MOVEMENT PATTERNS OF DESIGN ENGINEER IN DESKTOP AND IMMERSIVE ENVIRONMENTS

Mădălina Ioana Toma 1, Florin Gîrbacia 1, Csaba Antonya 1

(I) : Transilvania University of Brasov
Bdul. Eroilor 29, 500036, Brasov, Romania
Phone: +40268472496
E-mail : {madalina-ioana.toma,garbacia,antonya}@unitbv.ro

Abstract: Computer Aided Design (CAD) systems have become today the basic tools used to design and develop products in the engineering industry. On current CAD software, most of the editing commands are issued with the aid of widgets and alphanumeric data input devices, while research community is proposing the use of virtual reality environments for CAD modeling. This paper presents an experimental study conducted to analyze the added value of direct spatial input compared to the usage of 2D traditional user interface for the design process of geometrical models. The results indicate, that in spite of the variety of interface devices in the virtual environment which offers the user with a natural interaction, the modeling time is the same or even lower compared with a traditional desktop interface. Furthermore, the multimodal interface presents a higher physical stress factor, the hand movement distance being on average 2.3 times greater than the desktop interface.

Key words: virtual reality, physical ergonomics, multimodal interface, movement pattern, CAD modeling.

1. Introduction

Current Computer Aided Design (CAD) systems offers extremely rich modeling features and function which increase the productivity of the new products design. While the geometrical database is 3D since long time, the user interaction within this software has not significantly changed. At present time CAD tools use standard WIMP (Window, Icon, Menu, Pointer) desktop-based graphical user interfaces (GUI), and the interaction is made through keyboard, mouse and CRT/LCD display which are solely 2D devices.

Virtual Reality (VR) provides new perspectives for user interaction with CAD tools. Many research activities are currently focused to integrate CAD architecture inside a VR system in order to enhance the immersion feeling and user interaction interface [B1], [RC1], [W1]. In many applications VR technologies are used only for visualization and analysis of previously created CAD models [JH1], [RC1], [RS1], [S1], [B3]. Another emerging category of VR design applications are the VR-CAD integrated systems, which allows to create, modify and manipulate 3D models directly in the VR environment [B1], [DF1], [DG1], [W1], [IC1], [SO1]. Despite of the intensive research activities, none of them produced yet a significant impact for the development of the next generation CAD systems. For this reason it is necessary to develop experimental research in order to evaluate the impact of Virtual Reality technologies in the design process, and analyze their advantages and shortcomings.

Virtual environments are usually accompanied by major changes in the workplace, so the ergonomics of the new workplace must be reevaluated. Moreover, virtual environments present new concerns about the physical ergonomics [BH1], [N1].

In this paper we present an experimental study conducted to analyze the added value of direct spatial input compared to usage of 2D traditional user interface for the design process of geometrical models.

2. Experiment description

In this study, we want to answer to the following research questions:
1. Is direct 3D input useful for the design engineers?
2. What is the performance of 2D devices and direct 3D input for creation of 3D CAD models?
3. What is the most intuitive and natural interface for 3D CAD parts modeling?

Thus, we have devised and conducted an experiment to measure and record the movement patterns of participants in the design process of a CAD model using two modeling ways. The former is the traditional desktop workspace with 2D input (keyboard and mouse) and output (computer screen) peripherals. The latter consists of a multimodal immersive interface of an integrated CAD-VR system with direct 3D input. The results from this experiment will allow us to answer the three research questions.
2.1. Experimental apparatus

2.1.1. Traditional desktop workspace

The traditional CAD workspace used in the experiment consists of a desktop 3GHz Intel Core 2 Duo workstation with a 22 inch LCD monitor, a standard keyboard and an optical mouse, running SolidWorks commercial CAD software [S2]. For the purpose of capturing the head and hands movement the subject head and arms are fitted with 14 infrared reflective markers that are tracked by the 12 cameras of an OptiTrack optical tracking system [N2].

2.1.2. VR multimodal interface

A multimodal interface based on Virtual Reality technologies [GR1] provides an alternative to the traditional interface that uses 2D display, keyboard and mouse. Various VR devices are used: a large scale multi wall projection system called HoloCAVE or visual output; an optical tracker system for spatial tracking of user position and orientation; data gloves for fingers gesture recognition and voice recognition for input commands (Figure 1). The above presented solution enables modeling of solid objects by combining advantages of the VR technologies with available well-established Solidworks 3D CAD software [S2]. The chosen approach is to keep current CAD functions implemented by the software vendor and augment them with a VR user interface for an intuitive and natural way of interaction.

![Figure 1: Modeling of a part in the immersive environment](image)

The software configuration (Figure 2) is designed as a distributed highly modular network based on the strict separation of its VR system management into three layers: a Multi User Server performs the administration of the 3D model data and the users connected in the system, a Virtual Environment Server coordinates local projections and navigation and VRSolid client provides the interface to the SolidWorks application and handles all the aspects of user interaction.

