Interconnection between Different Types of Haptic Interface Devices: Absorption of Difference in Workspace Size

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Abstract

In this paper, we investigate the influences of difference in workspace size between two kinds of haptic interface devices (PHANToM and SPIDAR) on the efficiency of collaborative work. We also study mapping a workspace to a virtual space to absorb the difference in workspace size. By experiment, we demonstrate that the efficiency of the collaborative work is the best in the case where we set the virtual space size to the smaller workspace size (PHANToM's workspace size) and the workspace with the larger size (SPIDAR's workspace) is mapped to the virtual space only in the directions of axes where the workspace size is different from the virtual space size so that the workspace size corresponds to the virtual space size.

1. Introduction

In networked haptic environments, multiple users collaboratively operate objects in a virtual space by manipulating haptic interface devices [1]. Since the users can touch the objects, we can largely improve the efficiency of collaborative work such as remote surgery simulation and immerse ourselves in playing networked games. A variety of haptic interface devices such as pen-type and glove-type have been developed so far. However, the haptic interface devices have different specifications (e.g., the workspace size, position resolution, and exertable force) from each other. If we interconnect the devices over a network, the differences may cause some problems [2].

There are a few papers addressing the problems [2], [3]. In [2], Hirose *et al.* develop basic software called Haptic Interface Platform (HIP), which does not depend on types of haptic interface devices. Then, they show that users do not notice meaningful differences in hardness in an experiment where the users recognize the hardness of an object although the users manipulate different types of haptic interface devices. However, they do not sufficiently investigate methods that absorb the difference in specifications among the haptic interface devices.

In [3], the authors clarify the influences of difference in workspace size between PHANToM Omni [4] and PHANToM Desktop [4] for networked collaborative work and competitive work. They show that if the range of motion of a haptic interface device is not limited to a workspace which is smaller than the virtual space, there is no large influence of the difference on the efficiency of the collaborative work and the fairness of the competitive work. Otherwise, the efficiency of the collaborative work seriously deteriorates, and the fairness is damaged in the competitive work. However, PHANToM Omni and PHANToM Desktop are the same type of haptic interface devices, and the authors have not investigated work between haptic interface devices which have a large difference in specifications.

In this paper, we employ PHANToM Omni (just called PHANToM here) and SPIDAR-G AHS [5] (called SPIDAR) as haptic interface devices which have largely-different specifications such as the workspace size and position resolution. By experiment, we investigate the influences of difference in workspace size between PHANToM and SPIDAR on the efficiency of collaborative work.

The rest of this paper is organized as follows. Section 2 outlines the specifications of PHANToM and SPIDAR. Section 3 explains absorption methods of difference in workspace size. Section 4 describes a system model. Section 5 explains the method of the experiment, and experimental results are presented in Section 6. Section 7 concludes the paper.

2. Specifications of PHANToM and SPIDAR

PHANToM is a haptic interface device of point-type, and a user operates the stylus of PHANToM as if he/she had a pen. SPIDAR is also a point-type haptic interface device, and a user operates a globe (called the grip) hung with eight wires. Table 1 shows the specifications of PHANToM and SPIDAR. In this paper, we select the difference in workspace size from among the differences in the specifications and investigate absorption methods of the difference. Therefore, we adopt collaborative work in which the difference in specifications excluding the workspace size does not largely affect the efficiency of the work.

3. Absorption of Difference in Workspace Size

In this paper, we deal with collaborative work using PHANToM and SPIDAR. When we do collaborative work using haptic interface devices like PHANToM and SPIDAR, which have different sizes of workspace, there may

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Table 1. Specifications of PHANToM and SPIDAR.

Item		PHANToM	SPIDAR
Workspace size	Width [mm]	160	200
	Height [mm]	120	120
	Depth [mm]	70	200
Position resolution [mm]		0.055	0.015
Degree of freedom		3	6

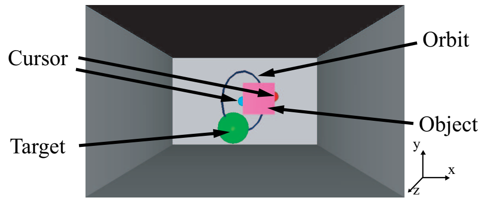

Figure 1. Displayed images of the virtual space.

Table 2. Methods of mapping for PHANToM and SPIDAR.

Method	PHANToM	SPIDAR
1	Case (1)	–
2	Case (2)	–
3	Case (3)	–
4	Case (1)	Case (1)
5	Case (2)	Case (1)
6	Case (3)	Case (1)
7	Case (2)	Case (3)
8	Case (3)	Case (3)
9	–	Case (1)
10	–	Case (3)

exist domains that one of the devices can reach but the other cannot do in a virtual space. Such domains disturb the collaborative work. Therefore, it is necessary to absorb the difference in workspace size among the devices in order to be able to work throughout the virtual space.

