



Experimental investigation of a collision avoidance controller for a bimanual multi-fingered haptic interface

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Abstract

To present three-directional forces at ten human fingertips, we previously developed a bimanual multi-fingered haptic interface consisting of two five-fingered haptic hands and two interface arms. However, there is a risk that the component parts of the haptic interface will collide while an operator is manipulating the interface. A collision could be hazardous for the operator, and thus collision avoidance is essential. To solve this problem, we propose a collision avoidance controller for the bimanual multi-fingered haptic interface. The proposed controller prevents collisions while reducing the collision-induced effects on the haptic display. We carried out several experiments, the results of which show the validity of the proposed collision avoidance controller for the bimanual multi-fingered haptic interface.

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1. Introduction

A haptic interface presents force sensations to an operator and enables communication with virtual environments through the force sensations. The operator can feel force sensations from the virtual environment and provide force information to the virtual environment. Unlike a traditional interface using visual and audio cues, the haptic interface is unique, as it provides bidirectional interaction between a human and the virtual environment [1–3]. Therefore, a haptic interface is a key input/output device between a human and the virtual environment.

In performing activities in our daily lives, we usually use both hands, and thus the realization of bimanual work with force sensations in the virtual environment is expected. It is important to exert force on both hands to make the sensation highly realistic to humans, and the realization

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of bimanual work with force sensations in the virtual environment will broaden the work that can be done in virtual environments and greatly expand the application of this technology. In areas such as telepresence, teleoperation of dual manipulators, and telemedicine, ungrounded-type (or exoskeleton-type) bimanual haptic interfaces [4–6] and grounded-type bimanual haptic interfaces [7–11] have been developed. We also have developed a bimanual haptic interface [12]. The most significant aspect of this haptic interface, namely the main difference our bimanual haptic interface and the existing bimanual haptic interface mentioned above, is that our bimanual haptic interface can present three-directional forces at all ten fingertips of both hands. However, our bimanual haptic interface consists of two five-fingered haptic hands and two interface arms, and there is a risk that the component parts of the haptic interface will collide while an operator is manipulating the interface. Such a collision could be hazardous for the operator. Safety is a primary issue for robots that work with human beings, and thus collision avoidance is essential for haptic interfaces.

The collision avoidance of the bimanual haptic interface discussed in this paper corresponds to the self-collision avoidance of humanoid robots and robots with dual arms, which has been researched aggressively (for example, see [13–18]). In [13], the robot is covered by an elastic sphere and cylinder. When the links of the robot approach and the danger of self-collision increase, contact between the elastic elements occurs and virtual force is generated that causes the links to avoid one another. Sugiura et al. [14] used spheres and sphere sweep lines to approximate the shape of the robot and generate virtual force for self-collision avoidance of the robot's segments. On the other hand, in [15,16], the artificial potential based on the minimum distance between the elements of the robot is introduced, and collision avoidance is realized by generating the reaction force based on the artificial potential field acting on the robot. These studies were focused on self-collision avoidance for humanoid robot arms, and self-collision avoidance for humanoid walking robots has also been proposed [17,18]. On the other hand, as the collision avoidance of an unimanual haptic interface, Komoguchi et al. [19] proposed a controller based on the gradient projection method, and they accomplished the collision avoidance of man–machine and machine–machine collisions. And Yoshikawa and Nagura [20] proposed an encountered-type haptic interface and they considered the collision between an operator's one finger and the haptic interface to realize a contact and noncontact state, namely, the interface touches and displays force to the finger when some virtual object in contact with the finger, and the interface tracks the operator's finger without contact when the finger is not in contact with the virtual object. However, the collision avoidance of the bimanual haptic interface was not considered.

Although there are many kinds of self-collision avoidance methods, there has not yet been a description of research that considers the force display to the ten fingertips of the human operator and self-collision avoidance simultaneously. We previously considered collision avoidance of the bimanual haptic interface [12] by using the same method as [13] and [14] (the so-called penalty method). This method was able to realize collision avoidance but not the force display to the human operator and the collision avoidance simultaneously. Namely, a controller that avoids collisions while maintaining good force display performance was not realized. The collision avoidance feature is indispensable; however, since the main aim of the haptic interface is to display force to the human operator, it is also important that the controller minimizes the collision-induced effects on the haptic display.

In this paper, we propose a controller that considers collision avoidance and the force display to the human operator simultaneously. The proposed controller avoids collisions while reducing the collision-induced effects on the haptic display. Furthermore, we apply the proposed collision

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