Virtual Reality-Based 3D Visualization of a PWR for The Internet Reactor Laboratory

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Abstract. Nuclear energy has an important role in achieving the target of zero carbon emission in 2060. In line with that, development of competent nuclear human resources through an effective and efficient infrastructures is important. Recent development of virtual reality technology might be a method to result an effective and efficient infrastructure by a feature of an immersive simulation-based tool for nuclear reactor education and training. This research has a focus on developing a virtual reality-based 3D visualization of a PWR for enhancing the recent existing internet Kartini reactor laboratory which has been used for distance learning of nuclear reactor physics and operation. Free software of Unity and Blender 3D is used to create a virtual environment of a PWR and to create 3D model of the power plant. A virtual reality machine of Oculus Quest 2 is used to access the 3D virtual reality model and the results show that the students can feel a real-like experience through the 3D virtual reality model. It enhances effectiveness of the internet Kartini reactor laboratory in imparting a nuclear power reactor plant knowledge. However, further development of a simulation code for calculation of the PWR's physical characteristics and its interfacing with the virtual reality 3D model are necessary to obtain the complete virtual system of the power reactor.

INTRODUCTION

Target of zero carbon emission in 2060 encourages the use of clean energy sources [1]. Nuclear energy is a clean energy source and it will have an important role in achieving the target [2]. Indonesia is expected to contribute in achieving the target by enhancing the use of renewable energy as well as nuclear energy.

International Atomic Energy Agency (IAEA) has determined 19 infrastructures as indicators of a country's readiness in applicating nuclear energy. Infrastructure of the nuclear human resources development is one of the important parts regarding the strict safety standards in nuclear activities. Competent nuclear reactor personnel will determine the satisfaction of the safety standards from the nuclear power plant construction until its operation [3].

Development of computer technology has pushed a lot of computer code application in nuclear field [4]. A computer-based simulator was built for personnel training of a nuclear power plant [5]. A lot of computer codes is also widely used for calculations of nuclear reactor design and safety analyses [6], [7]. These utilizations of computer technology have improved the effectiveness and efficiency of nuclear-related activities. Furthermore, recent development of virtual reality (VR) technology offers features of immersion, interaction and imagination which will more enhance the improvement. It has been applied in a lot of area including nuclear field [8], [9], [10], [11], [12]. Application of the VR technology in the computer-based facility for nuclear education and training might stimulate a real-like experiences of the nuclear learning without potential danger of radiation exposure. In a fusion reactor, it was applicated to save time and reduce costs [9]. A 3D model virtual reality was built to model water infiltration for radioactive waste [10]. It improves the understanding of the infiltration process. A virtual reality model was also applicate to dismantle a research reactor core assembly [11]. It is useful for understanding of dismantling a core assembly virtually before the real dismantle operation. A VR application for accident analysis of a nuclear reactor was conducted [12]. Application of the VR for an internet reactor laboratory, however, was not carried out yet. An application which integrates the VR's features with an online reactor laboratory might results both an effective and efficient education and training tool.

Kartini reactor is a research reactor belonged to the National Research and Innovation Agency (BRIN) of Indonesia. It has been utilized for nuclear education and training on reactor physics, reactor kinetics, and reactor operation [13]. An online platform using the reactor called as internet reactor laboratory (IRL) was developed to provide a distance learning of the reactor [14]. The IRL which is based on the real reactor operation, however, will consume the nuclear fuel of the reactor which is also applied for material research by neutron activation method. The IRL is also lack of giving real experiences for the students due to the use of video conference as the basis of teacher-student interaction.

A computer code-based simulator of the Kartini reactor was developed to offer an alternative tool for the reactor education and training based on simulation [15]. It also offers a course of reactor accident which cannot be simulated through the real reactor. An accident of excess reactivity due to a control rod ejection can be simulated to give understanding of emergency condition during an accident. Both the IRL and the simulator, however, are only related to education and training of a research reactor. Meanwhile, plant system of a nuclear power plant is different from that of a research reactor. This paper presents an improvement of the IRL by adding a visualization of a nuclear power reactor based on technology of virtual reality. An established reactor technology type of Pressurized Water Reactor (PWR) is chosen to be visualized through a 3D virtual reality model. The model will be useful for giving a real-like experience of introducing a nuclear power plant.

