

## A TANGIBLE 3D DESKTOP ENVIRONMENT WITH FORCE FEEDBACK

<sup>1</sup>YUSUKE OUCHI, <sup>2</sup>HIROAKI NISHINO, <sup>3</sup>TSUNEO KAGAWA

*Oita University*

{<sup>1</sup>v11e3008, <sup>2</sup>hn, <sup>3</sup>t-kagawa}@oita-u.ac.jp

KOUICHI UTSUMIYA

*Institute for Hypernetwork Society*

*utsumiya@oita-u.ac.jp*

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Various 3D desktop environments have been proposed and implemented in recent years. They don't, however, become a popular interaction method in HCI (human computer interface) research field. Restrictions appeared in mouse-based 3D operations such as difficulties in appropriately designating object's positions and directions in a 3D task space are major obstacles. In this paper, we propose to replace the mouse by a haptic device, an interaction device enabling easy object manipulations in the 3D task space. The haptic device also allows users to touch the objects with depth perceptions and feel some tactile sensations. It presents some special effects like shocks, vibrations, and weights when they touch the objects. We designed and developed a 3D operational environment allowing the users to treat the desktop interface as if it is a real world property coexisting with the haptic device. We describe the implementation method and operational interface of the proposed new 3D desktop environment empowered by the haptic device and two experiments conducted for verifying the effectiveness of the proposed system.

*Key words:* 3D desktop environment, force feedback, haptic device, graphical user interface  
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### 1 Introduction

A variety of 3D desktop environments have been proposed and implemented in recent years. As shown in Figure 1, a traditional 2D desktop environment with many open windows requires users to waste their time for finding a target window because of many overlaps between them. It significantly decreases the efficiency of GUI operations. The 3D desktop produces a more realistic operational environment by converting a 2D planar work space to a 3D spatial task space. Figure 2 shows a snapshot of the 3D desktop environment prototype designed and implemented in this study. It allows the users to neatly place the windows in three dimensions and easily select a target object.

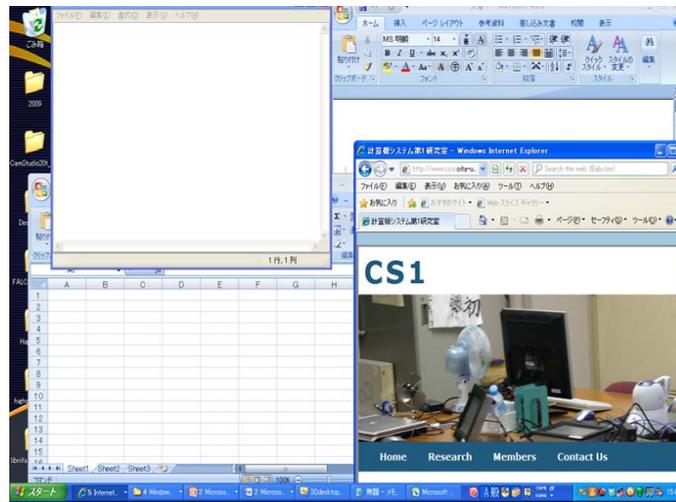


Figure 1 Standard 2D planar desktop screen in MS Windows.

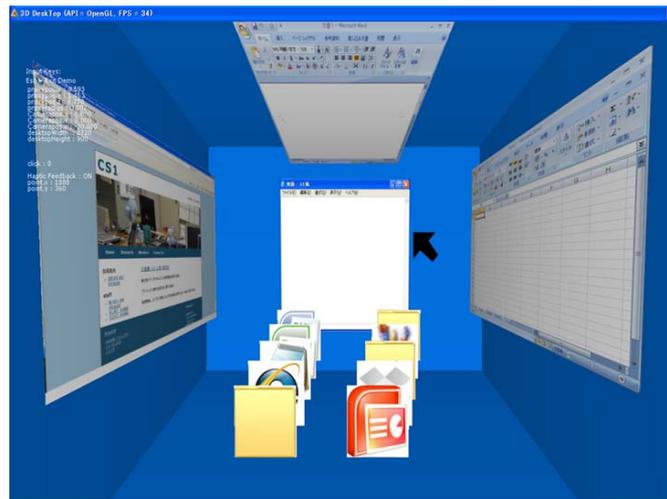


Figure 2 Proposed 3D desktop environment.

Although it can improve work efficiency, the research on the 3D desktop has not been progressed so far. A reason is the constraint of mouse operations. Most previously proposed 3D desktop environments in the HCI (human computer interface) research field visually implement 3D task spaces, but they mainly use a planar operational space with the mouse devices. Users cannot proficiently execute the operations in a depth direction because of the mismatch between the input part (2D mouse operation) and the 3D output part (3D graphics drawing). Therefore, they feel a sense of discomfort in controlling the 3D desktop operations with the 2D input device and they sometimes call such situation

as the 2.5D desktop. For this reason implementing a practical 3D desktop environment usable via natural and intuitive GUI operations is an important research goal in the HCI research field.

