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Improving the performance of DTP2 bilateral teleoperation control system with haptic augmentation

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HIGHLIGHTS

- An experimental haptic shared control system, called CAT developed at the DTP2.
- We investigate how the system integrates with the ITER compliant DTP2 RHCS.
- The effect of CAT experimentally assessed in an ITER relevant maintenance scenario.

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ABSTRACT

The remote maintenance of the ITER divertor is largely dependent on the usage of haptically teleoperated manipulators and man-in-the-loop operations. These maintenance operations are very demanding for the manipulator operators, yet vital for the success of the whole ITER experiment. Haptic shared control of the maintenance manipulators offers a promising solution for assisting the teleoperators in the maintenance tasks. A shared control system assists the operator by generating artificial guiding force effects and overlaying them on top of the haptic feedback from the teleoperation environment.

An experimental haptic shared control system, called the Computer Assisted Teleoperation (CAT) has been developed at the Divertor Test Platform 2 (DTP2). In this paper, we investigate the design of the system and how the system integrates with the ITER compliant DTP2 prototype Remote Handling Control System (RHCS). We also experimentally assess the effect of the guidance to the operator performance in an ITER-relevant maintenance scenario using the Water Hydraulic MANipulator (WHMAN), which is specially designed for the divertor maintenance. The result of the experiment gives suggestive indication that the CAT system improves the performance of the operators of the system.

1. Introduction

Haptic bilateral teleoperation is a challenging and mentally demanding job for the operators of robot control systems. It is especially difficult in cases such as the remote maintenance of the ITER divertor region. Particularly, the weights of the handled divertor components and required accuracies are high, and the space around the components is constricted [1]. Most of the divertor maintenance tasks require bilateral teleoperation (man-in-the-loop) due to the complex tasks and limited viewing system [2].

Virtual reality and operator support systems can be used to reduce the amount of mental and physical workload perceived by the operators and make teleoperation tasks faster and safer. Especially haptic shared control systems have been demonstrated to improve teleoperation results significantly (e.g. [3–5]). The concept of this kind of system, first proposed by Rosenberg [3], is to assist the operators during haptic bilateral teleoperation tasks by generating virtual forces based on virtual models of the teleoperation environment and sensor data from the slave manipulator. These artificial assisting forces are combined with force feedback signals from the teleoperation environment. The assisting forces make bilateral teleoperation more efficient and safer by guiding the operator to the point of interest in the teleoperation environment, and by damping motion when close to contact with protected areas of the teleoperation environment. A system called Computer Assisted Teleoperation (CAT) has been implemented at the Divertor Test Platform 2 (DTP2) to provide shared control mode for the operators.

The purpose of this paper is to investigate the effectiveness of the implemented CAT techniques in the DTP2 setup within an ITER representative Remote Handling Control System (RHCS). The effect of the guidance provided by CAT is evaluated in an ITER relevant divertor maintenance experiment. The slave device in

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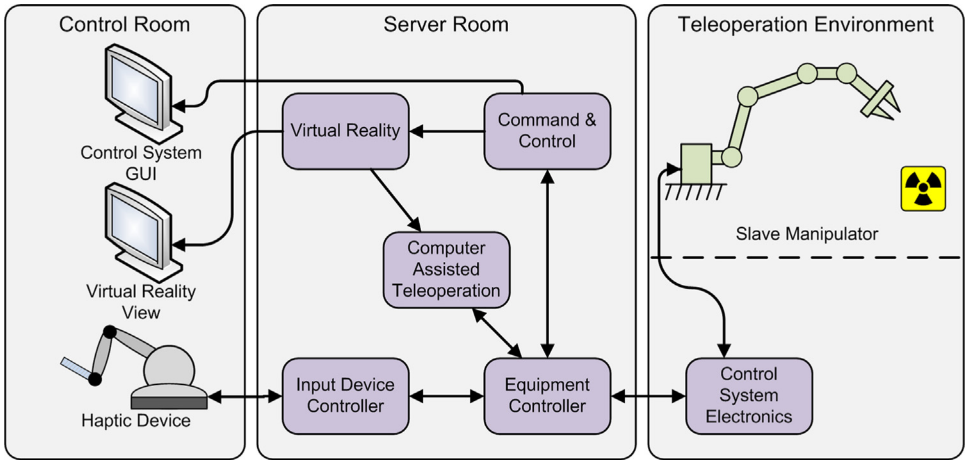

Fig. 1. Architectural view of subsystems contributing to the bilateral control of the WHMAN.

the experiment is the Water Hydraulic MANipulator (WHMAN), which has been developed for the divertor cassette replacement and ITER environmental conditions. During the experiment, the execution times of the teleoperation task and operator workload were observed to assess the performance of the CAT system.

Section 2 of this paper introduces the DTP2 RHCS and the manipulators, used in the shared control experiment. Section 3 introduces the CAT system and its integration to the DTP2 RHCS. Section 4 describes the shared control experiment and Section 5 the results of it. Section 6 is the discussion of results and Section 7 presents the conclusions.

2. Background

2.1. DTP2 Remote Handling Control System

The DTP2 RHCS architecture is an adaptation of the ITER RHCS architecture [6]. The parts of the control system that are related to the bilateral control of the manipulators are:

- Command & Control (C&C),
- Equipment Controller (EC),
- Input Device Controller (IDC),
- Input Device (ID),
- Computer Assisted Teleoperation (CAT),
- Virtual Reality (VR).

All of these subsystems, except the input device, are developed in-house for the DTP2 research. Relations between the subsystems are presented in Fig. 1.

The control system, introduced in Ref. [7], implements a master-slave bilateral teleoperation scheme, where a commercial haptic device (Phantom Premium 3.0 6 DOF) is used as the master and the WHMAN as the slave manipulator. The C&C subsystem provides operators with a graphical user interface for the devices. The VR subsystem provides a virtual representation of the teleoperation environment and is used for setting up the virtual models to the CAT system. The assisting virtual forces are reflected to the master side of the bilateral teleoperation system.

2.2. Slave manipulator

The slave manipulator used in this experiment is the WHMAN, introduced in Ref. [8]. This manipulator has been developed specifically for the environmental condition of the ITER divertor and maintenance tasks that require high agility (Fig. 2).

Fig. 2. 6 DOF Water Hydraulic MANipulator (WHMAN).

The WHMAN is composed of a robotic arm (with three rotational joints and one prismatic joint) and a spherical wrist (three rotational joints) that is attached to the end of the arm. The whole manipulator is installed on top of a linear joint. All the joints are used continuously and concurrently so that the manipulator achieves redundancy with eight active joints. A 6 Degree of Freedom (DOF) force sensor is attached to the tip of the manipulator. This allows contact force and torque measurements that are used for the haptic feedback.

2.3. Master device

The master device used with the DTP2 RHCS is a Phantom Premium 3.0 6-DOF-haptic device, manufactured by Geomagic-Sensable. The device provides force feedback in three translational degrees of freedom and torque feedback in three rotational degrees of freedom.

The work space of the haptic device is much smaller (approximately 900 mm × 900 mm × 300 mm) than the work space of the slave device (approximately 5000 mm × 4500 mm × 4500 mm) [8,9]. The movements between these manipulators are also scaled (5:1 ratio used in this experiment). To allow the usage of the manipulators with such different scales a push button is available on the haptic device handle for re-indexing. When the button is not pressed, the master manipulator is disengaged from the slave and can be repositioned independently. Pressing and holding the push button engages the master with the slave and the operator can start controlling the motion. The device also electrically recognizes the presence of the operator's hand and disables force feedback if the hand is not present.