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Abstract

Virtual reality (VR) interfaces have the potential to enhance the engineering design process, but before industry embraces them, the benefits must be understood and documented. The current research compared two software applications, one which uses a traditional human-computer interface (HCI) and one which uses a virtual reality HCI, that were developed to aid engineers in designing complex three-dimensional spherical mechanisms. Participants used each system to design a spherical mechanism and then evaluated the different interfaces. Participants rated their ability to interact with the computer images, their feelings about each interface, and their preferences for which interface device to use for certain tasks. The results indicated that participants preferred a traditional interface for interaction tasks and a VR interface for visual tasks. These results provide information about how to improve implementation of VR technology, specifically for complex three-dimensional design applications.

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ASSESSING THE EFFECTIVENESS OF TRADITIONAL AND VIRTUAL REALITY INTERFACES IN SPHERICAL MECHANISM DESIGN

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ABSTRACT

Virtual reality (VR) interfaces have the potential to enhance the engineering design process, but before industry embraces them, the benefits must be understood and documented. The current research compared two software applications, one which uses a traditional human-computer interface (HCI) and one which uses a virtual reality HCI, that were developed to aid engineers in designing complex three-dimensional spherical mechanisms. Participants used each system to design a spherical mechanism and then evaluated the different interfaces. Participants rated their ability to interact with the computer images, their feelings about each interface, and their preferences for which interface device to use for certain tasks. The results indicated that participants preferred a traditional interface for interaction tasks and a VR interface for visual tasks. These results provide information about how to improve implementation of VR technology, specifically for complex three-dimensional design applications.

INTRODUCTION

Virtual Reality (VR) applications attempt to use the senses as a basis for developing computer interaction tools in which natural body movements and gestures are used to manipulate information (e.g., Biocca, 1992; Burdea & Coiffet, 1994). Burdea and Coiffet (1994) described the goal of VR as providing an environment that is intuitive to use, is stimulating to the imagination, and also causes the user to become immersed in the computer data. In VR applications, instead of looking at a computer monitor and interacting with the computer images using a mouse, the user views the computer images with the aid of a three-dimensional (3D) visualization device, such as a head mounted display, and moves around in and interacts with the 3D environment with the aid of a 3D interaction device, such as a position-tracked instrumented glove. Additional features such as spatialized sound, haptic feedback, verbal communication with the environment, and olfactory cues may be added to the virtual environment to enhance the feeling of immersion or sense of presence (e.g., Hendrix & Barfield, 1996b; Steuer, 1992; Wann & Mon-Williams, 1996).

Because it offers the possibility of creating a seamless interface between the human and the computer, VR is quickly becoming a useful tool in many areas of engineering (e.g., Kobe, 1995; Mahoney, 1995; Puttré, 1992). Much of engineering deals with creating and analyzing 3D products, so it seems likely that a VR human-computer interface for engineering design would enhance the design process. Even though traditional graphics capabilities and interaction devices are powerful tools for accessing computer data, VR provides unique visualization and interaction capabilities not offered by the traditional HCI, and these capabilities might enhance the human's ability to understand computer generated information. On the downside, however, the VR devices are generally more expensive than the traditional monitor and mouse and the interface programming is more complex. For these reasons, the benefits of VR must be understood and documented before this technology will be widely embraced as an alternative HCI. Researchers must determine whether VR technology enhances or degrades performance of some task when compared to the typical HCI. This information can then be used to determine whether the advantage of using VR technology outweighs the expenses.

In the current research, we compared two applications, one a using a traditional HCI and the other using a VR HCI, that were developed to aid engineers in the design of spherical mechanisms. Mechanisms, which are fundamental components of machines, are mechanical devices that are used to transfer motion and/or force from a source to an output (Erdman & Sandor, 1991). As input is provided to one of the bodies, each subsequent body moves accordingly and a desired output motion is obtained. Most mechanisms are planar mechanisms that perform a specified task through movement in two-dimensional (2D) space. Spatial mechanisms, in contrast, perform fully 3D movement. Spherical mechanisms constitute one type of the more general category of spatial mechanisms and consist of linkages that have motion constrained to concentric spheres.

Because it is difficult to specify a spherical mechanism's design conditions in 3D and to understand the resultant motion, these simplest of spatial mechanisms are not in common use. Rather, a series of planar mechanisms are most often used to perform motion in 3D space. This results in a complex mechanism that is costly to manufacture and maintain (Kota & Erdman, 1997). To alleviate the difficulty experienced when designing spherical mechanisms, the Sphinx software was developed by Larochelle, Dooley, Murray, and McCarthy (1993). Sphinx uses a traditional interface consisting of a monitor for visualization and a desktop mouse for interaction.

