A Light Weight Virtual Reality-based Simulation Platform for Operating Construction Equipment

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February 4, 2018

Abstract

Background/Objectives: As a main commodity ranking the fifth in the world, the industry is continuously growing. In addition, as the construction machinery industry is going through acceleration and continuous growth, the need for construction of educational environment that forms the basis of the industry has emerged.

Methods/Statistical analysis: This paper aims to study a simulator platform that can operate in a universal PC environment utilizing a virtual reality development tool without using existing high-priced exclusive simulation equipment.

Findings: By establishing analysis and development processes of virtual reality development tools that can reduce initial development costs, this study examined realistic
mechanical joint motion control of excavator work equipment, design and embodiment of an upper swinging body and a lower travelling body, virtual reality space embodiment of a realistic simulator, and a simulator platform using a joystick.

**Improvements/Applications:** Result of embodying the simulator platform including modeling, texturing, and graphical user interface (GUI) embodiment, the design period was shortened by about 50%.

**Key Words:** Platform, Simulator, Virtual Reality, Construction Equipment, Light Weight, Quest3D.

1 Introduction

A simulator is produced to operate in a similar way to an original system and embodies virtual reality giving effects to users as if using a real system, and the purposes of its use are diverse: for research, for education and training, and for entertainment. The industries where simulators are applied include medicine, aviation, port, construction, civil engineering, and military training; it is actively used in different areas. Among such areas, the construction and machinery industry is a high value added-industry and accounts for a large portion among production, export, and trade balance of the general machinery industry and in particular, excavators among construction machines have merits such as multi-functionality and economy, and as a result, are heavy equipment most frequently used. As a main commodity ranking the fifth in the world, the industry is continuously growing. In addition, as the construction machinery industry is going through acceleration and continuous growth, the need for construction of educational environment that forms the basis of the industry has emerged.

Nonetheless, its educational environment and marketing methods are very poor compared with the market size, and the need for education and marketing has recently increased centered on relevant manufacturers. At current, construction machinery education is provided by relevant educational institutions of construction machinery companies or private educational institutions but due to expensive equipment and high operation costs, inferior equipment and educational facilities are provided and education and post man-
agement of good quality is not being done. Moreover, the relevant educational institutions of construction machinery companies provide better environment to trainees than private educational institutions but their number is small and insufficient to accommodate trainees. Because of such environment, the quality of education is low and personal, time, and monetary damages are occurring resulting from failure to more promptly respond when a problem occurs in the sites.

In order to resolve such problems, development of a simulator platform utilizing virtual reality technologies is necessary. This paper aims to study a simulator platform that can operate in a universal PC environment utilizing a virtual reality development tool without using existing high-priced exclusive simulation equipment. In addition, by establishing analysis and development processes of virtual reality development tools that can reduce initial development costs, this study intends to examine realistic mechanical joint motion control of excavator work equipment, design and embodiment of an upper swinging body and a lower travelling body, virtual reality space embodiment of a realistic simulator, and a simulator platform using a joystick.

2 Analysis of a Virtual Reality Development Tool

There are currently Quest3D and Virtools as virtual reality development tools with high flexibility in development and they are equipped with awareness and commerciality. Besides, there are many other virtual reality development tools but in consideration of the characteristics of this paper, examination of Quest3D and Virtools is most appropriate. Table 1 compares basic specifications of Quest3D and Virtools\(^2\textsuperscript{a}\).

Table 1. Comparison of Virtual Reality Development Tools
2.1 Graphical User Interface (GUI)-based Node Programming

Quest3D and Virtools have components of channels and building blocks. Quest3D and Virtools perform programming of a node type connecting such components. Unlike existing game engines’ or virtual reality (VR) engines’ programming that directly types codes of texts, GUI-based channels and building block components with each behavioral characteristic are made into nodes with a tree structure, thereby providing functions. Therefore, applications are developed in the form of visual nodes of logical structure and process of each project. Quest3D and Virtools have numerous components with each behavioral characteristic and if necessary, components are developed and used utilizing a software development kit.

2.2 Real-time rendering

Real-time rendering is ordinarily called a game engine or a rendering engine. It refers to outputting and exhibiting three-dimensional object such as surface properties of cameras and objects on a real-time basis under the given light source condition of three-dimensional environment by utilizing the functions of graphic accelerators with three-dimensional graphic library such as DirectX or OpenGL. Quest3D and Virtools are such real-time rendering methods, and further, by applying components without the compilation process of the
program composed to perform rendering of objects, intuitive real-
time rendering is made possible in the viewport. In addition, in
the object and post processing process, application of shader ef-
tects and shadow effects is reflected on a real-time basis. Because
of the predictability of the results, debugging time may be reduced.