We designed and developed the 3D desktop system to resolve the above mentioned problems as shown in Figure 2. The system visually presents the task space in 3D and allows the users to easily perform 3D manipulations. It also presents tactile sensations when they touch the icons displayed in the task space. As shown in Figure 3, we utilize a force feedback device called FALCON developed and marketed by Novint Technologies, Inc [1]. It enables the users to easily carry out spatial operations that are hard to manage by using the mouse devices. The users hold the grip part and freely control a pointing position by moving it from side to side, up and down, and back and forth. There are four buttons in the grip as shown in Figure 3 and the users can click on the buttons to execute additional functions. It also presents the tactile sensations when the users are manipulating the icons such as the weight and stiffness of the target object in the 3D task space. The users can efficiently perform the operations with the 3D visual and tactile presentations. We introduced a haptic computing engine called Haptx library developed and marketed by a Swedish company called Reachin Technologies, Inc. It enables to add various tactile effects on 3D graphics objects such as impactive force, gravitational force, and attraction force of magnet [2].

In this paper, we propose a new 3D desktop environment empowered by the force feedback device. In addition to the natural 3D input and output function, the system supports a more realistic interaction environment by taking advantage of the haptic device. It cannot only present the sensation of touch for the icons displayed on a screen, but also express some important attributes of files and folders such as their size and update frequency by their weights and stiffness. In the following sections, we describe related work, the implementation method, and evaluation experiments of the proposed 3D desktop system.



Figure 3 FALCOM force feedback device by Novint Technologies.

## 2 Related Work

Bump Top proposed by Agarawala et al. implemented a 3D desktop environment enabling GUI operations in a boxy virtual task space [3]. It only supports a mouse for manipulating objects such as

files and documents. It could present some special effects such as collisions between the objects by simulating their weights and inertial force. Looking Glass, a window manager for Java development environment, supports functions for resting windows against both sides of a screen and translucently drawing inactive windows [4]. It also allows users to easily find a target window by repositioning overlapped windows. 3DNA desktop developed and marketed by 3DNA, Inc. enables users to construct a whole desktop in a room-like 3D virtual space [5]. It allows them to get into the virtual space with the sense of arcade game and walk around for finding and activating necessary functions in the space. The users can manipulate the objects based on their colours and shapes as clues and intuitively operate them in the realistic virtual space. Task Gallery proposed by Robertson et al. implemented a common window manager with 3D metaphor [6]. The traditional 2D desktop applications can be managed in a 3D task space without any modifications.

These desktop environments basically use a mouse as a standard manipulation device. Because users need to manipulate the objects on a 2D surface, it is difficult to efficiently manipulate them. In the real world, the users put various tools and documents on a desktop and pick up necessary objects for manipulations at different times. If they need to pick up the objects set far back on the desktop, they need to find and grab the target ones by unblocking objects. The mouse is inefficient for executing such operations in the depth direction and brings discomfort to the users in such 3D manipulation tasks. As the mouse has become a primary device with the popularization of 2D desktop, so a new device and its utilization method is required for the wide spread use of the 3D desktop environments.

The above mentioned systems support very different functional specifications such as implementing operations with or without physical simulations, and allowing manipulations during movements or not. The current 2D desktop interface, on the other hand, is well standardized and provides similar manipulation methods for many years. Standardizing the interface is an important requirement for task efficiency improvements.

### 3 Development Environment and System Implementation Method

In this section, we describe the haptic application development environment and implementation method of the proposed 3D desktop system [7].

#### 3.1. Haptic Engine Architecture

We use a haptic engine called HaptX enabling 3D graphics applications to efficiently incorporate touch interactions. Figure 4 shows the HaptX architecture. It is developed and marketed by Reachin Technologies in Sweden. It supports Novint Technologies FALCON force feedback device as one of default haptic devices.

As shown in Figure 4, the HaptX engine consists of four libraries classified by their supporting functions and objectives as follow.

- (1) *FM (Force Model) library* generates various haptic effects such as the loading operation of firearms, the beating of the heart, the shock of an explosion, and the strength of a magnetic field.

- (2) *SM (Surface Model) library* presents various features of 3D geometric models such as the stiffness, softness, texture, and frictional force of the object surface. It enables applications to present complex haptic features by combining multiple effects such as a toughened stone wall and a feeling like velvety silk.
- (3) *PM (Physics Model) library* provides an interface with existing physics engines.
- (4) *NM (Navigation Model) library* provides functions for utilizing the haptic device as a mouse.

