User experience study on crane operator erection simulator using senso glove in a virtual reality environment

F Fahmi1, F Nainggolan2, B Siregar2, Soeharwinto1, M Zarlis2

1Department of Electrical Engineering, Faculty of Engineering, Universitas Sumatera Utara, Medan Indonesia
2Department of Information and Technology, Faculty of Computer Science and Information Technology, Universitas Sumatera Utara, Medan Indonesia

Corresponding author: fahmimm@usu.ac.id

Abstract – Failure or mistakes in operating the crane can cause an accident while working on the project site, mainly when it deals with heavy and extensive material, for example, in the steel erection process. Proper crane operation for steel erection training using Virtual Reality (VR) technology can overcome this problem effectively and efficiently. The level of interactivity in a VR system can be increased by using a controller that can observe the user's hand and finger movements. Senso Glove is a wireless glove that is able to read hand and finger movements and is able to provide vibrations. In the system developed in this study, Senso Glove is used as a system control tool to read hand movements and become the system input. In addition to input to the system, Senso Glove can also provide vibration to the user when the virtual hand is holding the lever on a crane in a virtual world or when the steel hit some part of construction during the process. Senso Glove's ability as a crane operator simulator control tool can be tested using the Usability Test. Therefore, USE Questionnaire was used with a Likert Scale as a media survey for system users. From the survey results, it was found that the user was easy to remember how to operate a crane with Senso Glove with an average value of 4.25 per 5 Likert scale. However, users also find Senso Glove challenging to learn by everyone with an average value of 2.95 per 5 Likert scale. This is due to the precision that is still difficult given by Senso Glove with the average value of virtual hand movements produced by Senso Glove is 3.15 per 5 Likert scale.

1. Introduction
As one of the heavy equipment, Cranes requires specialized training in order to reduce the potential accidents that can occur while working on the project site. Accidents that occur in the project field can cause massive losses and even loss of life [1], mainly when it deals with massive and extensive material, for example, in the steel erection process. The problems that occur in the construction field can be overcome effectively and efficiently by using Virtual Reality (VR) [2-4]. The risk of accidents that can occur when using heavy equipment such as cranes can also be reduced by using VR as a training medium [4].

In addition to its immersive appearance, VR can also increase the level of user interactivity with the system. Many applications have been developed in other areas, including in education, such as anatomy learning systems [5,6] in the medical field [7-9] or in culture preservation [17]. Some technology of VR controllers such as the VIVE controller, leap motion controller, and many others...
now become widely used [10,11]. One way to increase the level of user interactivity with a VR system is by stimulating the touch senses [12,13]. The sense of touch can be triggered by vibrations that can be felt by the hands of VR system users. Users can increase the feel the VR system that is getting closer to reality with the combination of the appearance and vibration felt.

Senso Glove is a tool that is able to observe hand and finger movements with an Inertial Measurement Unit (IMU) sensor. With Senso Glove's wireless capability with Bluetooth networks, users can move their hands freely. In addition to freehand reading, Senso Glove is also equipped with a motor that is capable of being vibrated by the system [14]. Vibration on Senso Glove, when worn by the user, is expected to increase the level of interactivity between the user and the VR system.

Increasing the level of user interactivity with the VR system is expected to be obtained by using the Senso Glove as a control tool. In addition to input to the system, Senso Glove can also provide vibration to the user when the virtual hand is holding the lever on a crane in a virtual world or when the steel hit some part of construction during the process. However, to obtain the level of acceptability and level of satisfaction of Senso Glove as a control device on the VR system requires a test to the user. Tests proposed in this study are Usability Tests using the USE Questionnaire [15]. In this paper, a user experience study of the level of usability, level of ease of use, level of ease to learn, and level of satisfaction was obtained and analyzed.