The VRSolid module retrieve and interpret command data from input devices, translate them in shape generation commands to Solidworks, retrieve model data from Solidworks, generate VRML files and sends them to the Holo-Cave visualization system. When the user creates an entity in the VR environment, the data is sent to the CAD solid modeler that executes the appropriate modeling command and via network the geometric and surface identification topological data is sent to the VR database. The result is the VRML file which contains all geometry information of the CAD models entities, discretized as triangle tessellations, and the topology structure stored as hierarchical relationships between parts, surfaces and tessellations. In this way each tessellation corresponds to only one surface and each surface corresponds to only one part. Each entity of the CAD model is treated as an individual object and has a unique identity that corresponds with the entity name from the CAD database.

The multimodal interface provides functions for creation of solids primitives (box, cone, cylinder, and sphere), extruding 2D closed profiles created previous and revolving a 2D profile around an axis.

![Figure 2: Experiments set-up](image)

The proposed configuration software is capable to display synchronized passive stereo 3D images on the multi-wall display environment and supports different VR devices. Each client holds the entire 3D scene, with only positions and perspectives being different. It also provides methods by which objects in virtual environment can be manipulated, added, or removed. The 3D representation is VRML2.0 (Virtual Reality Modeling Language) and the stereoscopic rendering of 3D models is done by BS Contact Stereo viewer [B2]. SolidWorks offers an API (Application Programming Interface) to create and access the CAD model data. The VR modules are implemented in C++ programming language.

2.1.3. Replacement of traditional WIMP interface

The conventional CAD systems use for generated CAD model visualization a traditional CRT/LCD 2D display. The disadvantage of this type of display for CAD systems it is the lack of depth cues. In order to overcome this disadvantage the multimodal interface employs for generated CAD models...
visualization a multipurpose large-scale multi-wall architecture, able to provide two modes for the 3D visualization: four side CAVE-like and Holobench functionality. Replacement of the 2D mouse in the VRCAD multimodal interface has been made by using lightweight Pinch Gloves tactile gloves, OptiTrack optical tracking system and voice commands. Keyboard is still used in the CAD conventional system for input of the alphanumeric data. In the VRSolid system this device has been replaced with voice commands. Voice commands are discrete words that are transmitted by the user through the use of a microphone. Microsoft Speech Recognition API was used for the implementation of voice commands.

2.2. Population
Eight volunteer participants (6 males, 2 females) from our department with a mean age of 23.7 participated in our experiment. They were all familiar with the commercial SolidWorks CAD systems, but none of them had previous experience with VR spatial devices and/or with multimodal interfaces. Before the test we allowed each participant to understand, familiarize and optimize the settings of voice command and 3D spatial input. The users had 30 minutes prior to the experiment, for practicing both interaction modalities for modeling of a 3D CAD model.

2.3. Experimental procedure
The experiment consists of modeling the simple part shown Figure 3, composed from two rectangle features, a cylinder and a blind pocket. The sample part was built on both traditional CAD system and multimodal immersive system.

![Figure 3: Sample part used in experiments](image)

In the first phase every subject modeled the 3D part using a traditional WIMP based commercial CAD. The modeling process can be break down in the eight major steps from Figure 4, which are repeated for each part’s feature.

In the second phase every user modeled the sample part using the above described multimodal interface in the following steps: the first box entity is created using the voice command “Rectangle” for activation of a 2D rectangle drawing feature. The 2D entity is draw according with the movements of the tracked hand. Insertion of control points is made by voice command “Enter” or by a finger gesture (touching one of the glove fingers). Then, the user extrudes the 2D sketch by using the voice command “Extrude”. After, the box is selected and the dimension is edited by moving the hand position or by specifying an alphanumeric value with the aid of “Number” vocal command followed by the specific digits and “Enter” vocal commands. The steps are repeated for the second box and cylinder feature.

![Figure 4: Modeling process in a desktop CAD application](image)

3. Results evaluation
For both interface we first analyzed the overall body posture, body member’s position and their movement pattern. For each subject we measured the drawing completion time, the hand movement distance and the number of modeling commands: mouse clicking and keyboard key pressing, and voice commands for the desktop and multimodal interface, respectively. The results values are presented in Table 1.

Body posture is essentially fixed in both cases, but while in the desktop workspace all the subjects were seated on a chair with the elbow resting on the chairs’ armrest, as in Figure 5, in the virtual environment case all subjects preferred to stay standing in front of the wall, even though a chair was available.

In the traditional desktop case the head movement was almost negligible, the eye movement being sufficient to cover the entire screen. Subjects in the Holo-CAVE presented a slightly larger head movement, but in total still within a few centimeters.