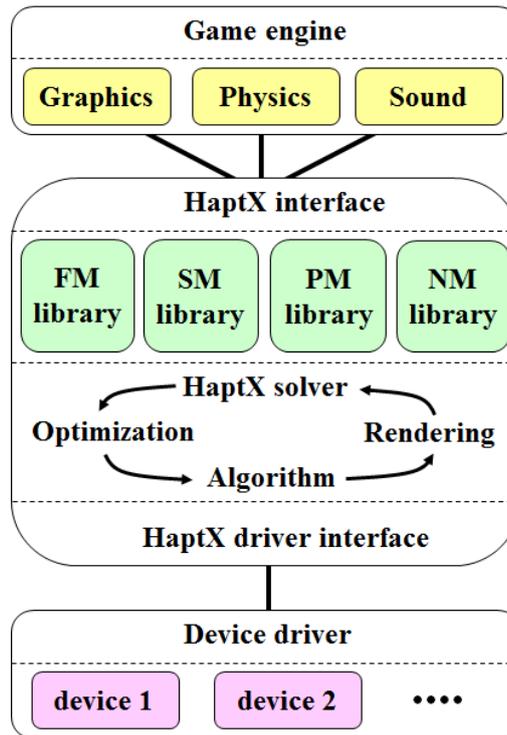


Figure 4 HaptX haptic engine architecture.

### 3.2. Graphics and Haptic Rendering Functions

The system uses OpenGL and HaptX for implementing 3D graphics and haptic rendering processes, respectively. OpenGL is a standard 3D graphics library usable on multiple operating systems including Windows, Macintosh OS, and Linux, and various platforms including computers and smart phones. It supports various functions required for graphics programming such as defining geometric information (vertices and topology of 3D objects) and transformations (translation, rotation, and scaling of 3D objects), positioning a viewpoint, setting light sources, and defining material properties of 3D objects. Haptic rendering functions supported in the HaptX libraries can be called in programs written by using either OpenGL or Windows DirectX.

The haptic rendering part of the system is implemented by combining the HaptX functions with the graphics operations controlled by OpenGL. Because the HaptX engine shares the 3D model and

texture information with OpenGL, it enables developers to effectively calculate reaction forces based on the shared data and generate the tactile effects through the FALCON force feedback device in their own applications. HaptX provides some functions for accessing and converting the shared data, and allowing the developers to efficiently write a haptic / graphic rendering control loop as shown in the middle box in Figure 4. It also provides additional functions for defining the object properties such as the degree of surface roughness or smoothness and the strength of vibrations and reaction forces generated when a user touches the object. HaptX supports the BMP (Bit MaP) file format for using as a texture image mapped on the object surface and the ASE (Adobe Swatch Exchange) format for saving and restoring colour scheme information.

#### 4 3D Desktop Operation Environment with Force Feedback

In this section, we describe the functions and operation environment of the proposed 3D desktop system. Figure 5 shows the initial screen of the system displayed right after the system start-up. The system draws the desktop space as if the user peeks into the room from a viewpoint set in front of the space. The default icons representing folders, files, Internet Explorer, MS office applications (word, excel, and power point), and a memo pad are placed in an anteroposterior direction to visually present the depth feeling of the task space. The system renders the walls and icons by mapping the colour (ASE) and image (BMP) data on plate-like 3D polygons.

The haptic cursor as shown in Figure 5 indicates the current position in the 3D task space. When the user holds the FALCON's grip part and moves it from side to side, up and down, and back and forth in the task space, the cursor moves in synchronization with the user's hand movements. Figure 6 shows a perspective view of the 3D desktop task space. Closer icons and windows are drawn as bigger objects depending on their distances from the viewpoint. The system also depicts the haptic cursor as a 3D object. The haptic cursor shown in Figure 6 is bigger than the one shown in Figure 5 because its current position is closer to the viewpoint. The system hides the 2D cursor appears in the Windows desktop when the 3D desktop is in an active state.

When the cursor collides with the walls, icons, and windows, the system calculates and presents a reaction force through the FALCON device. Therefore, the user can manipulate the objects with a good sense of reality by feeling the tactile sensation in addition to the visual information. The user can move the windows and icons by superimposing the cursor on the target object and dragging it with pressing the centre button on the FALCON grip. When he/she releases the button, the grabbed object is placed on the current cursor position in the 3D task space. If the user pushes an object with his/her force, the application programs associated with the object will be launched.

