-transfer task.

The first handle is a forearm-mounted handle that maps the surgeon's wrist degrees-of-freedom to that of the robotic end-effector [6]. This handle alleviates the surgeon of any wrist-fatigue and its intuitive movement mapping makes it easily adoptable. The second handle is a joystick-and-trigger handle with a rotating body that places the joystick to the position most comfortable for the surgeon, at a thumb abduction position. That position differs depending on hand-size and right- or left-handedness, making the use of a rotating body a convenient solution.

2) Randomised crossover user-study: The handles presented in the previous section were incorporated into a custom-designed virtual surgical task simulator and were assessed for their performance and ergonomics when compared with a standard neurosurgical grasper, to identify the superior handle design. The virtual task was performed by 9 novices with all 3 devices as part of a randomised crossover user-study. Their performance and ergonomics were evaluated both subjectively by themselves and objectively by a validated observational checklist [7].

In terms of performance and efficacy, the two robotic handles clearly outperformed the standard neurosurgical instrument. Between the two, the concept prototypes had very similar behaviours. As far as their learning-curves were concerned, the former was superior, whereas the latter appeared to be more time-efficient after training. Finally, during their ergonomic assessment, the rotating joystick-body handle proved to be the safest device to use for an extended amount of time according to a validated ergonomic measure.

C. Handheld robotic instrument adaptation

The superior ergonomic results of the rotating joystick-body handle, combined with the increased time and effort it would take to switch between forearm-mounted instruments during the endonasal approach, indicate that the more favourable handle amongst the two, is the former. Thus, current development focuses on the incorporation of electronics and the previously presented robotic end-effector into a handle with a rotating joystick-body, to form a fully functional robotic instrument prototype. A rendering of this prototype is shown in Fig. 3.

To incorporate electronics, as well as to create a robust coupling between the handle body and the robotic end-effector, the concept prototype presented in Fig. 2(b). needed redesign. A translational, rather than a rotational, joystick is used to make the device more compact, whereas the rotating joystick-body is now secured in place with a latch mechanism. The handle houses 3 miniature motors with their encoder adapters and motor controllers (FAULHABER, Schönaich, Germany).

It was fabricated with polylactic acid (PLA) plastic using the desktop 3D printer Ultimaker S5 (Ultimaker, Geldermalsen, Netherlands). Fig. 3 showcases the prototype handle body of the instrument as well as the end-effector fabricated in metal. With the development of the handle body of the instrument now finalised, the focus has shifted on the end-effector body.

CONCLUSIONS AND DISCUSSION

In this work, the current development of a novel handheld robotic instrument for minimally invasive neurosurgery was presented. The handle employs a miniature robotic end-effector and an ergonomically designed handle, aiming to increase the efficacy of keyhole neurosurgical approaches while also improving the procedural ergonomics associated with these complex procedures.

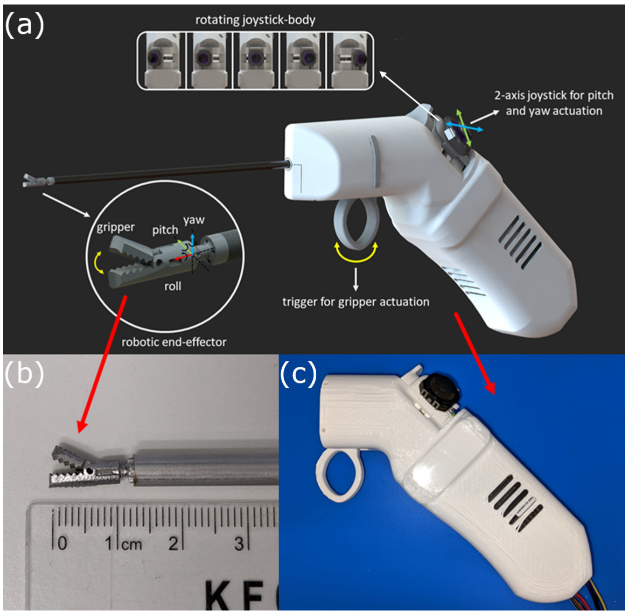

Fig. 3: Rendering of the robotic instrument, the metal end-effector, and a prototype of the actuating handle.

In future work, the development of the robotised prototype will be finalised, and its performance will be evaluated in laboratory and clinical experiments. After the efficacy of the instrument has been validated, the device will be re-evaluated for its human factors aiming to have developed a complete solution in terms of balance between performance and improved ergonomics.

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