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SPIDAR G&G: A Two-Handed Haptic Interface for Bimanual VR Interaction

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Abstract. In this paper, we propose a new haptic interface for tasks requiring two-handed manipulation. The system, named "SPIDAR-G&G", consists of a pair of string-based 6DOF haptic device called "SPIDAR-G". By grasping a special grip provided by each device, user can interact with virtual objects using both hands and accomplish life-like bimanual tasks in an intuitive manner. furthermore, the interface imparts user with the ability to feel different kind of force feedback. The system was evaluated by measuring "completion time" of a 3D pointing task, and shown to enhance interactivity for bimanual works.

1 Introduction

Most of the tasks that we perform in our daily life, involve the use of both hands for a wide variety of purposes ranging from a simple pickup tasks to a more complex and fine manipulation such as surgery tasks. However, both hands work all the time in concert with each other and in a seamless and spontaneous manner to acomplish desired tasks. Keeping such skillful interaction within virtual environemnet will be of great interest to many applications that require the use of both hands such as mechanical assembling, medical surgery, free form modering ...etc.

Many studies on two-handed action have been proposed and tested. Andrea Leganchuk et al. [1] have pointed out that bimanual manipulation may bring two types of advantages: manual and cognitive. Manual benefits come from increased time motion efficiency, due to the twice as many degrees of freedom as simulteneously available to the user. Cognitive benefits are due to reduction of load of mentally composing and visualizing the task at an unnaturally low level, which is imposed by traditional uni-manual techniques. Guiard [2] two-handed interface. According to Guiard, most of the common activities involve a division of tasks between both hands. Hence in order to accomplish a complex task, different roles are assigned to each hand in form of different subtasks to be performed.

Furthermore, Boud et al. [4] have pointed out that an assembly task as "The Tower of Hanoi"problem may need haptic feedback to support visual feedback in 3D manipulation task.

The current paper present a new haptic interface that provides user with the ability to use both hands to interact with virtual objects in an intuitive manner.

The design and setting of the interface took in consideration human's bi-manual working behavior so as it can be fitted for many bimanual manipulation but also feeling various kind of force interaction generated between hands and virtual objects.

1.1 Relate works

Many prototypes for two-handed operation have been developed. Such as, the 3-Draw system [5] which was developed for a CAD application, the ToolGlass and Magic Lenses system developed by Bier et al. [6]. Hinckley et al. designed the neuro-surgical planning system [7] with props interface where user manipulates two props, a head prop and a cutting plane prop with both hands. Responsive Workbench system [8] allowed users to naturally manipulate virtual objects with both hands by using a pair of gloves and a stylus as they are displayed on their tabletop VR devices. However, these bi-manual prototypes did not provide haptic feedback.

Based on the original SPIDAR [12] device, Sato et al. already presented a couple of both-handed devices known as Both-Hands-SPIDAR and SPIDAR-8. Both-Hands-SPIDAR [13] is based on two 3DOF version of SPIDAR embedded within the same working frame. Although the device have been proven to increase the level of reality during virtual object manipulation, it has few backdrops relation mainly to its 3DOF constrain and to the limitation of working area where strings connected to each hand my interfere with each other during wide rotation. SPIDAR-8 [15] is a two-handed, multi-fingered(four fingers for each hand) and string-based haptic feedback interface device which allows users to perceive force feedback via their fingertip caps. The device is very intuitive to use but due the number of involved string(24 in total) and their possible interference with each other during manipulation, the quality of force feedback is satisfactory only in a limited working space.

1.2 Our approach

Ideally, an effective device for virtual object manipulation should satisfy the following requirements:

1. The device should allow natural translational and rotational manipulation of virtual objects.
2. The device should provide force and torque feedback.

Furthermore, it is well stated in many publications that two-handed manipulation leads to faster completion than one-handed manipulation within the context of the interface. Thus to take advantage of user's existing bi-manual skills, it is recommended that the device allows a highly intuitive two-handed interface with 6DOF motion and 6DOF force feedback.

