Development of excavator training simulator using leap motion controller

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Abstract—Excavator is a heavy machinery that is used for many industries purposes. Controlling the excavator is not easy. Its operator has to be trained well in many skills to make sure it is safe, effective, and efficient while using the excavator. In this research, we proposed a virtual reality excavator simulator supported by a device called Leap Motion Controller that supports finger and hand motions as an input. This prototype will be developed than in the virtual reality environment to give a more real sensing to the user.

1. Introduction

Excavators are heavy equipment commonly used for excavation and flattening operations, material control, heavy lifting, and demolition work in the industry ranging from construction and forestry to agriculture and mining [1,2]. As one of a variety of heavy equipment, the use of excavators is not easy. Excavator operators must be adequately trained in a variety of capabilities to ensure safe, effective and efficient use of the equipment [1].

Excavator as heavy machinery is used for many industries purposes. Controlling the excavator is not easy. Its operator has to be trained well in many skills to make sure it is safe, effective, and efficient during using the excavator [1]. In this research, the author proposed a virtual reality excavator simulator supported by a device called Leap Motion Controller that supports finger and hand motions as an input.

Leap Motion Controller can improve the human and computer interaction [2,3]. By using this device, hands and fingers motions will be used to interact with the joystick and the lever inside the virtual simulator. The lever in front is used for moving the excavator forward and backward. And the joystick on the right side for boom and bucket, meanwhile the left joystick for arm and swing the upper body. These movements are based on SAE Controls.

Leap Motion Controller is a computer hardware sensor tool that supports hand and finger movements as input, which can be equated with functions like a mouse, but does not require direct contact with the hands or touch. Leap Motion Controller is a small, Universal Serial Bus (USB) peripheral device designed to be placed on a physical desktop, facing up. Using two monochromatic IR cameras and three infrared LEDs, the tool observes a surface resembling a hemisphere on top with a range of about 1 meter.
Leap Motion Controller can enhance human interaction with computers [3,4]. Leap Motion Controller is designed to track hand and finger movements. At the time the system is run, the user can perform various activities with hand gestures. This hand movement is observed by sensors in the Leap Motion Controller as inputs to perform various things that can trigger the occurrence of events in the program. In the simulated excavator, this hand movement will directly come into contact with the excavator control which is a three-dimensional model.

The use of excavators requires learning in advance to understand the functions of excavator control [5,6]. Various methods of teaching the use of excavators can be done to facilitate the learning process, one of them by using simulation [7]. Therefore, simulation with hand gesture reading system is needed as an option of learning method that can help learning the use of an excavator. The purpose of this research is the use of Leap Motion Controller as a tool for system simulation system learning use excavator.

2. Material and methods
In order to develop the excavator learning system with LMC, we deploy a method that utilizes hand gestures and finger movement in controlling the visualization of a specific excavator machinery. The hand gesture is a static or dynamic motion that is used as a communication tool between human and machine or among human that using sign language [6].

By monitoring the changes of space coordinate of hand palms and each segment of a finger, the system will execute specific action affecting the 3D visualization of excavator machinery, including showing the affecting part of the machine.

The system was based on the input of the hand and finger tracking data provided by LMC. A 3D object is displayed following the hand movement, whether the direction is right or left, or up and down. The changes of the object orientation due to motions of hand and gesture are immediately shown in real time on the screen.

Every movement will be represented by a hand animation on the user interface. Each specific hand gesture triggers a specific response in the system. For example, the left-hand gesture can control the camera. And right-hand gesture can show the labels /name of excavator object. Labels of each excavator objects are the outputs of this system. The architecture of the developed system is shown in Figure 1.

A. Three Dimensional Excavator Objects
A 3D excavator objects are used and will be displayed for the first time when user open the application. The 3D excavator objects are basically a file containing 3D models with the extension of *.obj. We developed 3D excavator objects created by specific software.

B. Leap Motion Controller (LMC)
Leap Motion Controller (www.leapmotion.com) can potentially revolutionize the human-computer interactions [7]. With two IR monochromatic camera and three LED infrared, this device tracks a hemisphere surface above it within a 1-meter radius.

Basically, LMC can detect hand motion and image as a whole, ignoring the detailed parts of the hand like finger joints and knuckles. Nowadays, LMC is capable of observing some detailed characteristic parts of the hand like knuckles, right or left, hand grabbing factor, etc. This development is called V2Tracking. The new version of LMC was used in this study.

C. Motion Tracking
Motion tracking process translated hand and finger motion as main input. These data are collected and processed by a specific part called Unity engine. Some of the possible inputs we developed in this system are described in detail in Figure 2.

The series of steps used starting from the input data in the form of observations of hand and finger movements by Leap Motion Controller. A three-dimensional object will be displayed following hand movements, be it right-handed, left-handed, or both. All hand gestures will be displayed as lightly as
possible in the user interface. When the hand of usage comes into contact with the control joystick inside the system, the excavator moves according to its function. The input of this system is a hand gesture that is read by Leap Motion Controller. The process in this system is the display of three-dimensional.