METHOD

A type of pressurized water reactor (PWR) is visualized in this application [16]. It consists of three main buildings which are the reactor, control room, and turbine/generator buildings. The complete schema of the virtual environment of the PWR is shown in Fig. 1. The reactor building contents the 3-D model of the PWR plant system which consists of the pressure vessel, steam generator, pressurizer and piping connecting the main components. The control building consists of 3D model of the computers visualizing the control system. Turbine/generator building contents the 3-D model of the turbines and the generator. The 3-D models were built by using a free software of Blend 3D. These models were compiled into the virtual environment by using free software of Unity.

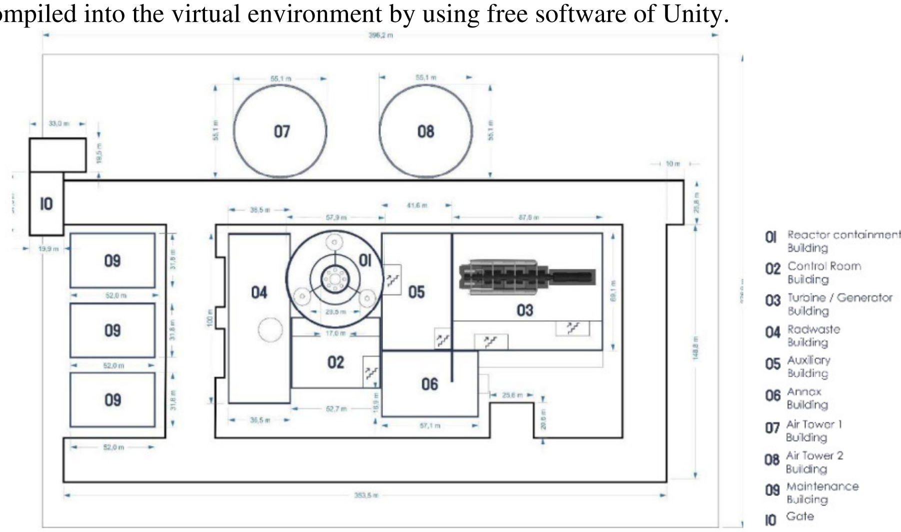


FIGURE 1. Schema of the virtual nuclear power plant area

The 3D virtual reality model of the PWR is provided for visit scenarios. Options of the visit scenarios is shown in Fig. 2. The student (player) must determine the option of visit through the visit menu. Afterwards, the player could conduct a visit through the virtual environment with views of components inside the chosen building or room. Access of the 3D virtual reality model is carried out by using Oculus Quest 2 as shown in Fig. 3. Internet network is needed to connect the 3 devices of the Oculus Quest 2, a computer, and a smart phone. The player will be immersed into the virtual environment by using the Oculus Quest 2, and non-players can see the visit through graphical user interface (GUI) which is displayed in the computer monitor. A projector can be used for a wider display. In this study, access to the virtual reality model is limited to one player.

