Haptics in Telerobotic Systems for Minimally Invasive Surgery

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9.1 Introduction

In the current practice of minimally invasive surgery (MIS) and therapy, a surgeon is faced with problems such as a lack of dexterity because of restricted port access to the surgical site, a lack of fine manipulation capability because of the long surgical instruments, visual problems including motion sickness and loss of localization, and significant degradation of touch sensation (haptic feedback) for the surgeon from the instrument and its contact with tissue. Some of the reasons for such degradation in the feedback of touch are that (1) the instruments include hinge mechanisms with significant friction, (2) the cannulae through which instruments are inserted introduce friction [6], and (3) the contact forces at the instrument tip can sometimes be very small compared with the relatively large forces supplied by the arm to move the instrument mass and the unsupported hand. As a result of this degradation in the haptic sensation for the surgeon, surgical tasks requiring accurate feeling of tissue characteristics such as palpation are difficult to perform in the minimally invasive mode.

The recent use of robots in surgical interventions has solved several of the above-mentioned problems associated with non-robotic surgery. For instance, the end tool of the da Vinci Surgical (robotic) System (Intuitive Surgical, Sunnyvale, Calif.) includes a wrist that adds three rotations to the motions conventionally available in a minimally invasive environment, in order to improve the surgeon’s dexterity. However, the current surgical robotic systems have not yet been successful in terms of restoring feedback of instrument/tissue contacts to the surgeon. While the da Vinci system is capable of providing force feedback to the surgeon in some directions, this feedback is of low quality and disabled by the manufacturer, mainly because in the absence of force sensors on the surgical tool the interactions between the robot and the patient’s body are estimated from outside the patient and are consequently plagued by disturbances, bias, and noise caused by the entry port.
The absence of haptic feedback to the surgeon about instrument/tissue interactions is a safety concern in MIS. For instance, in a study involving minimally invasive cholecystectomy, it was observed that inappropriate and excessive application of force was a main cause of perforation of the gallbladder [2]. Such a safety concern is especially significant if visual feedback to the surgeon is degraded, e.g., if fluids from the patient’s body cloud the camera lens or the instruments leave the limited field of view of the endoscopic camera. On the other hand, the presence of haptic feedback can provide the surgeon with the required perceptual information for optimal application of forces, thus reducing trauma to tissue. It can also shorten the task completion times by eliminating the need for prolonging the maneuvers and awaiting visual cues as to the strength of the grip, the softness of the tissue, etc. Lastly, for instruments with restricted maneuverability as in MIS, haptic feedback is expected to improve the precision of manipulation. Research has been done to evaluate the influence of haptic perception on human sensory and motor capabilities for several surgical tasks. For instance, the ability to sense the puncturing of different tissue layers during the needle insertion task improves when users receive haptic feedback [1]. Moreover, study of the effect of force feedback on performing blunt dissection has shown that it reduces the number of errors, the task completion time, and the magnitude of contact forces [14].

9.2 Mechanisms for Haptic Teleoperation

A master-slave system for robot-assisted MIS consists of three main parts: a robotic arm that holds and controls the endoscope, robotic arms that hold and actuate the surgical instruments, and a human-machine interface (HMI) for the surgical robot. In such a system, the surgeon operates using the HMI (the master), while the surgical robot (the slave) follows the surgeon’s hand maneuvers transmitted from the HMI inside the patient’s body. For feedback of instrument/tissue interactions to the surgeon’s hand during master–slave teleoperation, it is imperative to have an HMI that can reflect forces to the surgeon’s hand, in addition to a properly sensorized surgical tool that can measure its interaction with tissue. The master and slave subsystems of a haptic teleoperation system appropriate for use in a minimally invasive surgery/therapy environment are described next.