To satisfy the above assumptions and consideration, SPIDAR-G&G system was designed and developed based on a new version of SPIDAR system known as SPIDAR-G [16]. A 6DOF force feedback device with 1DOF in plus for the spherical grip element. The grip will be used to track hand movement as well as to grasp or release a virtual object (1DOF). Taking advantage of such device, SPIDAR-G&G system uses two SPIDAR-Gs to provides suitable environment for virtual bimanual tasks. Each hand has its own working space and able to feel different haptic sensations such as contact, weight, inertia, ...etc. being independent from each other, both hands can cooperate together to acomplish task in a natural manner. We believe that SPIDAR-G&G system could be effectively used for a number of applications such as virtual prototyping, virtual scruptureing, free form modeling, medical simulation,molecular simulation and tele-operation.

2 6DOF both-handed manipulation system –SPIDAR-G&G system

2.1 System configuration

SPIDAR-G&G's hardware configuration is illustrated in Fig. 1. As stated earlier, the system is composed mainly of two 6DOF haptic devices, a PC, and an LCD display. The PC controls and communicates with the haptic devices through two controllers which are attached directly to its USB port.

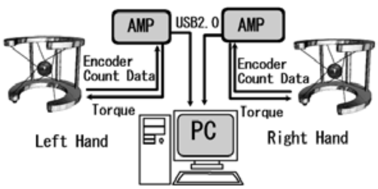


Fig. 1. System configuration for SPIDAR-G&G system

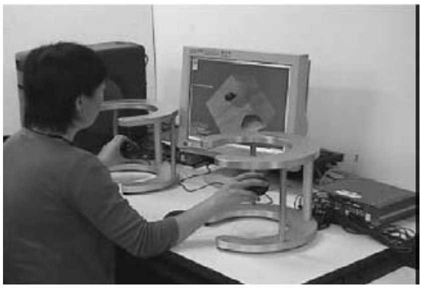


Fig. 2. Overview of SPIDAR-G&G system

The developed prototype of SPIDAR-G&G is shown in Fig. 2. Both devices are place about 40cm apart from each other and separated by a 17" LCD display where virtual objects are projected. To interact with the interface, user are required to grasp a special grip provided by each haptic device. The grip size is 3.25[cm] in radius and can be moved within the cubic frame of each haptic device (each frame side is 20cm length). It is important to note that the distance separating both devices was set in such way it provides comfortable working posture and do not interfere with bimanual manipulation.

2.2 The process of SPIDAR-G&G

The overall process of the system is described in Fig. 3. At first, the system gets position and orientation of each grip (which represent hand position) by measuring the strings' length. Secondly, the system calculates collision detection between virtual objects and user's hands. Finally, the system displays the appropriate force feedback by controlling the tension of each string. String's tension is generated by a DC motor and string length variation is detected in real-time by its respective encoder. The complete cycle (hand movement, Collision detection, force feedback creation) is repeated at a rate of $1[kHz]$, enough to display realistic sensation.