The difference in control paradigm between the two cases resulted in quite different hand movement patterns. In traditional desktop workspace the left arm was predominantly static with the hand resting over the keyboard, while the right hand holding the mouse presented the highest movement rate and distance. The movement pattern consist of translations [KE1], mostly in the xz plane, corresponding to moving the mouse or the hand above the keyboard, and
When using VR-aided CAD modeling system, all the subjects held their hands in front of their body, with the forearms perpendicular on the body. The movement was done from both the elbow joint and the hand joint, consisting of both translations and rotations of the hand. Compared with the traditional desktop workplace larger hand movement distances can be observed for the multimodal interface, according to Figure 7. For some subjects an increase in distance of 3 times was observed, while on average for this low complexity parts the increase in hand distance for the multimodal interface is 2.2 times. Figure 8 show that the command pattern is the same for both interfaces; the keyboard and mouse commands were simply replaced by voice commands.

The time consumed for modeling the part is about the same for both interfaces, slightly larger for the VR-based interface (Figure 9). However, considering the higher hand movement distance and the hardiness of operation for the multimodal interface we can state that for complex parts the completion time will be even higher than the desktop interface.

Conventional CAD interfaces use a 2D mouse and keyboard to activate commands from the menu, interact with the 3D object and navigation in the virtual environment. An evaluation questionnaire was given to the subjects at the end of the experiment. The questionnaire had twelve statements about specific aspects of interaction with CAD systems. The subjects had to express their level of agreement with each statement by choosing from the following ratings:

### Table 1: Experiment result values

<table>
<thead>
<tr>
<th>Subject</th>
<th>Time (seconds)</th>
<th>Distance (mm)</th>
<th>Commands</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Multimodal</td>
<td>Desktop</td>
<td>Mouse clicks</td>
</tr>
<tr>
<td>1</td>
<td>61</td>
<td>67</td>
<td>33</td>
</tr>
<tr>
<td>2</td>
<td>81</td>
<td>69</td>
<td>38</td>
</tr>
<tr>
<td>3</td>
<td>63</td>
<td>78</td>
<td>29</td>
</tr>
<tr>
<td>4</td>
<td>100</td>
<td>81</td>
<td>36</td>
</tr>
<tr>
<td>5</td>
<td>92</td>
<td>63</td>
<td>34</td>
</tr>
<tr>
<td>6</td>
<td>122</td>
<td>75</td>
<td>37</td>
</tr>
<tr>
<td>7</td>
<td>66</td>
<td>92</td>
<td>35</td>
</tr>
<tr>
<td>8</td>
<td>69</td>
<td>79</td>
<td>30</td>
</tr>
<tr>
<td>Average</td>
<td>81.75</td>
<td>75.50</td>
<td>34.00</td>
</tr>
</tbody>
</table>
completely agree, somehow agree, neutral, somehow disagree, and completely disagree. In comparison with the traditional CAD system the users appreciated the utilization of the VR multimodal interface as an interface for CAD database which offer an intuitive virtual environment where the user does not have to navigate through a series of windows and menus in order to achieve a desired action. The users appreciate also the possibility to use the voice commands and gestures which provide a natural way of giving commands. However, all subjects perceived the multimodal interface as more psychically demanding because of the wide variety of interaction ways. Overall, they had the feeling that they performed slower than by using a desktop workplace, as proven also by the completion time.

4. Conclusions

VR technologies represent very useful tools to visualize and interact with 3D models. Its integration within the product engineering applications represents the research challenge for the next future. In this paper a comparative study regarding modeling of 3D CAD models in multimodal VR interface and traditional desktop environment was presented. The advantages of immersive multimodal modeling compared with the traditional CAD interface are: better perception of the depth of the objects using immersive Holo-Cave visualization system, natural and intuitive interaction modalities by using of the voice recognition and gestures. But despite of these advantages this approach did not prove to be a powerful tool because it did not succeed to provide a considerable improvement to the operator efficiency and involves more physical movement of the hands.

Design and modeling using a VR based multimodal interface has advantages like the use of natural methods of interacting, use of real scale modeling, and real-time fully immersive and interactive visualization [DB1], [KL1], [L1]. However, our results show that for the creation of the sample part the traditional 2D desktop interface is still preferred over the multimodal VR-based interface. All the subjects completed the task in comparable time frames in both environments, but in the VR-based interface the hands movement was over a significant higher distance, and stressed more muscles than the traditional desktop interface. In the future work we will try to develop new improved VR-based interface by reducing the movement of the hand, but keeping the immersive feeling in the 3D environment.

5. Acknowledgments

The research described within this paper was supported through the Romanian National University Research Council CNCSIS – UEFISCSU, project number PNII – IDEI 608/2008 INCOGNITO.

References