This paper handles the following three cases in terms of the virtual space size. In one case, the virtual space size is set to the workspace size of SPIDAR. In another case, the virtual space size is set to the middle of the workspace sizes of PHANToM and SPIDAR (width: 180 mm, height: 120 mm, depth: 135 mm). In the other case, the virtual space size is set to the workspace size of PHANToM. Figure 1 show displayed images of the virtual space in the case where the virtual space size is set to the workspace size of SPIDAR (the target, object, cursors, and orbit in Fig. 1 will be explained in Subsection 3.2). In order to compare methods of mapping the workspace the size of which is different from the virtual space size to the virtual space, we deal with three cases as follows.

Case (1): The workspace size is not converted in the direction of the *x*-, *y*-, or *z*-axis (as shown in Fig. 1, the *x*-, *y*-, and *z*-axes represent the width, height, and depth, respectively, of the virtual space); that is, the positional information input from a haptic interface device is directly mapped to the positional information in the virtual space.

Case (2): The workspace is uniformly mapped to the virtual space in the directions of the *x*-, *y*-, and *z*-axes so that the size of the workspace corresponds to the size of the virtual space in the direction of an axis where there is the largest difference in size between the workspace and the virtual space.

Case (3): The workspace is mapped to the virtual space only in the directions of axes where the workspace size is different from the virtual space size so that the workspace size corresponds to the virtual space size.

3.1. Methods of Mapping

We investigate the influences on the efficiency of collaborative work for ten methods (see Table 2). In Methods 1, 2, and 3, the virtual space size is set to the workspace size of SPIDAR; the workspace of PHANToM is mapped to the virtual space. In Method 1, for example, we deal with case (1) for PHANToM, and the workspace of SPIDAR is not mapped to the virtual space since the workspace size of SPIDAR is equal to the virtual space size. In Methods 4 through 8, the workspaces of PHANToM and SPIDAR are mapped to the virtual space the size of which is set to the middle of the workspace sizes of PHANToM and SPIDAR. In Method 4, for instance, we deal with case (1) for PHANToM and case (1) for SPIDAR since the workspace size of PHANToM and SPIDAR are different from the virtual space size. Then, in Methods 9 and 10 where the virtual space size is set to the workspace size of PHANToM, the workspace of SPIDAR is mapped to the virtual space. In Method 9, for example, the workspace of PHANToM is not mapped to the virtual space since the workspace size of PHANToM is the same as the virtual space size, and we deal with case (1) for SPIDAR.

In Methods 4 through 8, we do not handle case (2) for SPIDAR. This is because the workspace size of SPIDAR in case (2) becomes smaller than the virtual space size in the direction of the *y*-axis by mapping; there exists a domain that the cursor (the cursor denotes the position of the device in the virtual space) of SPIDAR cannot reach in the virtual space. In Methods 7 and 8, the reason why we do not handle case (1) in terms of the PHANToM is that there exists a domain which PHANToM's cursor does not reach as described in the specifications of PHANToM.

In Methods 9 and 10, we do not deal with case (2) for SPIDAR since the workspace size of SPIDAR becomes smaller than the virtual space size in the direction of the *y*-axis in the case where the virtual space size is set to the workspace size of PHANToM.

3.2. Collaborative Work

Two users collaboratively move an object (a rigid cube with a side of 30 mm and with a mass of 500 g) by holding the cube between two cursors of PHANToM and SPIDAR in a 3-D virtual space (see Fig. 1). If the object is not pushed from both sides strongly to some extent, it drops on the floor. The gravitational acceleration is assumed to be 2.0 m/s^2. The cursor of each haptic interface device moves in the virtual space when a user manipulates the stylus or grip of the device with the user's hand. The two users lift and move the cube collaboratively so that the cube contains a target (a sphere), which revolves along a circular orbit at a constant velocity. Each orbit in a workspace is a circle with a radius of 30 mm. The plane on which the orbit exists is perpendicular to z-x plane and forms an angle of 45 degrees with x-y plane. We do not carry out collision detection among the target, the orbit, and the cube or cursors.

4. System Model

In this paper, we employ a client-server model which consists of two clients and a single server (see Fig. 2). Figure 2 shows functions at each client and the server. In the figure, PHANToM is employed as a haptic interface device at client 1, and SPIDAR is used at client 2.

