Chapter 15
Design and Implementation for Controlling Multiple Robotic Systems by a Single Operator Under Random Communication Delays

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ABSTRACT

Multiple robots can be tele-operated by a single operator to accomplish complicated tasks such as formation and co-transportation. Such systems are challenging because one operator needs to simultaneously tele-control multiple homogeneous and even heterogeneous robots. Besides, the communication between the operator and multi-robot system and the communication among the multiple robots are always subject to some communication constraints such as time delays. This chapter introduces a novel non-time based method to realize the single-operator-multi-robot (SOMR) teleoperation system with random communication delays. The problem is divided into a typical teleoperation problem and a multi-robot coordination problem. A non-time variable is taken as the system reference instead of the time to model and drive the system such that the random communication delays and some expected events could be automatically handled. Experiments implemented on a multi-robot system illustrate the effectiveness and advantages of the method.

INTRODUCTION

A swarm of robots can be combined together to provide strong power on accomplishing some complicated tasks. Integrating multiple robots into the robotic system can enhance the capacity, flexibility and efficiency of the robotic system (Scharf, Hadaegh, & Ploen, 2003). The multiple robots can be tele operated by a single operator and such structure can be applied to many areas including tele-surgery,

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tele-exploration, tele-patrol and other fields. This kind of system is called the single-operator-multi-robot (SOMR) teleoperation system.

The SOMR teleoperation system is challenging in many aspects.

First, there is only one operator in the system but he/she needs to control multiple robots simultaneously. Thus an efficient structure of one-control-more need to be designed. Second the robot systems may be heterogeneous. Different robots may have completely different designs and functions. Thus, a general coordination of these heterogeneous systems needs to be considered. Third, in SOMR system, not only the tele-operator and the multi-robot system communicate through physical communication media, but also the multiple robots communicate with each other through these media. These media include the Internet, telephone network, satellite network and other such forms. However, they are in the nature of communication constraints like time delays. In particular, for some media like the Internet, the time delays are completely random. It can be neither predicted nor assumed to be bounded. The limit of the communication media has significant effects on the stability of the SOMR teleoperation system. Fourth, the system should be able to handle some unexpected events such as unexpected stop of the robot and unexpected obstacles. This is also very important for the efficiency and safety of the SOMR teleoperation system.

Therefore, this chapter investigates the SOMR teleoperation system where the communication between the tele-operator and the remote multi-robot system and the communication among the multiple robots both exist and are both subject to random time delays.

In the chapter, a review of the SOMR systems is introduced and analyzed. Then, a non-time based SOMR teleoperation system under random time delays is designed. The system modeling and control are based on a non-time reference instead of a timed one. Therefore, the effects caused by time delays are eliminated. A method using a perceptive coordination reference is proposed to make the single operator be able to control multiple robots, move the robots track the desired trajectory and also satisfy the assigned coordination requirements such as formation. Furthermore, the designed system can also coordinate heterogeneous multi-robot system and handle expected events.

The designed method is experimentally implemented on a multi-mobile-manipulator system for multi-robot formation tasks. The experimental results demonstrated the effectiveness and advantages of the proposed method.

BACKGROUND

Some recent studies have been conducted on the control of multiple robotic systems by a single operator in various situations.

In (Suzuki, Sekine, Fujii, Asama, & Endo, 2000) and (Reinoso, Gil, Paya, & Julia, 2008), the multi-robot system was assumed to be highly autonomous. The operator sent high-level task formation control commands to multi-robot system, which were then carried out autonomously by the multi-robot system. The operator supervised the multi-robot system and sent commands by using the shared natural language when he/she thought it was necessary. This approach highly relied on the autonomy of the robots and its lack of safety.

A semi-autonomous bilateral tele-operation framework for the SOMR system was proposed in (Lee, Martinez-Palafox, & Spong, 2005) and (Lee & Spong, 2005). The dynamics of the multiple slave robots were decomposed into two decoupled systems while enforcing energetic passivity. The first system is the

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