When an application is running in the task space, a pair of windows, a real running application window and its virtual counterpart, are appeared. Figure 7 shows the screen captured when the Windows memo pad application is launched. The window marked as A is the virtual window displayed in the desktop space and is used for 3D manipulations with the FALCON device. The user selects the real window marked as B in the figure for typing texts. The user activates the desktop space for various 3D operations and selects and pushes the virtual window for returning to the real window of the running application. Therefore, he/she needs to switch operation modes between the 3D desktop and the Windows desktop environment.

As shown in Figure 8, the system displays the normal cursor used in the Windows desktop when the user selects the real window. Because the system allows the user to control the normal cursor by using the FALCON device, he/she doesn't need to use the mouse. The arrow keys on the FALCON grip shown in Figure 3 provide the same functions with the mouse buttons.

Launching multiple applications increases the number of displayed virtual windows and makes the task space a cluttered state. The system enables the user to efficiently rearrange the windows' positions. In Figure 2, three virtual windows are rested on the side walls and one on the ceiling in the 3D desktop space. These rearrangements are possible by simply moving each window toward a target wall surface. As shown in Figure 9, if the user moves a window toward a side wall, the window gradually turns around and finally leans over on the wall (pointed by a white arrow in Figure 9(a) through 9(c)) or on the ceiling (Figure 9(d) and 9(e)). Each window can be scaled by using the left (shrinking) and right (magnifying) buttons on the FALCON grip.

Appendix figures shown in the last three pages present a series of 3D desktop operations performed by the FALCON device.

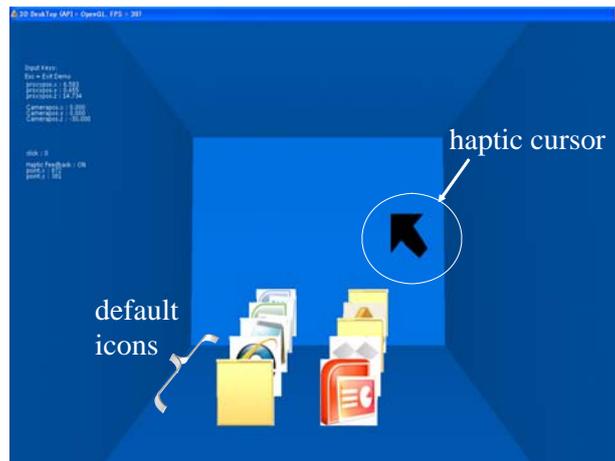


Figure 5 Initial screen displayed right after system start-up.

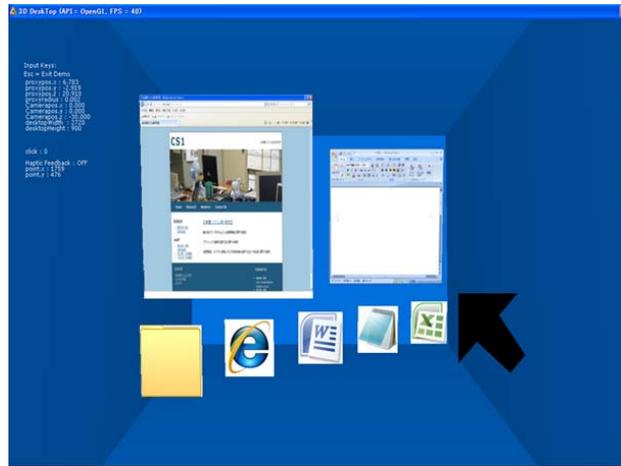


Figure 6 Perspective view of 3D desktop space.



Figure 7 A pair of windows appeared when the Windows memo pad application is launched.



(a) Haptic cursor used in 3D desktop environment (b) Normal cursor used in Windows desktop

Figure 8 Two types of cursors used in 3D and Windows desktop environments.

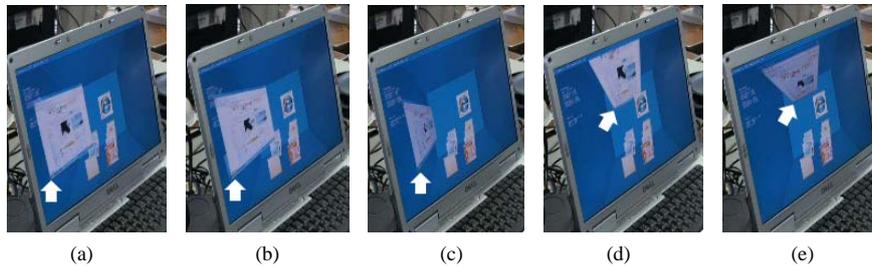


Figure 9 Arrangements of virtual window in 3D desktop, resting it to the side wall (a-c) and to the ceiling (d-e).

## 5 Experiments

In this section, we describe two experiments conducted for evaluating the effectiveness of the proposed 3D desktop environment. We also analyse the system usability based on the experimental results.

