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A cable-pulley transmission mechanism for surgical robot with backdrivable capability

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ABSTRACT

Compact actuators, low friction and back-drivable transmissions are essential components in haptic and impedance type surgical robotic systems, since their performances affect overall volume, force feedback capability and power consumption. An innovative miniaturized, low friction, back-drivable reducing mechanism for haptic or surgical robot applications has been designed, developed and evaluated. A new differential mechanism having a cable comprises a sheave wheel supported by a yolk is also implemented. Low friction and back-drivable, compared to conventional non-back-drivable mechanisms based on gear coupling, is achieved by means of differential cable driven method. The system has been integrated with a permanent-magnet DC motor and a drum on which a tendon is wound, and then finally connected to the remote end joint. Several experiments to validate the feasibility of the reducing device were carried out.

1. Introduction

Currently, teleoperated robotic surgery is performed unilaterally, that is, the surgeon receives no haptic feedback from the operating site other than the visual information from the endoscopic camera. The visual clues provided by the excellent 3D vision of current robotic systems act as a substitute for haptic feedback to the surgeon [1–3]. However, visual feedbacks are incapable of justifying the force magnitudes of dynamic motions. When handling delicate patient tissue, surgeon should ensure the gripped tissue is not damaging by the excessive force applied through the gripper and should maintain static grip force sufficient to firmly hold the patient's tissue as a lock [4–9]. To overcome this problem, many research groups have studied force sensing techniques for minimally invasive surgical robot system [10–14].

The lack of force feedback is largely due to the challenges associated with measuring the interaction forces between the surgical robot and the patient's tissue. Recently, a number of studies have been carried out to integrate force sensors into the surgical instruments for sensing the contact force at the instrument tip. King et al. [15] fabricated a multi-element tactile force sensor system to translate contact force distribution on the end effectors of a surgical robot. Although the proposed system can measure contact forces, it solely evaluates the system tactile perception. Hong and Jo [16] developed a compliant forceps to sense the grasp and pulling forces of the surgical instrument by using strain gauges at the rear of the forceps. However, the prototype proposed in this study can only sense single axis pulling force during tissue manipulation. Kim et al. [17] designed a forceps integrated with a four degree-of-freedom force sensor for minimally invasive robotic surgery. Experimental results show that the proposed force sensor can directly sense the normal and shear forces at the surgical instrument tip. However, this forceps can only measure the inner applied force at the front portion of the forceps. When needing the forces at other regions of the instrument tip, this force sensing forceps cannot meet this requirement.

Nevertheless, force sensors occupy space and cannot be placed sometimes where the force needed to be measured [18,19]. The first challenge for sensing the contact force is the size of the force sensor. The best interaction force sensing is obtained by integrating sensing elements with the tip part of surgical instrument inside the patient's body. However, such sensing elements location imposes critical size limitations. The normal diameter of the surgical instrument is 5 mm or 8 mm. Today, there is no off-the-shelf force sensor with such comparable size. Although, it is difficult to add force sensors directly to existing robotic

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