Osborn and Vance (1995) developed SphereVR, the first VR interface for spherical mechanism design. This was followed by VEMECS (Virtual Environment MEChanism Synthesis); a more sophisticated spherical mechanism design tool developed by Kraal (1996) in collaboration with the designers of Sphinx. Basically, VEMECS combined a VR interface with the Sphinx computational routines.

The design of spherical mechanisms was chosen as the focus of this study because 1) the design and evaluation task is fully three-dimensional and 2) two very similar software programs existed where one relied on a traditional interface and the other implemented VR interface for the same task. This study compared the interfaces of two spherical mechanism design software packages: a modified version of Sphinx, which uses a traditional interface, and VEMECS, which uses a VR interface.

METHOD

Participants completed a tutorial for the first software/interface package they were assigned and then used the interface to complete an exercise in which they designed a specific mechanism. Immediately after completing the first exercise, participants completed a questionnaire assessing their ability to complete the task with the interface. Exercise completion time also was recorded. Participants then went through the same steps for the other software/interface package. A final questionnaire asked participants to indicate which interaction device and which visualization device they preferred.

Participants

Thirty-two students (31 males and 1 female) with an average age of 22 years (range from 20 to 32) participated in the research. These individuals were either currently enrolled in or had previously taken a basic planar mechanism design course. Twenty-nine of the participants were recruited through a short presentation made in several classes. The presentation included a brief description of what a spherical mechanism was and how it worked. Students also were shown a working physical model of a spherical mechanism that they could hold and manipulate. The purpose of the study was explained and the approximate amount of time required was described. The students were paid $6 per hour and the study took approximately two hours. Three of the participants were recruited by friends in the classes and were accepted because they had fulfilled the requirement of having taken a basic planar mechanism design course. They also were given the short presentation on spherical mechanisms. None of the participants had any classroom training in designing or analyzing spherical mechanisms.

Software and Interface

VEMECS can be used with a number of different 3D interaction devices and 3D displays but for this study participants used a position-tracked glove for 3D interaction and stereo glasses for 3D visualization. No head tracking was provided in this VR interface. These interaction devices were selected since they are readily available and relatively inexpensive VR tools.

The version of Sphinx used for this study was modified from the original application. VEMECS, being a prototype software, did not implement all the features of Sphinx, which has been in development for several years, so some of the Sphinx features were hidden in order to make the functionality of these two software packages as comparable as possible. Specifically, the Type Map design procedure was not available to the participants. The modifications allowed a direct comparison between two different application interfaces that are used for the same type of design work and are based on the same functionality. Such a comparison will show whether design of spherical mechanisms is enhanced by the interaction and visualization provided in a virtual environment. Thus, although we use the name Sphinx throughout this article, it refers to the modified version of the software and not the full-featured version developed by Larochelle et al. (1993).

The two software/interface packages compared in this study were organized similarly in that the user performed the same basic steps to design a mechanism. These steps were:

1. The user specified four position points through which the output link of the mechanism should pass. Each position point was comprised of a location (x, y, z) and orientation (θx, θy, θz) on the surface of the design sphere.

2. Once the position points (locations and orientations) were specified, the software calculated all of the possible locations of the mechanism's 4 joints or axes. At this stage in the process, two infinities of solutions exist. The user then selected a location for the two joint pairs, which results in a fully specified four-bar spherical mechanism. [Note: In a real design situation, the user would select the location of two joint pairs (or axes) based on knowledge about space limitations of the resultant mechanism, available attachment points on neighboring structures, and other relevant constraints. In the current situation, there were no such constraints on axes selection.]

3. Once the axes were selected, the lengths of the mechanism's links were calculated and the final mechanism was displayed. The user animated the mechanism and visually analyzed the resultant motion.

4. By experimenting with different axes for the joints, animating the mechanism, and visually analyzing the result, the user was able to design a stable mechanism that would pass through the four position points in the desired ordering.

The major differences between Sphinx and VEMECS were in terms of interaction with the application and visualization of the design environment. Sphinx used a traditional point-and-click approach for interaction by employing a tabletop three-button mouse. In order to create the mechanism, a user interacted with traditional-looking menu buttons on the computer screen and manipulated the computer graphics using the mouse. Figure 1 shows the Sphinx interface. When using Sphinx, the user saw the mouse pointer and all of the 2D computer graphics on the monitor of the workstation. Sphinx used three different windows, displayed all at once, for each part of the design stage; that is, one window was used for placing position points, one for selecting axes, and one for viewing the mechanism. (See Figure 1.) Sphinx was implemented using a Silicon Graphics (SGI) Indy 200 MHZ single processor workstation using the IRIX 6.2 operating system with Indy-24 bit graphics on a 21 inch computer monitor.