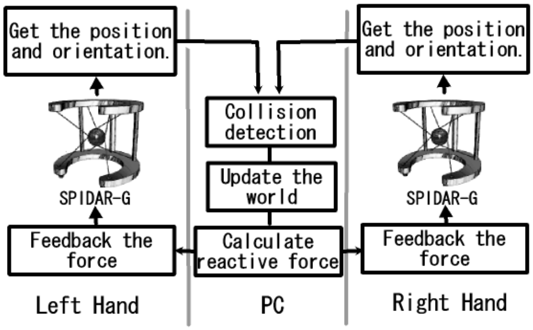


Fig. 3. The system process of SPIDAR-G&G

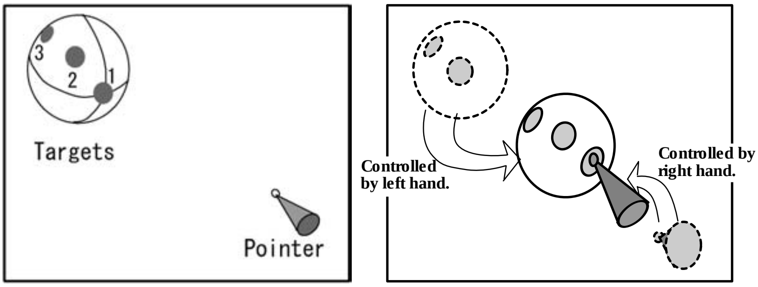
3 Evaluating the system

3.1 Experimental evaluation

In order to validate the efficiency of the proposed system, we performed an evaluation experiment with two different task conditions; one is a bimanual task using SPIDAR-G&G, the other is an uni-manual task using SPIDAR-G and keyboard. Subjects were asked to bring a virtual pointer into contact with a set of targets positioned on the surface of a floating virtual sphere. We call this task '3D pointing task'. We also tried to investigate the effect of haptic feedback cue on task performance by comparing time completion in two other conditions, with and without haptic feedback. During all experiments we measured time required to complete the 3D pointing task and use it as evaluation index during experiments' analysis.

3.2 Subjects and general procedures

Two men and a woman participated in the experiments after providing informed consent. Their ages were 23 to 25 years old. They didn't have handicap in visual sense and motor control. They were all right-handed and familiar with VR interfaces.



(a) The targets and the pointer

(b) The initial position and the complete position of the pointer and the sphere

Fig. 4. The 3D pointing task

The shape of targets and the pointer are shown in Fig. 4(a); the pointer was represented as a cone shape, and targets were red circles with radius of 1-cm in the surface on a sphere which had 9.5-cm radius. Scale of the pointer and targets were varied according to the spatial movement in depth.

Targets were located on three spots on the virtual sphere as: the center of front side (Target 1), the upper left side from Target 1 (Target 2), and the opposite side of upper left to Target 1 (Target 3). At each trial, the environment is re-initiated to its original setting where the pointer is placed in the front-lower-right side of the screen and the sphere is place on back-top-left side. Initially, Target 3 is not visible to subjects, therefore it should be rotated to complete the task.

Fig. 4(b) represents the initial position of the pointer and target sphere (drawn by dotted line) and their final position (drawn by solid line) at the time of task completion.

3.3 3D pointing tasks

before conducting the experiments, subjects were given enough time to experience the system under both visual and haptic feedback conditions to get accustomed with it. After that, experiments were performed in the following order.

1. Bi-manual task using SPIDAR-G&G without haptic feedback.
2. Uni-manual task using SPIDAR-G and keyboard without haptic feedback.
3. Bi-manual task using SPIDAR-G&G with haptic feedback.
4. Uni-manual task using SPIDAR-G and keyboard with haptic feedback.

In the case "without haptic feedback", subjects perceived task completion by visual feedback only. In the case "with haptic feedback", subjects could recognize the completion of tasks by feeling the physical contact that occurs between the pointer and the sphere. The task time was recorded from the moment the pointer started to move till the moment of the contact with a target occurred.

In each session, each subject performed 20 trials from Target 1 to Target 3 alternately for a total of 60 trials. Subjects were instructed beforehand to hold the floating sphere with left hand and the virtual pointer with the right hand. All actions (3D translation and 3D rotation) are allowed to accomplish the task. In the uni-manual task, the pointer and the sphere were controlled just by right hand. At the initial condition, the pointer was controlled by SPIDAR-G. Therefore, the subject was required to switch the control mode from the pointer to the sphere. Switching between two control modes was achieved by pushing the letter 'c' of the keyboard.

The strength of feedback force was defined as (1).

