

Interactive 3D Modeling with Virtual Reality

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Abstract

The immersive Virtual Reality (VR) environment transforms the way people learn, work, and communicate. While the traditional modeling tools such as Blender and AutoCAD are commonly used for industrial design today, handling 3D objects on a two-dimensional screen with a keyboard and mouse is very challenging. In this work, we introduce a VR modeling system named The Virtual Workshop supporting the design and manipulation of various 3D objects in virtual environments. The proposed system was developed for the Oculus Rift platform allowing a user to efficiently and precisely design 3D objects using two hands directly. The friendly system GUI supports the user to create new 3D objects from scratch using premade “basic objects” or alternatively to import an existing 3D object made in other applications. Meanwhile, the finished 3D models are stored in the standard OBJ file format and exported later for the development of 3D scenarios in other applications such as the Unity engine. From concept to design, the VR modeling system provides an open platform where the designers and the clients can better share their ideas as well as interactively refine the rendered virtual models in collaboration.

Introduction

As the Fourth Industrial Revolution (also referred to as industry 4.0) is around the corner, Virtual Reality (VR) has been attracting more and more attention from both academia and industry over the last decade. The development of head-mounted display (HMD) system and the 5th generation (5G) mobile network make many VR applications to be accessible for normal users. While many people simply associate VR with gaming and entertainment in our homes, this emerging technology has rapidly become the mainstream use in many workplaces for almost all world industries. More recently, the release of the Oculus Rift and the HTC Vive, two high-end HMD headset systems, have finally made the immersive VR experience to be within the reach of general public. The immersive VR environment transforms the way people learn, work, and communicate. VR technology can be a tremendous asset in many contexts such as entertainment, education and training, healthcare, as well as industrial design.

Although the traditional modeling tools such as Blender and AutoCAD are commonly used for industrial design today, handling 3D objects on a two-dimensional screen with a keyboard and mouse is very challenging. Moreover, these applications are difficult to provide the designers with the precise vision of the object that is being created. In contrast, users are not restricted by the two-dimensional interface and design tools in a VR environment. It is very convenient to adjust a 3D object to its actual size and examine it as one would in a real world. For example, a landscaper can use VR technologies to plan and polish the structures and pathways for a client’s future garden. The virtual landscape

model enables the client to explore different scene concepts and determine if the details are truly acceptable before the landscape project is constructed.

In this work, we introduce a novel VR modeling system named *The Virtual Workshop* supporting the design of various 3D objects in virtual environments. The proposed system was developed for the Oculus Rift platform allowing a user to efficiently and precisely design and manipulate 3D objects using two hands directly. More specifically, the application places a user in a selected virtual workshop with multiple room options. The communication between the user and the VR system is conducted through a convenient system control panel, which is near the user at all times. Using the Oculus Rift, the user operates available modeling tools (position, scale, rotation, material, etc.) located on the control panel to build various 3D geometries with its texture rendered in the workshop room. In addition, the system has an interactive Graphical User Interface (GUI) featuring the import/export option and the premade “basic objects” such as cube, sphere, cone, and cylinder. The system GUI supports the user to import existing 3D models or to create new 3D objects directly from premade “basic objects”. Meanwhile the finished virtual objects are exported from the Virtual Workshop system as commonly used 3D model file formats such as OBJ. These 3D models can be used later for the development of 3D scenarios in other applications such as the Unity engine. Alternatively, those 3D models extracted from other applications can be loaded into our Virtual Workshop system for further manipulations.

The proposed 3D VR modeling system was evaluated from two perspectives. We examined the system performance qualitatively based on the model rendering quality and then quantitatively based on the model rendering time over a dataset of 3D objects of various complexity and materials. These material samples were collected from a third party material library website. Experimental results demonstrate the proposed system is capable of visualizing the 3D modeling process efficiently in virtual environments where the user can interactively import, create, model, and export 3D objects. From concept to design, the VR modeling system has the potential to provide an open platform where the designers and the clients can better share their ideas as well as interactively refine the rendered virtual models in collaboration.