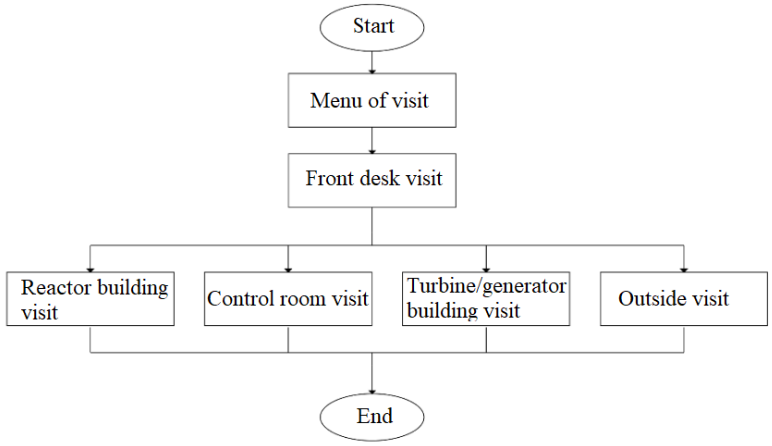


FIGURE 2. Scenario of virtual visits

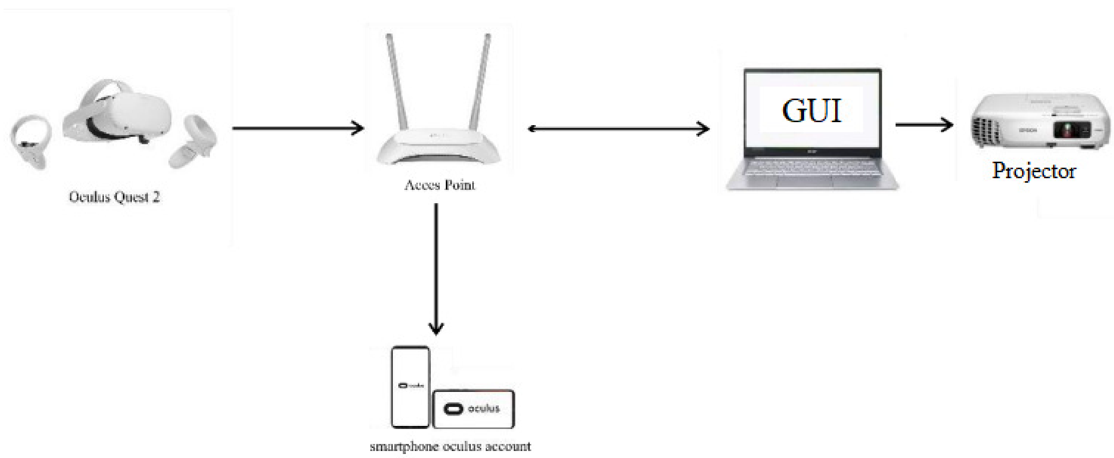


FIGURE 3. Access of the 3D virtual reality

RESULTS AND DISCUSSION

Fig. 4 shows the access of the 3D virtual reality model of a PWR. The player is immersed into the virtual reality model, while non-player people can see the scenario through the GUI display. View of the outside area of the virtual nuclear power plant is shown in Fig. 5. A site visit can be carried out starting from this point. A player will start experiencing a real-like area of the reactor. When the player enters to the inside area of the reactor, a menu display will be pop-up as shown in Fig. 6 and a scenario can be chosen. Afterwards the player can conduct a visit. Figure 7 shows the view of the reactor plant. At the closed view, the player can observe the 3D virtual reality model just like in the real component. Introduction to the plant system is available through a pop-up explanation of each component as shown in Fig. 7 (b). Fig. 8 shows the 3D virtual reality models of the control room and the turbine and generator.

FIGURE 4. Access of the 3D virtual reality model of a PWR by using Oculus Quest 2