2.3 Expansion platform
Quest3D is largely used for simulation and construction VR, and
Virtools are mainly used in the game area. As mentioned earlier,
Virtools is highly dependent on VSL script and as a result, ex-
hibits more flexibility in programming than Quest3D and may be
implanted into the Xbox360, PSP, or Nintendo Wii platforms. Cur-
rently, Quest3D provides only components that can utilize Nintendo
Wii controllers.

2.4 Weather System and Water Effect
Quest3D provides a template called Weather System. A template
is a superordinate concept of channels and a component where
channels customized in order to represent the weather environment
are node- programmed. By providing parameters that can con-
trol weather conditions suitable for the virtual reality embodied,
an environment like the reality may be embodied. Virtools does
not provide such template and its programming by a programmer
is done.

Water effect reflects light and the ambient environment on a
real-time basis and controls parameters, thereby being able to ex-
press diverse waves. Quest3D and Virtools provide water-effect
shader, and Quest3D’s effects is more realistic.

2.5 Contents Distribution and License Cost
Quest3D and Virtools may be distributed in the form of execution
file (EXE), installer, and web pages according to usage. Nonethe-
less, in the case of Virtools, there is license cost according to dis-
tribution forms in addition to license cost and additional package
cost, and when its publishing is made with execution files and in-
stallers, plug in should be separately purchased. The license cost of
a development software of Virtools is more than twice as costly as that of Quest3D but in the case of Quest3D, there is no additional cost once the license of the software is purchased.

In this paper, Quest3D was used after comparing their virtual reality development tools. The reason for utilizing Quest3D is that it is a low-cost type compared with Virtools and has functions and flexibility necessary to develop an excavator simulator.

3 Design of a simulator platform for an excavator

3.1 The structure of the excavator

As shown in Figure 1, the structure of the excavator is divided into three parts: work equipment, an upper swinging body, and a lower travelling body. The work equipment refers to equipment practically performing work and is composed of links among three joints—boom, arm, and bucket.

![Fig. 1. The Structure and Part Names of the Excavator](image-link)

Although it varies according to the weight and size of excavator equipment, the model in this paper has two boom cylinders, one arm cylinder, and one bucket cylinder and work equipment is operated through oil pressure.

The boom not only plays the role of connecting the bucket to the upper rotating body but also makes the excavating force greatest when the angle with the arm is 90 to 110 degrees during excavation work. The bucket is composed of four-joint links where the
guide link and the push link are connected in order to obtain a large working range. In addition, in order to heighten excavating power, the tooth is installed. The manipulation method of the work equipment is shown in Table 2.

Table 2. The Manipulation Method of Work Equipment’s Lever

<table>
<thead>
<tr>
<th></th>
<th>Left Lever</th>
<th>Right Lever</th>
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</thead>
<tbody>
<tr>
<td>Forward Movement</td>
<td>Spreading of the arm</td>
<td>Lowering of the boom</td>
</tr>
<tr>
<td>Backward Movement</td>
<td>Pulling of the arm</td>
<td>Lifting of the boom</td>
</tr>
<tr>
<td>Movement in the Left Side</td>
<td>Left rotating of the rotational body</td>
<td>Pulling of the bucket</td>
</tr>
<tr>
<td>Movement in the Right</td>
<td>Right rotating of the rotating body</td>
<td>Spreading of the bucket</td>
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</tbody>
</table>

3.2 Design of a Simulator Platform

As shown in Figure 2, when the excavator simulator is executed, CGR group is preferentially loaded. CGR is an extension used in Quest3D and stored, grouped, and managed in the form of CGR file. When the necessary loading of CGR object is complete, the main program is executed right away and then the simulator may be used. At this time, object view or driving experience may be selectively performed. Object view provides information on parts of the excavator to users and enables rotating and viewing of the detailed appearance of the parts using a mouse. Driving experience enables manipulation of the excavator from the first person angle or diverse angles against the three-dimensional construction site6,7,8.

Figure 3 defines the detailed structure of CGR group and the excavator simulator is composed of a user interface, graphic process,
and excavator control process modules. It has a detailed structure of individual independent type and is integrally managed by the main program. Such group developed in this module form may be executed independently, may be easily implanted in other projects, and has high efficiency in the development stage and in the maintenance and repair dimension.

Fig. 3. The Detailed Structure of the CGR Group Loading

At this time, if components required to implement the function occur, channels are developed by using SDK or if the shading effect is necessary, shader is applied by using FX composer. The process of modeling is shown in Figure 4. The design is roughly divided into Boom, Arm and Bucket. The design should be done in detail by splitting so that each part can move organically in the programming step.
4 Embodiment of an Excavator Simulator

4.1 Embodiment of an Upper Swinging Body

Figure 5 represents the upper swinging body imported to Quest3D, and a cockpit, an engine cover, an engine, a center joint, and the outer form of the upper swinging body are imported.
Animation of the TCB method was applied to the engine so that the piston and the accessory gears performed repetitive motion. A reflection map was applied to the glass plane of the cockpit in order to apply a sense of reality and the upper swinging body was able to rotate 360 degrees from side to side and a camera of the first person angle was installed. The camera was installed within the cockpit and the data on locations was set to be affected by the movement of the upper swinging body by referring to the upper swinging body’s motion data.