Related Work

Virtual Reality (VR) was first launched more than half a century ago when a head-mounted three-dimensional display system was introduced in 1968 [1]. However, the application of this technology was highly debated due to the limited functionalities for HMD devices and the lack of free movement for users [2]. Thanks to the rapid advance of computing technology in the 1990s, the adoption of Cave Automatic Virtual Environment (CAVE) sys-

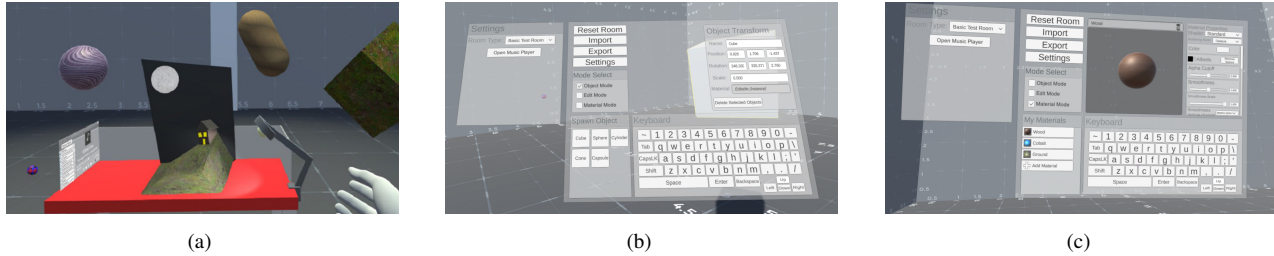


Figure 1. The Graphical User Interface (GUI) of the proposed The Virtual Workshop system: (a) A user modeling a 3D object in a studio room with an office desk at the center and multiple completed 3D objects in the background, (b) The layout of the system control panel in Object Mode, (c) The layout of the system control panel in Material Mode.

tem [3] and desktop VR with stereo glasses helped to provide a more interactive and immersive three-dimensional visualization [4]. The beginning of this century has seen the VR technology reached a sufficient level of maturity due to the reduction in both software and hardware costs [5], though the expansion of its application range was still restricted to the experimental environment.

More recently, the release of many state-of-the-art HMD headset systems has provided users immersive 3D experiences with improved ergonomics and significantly lowered costs. Consequently, aside from applications in directly relevant areas such as gaming and entertainment, VR technology is now extensively spread to educational [6, 7], medical [8], and industrial design [9, 10, 11] fields. Over the years, industrial practitioners have already recognized many limitations for modeling 3D objects on a two-dimensional computer screen. Fortunately, the VR technology provides a more convenient and precise solution for users to manipulate a 3D object to its actual size in virtual environments [12].

Methods

Today, VR has truly become one of the key technologies shaping the future of the industrial design and engineering [13, 14]. Meanwhile, high quality and low-cost HMD systems bring us immersive 3D experiences in virtual environments. However, unlike traditional CAD tools specifically designed for the purpose of industrial design, most portable HMD systems such as the Oculus Rift are highly optimized for consumer gaming and entertainment. Accordingly, the main challenge for many industrial practitioners is how to perform high standard 3D modeling using these new HMD devices.

Aiming to address the requirement of efficient and precise 3D modeling of industrial products, we introduce in this work a novel 3D VR modeling system named *The Virtual Workshop* supporting the design of 3D objects with different model shapes and material features in virtual environments. The VR system was developed for the Oculus Rift platform where a user is able to interactively and precisely develop 3D objects using his or her two hands. The VR system also provides the function to import previously made 3D objects and to export the completed 3D objects in the standard OBJ file format. More specifically, those 3D objects modeled in our VR system can be used later for creating 3D scenarios in other applications such as the Unity engine. Meanwhile, those 3D objects extracted from other applications can be loaded into the proposed VR modeling system for further manipulations.

The basic equipment for using this system should include a computer and a HMD system such as the Oculus Rift. A user

can perform various modeling operations for 3D objects using the HMD system connected to the computer. For example, through the Oculus Rift, the user can interact with the program using the Oculus Touch controllers. The main GUI between the user and the VR environment is a system control panel as shown in Figure 1. The user works on different modeling tasks by choosing different operation modes configured on the system control panel, which can be operated with the help of the Oculus Touch controllers.