VEMECS used a more natural approach for interaction through the use of a right handed Pinch™ glove (Fakespace, Inc., 1995) tracked by a Flock of Birds™ (Ascension Technology Corporation, 1996) magnetic position tracker, which provided full six degree-of-freedom (x, y, z, θx, θy, θz) information about where the glove was in 3D space. Using the Pinch™ glove, tasks were performed through a series of hand gestures such as pinching together the index finger and thumb. These gestures were used to select position points to be placed on the sphere, to select axes, and to select different menu items.

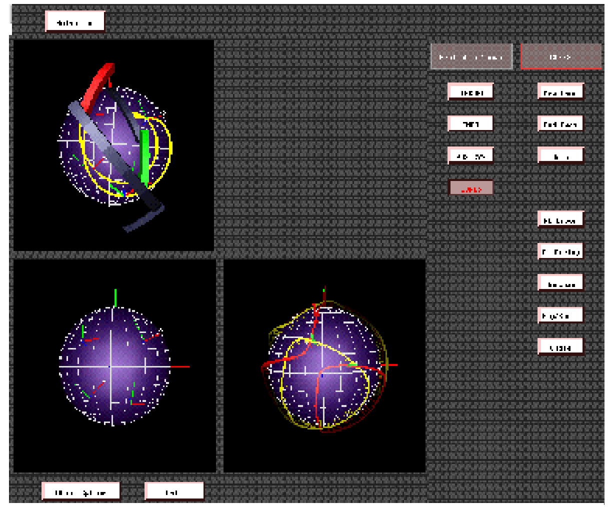

Figure 1: Sphinx display environment

Because the glove was equipped with a position tracker, the user could reach out to grab positions in 3D space. Stereoscopic images of the VEMECS environment were presented on a single projection screen (5' x 4') using CrystalEYES® (StereoGraphics Corporation, 1992) stereo glasses. When using VEMECS, users saw all computer graphics, including a graphic representation of their hand, projected in 3D. VEMECS used only one viewing space in which all design work was performed on the same design sphere. (See Figure 2). In addition to visual feedback about hand position, VEMECS provided auditory feedback, emitting audible tones when the graphic hand intersected with menu items or the design sphere during certain stages of the design. Virtual menus were displayed slightly "below" and "in front of" the design sphere, but users were free to move the sphere to a new location. VEMECS was implemented on a SGI Onyx with

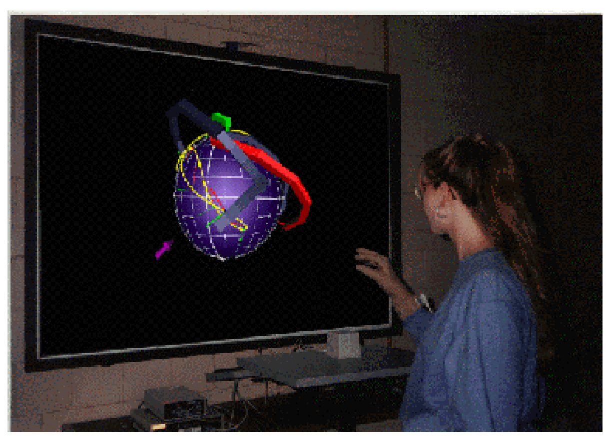

Figure 2: VEMECS interface (shown without CrystalEyes glasses and with the Cyberglove instead of the Pinch™ glove)

two 150 MHZ processors and RealityEngineII Graphics. [Note: Sphinx was used on a computer with less performance capability than the computer used for VEMECS. However, no degradation of performance was noticed when Sphinx ran on the lower level computer so it was judged suitable for this study.]

Stimuli

Two different exercises were used. Both exercises were exactly alike with the exception of the locations and orientations of the specified position points on the design sphere. These exercises instructed the user to design a mechanism that would move through four specified positions. Counterbalancing of exercises and interfaces insured that each exercise was assigned equally often across participants to each of the software applications and as both the first and the second exercise.

Immediately after completing the exercise with a software package the participant completed a questionnaire concerning the interface and exercise. One set of questions concerned the ability to place position points, orient position points, select axes, modify position points, modify axes, interact with the program, see position points, see the axes, visualize the mechanism shape, and see the mechanism pass through the position points. These questions were rated on a 5-point scale (1 = poor, 3 = indifferent, 5 = excellent). A second set of questions was rated on a 3-point scale (1 = yes, 2 = neutral, 3 = no). These more general questions asked whether the participant understood the tutorial, understood the exercise, or experienced any discomfort during the exercise. Finally, the last question asked whether the participant felt so involved in the exercise that "you lost track of time". This question was included to determine whether participants felt more involved in the VR application.

