Haptics in Surgical Robotics

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ABSTRACT

We experience haptic feedback during countless daily manual tasks which involve grasping, cutting, and manipulation of all kinds of objects and materials, either through direct contact with the hand and fingers, or mediated through handheld tools and instruments. Due to our experience and skill in these haptic tasks, it would be reasonable to surmise that the operator interfaces for teleoperated robotic minimally invasive surgery (RMIS) systems such as the well-known *da Vinci* from Intuitive [1] of Fig. 1 would benefit from inclusion of haptic force feedback to the user. Yet despite extensive research and development in the areas of tool-tissue interaction force sensing and haptic feedback to teleoperators, the adoption of haptic feedack in RMIS systems remains limited. This lack of haptic feedback in most RMIS procedures may be due to many different reasons, which will be presented in detail.

To add haptic feedback to a teleoperated robotic system, the control console must incorporate some actuated haptic interface device to present instrument and tissue interaction forces to the surgeon operator, such as the pen-based handheld device shown in Fig. 2 [2]. The robotic instruments must include a means of sensing of interaction forces, such as the multi-axis strain gauge sensor of Fig. 3 [3]. In the case of RMIS, it is a technical challenge to provide useful, accurate, reliable and biocompatible force sensing at the end of surgical instruments. Furthermore, experienced surgeons are accustomed to the lack of haptic feedback in manual MIS when passing laparoscopic instruments through minimally invasive incisions and trocars, and may find added force feedback to be unnatural or a distraction.

An extensive study of haptic feedback provided with a *da Vinci* system is provided in [4]. Comprehensive reviews of haptic feedback in RMIS are given in [5] and [6], with more recent results given in detail in [7] and [8].

Commercial surgical robot systems which incorporate some degree of haptic feedback include the Mako robotic arm knee arthroplasty system [9] from Stryker Corporation and the Senhance sugical system from Asensus [10]. The Mako system uses haptic feedback on the leader robot to implement virtual barriers to guide the surgeon to place bone implants accurately in both translation and orientation. The Senhance system has user feedback of actual tool-tissue interaction forces in minimally invasive surgery.

There are many technical challenges involved in providing useful haptic feedback in a surgical robot system with a sense of telepresence to the surgeon which is sufficient to conclusively improve surgical preformance. These difficulties are in the areas of sensing, control, and haptic display to the user. To sense instrument-tissue interaction forces in minimally invasive surgery, the sensor must be small enough to fit inside a minimally invasive surgical instrument, ideally near its tip, and it must be sterilizable, waterproof, and biocompatible. To effectively generate these haptic forces on the surgeon while operating the leader robot, there are potential issues in motion and force ranges, stability, impedance range, and response time to be overcome.

The development of methods to overcome the difficulties of haptic feedback in surgical robots has been an active area of research since the initial systems developed in the 1990s. Force sensing methods have included conventional

Fig. 1. *da Vinci* system robot and teleoperation console

Fig. 2. Handheld haptic interface device

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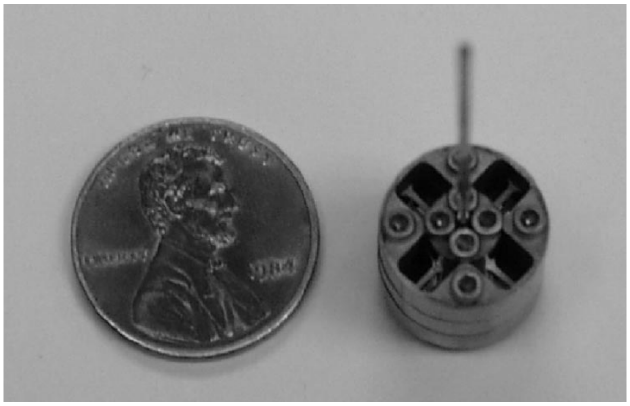

Fig. 3. Miniature instrument force sensor

strain gauge assemblies such as pictured in Fig. 3 and have progressed to more novel modalities, materials, and devices such as optical fibers, diffraction gratings, and semiconductor materials. Passivity control and multichannel communication methods have been developed to improve the fidelity of haptic feedback while assuring the stability of the teleoperation control system.

The *MiroSurge* surgical robot research system from the German Aerospace Center incorporates miniature six degree-of-freedom force and torque sensors and teleoperation interfaces with full 6 DOF force and torque haptic feedback to be used in several different areas in minimally invasive surgery [11]. Steady-hand human and robot cooperative manipulation was developed at Johns Hopkins University as an alternative to teleoperation for providing haptic force and torque feedback to the operator of a surgical robot system [12]. More recently, sensing methods have been developed to identify tissues by sensing electrical impedance rather than mechanical stiffness [13]. Autonomous functionality can also be integrated into the control of the teleoperation leader and follower robots in robotic surgery to compensate for difficulties in force and torque sensing and haptic feedback [14].

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