Chapter 11
Development and Simulation of an Adaptive Control System for the Teleoperation of Medical Robots

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ABSTRACT

This chapter presents the design and calculation procedure for a teleoperation and remote control of a medical robot that can help a doctor to use his hands/fingers to examine patients in remote areas. This teleoperation system is simple and low cost, connected to the global Internet system, and through the interaction with the master device, the medical doctor is able to communicate control signals for the slave device. This controller is robust to the time-variant delays and the environment uncertainties while assuring the stability and the high transparent performance. A novel theoretical framework and algorithms are developed with time forward observer-based adaptive controller and neural network-based multiple model. The system allows the medical doctor to feel the real sense of the remote environments.

1. INTRODUCTION

Teleoperation indicates the operation of a device at a distance. It is similar to remote control but normally associated with robotic systems in which a device operated by a human (master) is used to control a robot from a distance (master-slave control). Master-slave teleoperation has many applications including dangerous environments. The human operator interacts with the master device to generate control signals to send to the slave device. The slave device actually interacts with the remote environments while staying under the control of the human operator. Information collecting at the remote environments is then transmitted back to the human operator through the communication networks and the master device.

Varying time delays through the communication channel and the uncertainties of the remote environments are the most critical problems for
the stability and the transparent performance of a teleoperation system since they can cause bad performance and instability to the system. In this study, a novel framework for medical remote control is developed. It can assure the high level of transparent performance as the impedance felt by the medical doctor on the local site. This allows him feel the real sense of the remote environments to examine patients in remote locations.

The evolution of teleoperation has generated sophisticated systems in order to provide better solutions that the operator can feel as if he is present in the operation sites. Kikuchi et al. (1998) proposed a teleoperation system in dynamic environment with varying communication time delays. The proposed system consists of the stable bilateral teleoperation subsystems using the virtual time delay method. The visual information offers the prediction of the slave manipulator and the environment. Zhu and Salcudean (1999) introduced a novel stability guaranteed controller design for bilateral teleoperation under both position and rate control modes with arbitrary motion/force scaling. Boukhnifer and Ferreira (2006) showed that the application of wave variable transformation preserves the passivity of the teleoperation system in spite of communication delays and the varying scale factors.

Lawrence (1993) explored the trade-off transparency and stability in the presence of communication delays based on the concept of impedance. Impedance is a quantity that maps the input of a system to the output force. When a teleoperation system is ideal, the operator feels as if he is executing the task with his own hands on the scene. Ślawinski and Mut (2008) proposed defining transparency in the time domain and established a quantitative measure of how the human operator feels the remote system. It allows analyzing the effect of the time-varying delays on the system transparency.

Unknown and highly changeable attributes of remote environments make the development of fully comprehensive models impractical. A method of creating a selection of different simple models and dynamically selecting an appropriate one for a given time is proposed. Various methods have been developed for model detection. One of the most effective methods of model detection and usage is using multiple model neural networks. Multiple model neural networks are useful because they are powerful but also run fast enough to operate in real time. Most neural networks that are presently employed for artificial intelligence are based in statistical estimation, optimization and control theory. Chen et al. (2007) proposed a neural network based multiple model adaptive control for teleoperation systems. Decision controllers are designed to adaptively switch among all predictive controllers according to the performance target. This method can ensure the stability and transparent performance of the system. Smith and Hashtrudi-Zaad (2005) used two neural networks at the master and slave devices to improve the transparency and to compensate the effect of the time delays.

The aim of the chapter is to develop a simple and low cost teleoperation system operated over the Internet using TCP/IP and without a camera in the slave device. The system can be supported by a telephone or voice chat over Internet Protocol (VoIP) for a medical doctor who can use the hands/fingers to examine the remote patients. The idea for the system is based on the design for a medical tele-analyzer in Suebsomran and Parnichkun (2005). The developed system was shown to be robust to internal and external disturbances, model uncertainty and friction. Hashtrudi-Zaad and Salcudean (2002) introduced the mathematics the defines the stability of a teleoperation system. Minh et al. (2007) performed further research and analysis environmental uncertainty and verification. Chen et al. (2010) introduced methods to maintain the stability of uncertain cellular neural networks with interval time-varying delays. Park and Kwon (2009) proposed a novel stability criterion for the stability based on the Lyapunov function in terms of Linear Matrix Inequalities.
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