A final questionnaire asked participants to select the preferred interaction device (table top mouse or Pinch glove) and the preferred visualization device (monitor or stereo glasses) to use for spherical mechanism design and to indicate which interface (traditional or VR) sparked their interest more in spherical mechanisms.

Procedure

Upon arriving at the lab, participants completed a consent form and a short questionnaire that asked about prior experiences with mechanisms and computers. A software package and exercise were assigned to each participant for the first part of the session. Participants followed the tutorial for that particular software to learn how to use the application and to become familiar with the application's interface. Then participants used the software/interface to design a spherical mechanism that fit the specifications outlined in the exercise and afterwards completed the software questionnaire. Next, participants completed the tutorial for the second software, then completed an exercise similar to the first, and afterwards completed the questionnaire for the second software. Finally, after participants had used both applications and completed both exercises, they completed the final questionnaire.

The entire procedure took between one and two hours.

RESULTS

Analysis of variance statistics (ANOVA) were used to analyze the data. The level of significance was set at $p \leq .05$, where p is the probability that a difference is due to chance factors. Thus, a difference or an effect will be described as *reliable* when $p \leq .05$ and *marginally reliable* when $.05 < p \leq .10$.

Because of the counterbalancing procedures used, there were four groups (of eight participants each) who differed in the order of interface use and in which exercise was assigned to each interface. The four groups were:

a. VR interface first / Exercise 1 first
b. VR interface first / Exercise 2 first
c. Traditional interface first / Exercise 1 first
d. Traditional interface first / Exercise 2 first

Preliminary analyses showed that responses did not vary as a function of exercise, so data were collapsed over exercise reducing the group variable to two levels:

a. VR interface first
b. Traditional interface first

All participants were successful in creating a spherical mechanism with each type of software.

Group Characteristics

The groups were similar in their answer to almost every item on the questionnaire assessing prior experience with computers and mechanisms. Everyone reported familiarity with use of computer workstations. Only four persons in the Traditional interface first group and two persons in the VR interface first group reported any prior experience with VR. The average responses to the other items on the questionnaire (1 = low, 5 = high) are shown in Table 1 for each group. There

	Traditional first		VR first	
	Mean	Std. Err.	Mean	Std. Err.
Computer knowledge	3.0	0.18	3.1	0.17
Planar mechanism knowledge	3.3	0.22	2.9	0.23
Spatial mechanism knowledge	1.3	0.17	1.2	0.16
Interest in mechanisms	3.4	0.22	4.1	0.19
Weekly computer use (hours)	10.1	1.42	10.6	2.30

Table 1: Pretest Questions Responses

were no reliable group differences in self-reported knowledge about computers, knowledge about planar mechanisms, or knowledge about spatial mechanisms, or hours of computer use (all $p > .19$). However, the VR interface first group reported a reliably higher level of interest in mechanism design than did the Traditional interface first group, $F(30) = 4.49$, *MSE* (mean square error) = .70, $p = .04$.

Completion Time

The time to complete the tutorials is shown in Figure 3 as a function of Group and Interface. An ANOVA of tutorial completion time with group (Traditional first versus VR first) as a between-subjects variable and interface (traditional versus VR) as a within-subjects variable was performed. (Note: one participant failed to record tutorial completion time).

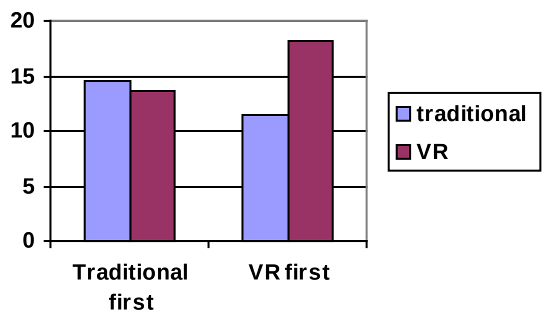

Figure 3: Mean number of minutes to complete the tutorial

The VEMECS tutorial generally took longer to complete than the Sphinx tutorial and the analysis revealed that, this difference was reliable, $F(1, 29) = 7.06$, $MSE = 18.41$, $p = .013$. However, this effect was qualified by a reliable Group x Interface interaction, $F(1, 29) = 12.37$, $MSE = 18.41$, $p = .002$. The interaction means that the order of the interface was important. Inspection of the means suggests that practice effects (learning) occurred such that the second tutorial (the two inner bars) generally took less time than the first (the two outer bars) and the benefit to being second was greater for the VR interface than for the traditional interface.

