microCYCLOPS: A Robotic System for Microsurgical Applications

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INTRODUCTION

In previous work a prototype named *neuroCYCLOPS* was developed and tested [1]. The prototype is a manually controlled tendon-driven instrument based on the original *CYCLOPS* concept [2]. The *neuroCYCLOPS* is combined with the cylindrical tissue retraction device Neuroendoport^{SM} (NEP) and allows for accurate dissection of deep-seated brain lesions [3]. Experimental validation on an FLS pick-and-place task demonstrated accurate and safe control, without significant increase in task execution time when compared to conventional rigid instruments. Additionally, the device has a wider range of motion compared to standard rigid instruments (Fig. 1B). The current abstract focuses on the development of a robotic system based on *neuroCYCLOPS*. Although neurosurgery was initially targeted, tubular tissue retraction devices are used in many microsurgical applications, allowing the concept of *neuroCYCLOPS* to be applied more broadly. Applications include *Transanal Endoscopic Microsurgery* (TEM) and *Laryngeal Microsurgery*. The ***micro**CYCLOPS* robotic system presented here is designed for these applications and to the authors' knowledge is the first of its kind.

PROTOTYPE DESIGN

Fig. 1 shows the prototype *microCYCLOPS* robot, which consists of a standard flexible endoscopic grasper (FB-19N-1, Olympus, Japan) that can be controlled in a master-slave configuration. The design is based on a cylindrical tissue retractor with 21mm inner diameter.

In this design, 8 tendons are used with the tendon-driven *CYCLOPS* configuration, independently actuated by servomotors (2232S024BX4 CCD-3830 + 22F 25:1 Brushless DC, Faulhaber, Germany). The tendons are guided through Bowden cables to the remote motor units, thereby reducing the weight and size of the robot inserted in the tissue retractor. The 8 tendons are used for the actuation of 4 degrees of freedom (DOF), *y* and *z* translations, and *yaw* and *pitch* as shown in Fig. 1C. For movement along the *X*-axis two motors (Dynamixel RX-24F, Robotis, Korea) are symmetrically actuated to operate a rack and pinion mechanism (indicated in Fig. 1D as D1 and D2). The rack is incorporated with the inner-tube/scaffold of the *microCYCLOPS*. By using two motors, asymmetrical forces are avoided and in further developments actuation of each motor can be used for independent actuation of two instruments for bimanual control. A third Dynamixel motor (coupled at D3, Fig. 1C) is used for the rotational movement of the tool, which is achieved by using the torsional rigidity of the grasper. A servomotor (S3305, Futaba Corporation, Japan) is used to actuate the opening and closing of the