2. Material and Method
The system developed was carried out by using VR headsets for display media and haptic glove for system control devices. The VR headset used on the system is the HTC VIVE VR headset, and the haptic glove used on the system is the Senso Glove. The use of a VR headset gives users the sensation of being able to see around the virtual world on a 360-degree system. The Senso Glove (Figure 1) is used as a control device by observing the user's hand and finger movements, which are used as input to grasp and move the control lever on the virtual crane. The movement of the virtual control lever functions in accordance with the features contained in Table 1.

![Figure 1. A pair of Senso Glove and Senso Glove when used on Unity3D](image)

| Features         | Function                                                                 |
|------------------|--------------------------------------------------------------------------|
| The right joystick | To move the pole to go up or down when moving left or right               |
| The right joystick | To move the boom to go up or down when moving back or front               |
| The left joystick  | To move the upper body of the crane to rotate counter-clockwise when left or clockwise when right |

As for the movement of the boom (an arm of the crane) and the anchor, which is moved by the right lever on the system functions with equation (1) and equation (2) follows.

\[
\theta_1 = |\sin \alpha| \times \alpha \times \delta
\]  

(1)
\[ \theta_2 = |\sin \beta| \times \beta \times \delta \]  \hspace{1cm} (2)

Where in Equation (1) is the position of the boom on the z-axis coordinate degrees, and \( \alpha \) is the right joystick position on the x-axis. While \( \delta \) is a constant to set the comfort level of the boom to the right lever. The right lever is not driven by a button but by holding the user's right hand wearing Senso Glove. When holding the right lever, the sensation of vibration will be felt by the user's right hand.

![Figure 2. Crane parts which can be controlled by a joystick](image)

In Eq (2), \( \theta_2 \) is the position of the anchor on the y-axis coordinates that can go up and down. While \( \beta \) is the degree of coordinates of the z-axis by the right lever and \( \delta \) is a constant to adjust the comfort level of the movement of the anchor to the movement of the right lever. When it is moved, vibrations can also be felt by the user, which is triggered by grasping the right lever by the user's hand.

The movement of the top of the crane, which is controlled by the left lever on the system functions with the following Equation (3).

\[ \theta_3 = |\sin \gamma| \times \gamma \times \delta \]  \hspace{1cm} (3)

In Equation (3), the degree of rotation of the top of the crane is \( \theta_3 \). While \( \gamma \) is the degree of rotation of the left lever on the z-axis coordinates and \( \delta \) is a constant to set the comfort level of the rotation of the top of the crane to the rotation of the left lever. Just as when the right lever is held, the user will also feel the feedback in the form of vibrations when grasping the left lever with a virtual hand.
In the system that has been developed, users can operate cranes to make steel erections. Steel erection is a process for raising, adjusting, and tightening, which can involve cranes [16]. This process can be done by the user by moving the virtual lever and operating the crane so that the anchor reaches a certain distance from the steel. Then the steel will be connected to the anchor automatically by the system. Steel connected to the anchor can be raised by the user by moving the anchor and boom on the crane. When steel is placed on the foundation, the steel will be installed and tightened automatically by the system.

To obtain a quantitative value of user experience, a survey of 20 respondents was conducted to obtain a level of acceptability and user satisfaction. This survey was conducted by giving a number of questionnaires to respondents after respondents were asked to use the VR simulation system. The questionnaire used was the USE Questioner using the 4-Point Likert Scale [15]. The statements used in the survey in this study are in Table 2, and the Likert Scale used is found in Table 3.