The time to complete the actual exercises (Figure 4) showed a similar overall pattern of mean time to that found for the tutorials. Solving a problem with the VR interface generally took longer than with the traditional interface, and this difference was reliable, $F(1, 30) = 9.14$, $MSE = 42.14$, $p = .005$. The Group x Interface interaction effect was marginally reliable, $F(1, 30) = 3.63$, $MSE = 42.14$, $p = .07$, suggesting once again that the benefit of being second was greater for the VR interface than the traditional interface.

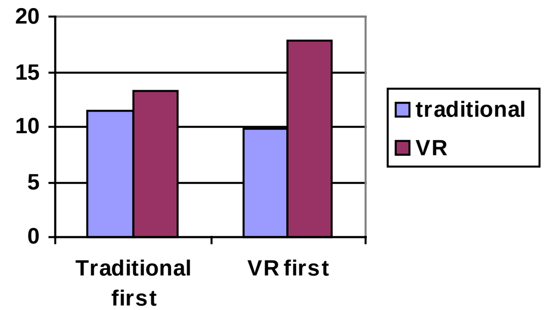

Figure 4: Mean number of minutes to complete the exercise

Evaluating Task Com*p*onents

After completion of each exercise, participants were asked to rate on a 5-point scale (with higher ratings being better):

a. the ability to interact with (locate, orient, and modify) position points,
b. the ability to interact with (select and modify) axes,
c. the overall ability to interact with the program,
d. the ability to see points,
e. the ability to see the axes,
f. the ability to visualize the mechanism shape, and
g. the ability to see the mechanism pass through the points.

We had assumed that the responses to the interaction questions would show similar patterns as would the responses to the seeing/visualizing questions and had planned to reduce scores to these two variables. Preliminary analyses of the responses, however, showed one pattern of responses to all the questions involving position points, one pattern of responses to all the questions involving axes, and one pattern of responses to the two questions involving the mechanism as a whole. Therefore, the responses to the position points questions were averaged to get a "working with position points" score, the responses to the axes questions were averaged to get a "working with axes" score, and the responses to the two mechanism questions were averaged to get a "visualizing the mechanism" score. For each combined score, and for the responses to the overall interaction question, an ANOVA was performed with Group as a between-subjects variable and Interface as a within-subjects variable.

The average “working with position points” scores are shown in Figure 5. The VR first group scores were higher than the Traditional first group scores and this was a reliable effect, $F(1, 30) = 18.68$, $MSE = 0.45$, $p < .001$. The traditional interface received higher scores in general than the VR interface and this was a reliable effect, $F(1, 30) = 61.88$, $MSE = 0.23$, $p < .001$. The interaction effect was not reliable.

The average “working with axes” scores are shown in Figure 6. The ANOVA showed a somewhat more complex

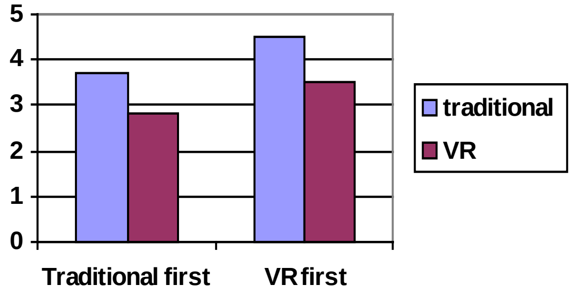

Figure 5: Mean responses for "working with position points"

pattern than was found for “working with position points”. The VR first group reported higher scores than the Traditional first group, and this difference was marginally reliable, $F(1, 30) = 4.12$, $MSE = 1.37$, $p = .051$. The VR interface also had higher scores than the traditional interface, and this difference was marginally reliable, $F(1, 30) = 4.04$, $MSE = 0.53$, $p = .054$. However, in this case there was an interaction effect that was reliable, $F(1, 30) = 12.26$, $MSE = 0.53$, $p = .002$. The interaction effect is not easily interpretable. One possibility is that naive participants (i.e., participants during their first trial) showed a real preference for working with axes using the VR interface over the traditional interface, and then experience, either with designing spherical mechanisms or with both types of software, modified that preference. However, the preference for the VR interface on the first exercise also could reflect the fact that there was a tendency for the VR first group to give higher ratings in general. Regardless, when working with axes, there was not the preference for the traditional interface that was found when working with position points. If there was any interface difference, the VR interface was preferred. Possible reasons for the difference between working with position points and working with axes are described in the Discussion section.