### 5.1. Experiment 1

#### 5.1.1. Experimental Procedure

We conducted the first experiment for investigating whether the existence of haptic modality has an effect on the operability of the 3D desktop environment. We employed ten university students (five male and five female) as subjects. After we briefly explained the system components (windows, icons, and a cursor) and their operation method, we asked the subjects to perform the experimental task according to the following procedure.

- (1) Launch the memo pad application,
- (2) Launch the Internet Explorer,
- (3) Search “Oita University web page” in the Internet Explorer,
- (4) Copy the contents of the found web page and paste them to the memo pad, and
- (5) Save the contents as a file with a specific name.

We asked them for performing the above mentioned procedure twice, one trial with force feedback presentation through the FALCON device and the other without force feedback. After the two trials, we asked the subjects about the following three questions.

Q1: Which trial is easier to operate, with or without force feedback? Show us its reason as well.

Q2: Do you feel difficult to operate in the procedure and which step if any?

Q3: Do you have any additional functions required in the system?

While one male subject had an experience for using the force feedback device before the experiment, all others were unfamiliar with the device. They were expected to accustom themselves to operate the FALCON device according to the progress of the experimental procedure. Therefore, we divide them into two groups (five each in group A and B) and reverse the order for presenting the force sensation. In group A, the force is presented in the first trial and no force in the second. The group B experimented in reverse order.

### 5.1.2. Experimental Result

As for Question 1, six subjects (three of each group) concluded the trial with force feedback was better while the remaining four (two of each group) supported the one without force feedback. The six force feedback supporters include three males and three females. There are two males and two females in gainsayer. We received the following opinions from positive supporters.

- Touch feeling exerted by the reaction force helps the object manipulations especially window opening operations (launching applications).
- The combination of force presentation and depth visualization helps the 3D object manipulations in the task space.

On the other hand, negator pointed out the following issues.

- Force presentation is not good for a task for many hours.
- Force presentation makes the launching operation a harder task to manage.

As for Question 2, we got the following opinions.

- Pushing the objects with resisting the exerted force is a tiring job.
- Selecting a specific icon is difficult.
- Manipulating overlapping windows and icons are difficult.

Finally for Question 3, we got the following opinions.

- Force presentation provides the better environment for 3D object manipulations but a function for adjusting the force strength is required.
- Controlling the normal Windows cursor by using the FALCON device cannot support an identical environment with mouse (ex. right button click is not supported in the device).
- Drawing the 3D icon at a rakish angle is better for visibility.

### 5.1.3. Discussions

As can be seen in the experimental result, the number of subjects who supported the operation environment with force feedback was slightly higher than negator in both groups, though we cannot judge the difference statistically. As indicated by some positive supporters, the haptic device is good for both in input (3D manipulations) and output (realistic feeling of 3D object) parts in the proposed 3D desktop environment. It shows a new way of integrating the haptic technology not only as computer interface but also as a controller of consumer electronics.

Most negative subjects indicated that the application launching operation by pushing the icon is difficult. One reason is the applied force strength is not small. The other reason is the operation may fail depending on the pushing direction of the FALCON device. The latter miss operations were frequently observed in the experiment. This result suggests that we should allow the user to push the object with smaller force for improving the pushing operation or provide alternative operations such as button clicks to open the object. The function for tuning the force strength also is another important enhancement to improve the system usability.

No one indicated the difficulty of using the FALCON device for controlling the normal cursor in the Windows desktop operation mode. As someone pointed, however, the current haptic interface with FALCON doesn't implement an identical function with the mouse. Providing the same functionalities with mouse also is important for the haptic interface to realize a unified environment operated by a single FALCON device.

As a long term research goal, we would like to generate a way of using the haptic modality as not only a supplementary channel but a principal one. Finding a specific target among huge number of records in a database is a good example. Let us assume that a network administrator monitors a wide area network and he/she needs to detect any broken links on the huge network. Even if he/she can look at the network configuration visually, it is not an easy task to quickly identify one and all broken links. If he/she can explore the configuration with some haptic feeling, he/she can rapidly go over the whole space and detect the targets. The application scenarios for appealing the potential ability of the haptic interface are very important in our future work.

## 5.2. Experiment 2

### 5.2.1. Experimental Procedure

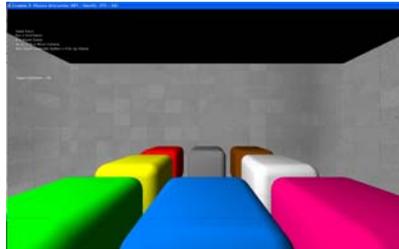
We conducted the second experiment to see if the haptic modality works for improving the operational performance of 3D spatial interactions. We employed 24 subjects (fourteen male students, nine female students, and one male professor). We asked subjects to perform the undermentioned two tasks for specified periods and answer a questionnaire for assessing several issues.

