Fusion Engineering and Design 104 (2016) 93–100

Contents lists available at ScienceDirect

Fusion Engineering and Design

journal homepage: www.elsevier.com/locate/fusengdes

Hand-eye coordinative remote maintenance in a tokamak vessel

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HIGHLIGHTS

- If there is not rotation between the visual coordinate frame ($O_eX_eY_e$) and hand coordinate frame ($O_hX_hY_h$), a person can coordinate the movement between hand and eye easily.
- We establish an alignment between the movement of the operator's hand and the visual scene of the end-effector as displayed on the monitor.
- A potential function is set up in a simplified vacuum vessel model to provide a fast collision checking, and the alignment between repulsive force and Omega 7 feedback force is accomplished.
- We carry out an experiment to evaluate its performance in a remote handling task.

ARTICLE INFO

Article history:
Received 30 June 2015
Received in revised form
11 December 2015
Accepted 5 January 2016
Available online 18 February 2016

Keywords:
Remote handling
Tokamak
Hand-eye coordination
Collision avoidance

ABSTRACT

The reliability is vitally important for the remote maintenance in a tokamak vessel. In order to establish a more accurate and safer remote handling system, a hand-eye coordination method and an artificial potential function based collision avoidance method were proposed in this paper. At the end of this paper, these methods were implemented to a bolts tightening maintenance task, which was carried out in our 1/10 scale tokamak model. Experiment results have verified the value of the hand-eye coordination method and the collision avoidance method.

1. Introduction

Tokamak is common used to contain plasma in a nuclear device, but the maintenance of the hundreds of components is an important issue. Take the world's largest nuclear fusion research facility, ITER vacuum vessel, for example, about 440 individual blanket modules are assembled onto the inner surfaces of the vessel and from time to time it becomes necessary to replace an individual module when it is out of order. Given the obvious dangers of ionizing radiation to human beings during blanket maintenance [1], an effective remote maintenance solution is required.

The accuracy and safety are two vital issues in remote handling tasks. These two issues are influenced by both mechatronic system and human operator, which is a little difference from a traditional programmed system. Since we have designed a high accuracy machine, the remaining task is to design a human friendly operation system. In this paper, a hand-eye coordination method was proposed to make sure the movement of the teleoperated manipulator's end-effector on the monitor will align to the operator's hand movement. Besides, the classical artificial potential functions were introduced into our testing system, which can set up a haptic remote handling system to avoid invisible collision.

What' more, this paper is organized as follows: firstly, the model of the remote handling task is introduced. This consists of a tokamak vessel model, a remote handling manipulator and a master device. Secondly, the hand-eye coordination method is introduced and realized. Besides, the artificial potential functions are utilized for collision avoidance. Then the most basic task during blanket maintenance (tightening bolts) is performed on our research platform to demonstrate the effectiveness of these methods. Finally, we draw some conclusions and make some discussions.

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http://dx.doi.org/10.1016/j.fusengdes.2016.01.006
0920-3796/

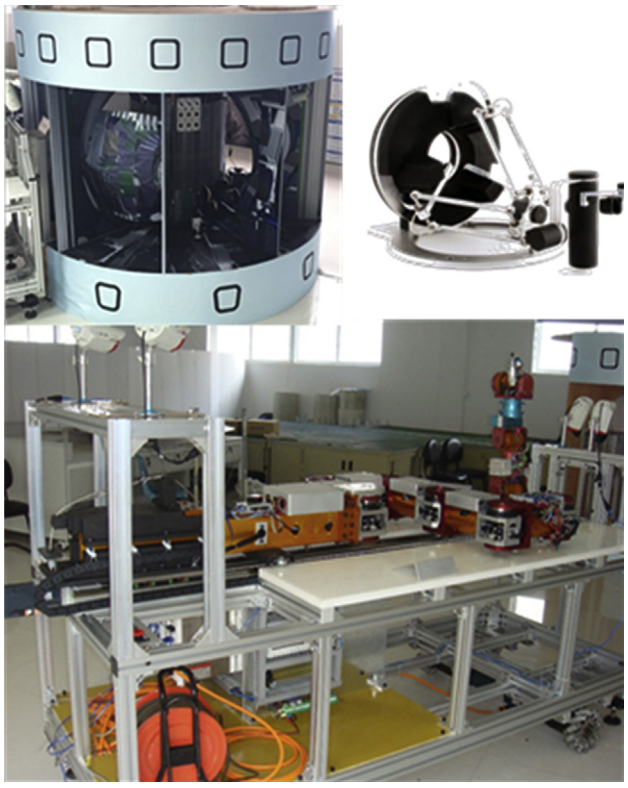

Fig. 1. Our platform: a 1/10 scale tokamak model, a haptic device Omega 7 and a remote handling manipulator.