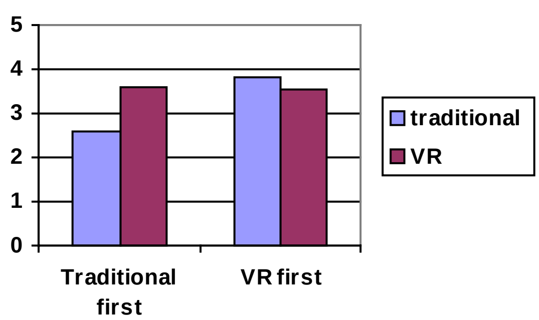

Figure 6: Mean responses for "working with axes"

The average responses to the question about the “overall ability to interact” with the program are shown Figure 7. The VR first group reported higher scores and this was a reliable effect, $F(1, 30) = 12.31$, $MSE = 0.73$, $p = .001$. The traditional interface received higher scores and this also was reliable, $F(1, 30) = 11.24$, $MSE = 0.67$, $p = .002$. The interaction effect was not reliable. The pattern of responses was nearly identical to that found for “working with position points”, suggesting that participants considered working with position points to be the major component of the task.

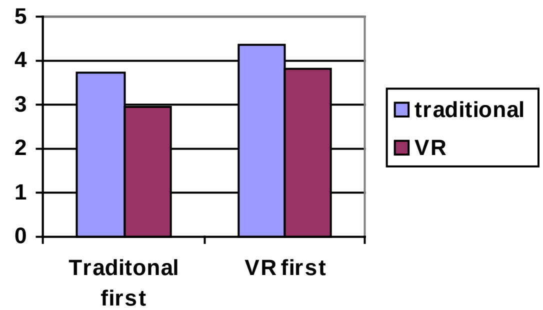

Figure 7: Mean responses for "overall ability to interact"

The average mechanism visualization responses are shown in Figure 8. The VR first group scores did not differ reliably from the Traditional first group scores. The VR interface did receive higher scores than the traditional interface, and the difference was reliable, $F(1, 30) = 9.65$, $MSE = 0.55$, $p = .004$.

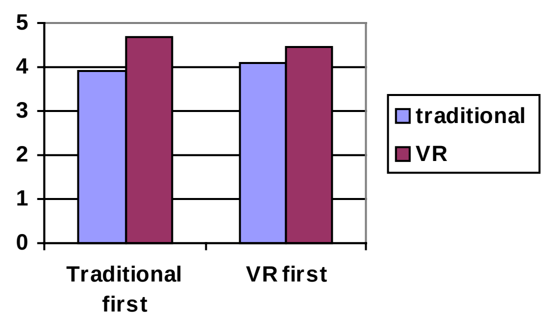

Figure 8: Mean responses for "visualizing the mechanism"

General Evaluation

After evaluating the components of the task, participants were asked to rate on a 3-point scale (1 = yes, 2 = neutral, 3 = no) whether they understood the information in the tutorials and whether they understood the exercise. The first two rows of Table 2 show the average responses to these questions as a function of Group and Interface. The responses were primarily

	Traditional first				VR first			
	Traditional		VR		Traditional		VR	
	Mean	Std. Err.	Mean	Std. Err.	Mean	Std. Err.	Mean	Std. Err.
Understood tutorial	1.2	.14	1.1	.09	1.1	.13	1.5	.16
Understood exercise	1.0	.00	1.1	.13	1.1	.06	1.1	.09
Experienced discomfort	2.3	.24	1.8	.23	2.8	.17	2.3	.24
Lost track of time	1.7	.20	1.8	.19	2.3	.24	1.8	.21

Table 2: General Evaluation Responses

yes; ANOVAs showed no reliable differences due to Group or to Interface.

Participants also were asked whether they experienced discomfort during the task and whether they had become so involved in the exercise that they lost track of time. Responses to those questions are shown in the bottom two rows of Table 2. The average response was neutral to the latter question and the ANOVA showed no reliable differences. Although most of the responses to the discomfort question were no, the ANOVA showed that the Traditional first group reported reliably more discomfort than the VR first group, $F(1, 30) = 6.02$, $MSE = 0.66$, $p = .02$. In terms of comparing the interfaces, the VR interface was associated with reliably more discomfort than the traditional interface, $F(1, 30) = 4.45$, $MSE = 0.90$, $p = .04$. Persons who selected yes to the discomfort question were asked to describe in writing the source of the discomfort. No two of the seven responses describing discomfort with the traditional interface were similar. Of the 14 responses describing discomfort with the VR interface, eight referred to the hand/arm/glove and two referred to vertigo/headache.

Final Questions

After completion of both exercises, participants were asked to indicate:

a. which interaction device (mouse versus Pinch™ glove) allowed better interaction with the software,
b. which viewing device (computer monitor versus CrystalEYES®) provided better visual feedback about the mechanism, and
c. which software package sparked their interest more in spherical mechanisms.