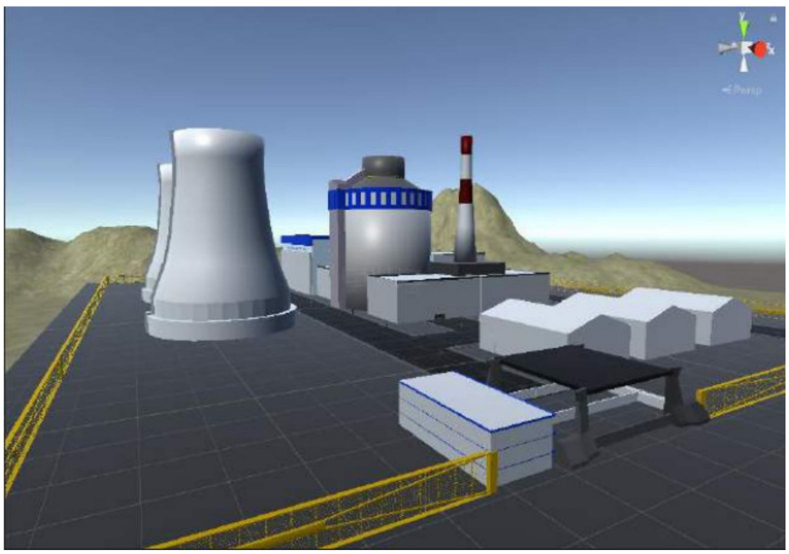
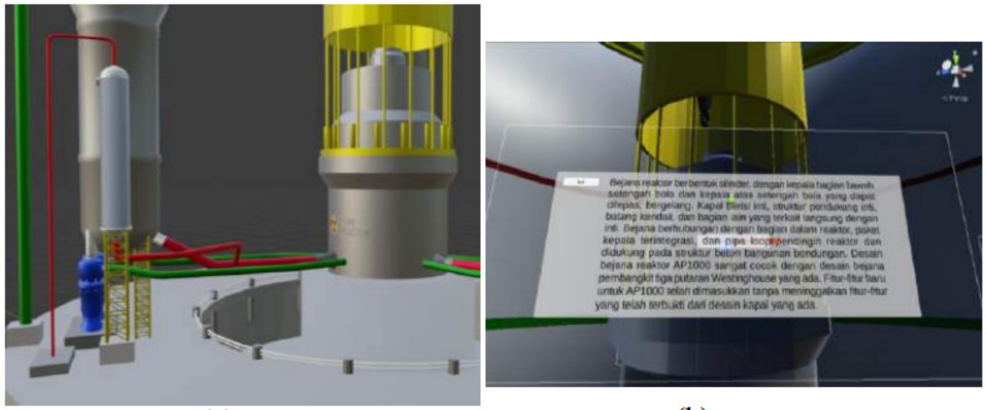


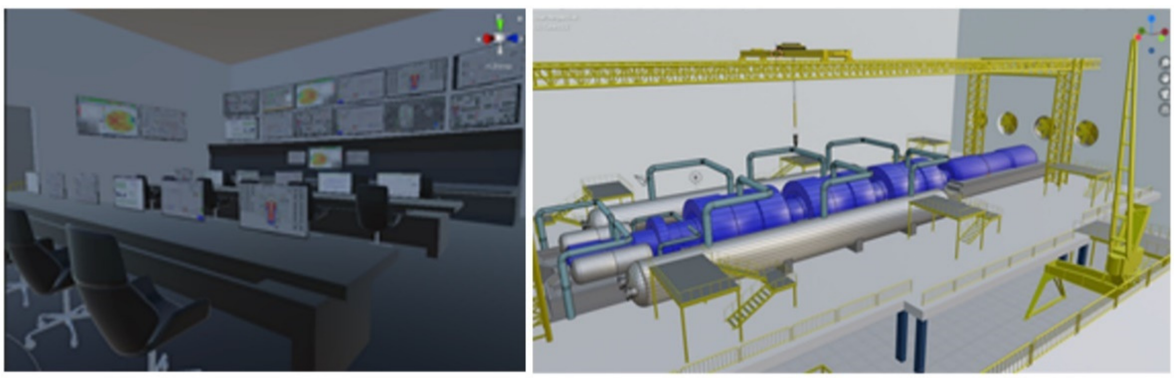
FIGURE 5. The 3D virtual reality visualization of the reactor area

FIGURE 6. Main menu for choosing an option of the visit scenario



(a) (b)

FIGURE 7. (a) The plant's component from at a close view, (b) Pop-up of the component's explanation



(a) (b)

FIGURE 8. Three-dimension visualization: (a) control room, (b) turbine and generator

Performance test was conducted to measure the ability of the hardware of Oculus in running the platform and to measure the ability of the platform in rendering the 3D model. Fig. 9 shows the performance of the platform. Average speed which can be reached by the hardware is 66.18 fps (frame per second). It means that the CPU (central processing unit) needs average time of 0.02 s in rendering the 3D model. Spectrum of rendering time as function of the position is shown in Fig. 10. Red color shows area with decreasing speed, while green color shows area with high speed of rendering. White color is area which cannot be accessed by the player. Speed of the rendering is determined by the number of 3D objects to be visualized.

