21

Robot Assisted Force Feedback Surgery

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Summary. Minimally invasive surgery characterizes a sophisticated operation technique in which long, slender instruments are inserted into the patient through small incisions. Though providing crucial benefits compared to open surgery (i.e. reduced tissue traumatization) it is also faced with a number of disadvantages. One of the major problems is that the surgeon cannot access the operating field directly and, therefore, can neither palpate tissue nor sense forces sufficiently. Furthermore, the dexterity of the surgeon is reduced as the instruments have to be pivoted around an invariant point.

To overcome some of the drawbacks, telepresence constitutes a promising approach. The surgical instruments can be equipped with miniaturized force/torque sensors and contact forces can be displayed to the surgeon using a suitable man-machine interface. Furthermore, instruments can be built with additional degrees of freedom at the distal end, providing full dexterity inside the patient's body. Thanks to telepresence the surgeon regains direct access to the operating field, similar to open surgery.

In this chapter a prototypical force reflecting minimally invasive robotic surgery system based on two surgical robots is presented. The robots are equipped with a sensorized scalpel and a stereo laparoscope for visual feedback. The operator console consists of a PHANToM force feedback device and a stereoscopic display. Experimental results of a tissue dissection task revealed significant differences between manual and robot assisted surgery. At the end of the chapter some conclusions based on the experimental evaluation are drawn, showing that both, manual and robotic minimally invasive surgery have specific advantages.

21.1 Introduction and Motivation

In conventional open surgery the surgeon has full access to the operation area and thus can use all senses for the demanding task of surgery. In contrast to this, in minimally invasive surgery the access is restricted as the surgeon works with long instruments through small incisions.

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In this section the peculiarities of manual minimally invasive surgery (MIS) are described and advantages as well as disadvantages are discussed. Subsequently, a short introduction in minimally invasive robotic surgery (MIRS) is given which illustrates the research needs.

21.1.1 Minimally Invasive Surgery

Minimally invasive surgery is an operation technique which was established in the 1980s. In contrast to conventional, open surgery there is no direct access to the operating field and the surgeon employs long, slender instruments. These are inserted into the patient through narrow incisions which are typically slightly bigger than the instrument diameter (see Fig. 21.1).

The main advantages of MIS, compared to open surgery, are reduced pain and trauma, shorter hospitalisation, shorter rehabilitation time and cosmetic advantages. However, MIS is faced with at least three major disadvantages [1]: (a) As the surgeon does not have direct access to the operating field the tissue cannot be palpated any more. (b) Because of the relatively high friction in the trocar[1] and due to the torques which are necessary to rotate the instrument around the entry point, the contact forces between instrument and tissue can hardly be sensed. This is especially true when the trocar is placed in the intercostal space (between the ribs). (c) As the instruments have to be pivoted around an invariant fulcrum point (see Fig. 21.1), intuitive direct hand-eye coordination is lost. Furthermore, due to kinematic restrictions only four degrees of freedom (DoF) remain inside the body of the patient. Therefore, the surgeon cannot reach any point in the work space at arbitrary orientation. This is a main drawback of MIS, which makes complex tasks like knot tying very time consuming and requires intensive training [2, 3]. As a consequence MIS did not prevail as desired by patients as well as by surgeons and while most standard cholecystectomies (gall bladder removal) are performed minimally invasively in the industrialised world, MIS is hardly used in any other procedure to this extent.

21.1.2 Minimally Invasive Robotic Surgery

Robotic and mechatronic systems become a key technology for coping with the drawbacks of manual MIS. Together with telemanipulation techniques they enable a surgeon to regain full access to the operation field. Minimally invasive robotic surgery provides at least five potential advantages: (a) Small force/torque sensors placed near the instrument tip can measure manipulation forces/torques directly and thus, provide kinesthetic feedback when displayed to the surgeon [4]. (b) Actuated instruments with two additional DoF give back full dexterity inside the human body. (c) The undesired reverse hand motion can be avoided by appropriate control algorithms [5]. (d) More accurate movements are possible as the surgeon's hand motion can be scaled down before being transmitted to

[1] The trocar is a surgical instrument, which makes it possible to create incisions in a visceral cavity (i.e. thorax, abdominal cavity) and keep it open with the aid of a tube.