Client 1 performs haptic simulation by repeating the servo loop at a rate of 1 kHz [6]. The client inputs/outputs a stream of *media units* (*MUs*), each of which is the information unit for intra-stream synchronization, at the rate; that is, an MU is input/output every millisecond. Each MU contains the identification (ID) number of the client, the positional information of the cursor of PHANToM, and the sequence number of the servo loop, which we use instead of the timestamp of the MU [7]. MUs input at the client are transmitted to the server. Client 2 carries out haptic simulation at 1 kHz by using a timer and inputs/outputs a stream of MUs in the same way as that at client 1.

The server receives MUs from the two clients, and it calculates the position of the object based on the spring-damper model [6] by using the MUs every millisecond. Then, the positional information is transmitted as an MU to the two clients.

We employ *Skipping* [7] for intra-steam synchronization control at the clients. Skipping outputs MUs on receiving them. When each client receives an MU, the client updates the position of the object after carrying out the intra-stream synchronization control and calculates the reaction force applied to the user.

5. Method of Experiment

5.1. Experimental System

As shown in Fig. 3, our experimental system consists of a single server (CPU: Pentium4 2.8 GHz, OS: WindowsXP) and two clients (CPU: Pentium4 2.8 GHz, OS: WindowsXP). As described earlier, client 1 has PHANToM, and client 2 has SPIDAR. The server is connected to the two clients via an Ethernet switching hub (100 Mbps). The size of an MU (includes the ID number of the client, the positional information of cursor, and the sequence number) from each client to the server is 32 bytes, and that (includes the positional information of the object, the positional information of the two clients' cursors, and the sequence number) from the server to each client is 56 bytes. MUs are transmitted by UDP.

5.2. Performance Measure

As a performance measure, we employ the *average distance between cube and target* [7] in the experiment on the collaborative work. The average distance between cube and target is the mean distance between the centers of them. This measure is related to the accuracy of the collaborative work. Small values of the average distance indicate that the cube follows the target precisely; this signifies that the efficiency of the collaborative work is good.

In the experiment, two of the authors manipulate the haptic interface devices at the clients. We investigate the average distance between cube and target for the ten methods. The experiment for each method is repeatedly carried out 30 times, and the measurement time of each experimental run is 30 seconds.

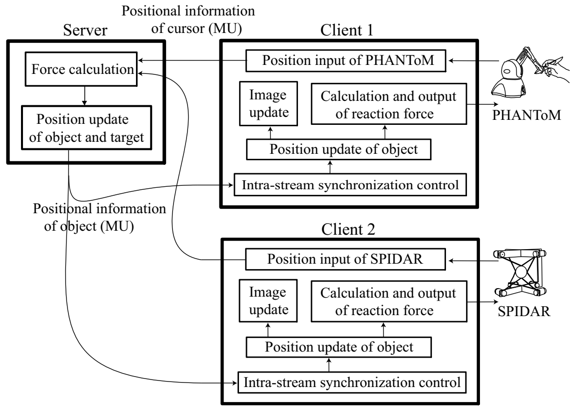

Figure 2. Functions at each client and the server.

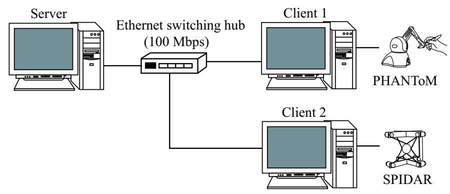

Figure 3. Configuration of the experimental system.

6. Experimental Results

We show the average distance between cube and target for the ten methods in Fig. 4, where we also display the 95 % confidence intervals.

In Fig. 4, we see that the average distances between cube and target of Methods 1, 4, and 9 are almost the same. This is because the workspace size is not converted in the direction of the x-, y-, or z-axis and the positional information in the workspace is directly mapped to that in the virtual space. Therefore, the difference in the efficiency of the collaborative work among the three methods is negligible.

From Fig. 4, we also find that the average distance of Method 1 is smaller than that of Method 2, which is smaller than that of Method 3. Therefore, the efficiency of the collaborative work in the case with mapping is worse than that in the case without mapping when the virtual space size is set to SPIDAR's workspace size. This is because when the virtual space is set to the workspace size of SPIDAR and we deal with case (3) in terms of PHANToM, the collaborative work is difficult; note that the cursor moves largely with a small motion of PHANToM's stylus in this case. Moreover, from a comparison between Methods 2 and 3, we notice that the average distance in case (3) is larger than that in

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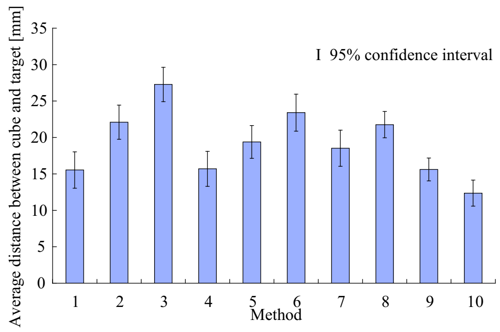

Figure 4. Average distance between cube and target.

case (2). This reason is as follows. The movement distances of cursor in the directions of some axes in the case where the workspace is mapped to the virtual space only in the directions of the axes are different from those in the directions of the other axes in the virtual space even if the motion distances of device in the directions of the three axes are the same in the workspace. Then, the collaborative work with case (3) is more difficult than that with case (2). We can see the same relationships among Methods 4, 5, and 6 and Methods 4, 7, and 8 as those among Methods 1, 2, and 3.