- *Task 1 for 3D puzzle exercise:* We asked the subjects to change the 3D block placement from its initial layout as shown in Figure 10(a) to a target pattern as shown in Figure 10(b). Then, we asked them to change the layout again from the initial to the other target pattern as shown in Figure 10(c). We set the time restriction for each task up to two minutes.
- *Task2 for 3D building block exercise:* We asked the subjects to building up the three blocks laid on the floor as shown in Figure 11(a). Figure 11(b) shows the final target pattern. The base block (green block) is fixed on the floor and the subjects need to pick other two blocks (red and yellow blocks) up and put them on the base block. This is a somewhat more difficult exercise than the task 1. We set the time restriction for the task up to three minutes.

We asked the subjects to perform each task twice with or without haptic modality. The force feedback mode presents some special effects such as the block's gravity and inertia, and collisions between the blocks. The subjects need to perform the tasks only with visual information in the mode without force feedback. Because most subjects have never used the FALCON device, we firstly explained the difference between these two modes and asked them to make the target patterns as neat as possible.

The subjects should become familiar with the operations along the progress of experimental procedure. Therefore, we divided the subjects into two groups (A and B) and applied a different operational sequence for each group to minimize the impact of habituation on the results. The subjects in group A perform the first task with force feedback and then attempt the other task without force

feedback. The subjects in group B experimented in reverse order. Group A is composed of eight males and four females and group B is of seven males and five females.



(a) Initial layout of 3D blocks.

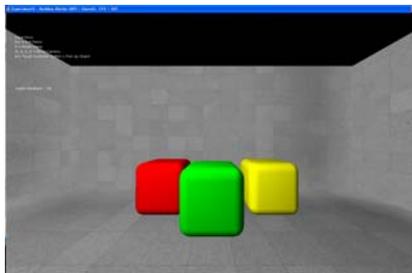


(b) Target arrangement pattern 1.

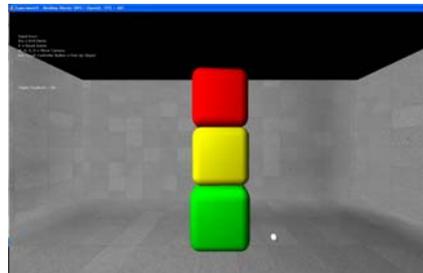


(c) Target arrangement pattern 2.

Figure 10 Task 1 for changing the block layout put on a floor.



(a) Initial layout of 3D blocks.



(b) Target upheaped blocks.

Figure 11 Task 2 for building up three blocks layout put on a floor.

We asked the subject to answer the questionnaire after they completed the two tasks. The questionnaire consists of the following four items and the subjects rate each item in five ranks from one (very bad) to five (very good).

Item1: Easiness for 3D object manipulations.

Item 2: Unpleasant sensation or stress of 3D object manipulations.

Item 3: Degree of achievement for the experimental tasks.

Item 4: Impact of force feedback for the experimental tasks (only applied for tasks with force feedback).

### 5.2.2. *Experimental Result*

The graphs in Figure 12 show the results of the experiment. Figures 12(a) and 12(b) show the results of tasks performed by group A, 12(c) and 12(d) are the results by group B, 12(e) and 12(f) show the total average values. The vertical and horizontal axes of each graph denote the average ranks by the subjects and the evaluation items as described in Section 5.2.1, respectively.

The average ranks of the tasks performed with force feedback are higher than the tasks without force feedback for all the cases. A certain degree of task order effect was observed in the task 1. The difference between the tasks with or without force feedback in group B (Figure 12(c)) is larger and more obvious than the results in group A (Figure 12(a)). All subjects in group B performed the first task without force feedback and the second with force feedback. Therefore, the habituation of the 3D manipulations is considered to magnify the effectiveness of the force feedback. As for the task 2, the difference between the two average rates with and without force feedback is clear in both groups. Because the task difficulty is higher than the task 1, the force feedback makes positive effects for both groups independent of the task order. We, therefore, found that the force feedback has some effects on improving the easiness, sensations, and subject's feeling of accomplishment for 3D manipulation tasks. No gender-based difference, however, was observed on the results.

We received the following opinions from subjects who gave the tasks with force feedback high marks.