The Virtual Workshop modeling system consists of three basic functional components: (a). An *Object Mode* performs 3D object creation. The system allows users to create a 3D object from scratch using premade “basic objects” or alternatively to import an existing 3D object made in other applications; (b). An *Edit Mode* performs geometric manipulation of the created 3D objects; (c). A *Material Mode* adds additional material features such as color, texture, and lighting for the edited 3D objects. Users can preview the selected material features on the control panel and apply these features to the selected objects later. Shown in Figure 2 is the high-level logic overview of the described 3D VR modeling system.

Object Mode

Figure 1 demonstrates the GUI of the proposed system. The main control panel is attached to the left hand of the user and can be disabled using the start button of the HMD controller. The panel b of Figure 1 shows the layout of the control panel when the system operates in *Object Mode*. When the proposed VR system first starts, this panel displays no information since no object is available for selection. However, the user is able to start a new project conveniently using premade “basic objects” supported by the system such as cube, sphere, cone, and cylinder. For example, a cylinder could be used to create a cup while a cube could be used to create a table. To place a new object at an accurate location of the virtual workshop room, we designed a special item called *3D Cursor* to indicate the position of the newly created object. This special item cannot be deleted or edited, but can be moved around the room so the user can control where the new object is spawned in.

When operating in object mode, the VR system allows a user to select a single or multiple 3D objects physically by hand with the help of a HMD controller. Meanwhile, the system control panel displays the current position, rotation, scale, material, and name of the most recently selected object. As the user moves the object around the workshop room, the above object property information changes accordingly. On the other hand, the user can modify the space position, rotation angle, and relative size of the

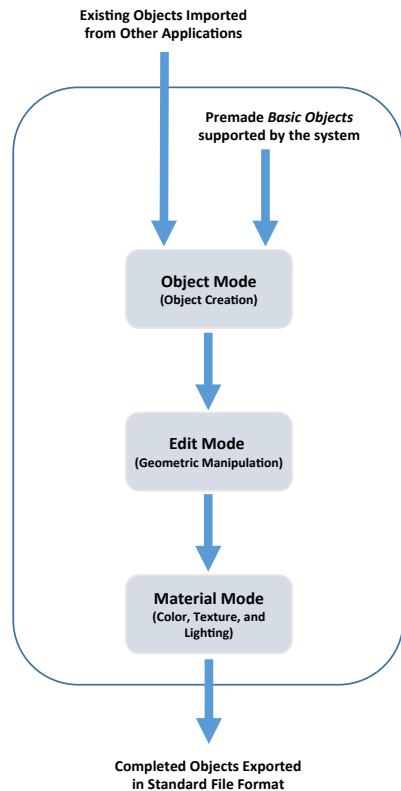


Figure 2. The overview of the proposed 3D VR modeling system: In Object Mode, the system allows a user to create a 3D object from scratch using premade “basic objects” or alternatively to import an existing 3D object made in other applications. In Edit Mode, the user can further perform various geometric manipulations of the created 3D objects. Finally, in Material Mode, additional material features such as color, texture, and lighting can be added for the edited 3D objects. Since all 3D models are stored in the standard OBJ file format, the completed 3D models can be exported and used for the development of 3D scenarios in other applications.

selected object by updating the above information using the system control panel.

Edit Mode

Upon the creation or the import of a 3D object, the VR system can be switched to operate in *Edit Mode*. Note that edit mode can only be activated when at least one object is selected. If multiple objects are selected, only the most recently selected object, where the edges are highlighted in yellow color, can be edited. After switching to edit mode, blue handles are placed over every vertices of the selected object. As shown in Figure 3, these handles are convenient for the user to perform further geometric manipulations for the selected 3D object. When the shape modeling is completed, the system can be switched back to *Object Mode* for precise adjustment on position, rotation, or scale for the selected object. Any geometric changes applied to the object retain during the switching process between different system operation modes.