![Diagram](image)

**Figure 1.** Proposed general architecture

Joystick model that when driven by a three-dimensional hand model will move the excavator in accordance with its function. The output of the system is the movement of the excavator in accordance with the control system.

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1. Palm Position: (124.5348, 197.2908, 147.022)
   UnityEngine::Debug::Log(Object)
2. Hand Movement: (-0.2135353, 0.2036763, -0.5434446)
   UnityEngine::Debug::Log(Object)
3. Palm Position: (-137.0937, 220.7324, 146.0896)
   UnityEngine::Debug::Log(Object)
4. Rotating to: 2.96177
   UnityEngine::Debug::Log(Object)
5. Rotating counterclockwise
   UnityEngine::Debug::Log(Object)
6. Rotating to: 2.858897
   UnityEngine::Debug::Log(Object)
7. Rotating counterclockwise
   UnityEngine::Debug::Log(Object)
8. Rotating to: 2.778276
   UnityEngine::Debug::Log(Object)
9. Rotating counterclockwise
   UnityEngine::Debug::Log(Object)
10. Hand Movement: (-0.3014786, 0.1170927, -0.5710481)
    UnityEngine::Debug::Log(Object)
11. Palm Position: (-138.0211, 221.0192, 145.2878)
    UnityEngine::Debug::Log(Object)
12. Rotating to: 0.203953
    UnityEngine::Debug::Log(Object)
13. Rotating clockwise
    UnityEngine::Debug::Log(Object)
```

**Figure 2.** Hand and finger tracking data in Unity engine
These motion tracking data are being examined by the system, whether it is a specific gesture or simply general hand movement. In general, hand gestures corresponding to specific responses, that we use as the control of navigation system can be categorized as below:

D. Levers and joysticks movement as a trigger for moving the excavator.
1. Lever movement to move the excavator forward and backward.
2. Joystick movement to rotate the boom, arm, bucket, and upper body of the excavator.

The lever movement is used to determine the speed and the turn value of the excavator as shown in the equation (1) and equation (2).

\[ x = (L_1 + L_2) \times C \]  \hspace{1cm} (1)

\[ \alpha = (L_1 - L_2) \times C \]  \hspace{1cm} (2)

Which \( x \) is translation value of the excavator and \( \alpha \) is rotation value of the excavator. \( L_1 \) is the left lever rotation value and \( L_2 \) is the right lever. \( C \) is a constant value for the translation speed and rotation speed. When only the right lever is rotated forward by the virtual hand movement, the excavator will be moving forward and turn to the left simultaneously. And if it is the left lever, the excavator will be moving forward and turn to the right simultaneously. If both levers are rotated forward, the excavator will be moving straight forward.

Meanwhile, to rotate the boom, arm, bucket, and upper body of the excavator, equation (3) is used.

\[ \theta_t = \theta_0 - \beta \times C \]  \hspace{1cm} (3)

The function rotation of the left and right joysticks is determined by the axis the rotation. The left and right joysticks can only move is x and z-axis. There are 4 functions can be done by rotating the joystick in x and z-axis.

a) The arm rotation is determined by the rotation of the left joystick in the x-axis.
b) The upper body rotation is determined by the rotation of the left joystick in the z-axis.
c) The boom rotation is determined by the rotation of the right joystick in the x-axis.
d) The bucket rotation is determined by the rotation of the right joystick in the z-axis.

The equation (3) shows that \( \theta_t \) is the final value of the angle of the part of the excavator (either arm, upper body, boom, or bucket) and \( \theta_0 \) is the initial value of the angle. Meanwhile \( \beta \) is value of the angle of each joystick in each corresponding axis and, \( C \) is constant value for speed.

![Figure 3. Parts of the excavator](image-url)
3. Results
The result of this research reached a point where the user can learn about the basic of operating an excavator. Although the real excavator still has another button or lever that is customized and different for each own particular purpose. The result of the system is shown below:

![Image of excavator control scheme]

Figure 4. Display of controlling scheme in ExcaVR

Compare to other techniques that currently available [2,3], excavator learning system using LMC has an advantage in its level of interactivity with users. LMC provides a fully interactive system that enables user gain more experiences and sense of adventure. This is important in the learning process that the more interactive the learning system, the more effective the learning process will be expected.

In the future, a study to increase the precision of LMC is needed. It is good to synchronize the hand movement showed on the screen compatible with the real hand movement. This compatibility will increase the easiness of. Furthermore, more detailed part of the excavator can be developed using more detail atlas involving more excavator objects in order to provide complete database of the excavator.

The benefits of this research are:
1. Create an interactive excavator simulation system with the user.
2. Understand how Leap Motion Controller works and implementation of a system.
3. Reduced cost utilization compared to some excavator simulations.

4. Conclusion
We have successfully developed a 3D excavator navigation using Leap Motion Controller for learning process in medical education. Based on the results, users were satisfied when using the system and agreed that it could be used as an effective supportive device in a 3D excavator learning process. Leap Motion Controller can be used as a controlling device for excavator simulator in virtual reality. The users can see their virtual hand directly inside. This will help the human and computer interaction in the system. To avoid unnecessary deviations and extensions, the author uses a system for excavator control only on the joystick.
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