

Design of a Flexural Transmission for a Dexterous Telesurgical Robot for Throat and Upper Airway: A Preliminary Result

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INTRODUCTION

It has been perceived by the community that one of the future significant challenges for designing surgical robots is the enhancement of robot's mobility subject to the confined environments. Recently, Simaan, Taylor *et al.* [1-5] have developed a telesurgical robot for this kind of concerns. Their purpose is to design a high-dexterous surgical robot which can effectively work in a confined environment such as the throat and upper airway.

The aforementioned robotic system uses the master-and-slave concept as its structure. It basically consists of a *da Vinci* master, a stereoscopic capture and display subsystem, and a dual-arm robotic slave [5]. The master console is maneuvered by the surgeon to control the slave robotic arms, and the two slaves are supposed working together in a narrow space, like the throat and airway, to carry out the surgical operation cooperatively. Subject to the confined environment, the workspace of the slave robotic arms is limited by a long, narrow and irregularly shaped throat which can be described by a 50mm long cylinder with 40mm in diameter located 180-250mm axially down the throat [5]. Limited by the long and narrow channel, the slave arms are expected to do dexterous surgical operation such as suturing and tying knot via its end-effectors which are located in the confined working space.

Based on the design requirements and specifications as described above, the slave robotic arm has been so-designed with a lengthy structure, Fig. 1(a). Basically, it is composed of a gross actuation unit, a hollow transmission tube and a distal dexterous unit (DDU) at which the surgical operation will be performed. The hollow transmission tube attaches the actuation unit and the DDU at its both ends, and it houses four superelastic wires for delivering the motor motion from the actuation unit to the DDU. The DDU adopts a multi-backbone snake-like robot [1] as shown in Fig. 1(b), from which the pitch-and-roll motion of the moving platform is controlled by the three outer wires (Element 3) and the grasping of the gripper is controlled by the central wire (Element 4). The whole robotic arm is engaged with a screw mechanism called the "z-θ stage" which is attached to the frame and is used to provide the yaw motion and the top-and-down motion for the DDU.

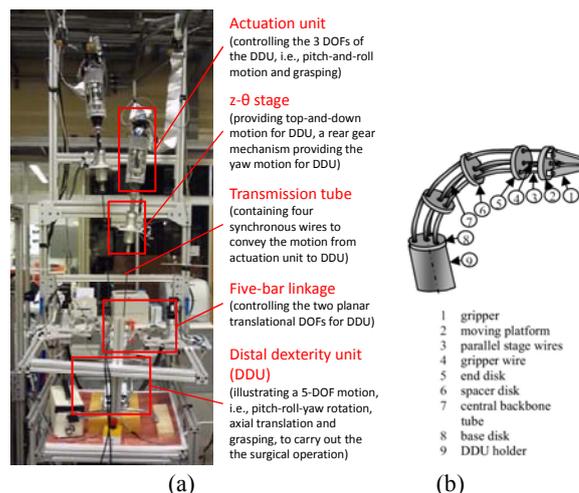


Fig. 1 (a) The composition of the slave robotic arms; (b) The DDU (Distal Dexterity Unit) [1]

From above, we can realize that when the DDU is illustrating a continuous movement that may incorporate top-and-down, roll-pitch-yaw and grasping motions as a whole, the transmission tube will experience an axial translational motion associated with a spin rotation, and the four embedded wires will follow the spin rotation of the tube but will also be bended and selectively pushed and/or pulled simultaneously. Notice that each slave robotic arm here is equipped with a five-bar linkage for controlling the quasi-planar 2-DOF motion of the DDU derived from the bending of the transmission tube. However, this set-up may be eliminated when the tube adopts a relatively rigid material for the purpose of precise control.