4.2 Embodiment of The Lower travelling Body

As shown in Figure 6, physical engine channels necessary for travelling exist and are applied to each wheel object. The wheel objects are linked to each travelling physical engine and are influenced by movement of physical engines.
The physical object is linked to the object to be operated, and as shown in the input channels of backward, left, and right in the lower left side of the figure, numeric data calculated using numerical formulas on speed and rotation is delivered to the physical channel linked according to the input of forward, backward, left, and right. A or B receives input signals from the channel of \((A-B)*C*TC\). Each A or B receives the value of zero or one. C controls the speed through the value. TC refers to tick counter, and sometimes calculation is performed more swiftly in a computer with high system specifications and TC is used to prevent this and maintain the speed at 1/25 second. ODE Car Movement physical channel controls speed and ODE Car Steering controls rotation of the vehicle.

4.3 Embodiment of Work Equipment

The work equipment and upper swinging body operate according to the manipulation of the joy stick. Figure 7 shows bucket operation. The top-level channel represents the bucket and the objects of push link and guide link connected to the bucket. Movement is controlled through Motion, lower channel of Bucket, the last object channel.
Limit Value, which is the core part of embodying the lowest work equipment, is referred to. The Limit Value channel receives input of analogue form and input of spreading and pulling bucket. These inputs influence the Rotation data of the upper Motion channel in the direction of Y axis. The range of motion of the bucket is restricted using the Envelop channel so that when the range is exceeded, motion does not occur. The push link and the guide link were established to change together with absolute location data by referring to Motion data of the bucket and Limit Value channel. The movement of bucket cylinder represents not linear location data but nonlinear location data.

Fig. 7. Bucket Operation Embodying Channel Tree

The arm was programmed in the same way as that of bucket movement and link was established so as to refer to Motion data of the boom according to the hierarchical structure of the work equipment. The arm was programmed in the same way as that of bucket movement and link was established so as to refer to Motion data of the boom according to the hierarchical structure of the work equipment.

Fig. 8. Arm Operation Embodying Channel Tree
Figure 8 refers to operation embodiment of the arm. The left object channel refers to the arm and the right one is arm cylinder. The two objects consult Motion data of the boom and operates by receiving input data of the joy stick through Limit Value of the arm object channel.

![Channel Tree](image)

Fig. 9. Boom’s Operation Embodying Channel Tree

Figure 9 refers to channel tree embodying boom operation. The left one is boom object and the right one is boom cylinder. Operation is made according to the input of joy stick through Limit Value of boom object and the boom cylinder is controlled by referring to Limit Value linked to the boom object. Here, the nonlinear movement of the cylinder utilized Envelop channels, and shows the motion curve in the left graph.

### 4.4 Multiple Camera

The multiple camera was embodied so that when the button was pressed, the point of view of the screen changed. This is a secondary function to see how the work is done while experiencing excavation work using the simulator. As shown in Figure 10, it was embodied so that the camera linked to the excavator was converted through the channel switch. The value channel in the left side of the channel switch changes from value zero to four according to button selection and accordingly, a camera is selected.
5 Conclusion

This paper embodied an excavator simulator using Quest3D, a virtual reality development tool. The study focus was on realistic expression of the excavator simulator’s mechanical movements and the shortening of development time enabling increase in graphic quality and the lowering of development cost. The simulator of this paper exhibited higher graphic quality than those studied domestically and embodied realistic movement of mechanical joints. In addition, in order to heighten educational effect of repair on detailed parts of an excavator, object view was applied to the simulator, thereby additionally embodying functions that can provide detailed information on parts and heighten understanding of parts.

In addition, the embodied simulator did not use equipment of high specifications and price and may operate under an environment of PC for individuals. According to the result of embodying a simulator platform such as modeling, texturing, and GUI, the design period was shortened by about 50 percent. The simulator platform embodied in this paper enabled interaction with a user through
three-dimensional real-time imaging and therefore has high educational effect. Expected effects include increase in work efficiency, cost saving during education and training, and prevention against safety accidents in actual operation of construction machinery.

The currently embodied excavator simulator focused on embodying mechanical movements of the excavator work equipment, the swinging function of the upper swinging body, and the travelling function of the lower travelling body. Future researches including interaction between the bucket of the work equipment and the ground, and replacement of work equipment and operation embodiment for different types of work are necessary.

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