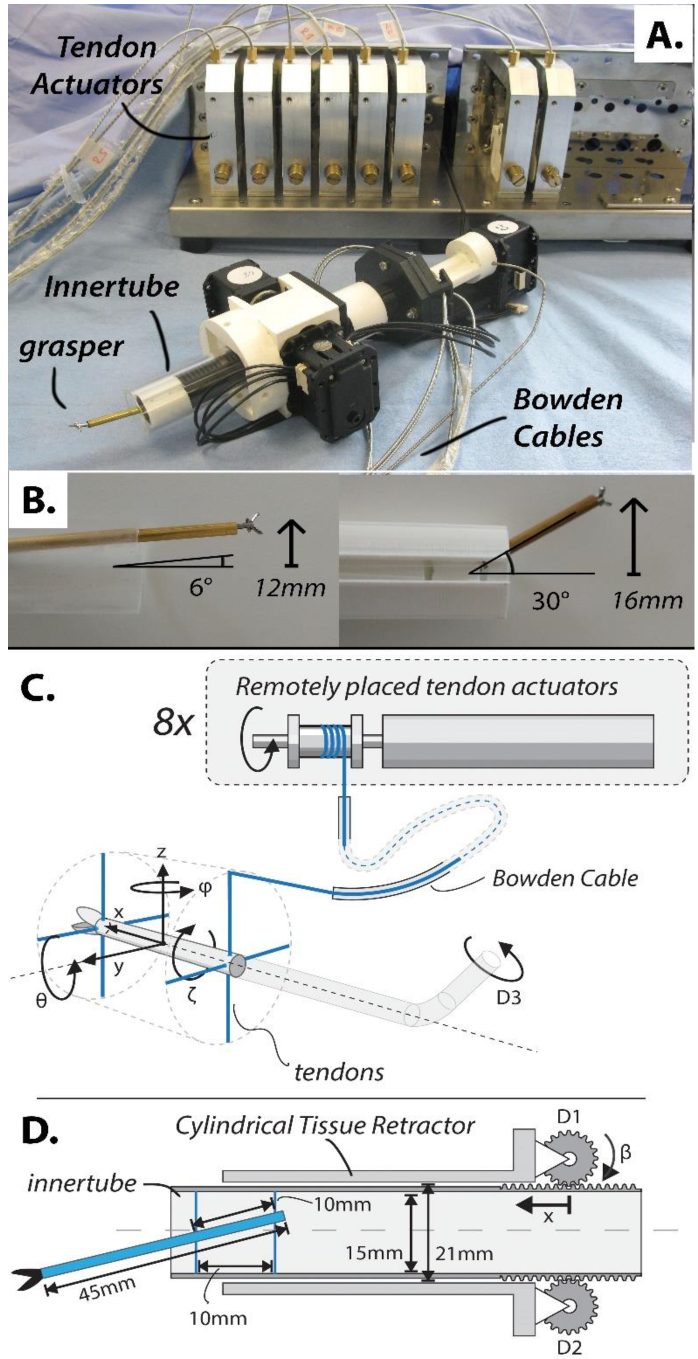

Fig. 1 – A) The *microCYCLOPS*, including the tendon motor actuators **B)** The increased range of motion of the *neuroCYCLOPS* (right) compared to rigid instruments (left), shown in earlier work [1] **C)** The *CYCLOPS* tendon configuration using 8 tendons to actuate y, z, θ and ϕ. The rolling motion of the instrument (ζ) is achieved by coupling the instrument to a motor at D3. **D)** The tubular scaffold placed into the cylindrical tissue retractor, actuated in x by two motors D1 and D2.

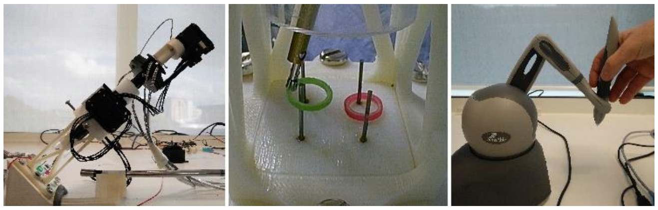

Fig. 2 – **Left:** The device placed into the setup for the pick-and-place task, and endoscope placement under an angle of 45 degree. **Middle:** View from the endoscope. **Right:** The orientation of the stylus master controller.

grasper. The majority of the system is 3D printed using an Ultimaker 2+ Extended (Ultimaker BV, The Netherlands).

At the motor side, load cells (LCL-020, Omega Engineering Inc, USA) are used to measure tension in the tendons, and acquired using a DAQ (i100, GW Instruments Inc, USA). Currently, the force sensing capability is only used for calibration purposes and to prevent excessive forces in the tendons. In future systems this feature will allow for the introduction of haptic feedback. A Phantom Omni (Geomagic, USA) haptic device was used for the master side of the system.

In particular for microsurgical applications, there are multiple reasons why it may be desirable to have 8 tendons driving 4 DOF, while 6 tendons would be sufficient [2]. Firstly, using 8 tendons allows for a larger reachable workspace. Secondly, by actuating the X-axis independently from the tendon-driven mechanism, an even larger reachable workspace is realized. The original *CYCLOPS* uses the tendons for actuation along the X-axis, achieved by increasing the distance between the entry points on the scaffold. However, this is at the expense of dexterous workspace due to singularities and less control over the force exertion of the end-effector. By decoupling the movement on the X-axis, the dexterity in the DOF denoted by y, z, θ and ϕ in Fig. 1C is not compromised, while also allowing for large movement along this axis. Lastly, the redundancy of the antagonistically placed tendons allows for finer control of the stiffness in each of the available DOF, resulting in an extra tuneable parameter used for robotic control [4]. For surgical applications, a controllable stiffness can be useful to prevent damage to delicate tissues, while still offering higher rigidity when required.

EXPERIMENTAL SETUP

A pilot study has been conducted to compare the robotic prototype against conventional rigid instruments. During the pick-and-place task, completion time and amount of clashes of the instruments with peripheral structures were measured. The amount of clashes is considered a metric for stability and controllability of the instrument, and was recorded by making the instruments (anode) and task environment (cathode) conductive, and detecting contact with an Arduino Mega (Arduino, Italy). The workspace in which the task was performed was based on a previous study, indicating a 30x30x90mm opening for neurosurgical applications [5], although the space requirements for other procedures are expected to be more relaxed. During the experiments, a 3D endoscope (Endoeye Flex 3D, Olympus, Japan) was used for visualisation, and placed at an orientation of 45 degrees. The stylus of the master device was oriented vertically to coincide with that of the end-effector on the endoscope screen (Fig. 2). Haptic feedback of the master device was not used. After each task, the novice participants filled in a NASA-TLX questionnaire. The instrument first used by each participant was randomized to reduce bias towards a specific instrument.

RESULTS

The results for n = 11 participants are shown in Table 1. The initial study showed no significant difference in time (p=0.091), or reduction of amount of clashes when comparing the *microCYCLOPS* with rigid instruments (p=0.172, one-tailed paired t-test).

Table 1 – Results of the pick and place task for n = 11.

	microCYCLOPS	***Rigid Instruments***	***p-value***
Clashes [#]	16.6 ± 12.8	21.6 ± 11.48	0.174
Time [s]	47.0 ± 19.6	38.0 ± 12.2	0.091
NASA-TLX [-]	45.5 ± 18.6	67.1 ± 23.4	**0.001***

DISCUSSION

We have demonstrated a fully robotized extension of the original *neuroCYCLOPS* system. The study has shown that the *microCYCLOPS* could achieve performance comparable to rigid instruments, with the novice participants perceiving the workload lower when compared to rigid instruments currently used in practice. It is important to take into account that this first prototype has not been optimized for intuitive control, haptic feedback or with additional human enhancing capabilities (e.g., motion scaling and guidance). Therefore, it is likely that future developments will yield better results in terms of controllability and intuitive control of the *microCYCLOPS*. Current development focuses on the introduction of a second instrument for bimanual control and the evaluation of this concept for different microsurgical applications.

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