2. Research platform

As shown in Fig. 1, our platform consists of a 1/10 scale tokamak model, a haptic device Omega 7 and a remote handling manipulator. The size of the tokamak model is determined in accordance with [2,3], and an iron plate is assembled on the first wall of the vessel model as a blanket. As for the master device, the haptic device Omega 7, whose kinematics solution can be obtained easily, is adopted [4]. The most important part is the remote handling manipulator, which includes: an omnidirectional transfer vehicle (OTV); a load-carrying and transmission robot (LCT-Robot); and a 6-dof teleoperated manipulator (TOM). The TOM is mounted on the last link of the LCT-Robot, and the LCT-Robot is mounted on the OTV.

Fig. 2 demonstrates the blanket maintenance tasks: First, the position of the target blanket module should be determined. Following this, the TOM is then transported into the vacuum vessel model and near the target blanket module to make sure that the working area lies in the TOM's workspace. Lastly, the maintenance personnel can loosen (or tighten) the bolts through dexterous handling of the Omega 7 device.

3. Hand-eye coordinative teleoperation

According to the results of an earlier research [5], if the movement of one's hand is aligned to the movement in his/her eyes, a person can finish a writing task more accurately and effectively. This alignment between the hand motion and visual image is known as hand-eye coordination. In remote handling tasks, the operator handles a master device to control the slave manipulators while monitoring these manipulators via cameras. The camera (monitor) serves as the operator's "eyes", and the tele-operated manipulator as the operator's "hand", thus the hand-eye coordination is very important in remote handling tasks.

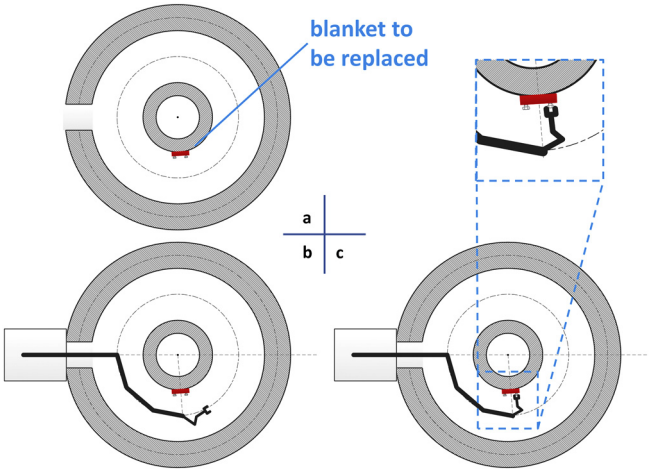

Fig. 2. Demonstration of blanket maintenance tasks: (a) determine the position of the blanket module to be replaced, (b) the OTV docks with the access port of vacuum vessel model, then the LCT-Robot carries the TOM and transports it next to the target blanket module, (c) the operator use the Omega 7 to teleoperate the 6-dof TOM, and loosen (or tighten) the bolts.

In general case, there would be several cameras deployed from different views in a remote handling system, and these cameras are fixed with the robot arm base frame. However, it's impossible to mounted cameras in the tokamak vessel, and the only option is to mount these cameras on the robot. Furthermore, a camera mounted on the robot hand frame would obtain a better view than that mounted on the robot base frame, so only one camera is mounted on the link between 5th joint and the 6th joint. The hand-eye coordinative issue would be much more complex in this camera-in-hand system due to the time-varying relationship caused by the arm movements.

3.1. Hand-eye coordination for the human being

Hand-eye coordination, which can be accomplished before seven years old for human beings, is the ability to coordinate the visual information, and then control and guide the hands towards the accomplishment of a given mission [6].

Hand-eye coordination is the alignment between the hand motion and visual image. Fig. 3 illustrates the hand-eye coordination phenomenon of human being. If a person wants to move his hand from one place to the other, he will first estimate the distance vector $\boldsymbol{V}_{eye}$ from the start point (the circle) to the goal point (the rectangle), then he will move his hand in the same direction of $\boldsymbol{V}_{eye}$, and finally reach the goal point. The hand-eye coordination is important for human to accomplish a given task effectively and safely. Mathematically, if there is not rotation between the visual coordinate frame $(O_eX_eY_e)$ and hand coordinate frame $(O_hX_hY_h)$, a person can coordinate the movement between hand and eye easily.

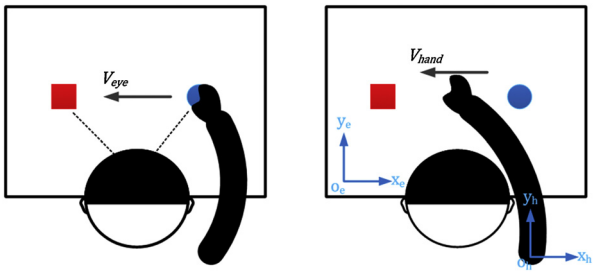

Fig. 3. Demonstration of hand-eye coordination of the human being.