These comparisons were made on a "select one or the other basis" and were not ranked on a 5-point scale. The results show that the mouse was judged to be the preferred interaction device by 93.8% of the participants, with no reliable difference between the VR first or the Traditional first groups. CrystalEYES® was judged to provide better visual feedback by 75% of the participants. This preference for CrystalEYES® was reliably higher in the Traditional first group (93.8%) than in the VR first group (56.2%), $X^2(1) = 6.00$, $p = .014$. The group difference could represent some type of recency effect with a bias towards the last used device. VEMECS was chosen as the program that sparked more interest by 66.7% of the participants, with no reliable difference between the groups.

The final general question asked the participants to indicate which interface sparked more interest in spherical mechanism design. In spite of the fact that VEMECS was not overly immersive, 62.5% of the participants chose the VR interface.

DISCUSSION

The VR interface and the traditional interface differed primarily in two ways: visualization and interaction. We expected that participants would prefer the VR interface over the traditional interface for designing spherical mechanisms because it allowed 3D visualization and spherical mechanisms require consideration of three dimensions. We also expected that participants would find interaction with the Pinch™ glove to be preferred over the interaction available with the desktop mouse. The results derived from both immediate ratings of each interface and from a final direct comparison supported the first expectation, but not the second, and they highlight the need to empirically assess the usefulness of VR for specific tasks (e.g., Kozak, Hancock, Arthur, & Chrysler, 1993).

Results showed that participants preferred the stereo glasses for visually interpreting information for spherical mechanism design. The preference was indicated both on the questionnaire completed immediately after each exercise and on the final questionnaire. Hendrix and Barfield (1996a) emphasized the importance of stereoscopic visualization by showing that a stereoscopic display is more realistic for presenting spatial information in a virtual environment and enables users to better interact with the virtual environment. The stereographic visual effects of the VR interface created fully 3D images giving a spatial quality not provided by a computer monitor visual interface. Participant responses confirmed that this type of spatial quality is preferred for visualizing complex 3D objects, such as spherical mechanisms.

We expected that participants would prefer to complete the exercises with the Pinch™ glove rather than the mouse because the glove allowed the use of natural hand movements to manipulate the computer data. However, the results showed a pattern that favored the mouse in three out of four instances. First, when making the immediate ratings of their ability to place the four position points on the design sphere ("working with position points”), participants indicated a preference for the mouse. Second, when rating their overall ability to interact with the program, participants gave higher ratings to the traditional interface. Third, when directly asked which interaction device they preferred, participants chose the mouse. But fourth, when making the immediate ratings of their ability to choose axes for the revolute joints of the spherical mechanism (“working with axes”), participants did not give generally higher ratings to either application, although there was a higher rating for the VR interface on the first exercise.

A closer examination of the specific ways that participants interacted with the two applications suggests that the pattern of results is determined by complexity of subtasks within the application. In designing a four-bar spherical mechanism, four position points must be placed on the design sphere. In Sphinx, a position point initially appeared on the surface of the design sphere. Users altered the longitude, latitude, or roll (orientation), but the point stayed located on the surface of the sphere. In VEMECS, to place positions, the user selected a menu item and a position point appeared attached to the end of the virtual index finger. This point needed to be moved in 3D space until it was placed on the design sphere. When the virtual hand intersected the design sphere, the position point attached to the surface. Users could then adjust the position point by adjusting their hand until the position point was in the desired location and orientation. Kraal (1996) assumed in the development of the VEMECS software that adding this ability to place the position on the sphere would increase the usability of the program by providing more 3D interaction. The results of this study indicate that was not the case. Moving the position point from the virtual menu to intersect with the design sphere was an additional step that was not present in the Sphinx software. Thus, while it is true that the VEMECS interaction concerning the placement of position points was more natural, this additional feature made the task more complex. Participants’ immediate ratings of “working with position points” reflected the additional complexity in the preference for the simpler task. Participant ratings of overall ability to interact mirrored the ratings for placing of position points, suggesting that participants viewed position point placement as the primary subtask in the exercise. The fact that they showed a preference for the mouse on the final questionnaire also fits this interpretation. The additional complexity also could be contributing to the increased time required to use VEMECS to complete the exercises.

The interaction task of defining axes for the revolute joints of the mechanism also varied between the VR interface and the traditional interface. In this case, however, the VR interface provided the easier interface and the results indicated that if there was any software difference, the VR interface was preferred for this subtask. When using Sphinx, users had to rotate the design sphere, upon which were attached the many possible axes, until the desired axis was drawn in the plane of the computer screen. An axis that was pointing out at the user could not be selected until the sphere was rotated such that the axis was aligned with the computer screen. Users could then select that axis by pointing with the mouse cursor and clicking the left mouse button. Axis selection using VEMECS simply required users to touch the desired axis with the index finger of the virtual hand, no matter what its orientation, and the axis was selected. No manipulation of the design sphere was required.

