Development of an integrated torque sensor-motor module for haptic feedback in teleoperated robot-assisted surgery

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Introduction:

Robot-assisted surgery has been achieved in various fields of minimally invasive surgery in appendectomy, cardiotomy, etc. by the state-of-the-art surgical system the da Vinci system. The da Vinci system has enabled the replication of surgeon's delicate and dexterous hand motions inside the patient's body through small surgical instruments. Although the effectiveness of haptic feedback in robot-assisted teleoperated surgery has not yet been fully investigated, it is evident that surgeons can benefit from haptic feedback in robotic surgery.

Surgeons often experience the rupture of surgical thread during anastomosis during surgery with the da Vinci. To give Haptic feedback to the surgeon, A.M. Okamura et al. researched the effect of visual haptic feedback with modified da Vinci surgical instruments. E.U. Braun et al. also tried to provide haptic feedback using a haptic device with modified instruments. This research focuses on the development of an integrated torque sensor/motor module that can be directly applied to the da Vinci system for haptic feedback.

Objective:

We propose to add the haptic feedback in the da Vinci like robot using unmodified da Vinci surgical instrument as shown in Fig. 1. Modification of surgical instruments to measure interaction forces during surgery can be very difficult and can degrade the system's overall performance. We propose a method of implementing haptic feedback in the da Vinci like system by introducing an integrated torque sensor-motor module that can be substitute original motors.

In this paper, we present the design and development of a novel integrated torque sensor-motor module and report the experimental result of the performance evaluation.

Methods:

For design of a torque sensor, we have considered the followings requirements: (1) easy integration with motors (2) high sensitivity in torque measurement and (3) high tensile strength against plastic deformation. A torque sensor with the shape of a hollow cylinder was chosen as shown in Fig. 2. As a result, the sensor-motor module is totally integrated into small package, and it can substitute an original motor with a small modification in the system. We can obtain applied torque by measuring the strain of the sensor body because applied joint torque is measured by the deformation of the sensor beam. Assuming a linearly elastic material, we can approximate a linear relationship between the applied torque and strain described by

$$\sigma = \varepsilon E \qquad (1)$$

where σ, ε and E are the stress, the strain and the Young's modulus, respectively. That is, the sensitivity is proportional to the deformation of the sensor body.

Since sensor material needs to have a linear strain-stress property, steel is chosen as the material for the joint torque sensor. The optimal dimensions with respect to sustainable torque were determined using the finite element analysis.

Results:

Four strain gauges are attached at four points where the maximum strain occurs. These four strain gauges construct a full Wheatstone-Bridge. The torque is converted to the voltage through an amplifier board and an A/D converter.

Fig. 3 shows the voltage output versus the applied torque. As shown in Fig. 3, the graph is fairly linear and the slope of the line indicates sensor calibration coefficient of $\alpha = 90.37\ \mathrm{mV/mN}$. The torque versus the voltage output is linear with 0.2% maximum error by curve-fitting.

Conclusions:

We've designed a new type of an integrated torque sensor-motor module to implement haptic feedback in the da Vinci's surgical instruments. The proposed torque sensor/motor module has a totally integrated design that can replace a nominal motor. It also shows linear stress-strain relation and inherent high sensitivity.

To evaluate the proposed module's usability with the da Vinci system, we are designing a coupler that allows direct attachment of the surgical instrument to senor/motor module. Also, the forces which are measured from the da Vinci surgical instruments are highly coupled. Hence the decoupling the forces and mapping to the master device are needed. We will use a PHANToM haptic device as a master device. The details of experimental results will be presented within a few months.

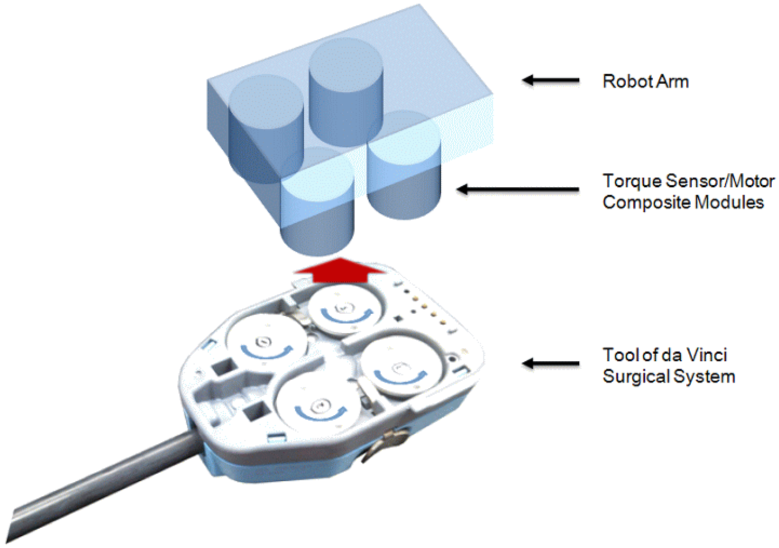
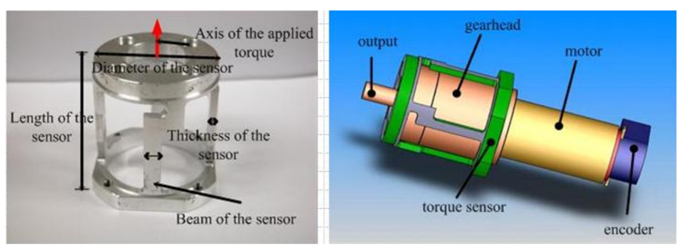


Fig.1 Adding haptic sensing to the da Vinci surgical instrument



(a) (b)

Fig.2 The integrated torque sensor-motor module

(a) A newly designed joint torque sensor (b) A torque sensor assembled with a motor

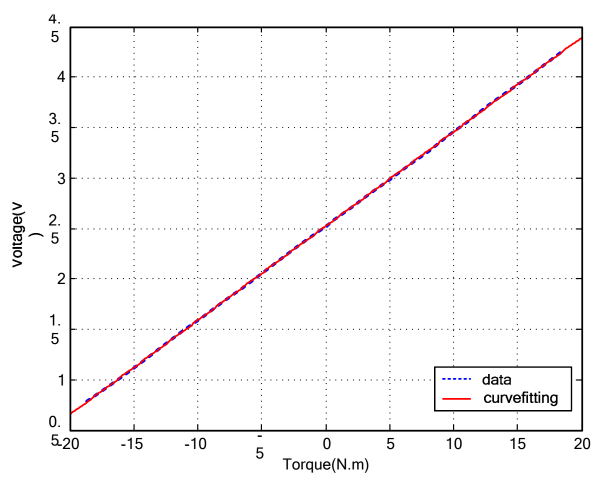


Fig. 3 Sensor output versus applied torque