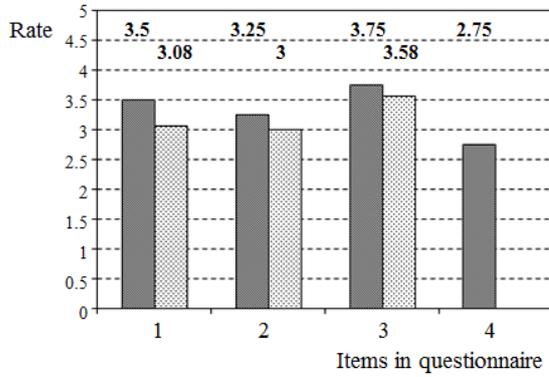
- Force feedback is a good way to figure out if the subject reaches to the target object.
- It is useful to explore the occluded object by touching it.
- It makes the tasks just like playing games.
- It was difficult to appropriately controlling the FALCON device especially for moving it to depth direction without force feedback.

On the other hand, subjects who supported the tasks without force feedback pointed out the following issues.

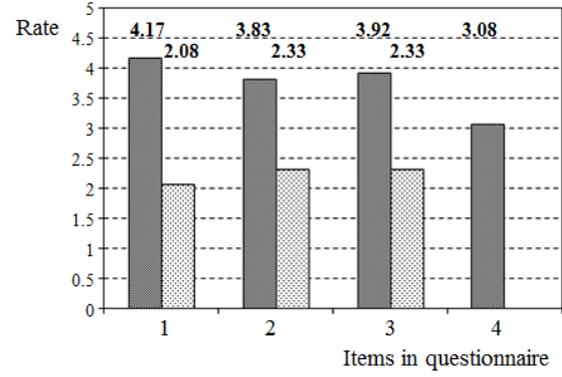
- It takes some time to become accustomed to properly applying force to the device.
- Some tasks with force feedback make the subject tired.

### 5.2.3. *Discussions*

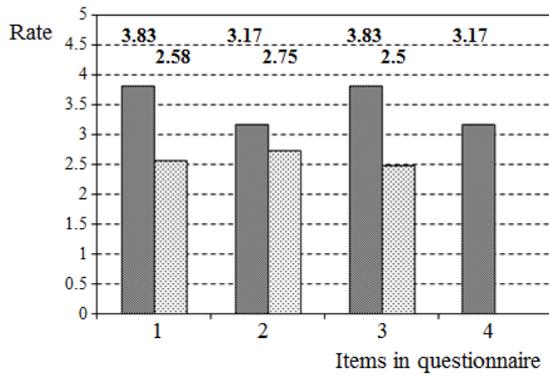
Adding the touch sensation to the 3D spatial manipulation is effective because the rates for the tasks with force feedback is higher than their counterparts without force feedback in all cases as shown in the graphs in Figure 12. According to the questionnaire survey, the force feedback gives a useful clue for noticing the cursor's position and the distance to the target object in a 3D task space to the subjects. It contributes to make the 3D tasks a realistic and intuitive one to operate.



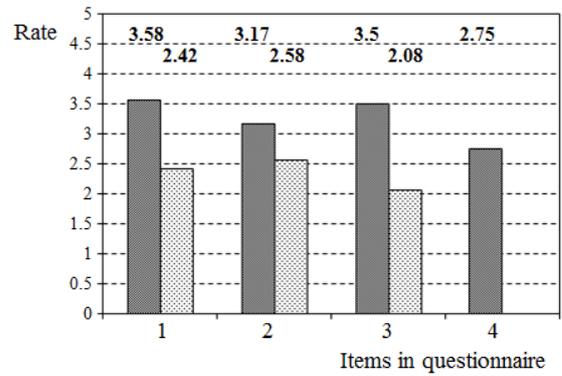
(a) Result of task 1 by group A.



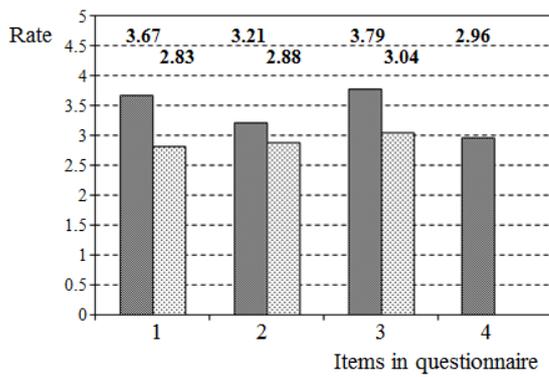
(b) Result of task 2 by group A.



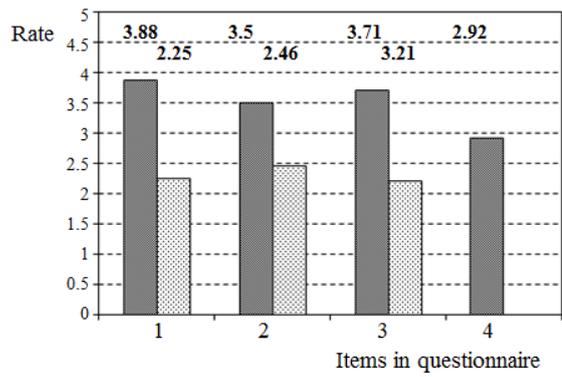
(c) Result of task 1 by group B.