In summary, the interaction results suggest that a participant’s preferred interface is linked to how a particular task is implemented in the virtual environment as opposed to the functionality of the interaction device itself. When the requirements of the task changed, the preference for the interaction device also changed. In both cases, working with position points and working with axes, users preferred the simpler task regardless of the interface device. A simplification of the position point placement process in VEMECS likely would improve participants’ overall evaluation of the Pinch™ glove interface.

Results showed that users generally took more time to complete the exercise using the VR interface. Several factors likely contributed to this outcome. As described earlier, the position point placement procedure was more complex in VEMECS and since there were four position points to be placed, this task comprised a good portion of the overall exercise time. The interfaces also differed in familiarity. Everyone indicated prior experience with a mouse, while very few indicated prior experience with VR. As familiarity with a situation increases, a schema is developed that begins to automatically handle much of the routine information processing associated with the situation (e.g., Alba & Hasher, 1983; Neisser, 1976), freeing up limited-capacity resources to handle other tasks (e.g., Shiffrin & Schneider, 1977). Participants likely have appropriate point-and-click schemata for interacting with computer images. Thus, although the hand gestures used with the Pinch™ glove might be more natural in dealing with real objects in the world, the mouse could, as a result of past experience, be more natural for dealing with computer data. Providing training in the use of the Pinch™ glove and allowing participants to become accustomed to seeing computer graphics in 3D with the CrystalEYES® before actually using VEMECS would lead to the development of schemata for using the devices and likely would reduce the amount of time required for participants to perform the tutorial and exercise associated with the VEMECS application.

The response to the "loosing track of time" question produced primarily neutral responses for both software applications. We had expected that because of the use of VR technology, the VEMECS participants would be very engrossed in the task of designing spherical mechanisms and, therefore, that they would become more immersed in the application. This was not the case and, in hindsight, makes sense because an environment in which the user stands outside and reaches in is not considered to be truly immersive (Pimentel & Teixeira, 1993). A truly immersive environment would provide a surrounding consisting only of the computer images and head tracking would allow the computer viewpoint to change to match the participant's viewpoint. In spite of the fact that VEMECS was not overly immersive, however, in response to the question asking which interface sparked more interest in spherical mechanism design, the VR interface was preferred.

CONCLUSIONS

The purpose of the study was to compare using a traditional human-computer interface to using a virtual reality human-computer interface for design of spherical mechanisms.

Barfield and Furness (1995) stated that in order for VR to be an effective tool, VR applications must enable the user to perform more efficiently and effectively than if they did not have the tool. VR application developers must convince industry that VR technology is an effective interface for interpreting and manipulating information for design, evaluation, and training before industry commits to using VR technology as part of the design process. The current research was part of this process. It compared designing spherical mechanisms with two applications, one that used a traditional interface and one that used a VR interface. In general, it took longer to complete the exercise with the VR interface, but the VR interface did appear to generate more interest among participants in spherical mechanisms. We had originally thought that except for the addition of VR capabilities through the use of the Pinch™ glove and CrysalEYES stereo glasses, the two applications were equivalent. The results indicated that participants preferred a traditional interface for interaction tasks and a VR interface for visual tasks, but the former preference may have reflected differences between the software in the complexity of how each task was implemented

The VR environment implemented in the current research was relatively simple. An environment in which the user stands outside and reaches, such as the VEMECS display on a wall mounted screen, is not considered fully immersive (Pimentel & Teixeira, 1993). Participants should be able to walk up to and around the mechanism as opposed to reaching in and pulling it closer to rotate it. Such an immersive environment should enhance both interaction and visualization of the virtual environment (e.g., Gilkey & Weisenberger, 1995) and would provide a more comprehensive test of the effectiveness of VR in the design of spherical mechanisms. The addition of haptic feedback (Fabiani, Burdea, Langrana, & Gomez, 1996) and head tracking (Barfield, Hendrix, & Bystrom, 1997) would be steps in that direction. For example, haptic feedback could enable users to feel the design sphere as they are placing a position point on the sphere. Head tracking could enable users to walk around and move into a more comfortable position for interacting with the design environment. Not only would head tracking provide users with improved interactivity, but instead of moving and manipulating objects into the desired position for seeing the design sphere and the mechanism, users could physically move into the desired position. Being able to move into a more comfortable position for interacting with the design sphere likely would reduce the arm fatigue experienced by several of the participants after using VEMECS. Of course, the improved VEMECS would need to be compared to an application that used traditional interfaces that was otherwise comparable to determine whether any differences in performance, either positive or negative, were due to the use of VR.

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