Grasping force estimation in robotic forceps using a soft pneumatic actuator with a built-in sensor

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Highlights
- A leakless silicone rubber actuator is embedded in the grasper of a robotic forceps
- Strain gauge is inserted during the fabrication process of the actuator
- Grasping force is estimated using the strain measurement and air pressure

Abstract
In this paper, we propose a forceps grasper using a soft actuator that can estimate grasping force. The grasper consists of a small cylinder and a slider-crank mechanism embedded at the tip of the forceps. A pneumatic soft actuator made of silicone is fabricated and inserted in the cylinder. The grasper is actuated by inflating the soft actuator. It causes no leakage of air, as well as lightweight and disposable. The developed soft actuator has a built-in strain gauge to measure the displacement of the actuator. By combing the measurements of the strain gauge and the internal pressure, it can estimate the grasping force. We investigated the relationship between the air pressure in the soft actuator and the opening angle of the grasper in order to estimate the force without a force sensor. First, the soft actuator is pressurized from 0kPa to 160kPa at intervals of 10kPa, and the opening angle of the grasper is measured for each pressure without any load on the grasper. The linearity of the soft actuator between the pressure and the opening angle is confirmed. Then, the experiment with the same protocol is conducted while the grasper grasps a force sensor. The estimated force and the output of the force sensor are compared to show the effectiveness of the proposed method.

Key words: Soft Actuator, Pneumatics, Laparoscopic Surgery, Grasping Force Estimation, Grasper

1. Introduction
Surgical assist robots including those for laparoscopic surgery have largely been developed [1][2]. Particularly da Vinci (Intuitive Surgical, Inc.) is a famous surgical assist robot [3]. Da Vinci makes laparoscopic surgery easier, by filtering tremor of human hand and intuitive master-slave control system. One drawback compared to conventional surgery is the lack of the force sensation, because there are no mechanical connection between the surgeon console and the patient-side robot.

Aiming at a surgical robot with force feedback function, our laboratory have been developed a surgical robot “IBIS” [4][5]. It is pneumatically-driven and the external force applied to the forceps can be estimated by air pressure. Three-DOF haptic feedback was possible in our previous system. Not only the translational force, but also the grasping force is necessary for accurate and safe surgery [6-8], which was not implemented in IBIS.

Recently, studies of the force measurement in surgical instruments have been carried out. In ref. [9], a four-degree-of-freedom (DOF) force sensor is embedded at the grasper. By adopting the capacitive principle, the sensor can measure normal and shear force directly. Kuwano et.al. developed a forceps that can measure the grasping force with a MEMS tactile sensor [10]. The sensor can measure 3DOFs by cantilevers and beams fabricated in the sensor.
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