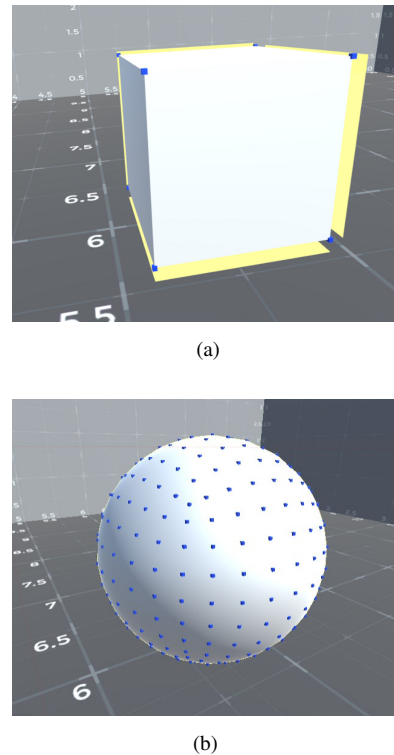


Figure 3. Two samples of 3D object with editing handles when the proposed system operates in Edit Mode: (a) A selected cube object with handles highlighted in blue color, and (b) A normal sphere object with handles highlighted in blue color.

Material Mode

The final stage of the 3D object modeling is applying additional material features. This process is conducted when the VR system operates in *Material Mode*. In this mode, the user can apply material features such as color, texture, and lighting to a target 3D object. As shown in the panel c of Figure 1, a list of the available materials will be displayed along with an “Add Material” option at the bottom. At first, there are no materials to select as the user has not created any upon first using material mode. Once “Add Material” is selected, a default material is applied to a sphere object which is further displayed in a preview window. A “Shader” menu associated with the selected material is located to the right of the preview window. The user may adjust the material properties such as color and lighting using the “Shader” menu. When the user intends to apply a material to a 3D object, he or she may grab the sphere representing the material in the preview panel and release it onto the object. Materials can be deleted from the list, which will cause any objects containing that material to revert back to the default material. Finally, all imported objects have their materials displayed on the material list automatically.

Import/Export and System Settings

The proposed VR system also features the *Import/Export* option. When “Import” option is selected on the control panel, the GUI opens the local file directory containing all available 3D objects stored in the standard OBJ file format. When the user select one of these OBJ files, it is spawned in at a preset location indi-

cated by the *3D Cursor* discussed earlier in this section. On the other hand, completed 3D objects can be exported in the standard OBJ format when the “Export” option is selected. In addition, previously exported objects can be imported back into the VR system using the “Import” option. All 3D objects modeled with our VR system can be used later for the development of 3D scenarios in other applications

Finally, the *System Settings* option allows the user to choose different types of workshop room. The default room is “Basic Test Room”. If the user prefers to model 3D objects of standard size in a traditional workshop studio environment, “Office Desk” room is a good choice. Alternatively, if the 3D objects to be manipulated are very large, “Void Space” room however is more appropriate.

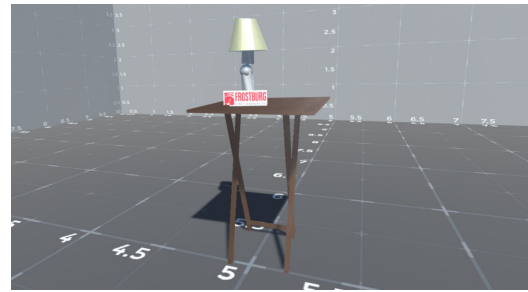
Results

The proposed 3D VR modeling system was written in Microsoft’s C# language using the Unity engine [15]. We developed the proposed system for the Oculus Rift platform supported by Windows 10(X64) operating system. Key bindings support the Oculus Touch controllers and cannot be reconfigured at this time. Programming was performed using Microsoft Visual Studio 2019 within the IntelliJ Idea Development Environment. The VR system is executed on a common Lenovo Legion Y520 laptop which has an Intel Core i7-7700HQ processor running at 2.8 GHz with 16GB of memory. Graphics API is DX10, DX11, and DX12 capable. The application uses about 30% CPU, 29% GPU, and 70% system memory while processing multiple high vertex polygon models.

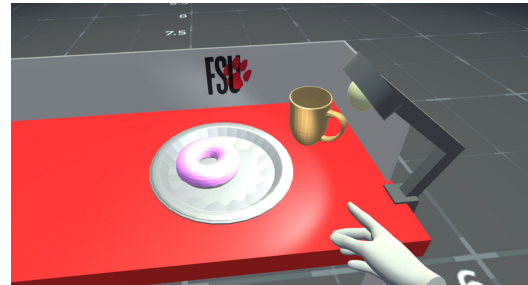
We first qualitatively evaluate the performance of the VR modeling system by allowing users to create 3D objects directly by two hands on the platform of the Oculus Rift. As shown in Figure 4, college students can use the system to create and edit a variety of virtual scenarios with 3D objects of distinct shapes and materials. These 3D models can be stored in the standard OBJ file format and further be used for building 3D scenarios in other applications.