Furthermore, in Fig. 4, the average distance of Method 10 is smaller than that of Method 9. This is because when the workspace of SPIDAR is mapped to the virtual space the size of which is set to the workspace size of PHANToM, the distance of cursor movement in the virtual space is smaller than that of SPIDAR's grip movement in the workspace; thus, we can do the collaborative work more precisely in Method 10. Figure 4 reveals that Method 10 has the smallest average distance among the ten methods. Therefore, Method 10 is the most efficient.

From the above observations, we can say that when we do the collaborative work by using two kinds of haptic interface devices which have largely-different specifications, the efficiency of the collaborative work is the best in the case where the virtual space size is set to PHANToM's workspace size and the workspace of SPIDAR is mapped to the virtual space only in the directions of axes where the workspace size is different from the virtual space size so that the workspace size corresponds to the virtual space size. Also, the collaborative work in the case where the workspace is uniformly mapped to the virtual space in the directions of the three axes is more efficient than that in the case where the workspace is mapped to the virtual space in the directions of only one or two axes. Note that in [3], if the range of motion of a haptic interface device is not limited to a workspace which is smaller than the virtual space, there is no large difference in the efficiency of the collaborative work among methods of mapping; this is because haptic interface devices which do not have largely-different specifications are used. However, in this study, where we deal with two kinds of haptic interface devices which have largely-different specifications, there is a large difference in the efficiency of the collaborative work among the 10 methods of mapping; therefore, we need to pay attention to how to make mapping.

7. Conclusions

This paper dealt with collaborative work by using two kinds of haptic interface devices (PHANToM and SPIDAR) which have largely-different specifications. We investigated the influences of difference in workspace size between PHANToM and SPIDAR on the efficiency of the collaborative work. As a result, we found that the efficiency of the collaborative work is the best in the case where the virtual space size is set to PHANToM's workspace size and the workspace of SPIDAR is mapped to the virtual space only in the directions of axes where the workspace size is different from the virtual space size so that the workspace size corresponds to the virtual space size. Moreover, the collaborative work in the case where the workspace is uniformly mapped to the virtual space in the directions of the three axes is more efficient than that in the case where the workspace is mapped to the virtual space in the directions of only one or two axes.

As the next step of our research, we will investigate the influence of the difference in specifications excluding the workspace size on the efficiency of the collaborative work. We also need to examine the efficiency of the collaborative work in the case where large network delays and/or delay jitter exist. Furthermore, it is necessary to clarify the influence of mapping of the workspace to the virtual space on the easiness of the collaborative work by subjective assessment.

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References

[1] M. A. Srinivasan and C. Basdogan. Haptics in virtual environments: Taxonomy, research status, and challenges. *Computers and Graphics*, 21(4):393–404, Apr. 1997. 1

[2] M. Hirose, H. Iwata, Y. Ikei, T. Ogi, K. Hirota, H. Yano, and N. Kakehi. Development of haptic interface platform (HIP) (in Japanese). *TVRSJ*, 10(3):111–119, Sep. 1998. 1

[3] S. Kameyama and Y. Ishibashi. Influences of difference in workspace size between haptic interface devices on networked collaborative and competitive work. *Proc. SPIE Optics East, Multimedia Systems and Applications X*, 6777(30), Sep. 2007. 1, 4

[4] J. K. Salisbury and M. A. Srinivasan. Phantom-based haptic interaction with virtual objects. *IEEE Computer Graphics and Applications*, 17(5):6–10, Sep. 1997. 1

[5] S. Kim, J. J. Berkley, and M. Sato. A novel seven degree of freedom haptic device for engineering design. *Virtual Reality*, 6(4):217–228, Aug. 2003. 1

[6] SensAble Technologies, Inc. 3D touch SDK OpenHaptics toolkit programmers guide version 1.0. 2004. 3

[7] Y. Ishibashi, S. Tasaka, and T. Hasegawa. The virtual-time rendering algorithm for haptic media synchronization in networked virtual environments. *Proc. the 16th International Workshop on Communication Quality & Reliability (CQR'02)*, pages 213–217, May 2002. 3