(d) Result of task 2 by group B.



(e) Result of task 1 in total.



(f) Result of task 2 in total.

: task with force feedback    
 : task without force feedback

Figure 12 Result of experiment 2.

We observed that the effect of the touch sensation depends on the task's difficulty level as described in Section 5.2.2. A few subjects in group A remark the difficulty for controlling the FALCON device with appropriate force in the task 1. Group B's subjects, however, are very good at managing the device because they seem to become accustomed through the first task's exercise without force feedback. In the task 2, a more difficult task than the task 1, both groups' subjects rated the tasks with force feedback significantly higher than the ones without it. It suggests that the touch sensations give the positive effects for solving complex 3D manipulations such as building up the blocks on a line.

A subject mentioned manipulations with force feedback induced fatigue. We used a fixed set of simulation parameters for generating a reaction force in this experiment. This suggests that we need to consider an adaptive method for presenting force feedback by the device. For example, changing the force strength depending on the sort of manipulations or user's preference should improve the operational environment by reducing the user's stress in the work for long hours.

## 6 Conclusions

We proposed a new 3D desktop environment for solving problems found in some previously proposed 3D desktop systems. We adopted a haptic device, the FLACON force feedback device, as a single unified operation device. The proposed system implemented a realistic desktop space by visually presenting the space with 3D computer graphics and giving the users an additional modality, a sense of touch, through the haptic device. We conducted two experiments to validate the effectiveness of the proposed 3D desktop environment with haptic modality. We found that the proposed method is good for presenting the depth perception in a 3D task space and improve the intuitiveness of complex 3D operations.

Although the experimental results are fairly promising for applying the force feedback device in a 3D desktop environment, we would like to conduct an extensive evaluation with larger number of subjects in the near future. Analysing tasks used in a 3D space and improving them to be more realistic and natural ones are important future work for making the system more practical [8].

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**Appendix: Example 3D desktop operations by using FALCON force feedback device**

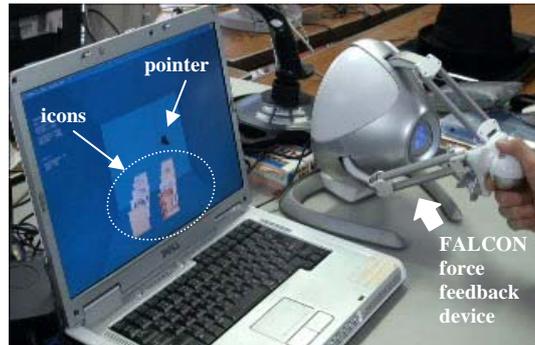


Figure A1 *Initial screen of 3D desktop environment.* Icons representing applications such as Internet Explorer, MS Office components, and text editor (memo pad), are placed on the bottom of a 3D task space.

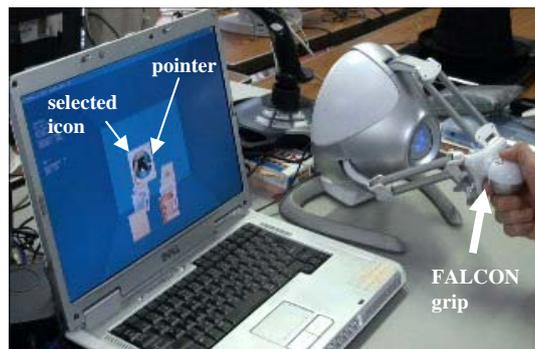


Figure A2 *Selecting a specific icon.* A user can select a specific icon by pointing it by FALCON and drags it by moving the FALCON grip with pushing a button on the grip.



Figure A3 *Launching an application associated with the selected icon.* The system presents a reaction force through the FALCON device when the user touches the icon. He/she can launch the application by pushing the selected icon with resisting the presented force by the FALCON device. Internet Explorer is selected and launched in this example.



Figure A4 *Arranging the activated window.* The user can arrange the activated window by grabbing and moving it towards a wall in the 3D task space. The window gradually turns around to finally rest on the wall.



Figure A5 *Launching multiple applications.* The user can easily launch multiple applications in the same way and efficiently perform desktop operations by switching them in the 3D task space.



Figure A6 *Rearranging the activated multiple windows.* The desktop space becomes cluttered with the activated windows. The user can rearrange the windows by moving them towards the walls and ceiling for better viewing the all activated applications and easily finding a target one.