With default system settings, we further evaluate the quantitative performance of our system on *Model Rendering Time* for 3D objects with different complexities represented by the number of vertices. The model rendering time measures the average amount of time required for one single 3D model to be graphically rendered. As shown in Figure 5, the complexity of 3D objects such as the sphere object in the figure is modeled with different number of vertices. The 3D sphere models used in the experiments are constructed with 12 vertices, 42 vertices, 162 vertices, 642 vertices, and 2562 vertices, respectively. The model rendering performance of the proposed system was also examined by rendering the surface of 3D objects covered by various types of texture with different resolutions. We obtained these textures from a third party online material library Poliigon [16]. The textures used for the experiment include dirt, metal, root, rope, wood, as well as no texture. All of those selected textures were tested with 1K, 2K, 3K, and 4K resolutions, respectively.

As a comparison, we measure the model rendering time for 3D objects of different complexities and with different surface textures. Experimental results shown in Figure 6 demonstrate that the proposed system achieves very short rendering latency for the 3D objects with various types of texture. On average, the model rendering time for most 3D objects with normal complexity is less



(a)



(b)

Figure 4. Two sample virtual scenarios with multiple 3D objects created using the proposed VR modeling system: (a) A lamp on top of a small table, and (b) A light breakfast on top of a studio desk with a Frostburg State University Bobcats logo.

than 0.02 seconds. When the 3D object complexity represented by the number of vertices increases, the corresponding model rendering time increases as well. This observation also holds for 3D objects with no surface texture. Meanwhile, texture samples of higher resolution take more model rendering time than those samples of lower resolution. This is expected, as high quality texture samples require more computation time for the VR system. These results show that the proposed system is useful in fast and precise modeling of 3D objects in virtual environments.

Conclusions

Due to the maturity of both hardware and software, VR technology has seen significant growth and adoption since the original vision of *The Ultimate Display* [17] inspired by Ivan Sutherland more than half a century ago. Not only being used in the most predictable areas such as gaming and entertainment, VR technology is now also widely used in many fields of industrial design and engineering. However, traditional CAD modeling tools are difficult to handle 3D objects on a two-dimensional screen and to provide the designers with the precise vision of the object. Thanks to the contributions from both academia and industry, the booming of state-of-the-art HMD devices significantly enhances users the immersive 3D experiences with improved ergonomics and lowered costs. In this work, we introduce a novel VR system developed for the Oculus Rift platform aiming to support real-time 3D model design and rendering in virtual environments. First of all, the VR application allows a user to interact with it through a friendly GUI using the Oculus Touch controllers. The user can conveniently complete product design tasks via the main control panel with various modeling tools. Moreover, the VR modeling system op-

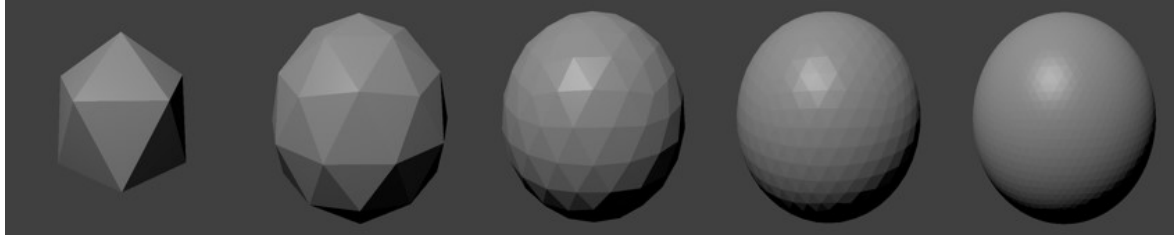


Figure 5. The complexity of 3D objects such as the sphere object shown above is modeled with different number of vertices (From left to right: 12 vertices, 42 vertices, 162 vertices, 642 vertices, and 2562 vertices, respectively).