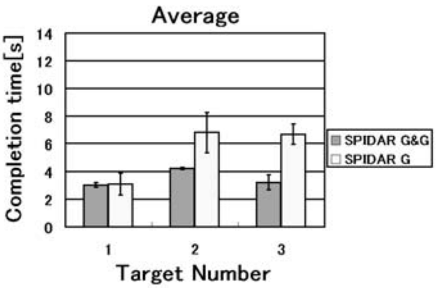
$$F = d_s k + \epsilon, \qquad (1)$$

where d_s is the distance in which the tip of the pointer invaded into the sphere, k is the coefficient for deciding strength of feedback force, and ϵ is the offset for informing the user that it was contacted each other (by emphasizing the tactile emitting strong force when the pointer touched the sphere.) In this experiment, ϵ set to $2.9[N]$.

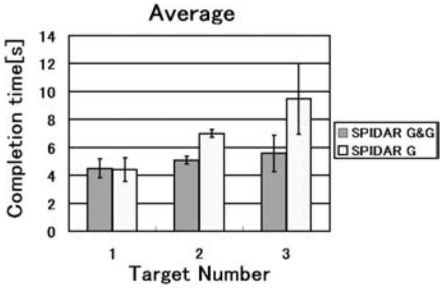
3.4 Experimental results

The average in the completion time is illustrated in Fig. 5 for all three subjects. Fig. 5(a) shows the result with haptic feedback, and the Fig. 5(b) without haptic feedback. Each number of a horizontal axis denotes the target respectively. Each error bar denotes the standard deviation in the average of the completion time for each subject.

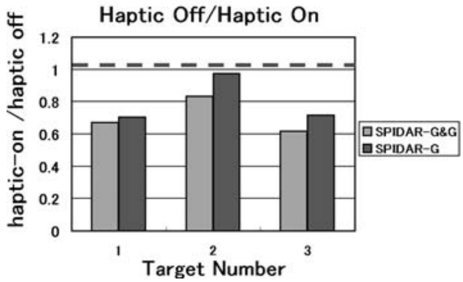
As expected, the task time of uni-manual manipulation by using SPIDAR-G alone was longer than bi-manual manipulation by using SPIDAR-G&G over most task conditions. Another remarkable observation is that in the case of SPIDAR-G, the task time showed a tendency to increase as task requirement got difficult. Whereas in the case of SPIDAR-G&G, it took shorter time to complete the task. There was also a slight difference in task time among the three targets. It means that the bi-manual manipulation using SPIDAR-G&G promotes the task efficiency because it enables the user to execute the spatial and temporal bi-manual cooperation task simultaneously.



(a) With haptic feedback



(b) Without haptic feedback



(c) Ratio of "without haptic feedback" for "with haptic feedback" of 3D pointing task in the SPIDAR-G&G.

Fig. 5. Average completion time of 3D pointing tasks.

Fig. 5(c) shows the ratio of completion time between using haptic feedback and not using haptic feedback. We observed that the task time decreased when haptic feedback was provided over all tasks conditions.

It shows that task efficiency largely depends on the haptic feedback in 3D pointing tasks. About this result, all subjects performed tasks with haptic feedback conditions before experiments without haptic feedback. So that, we must consider about effect that users had learned the task.

From these results, we found out that our proposed system, SPIDAR-G&G, is relatively effective for performing 3D pointing task compared with conventional uni-manual haptic interface.

4 Conclusion and future work

In this paper we described our new haptic feedback interface SPIDAR-G&G system for two handed 6DOF manipulation. Distinct advantages of our system were as following;

- The system takes advantage of the user's existing bimanual skills.
- Users can express complex spatial relation with two easy-to-use grips and control the motion of a virtual object.
- Users can intuitively manipulate the objects with 6DOF translational and rotational motion.
- Users can manipulate a virtual object with 6DOF haptic feedback with some kind of virtual sensation.

The evaluation experiment showed that two-handed manipulation takes shorter completion time than one-handed 6DOF manipulation. The result indicated that two-handed manipulation with the tension based haptic interface can control more intuitive and efficient for a virtual object.

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