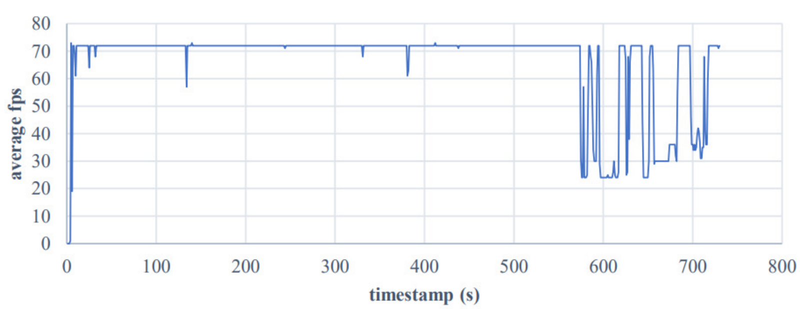


FIGURE 9. Performance of the platform

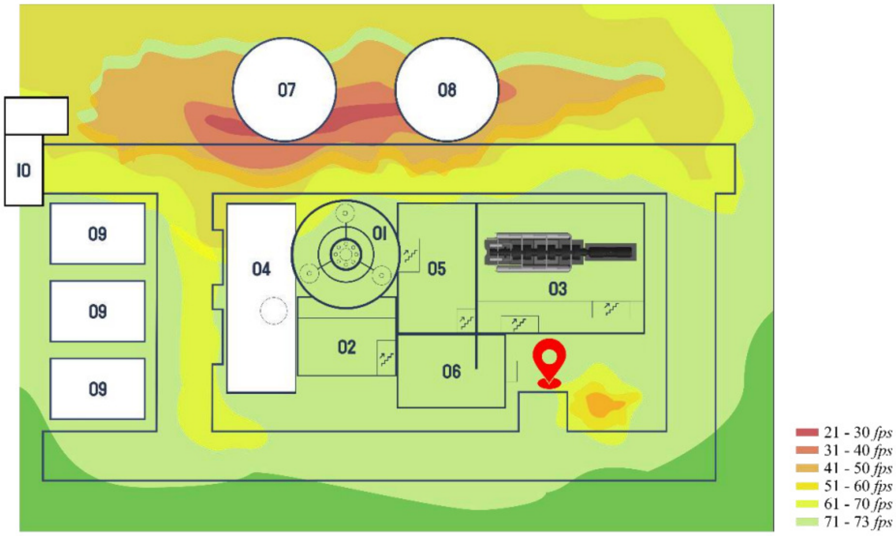


FIGURE 10. Spectrum of rendering speed

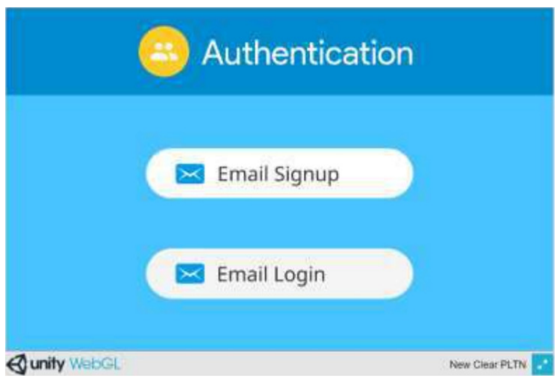


FIGURE 9. Online access of the VR 3D model by email address-based registration

The VR 3D model can be access online through a web provided by Unity. Registration by email address is required. Fig. 9 shows the authentication of the registration. Further development of the online access, however, still need to be improved. Besides, the 3D virtual reality model of a PWR, however, still presents only a visualization of the power reactor that the students (player) can introduce the plant through an immersive site visit. A calculation code of the plant is necessary to be added to complete the dynamics of interaction in which reactor operation data will be generated by the operation action of the player (student). It will be the future development of the simulation tool. Besides, more detailed visualization of the plant system is necessary to be improved.

CONCLUSION

A 3D virtual reality model of a nuclear power reactor was resulted. It has a potential to enhance the feature of the current internet reactor laboratory through a real-like experiences of reactor visit which will improve the effectiveness and efficiency of the reactor learning. A virtual site visit can be conducted by using the model. However, further development is necessary to integrate the 3D virtual reality model with the existing platform of the internet Kartini reactor laboratory. Besides, further development of a simulation code for calculation of the PWR's physical characteristics and its interfacing with the virtual reality 3D model are necessary to obtain the complete virtual system of the power reactor.

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