erates in three related modes which can be easily switched back and forth: (a). In *Object Mode*, an user is allowed to create a 3D object from scratch using premade basic objects or alternatively to import an existing 3D object made in other applications; (b). In *Edit Mode*, the user performs geometric manipulation to adjust the physical shape of the created 3D objects; (c). In *Material Mode*, the user can apply additional material features such as color, texture, and lighting to the edited 3D objects. Finally, all 3D models are stored in the standard OBJ file format and can be easily exported to create 3D scenarios in other applications. The described VR modeling system is portable and user-friendly for industrial practitioners to enhance the experiences of 3D product design. Experimental results have demonstrated that the proposed system can support more accurate depiction and immersive creation of 3D models

Our 3D VR modeling system is still in a prototype state, but after further development and refinement we intend to perform user studies in order to assess the usability of the technique and guide further interaction design. In our preliminary experiments we have achieved promising performance in modeling 3D objects in virtual environments, but supporting more complex objects with very large number of vertices will likely require additional optimizations. Some potential extensions are achievable for the proposed system in the near future: (a). Build an UVmap editor allowing the user to determine how the material wraps its textures around an object; (b). Support direct edge and face selection in *Edit Mode* for more complicated operations such as extrude and subdivide; (c). Add a snap-drag feature for more precision in object movement by forcing an object to move along the X, Y, and Z axis while a certain button is held; (d). Save the current state of the workshop room and recreate it later for long projects that require multiple days of work; (e). Replace normal movement controls with the locomotion feature to improve usability and reduce motion sickness for users. We have already demonstrated the feasibility of the proposed system for rapid and precise 3D industrial modeling in virtual environments using portable and low-cost HMD devices. The ultimate goal of this VR modeling system is to provide an open platform where the designers and the clients can better share their ideas as well as interactively refine the rendered virtual models in collaboration.

Acknowledgments

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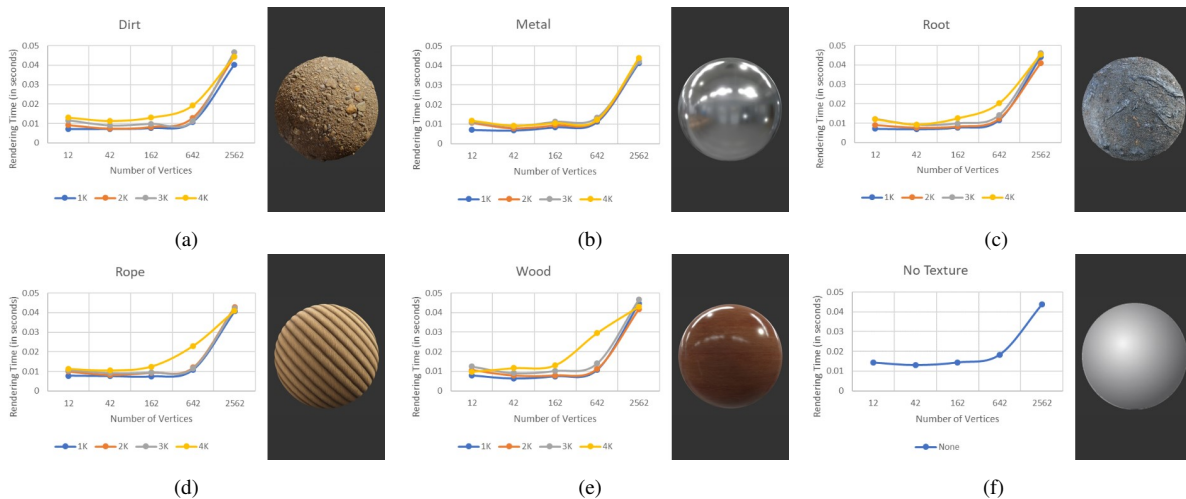


Figure 6. The Model Rendering Time comparison for 3D objects with different numbers of vertices using the proposed system: (a) Dirt texture of 1K, 2K, 3K and 4K resolutions; (b) Metal texture of 1K, 2K, 3K and 4K resolutions; (c) Root texture of 1K, 2K, 3K and 4K resolutions; (d) Rope texture of 1K, 2K, 3K and 4K resolutions; (e) Wood texture of 1K, 2K, 3K and 4K resolutions; (f) No texture.

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