| Nr. | Statement |
|-----|-----------|
| 1.  | In my opinion, the simulation of the Crane with Senso Glove is handy to be a Crane operation training simulation. |
| 2.  | In my opinion, a Crane simulation with Senso Glove can facilitate the use of cranes in the real world. |
| 3.  | I think the Crane simulation with Senso Glove is very interactive. |
| 4.  | Crane Simulation with Senso Glove functions according to my expectations. |
| 5.  | The thrill that Senso Glove gave me was exciting and interactive. |
| 6.  | Crane Simulation with Senso Glove is easy to use. |
| 7.  | I think the crane simulation with Senso Glove is easy for anyone to use. |
| 8.  | I need several times to fail to use Crane simulation with Senso Glove successfully. |
| 9.  | I quickly learn gestures to control a Crane simulation system with Senso Glove. |
| 10. | I can easily remember how to use the Crane simulation system with Senso Glove. |
| 11. | I like the look of the virtual hand used. |
| 12. | The virtual hand movements in the system move according to my hand movements. |
| 13. | I am satisfied with the whole Crane simulation system with Senso Glove. |
| 14. | I am satisfied with the vibration feedback from Senso Glove. |
| 15. | I am satisfied with the look of the virtual hand that matches my hand movements. |
3. Results and Discussion
The output of this study was the values of a survey of User Experience with the statements presented in Table 2. Before conducting a survey, respondents are given a brief explanation of how the system works and how to control it. Then the respondent was asked to grab the lever and hold it. Respondents were also asked to try to erect steel in the system. There are 20 respondents in this survey with the age range of respondents between 20 to 30 years and various professions. The results of the survey conducted on these respondents are in Table 4 and Figure 4.

Table 3. A 4-Point Likert Scale Used in Surveys

| Scale of Agreement | Satisfaction Scale | Score |
|--------------------|--------------------|-------|
| Strongly Disagree (STS) | Very Dissatisfied (STP) | 1     |
| Disagree (TS) | Dissatisfied (TP) | 2     |
| Agree (S) | Satisfied (P) | 4     |
| Strongly Agree (SS) | Very Satisfied (SP) | 5     |

Table 4. List of Crane Simulator Survey Statements

| Nr. | Statement                                                                 | Score Average |
|-----|---------------------------------------------------------------------------|---------------|
| 1.  | In my opinion, the simulation of the Crane with Senso Glove is handy to be a Crane operation training simulation. | 3.8           |
| 2.  | In my opinion, a Crane simulation with Senso Glove can facilitate the use of cranes in the real world. | 3.65          |
| 3.  | I think the Crane simulation with Senso Glove is very interactive. | 3.6           |
| 4.  | Crane Simulation with Senso Glove functions according to my expectations. | 3.3           |
| 5.  | The thrill that Senso Glove gave me was exciting and interactive. | 3.95          |
| 6.  | Crane Simulation with Senso Glove is easy to use. | 3.35          |
| 7.  | I think the crane simulation with Senso Glove is easy for anyone to use. | 2.95          |
| 8.  | I need several times to fail to use Crane simulation with Senso Glove successfully. | 3.85          |
| 9.  | I quickly learn gestures to control a Crane simulation system with Senso Glove. | 3.5           |
| 10. | I can easily remember how to use the Crane simulation system with Senso Glove. | 4.25          |
| 11. | I like the look of the virtual hand used. | 3.85          |
| 12. | The virtual hand movements in the system move according to my hand movements. | 3.15          |
| 13. | I am satisfied with the whole Crane simulation system with Senso Glove. | 3.65          |
| 14. | I am satisfied with the vibration feedback from Senso Glove. | 3.9           |
| 15. | I am satisfied with the look of the virtual hand that matches my hand movements. | 3.55          |
4. Conclusions
From the results of a survey conducted, we obtained the highest average value of 4.25 for ease of remembering how to use the system. This statement is the only question that reaches value 4, the value of agreement on the statement, while no other statements reach scale 4. The lowest average value in the system is in statement 7, which reads, 'I think the crane simulation with Senso Glove is easy to use by anyone' with an average value of 2.95. This is related to the precision of the Senso Glove, which is challenging to control. Users find it difficult to move Senso Glove to their preferences. This low level of precision from Senso Glove makes the system difficult to learn and satisfies the user.

Even so, the level of acceptability to vibration and satisfaction of vibration feedback in the system can reach an average value of 3.95 and 3.9, respectively. This means that the vibrations in the crane simulation system almost meet the level of user satisfaction. Vibration sensation in the crane simulation system increases the level of user interactivity so that users feel they are operating a real crane.

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