The above design for a single robotic arm has been successfully implemented as presented in [1-5]. However, when the two robotic arms are to be collaboratively operated in a confined environment, a crucial problem appears that, due to the relatively large actuation units (74.60mm in diameter), the two slave robotic arms cannot work in-parallel within a satisfied distance to each other (<40mm). Without modifying the actuation unit, the design of a feasible transmission that can deliver motion from the far end to the two DDUs which are working closely at a long and narrow channel therefore becomes a great challenge to be overcome.

MATERIALS AND METHOD

A novel flexural transmission for the slave robotic arm is proposed in this paper (see Fig. 2(a) and (b)). The basic design idea is as follows. First, the straight, long transmission flow is decomposed into three parts: the upper, intermediate and lower tubes. The upper and lower tubes are placed in parallel with a satisfied offset for avoiding the collision between the two actuation units. Then, two special hollow flexible joints (see Fig. 3(b)) are used to connect the upper and intermediate tubes as well as the intermediate and lower tubes, respectively. In order to assure the four wires staying at the same relative locations after a finite spin rotation, a tube cover with four centrally-distributed holes is attached to both ends of each three tubes (see Fig. 3(c)). Then, the four wires are guided to pass through the holes one-to-one for each cover, from the upper tube, intermediate tube to lower tube. Finally, the upper segments of the wires are connected to the motors in the actuation unit, while the lower segments are connected to the DDU.

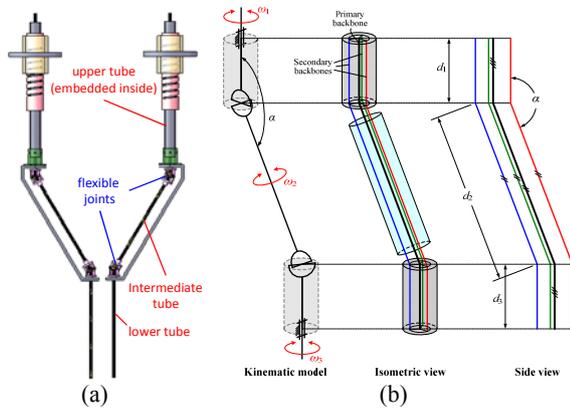


Fig. 2 The proposed concept: (a) the robotic dual-arm; and (b) the geometrical interpretation of the wire arrangement

RESULTS

A simplified SolidWorks model, which replaces the flexible joints by Hooke's joints, was built. Under this computer-aid test-rig, our new design shows that the distance between the two parallel lower tubes of the dual-arm can be potentially reduced to 28mm, measured from the symmetrical axes of the tubes, and even less (depending on the strength of the material of the housing). Also, the simulation result shows that, thanks to the use of double Hooke's joints, the spin motion between the upper and lower tubes can be transferred without any speed reduction, i.e., a 1:1 speed ratio. To further examine the actual transmission between the tubes and wires, a prototype of the flexural transmission is constructed as shown in Fig. 3. Based on a manual testing, it proves that (1) the transmission between the upper and lower tubes possesses a 1:1 speed ratio; (2) the four wire segments embedded in the upper and lower tubes can completely follow the spin rotation of their associated tubes without any speed reduction and length compensation during transmission; and (3) each wire can be independently pushed and pulled when the tubes are rotating.

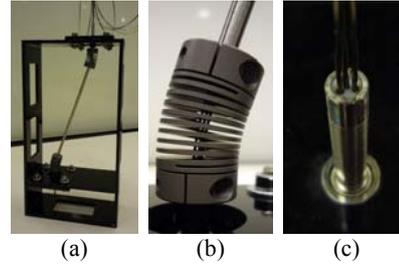


Fig. 3 Prototype of the flexural transmission: (a) overall assemblage; (b) hollow flexible joint; and (c) tube cover

DISCUSSION

The proposed transmission has demonstrated its feasibility in kinematics; however, the surface contact between the wires, tubes and tube covers might incur an unexpected friction force that will request more actuation powers for manipulating the DDU or will stop the transmission itself. The future work of this study will be concentrating on this potential problem.

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