

Chapter 17

Biomedical Robotics for Healthcare

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ABSTRACT

Haptic information is crucial in the execution of precise and dexterous manipulations. During minimally invasive surgery, medical doctors are required to indirectly sense force-related information from body organ tissue via forceps because they cannot directly touch the tissue. The evaluation of force-based skill is critical in the judgment of whether a person has adequate manipulation skills to conduct surgery procedures. Currently, simulation training in minimally invasive surgery is a required component of general surgery residency training. A primary obstacle in the development of a training simulator with a haptic feedback capability is its high cost. This chapter addresses two research issues that must be integrated in the development of a cost-effective haptic training system: the challenge of skill evaluation during laparoscopic surgery by measuring the force applied to forceps, and a novel haptic display based on a haptic augmented reality (AR) technique.

INTRODUCTION

Minimally invasive surgery has gained popularity due to the advantages of small incisions, rapid recovery of patients, and reduction of medical costs. However, surgery conducted under an

endoscopic camera is challenging for surgeons because they typically cannot precisely determine the size of body organs or the distance between the organs and forceps due to the limitations in stereo visual perceptions. As a result, the objective and quantitative evaluation of surgical skills remains an unresolved issue.

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Currently, simulation in a minimally invasive surgery training environment is considered essential and is a required component of general surgery residency training. Many surgical simulators have been developed to efficiently and safely hone surgical skills. These simulators function through various levels of virtual reality, including high-fidelity virtual reality (VR) and visual augmented reality (AR) (Botden, Buzink, Schijven, & Jakimowicz, 2007; Hance, Aggarwal, Undre, Patel, Selvapatt, & Darzi, 2004; Van Sickle, 2005). According to various studies (Grantcharov, Kristiansen, & Bendix, 2004; Panait, Akkary, Bell, Roberts, Dudrick & Duffy, 2009; Seymour, Gallagher, & Roman, 2002), a force feedback capability is a fundamental feature of these programs that helps to improve skill in real-world minimally invasive surgery.

Haptic display is one of the most promising interfaces in the human-computer interaction tool that provides users with nuanced information in a virtual environment. PHANToM is one of the most widely used commercially available haptic devices. PHANToM has a serial link mechanism, and it can exert force along multiple axes and torques at the pen tip. Sato's research group has developed a series of wire-driven haptic devices (SPIDAR series) (Kim, Hasegawa, Koike, & Sato, 2002; Murayama, Luo, Akahane, Hasegawa, & Sato, 2004; Sato, Hirata & Kawarada, 1992). For example, SPIDAR-G has seven degrees of freedom (DOF) force feedbacks, including three DOF for translation, three DOF for rotation, and one DOF for grasp. It exhibits a smooth force feedback with minimal inertia, no backlash, scalability and safety. Arata et al. have developed a haptic device that can exert three-axis force control (DELTA-4) (Arata, Kondo, Sagaguchi, & Fujimoto, 2009). The parallel link mechanism of the DELTA-4 contributes to the high rigidity of the device. These devices enable kinesthetic haptic interactions with a virtual environment. The primary issue in the development of VR simulators with force feedback capability is the extremely high cost of integrating the equipment with the simulator to

give users natural and comfortable haptic sensations (Salkini, Doarn, Kiehl, Broderick, Donovan & Gaitonde, 2010; Thompson, Leonard, Doarn, Roesch, & Broderick, 2011). Modeling the complex force response of a viscoelastic object is still a challenging issue. Many modeling methods have been proposed that simulate the deformation and calculate the reaction force of a viscoelastic object (Ghoi, Kim, Han, Ahn, & Kim, 2009; Lim, Deo, Singh, Jones & De, 2009; Wu and Heng, 2005). In order to calculate the deformation of a complicated model, a large calculation cost is required. Moreover, high performance haptic feedback systems usually require sophisticated actuators and sensors, and consequently, such systems are not cost-effective.

In this chapter, two research studies are addressed in detail. The first study aims to explore the challenge of skill evaluation in a laparoscopic surgery by measuring the force applied to forceps, whereas the second study describes a novel haptic display based on a haptic augmented reality (AR) technique. These studies employ a cost-effective force measurement to evaluate the skills in surgical operations and a cost-effective haptic display to provide a surgical simulator with a haptic feedback capability.

AUTOMATIC CLASSIFICATION AND SKILL ASSESSMENT OF FORCEPS MANIPULATION

This study aims to develop a skill assessment environment of forceps manipulation through the automatic, real-time classification of basic manipulations executed during a minimally invasive surgery.

Automatic Classification of Forceps Manipulation

Basic manipulations were defined by observing the laparoscopic surgery videos of a cholecystec-

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