Development of virtual laboratory applications based on virtual reality using the requirements engineering method

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Abstract. The virtual laboratory application that has been designed in Industrial Engineering Department of Diponegoro University can simulate several work operations on turning machines as well as the introduction of tools to the work process bench. In addition to these aspects, applications that have been designed also do not provide a virtual environment that has complete equipment such as in a production system laboratory. Another drawback is that there is no usage guide in the form of a video tutorial for an initial understanding of users when operating a work operation on a turning machine. In practice, mistakes still occur frequently in working on turning machines. According to students, errors often occur due to a lack of understanding from students themselves even though virtual reality tools have been provided in the training of turning machine operations. Based on that problem this research tries to develop virtual laboratory using the Requirement Engineering method and HTC VIVE Pro Full Kit hardware that can correct the shortcomings of the previous development. The output of this research is a virtual reality-based virtual laboratory application that has been tested and evaluated by considering several aspects such as interaction, visualization, information, reusability, performance, and reliability.

1. Introduction

Education is important for the progress of a nation, therefore, to become a great nation, good education technique is certainly being considered as a way to achieve the goal for every country in the world. Along with the times, the world of education must innovate quickly and integrated \cite{1}. Indonesia plans to overhaul the education curriculum with more emphasis on STEAM (Science, Technology, Engineering, the Arts, and Mathematics), aligning the national education curriculum with future industrial needs \cite{2}. The industrial revolution 4.0 is a concept of automation carried out by machines without the need for human labour in its application. Diponegoro University (Undip) as one of educational institutions in Indonesia try to implement it. The technology applied in each faculty is different, depending on the needs of the lecture activities. Industrial Engineering Department has conducted learning using technology, as an example preliminary practices that held by production system laboratories which intended as training media before conducting practicum manufacturing processes using virtual laboratory applications based on virtual reality. The virtual laboratory application that has been designed can simulate several work operations on turning machines which include zero, facing, conventional, and cut off settings, as well as the introduction of tools to the bench work process. The application has been designed to meet several aspects such as visualization and information, animation, reliability, and reusability. In addition to these aspects, applications that have been designed also do not provide a virtual environment that has complete equipment such as in a production system laboratory. Another drawback is that there is no usage guide in the form of a video tutorial for an initial understanding of users when operating a work operation on a turning machine \cite{3}. In carrying out
practical activities, errors still often occur in working on turning machines. There are 57.9% of students making mistakes on turning machines with the total number of respondents being 75 students. According to students, mistakes often occur due to a lack of understanding from students themselves in operating the turning machine. Although there are virtual reality tools in the training of turning machines, there are still many mistakes in turning machines. Based on the problems and conditions that have been explained, an improvement in the development of a virtual laboratory will be carried out using methods and hardware that can correct the shortcomings of the previous development. The method used in developing virtual laboratory applications in this study is the requirements engineering method. Requirements engineering is a systematic and disciplined approach to the specification and management of requirements to identify relevant needs, reaching an agreement between stakeholders regarding these requirements, documenting them according to given standards, and managing them systematically and also to understand and document their wants and needs. Stakeholders, determine and manage requirements to minimize the risk of delivery of the system that does not meet the wants and needs of the stakeholders [4]. The output of this research is a virtual reality-based virtual laboratory application that has been tested and evaluated by considering several aspects such as interaction, visualization, information, reusability, performance, and reliability.

2. Literature Review
This section explains the literature used in designing a virtual laboratory based on virtual reality. Some important literature that will be used will be briefly explained as follows:

2.1. Human-Computer Interaction Framework
Human-computer interaction (HCI) is a discipline that examines communication or interaction between users and systems. Users are individuals or groups that work together, the order of users in an organization, each of which deals with some part of the task or process [5].

2.2. Virtual Laboratory Based on Virtual Reality
A virtual laboratory is an interactive environment for creating and conducting simulation experiments consisting of dependent domains of simulation programs, experimental units that include data files, tools that operate on objects, and reference books [6]. The virtual laboratory simulates the device, including all necessary parameters, so students can work in a complete and realistic environment. The level of reality that is simulated and the software used are different. Some show temporary two-dimensional images that use virtual reality to simulate real [7].

2.3. Requirement Engineering
Requirements engineering is a systematic and disciplined approach to the specification and management of requirements to identify relevant needs, reaching an agreement between stakeholders regarding these requirements, documenting them according to given standards, and managing them systematically and also to understand and document their wants and needs. Stakeholders, determine and manage requirements to minimize the risk of delivery of the system that does not meet the wants and needs of the stakeholders [4]. The Requirements Engineering method consists of four phases as follows Requirements Elicitation, Requirements Documentation, Requirements Validation and Negotiation, and Requirement Management [4].

2.4. Unity 3D Game Engine
Unity 3D is a cross-platform based game engine. Unity can be used to make a game that can be used on computer devices, Android smartphones, iPhone, PS3, and even X-BOX. Unity 3D is a software designed to create or develop applications with 2D and 3D views. Unity 3D has the function of making 3D objects like real objects that are affected by gravity, colliding, sound, script, animation, artificially intelligent, network, threading, and animated graphics [3].
2.5. **HTC Vive Pro**

HTC VIVE Pro Full Kit is a VR headset developed by an American company, HTC Corporation. This company is seen as Oculus's main competitor in the VR entertainment field (especially in PC games). The goal of HTC is to attract users who are interested in virtual collaboration and design of products and other applications. The HTC VIVE Pro Full Kit combines sensors and translates them into motion in the VR system in Real-time. HTC VIVE Pro Full Kit has a precise tracking feature to use two controllers that are used to facilitate user interaction and two base station 2.0 which are used to monitor room 5m x 5m where the user is located. HTC VIVE Pro Full Kit has input specifications such as a multifunction trackpad, grip buttons, dual-stage trigger, system button, and menu button. HTC VIVE Pro Full Kit also has sensors such as SteamVR Tracking, G-sensor, gyroscope, proximity, and IPD sensor. Also, the HTC VIVE Pro Full Kit has a connection using Bluetooth, and a USB type C port to connect to the computer.

2.6. **Evaluation Method**

Evaluation is the final stage of the design process that used to validate the results of the design needs, desires, and expectations of users. In designing virtual reality applications, evaluation is included in the design phase that must be done. The main purpose of the evaluation is to measure the suitability of the product. In digital products such as virtual reality, there have been a variety of previous studies using various aspects of the evaluation conducted. In previous studies, we have used several aspects such as visualization and information, animation, reliability, and usability [3]. Evaluation methods in the form of filling out questionnaires to several questionnaires using the scale of Strongly Agree (SS), Agree (S), Disagree (TS), and Highly Disagree (STS). The results of the questionnaire are then processed and generalized to get the conclusions of the evaluation results [3].

3. **Research Design**

3.1. **Research Objective**

This study aims to: (1) identify and develop user persona, user goals, and user requirements in the virtual laboratory application to be designed; (2) creating a virtual laboratory application based on user persona, user goals, and user requirements compiled using Unity 3D; (3) explain the process of integrating virtual laboratory applications in virtual reality using the HTC Vive Pro Full Kit Headset; and (4) evaluate the developed virtual laboratory applications.

3.2. **Research Instrument**

This research was conducted in the Industrial Engineering Department at production system laboratory of Diponegoro University. This study involved industrial engineering students and production systems laboratory assistants as users, Lecturers of the Department of Industrial Engineering, ergonomists, and software experts as an expert. This design includes depicting a production system laboratory situation and providing simulations of turning machine operations. This research was carried out by three other industrial engineering students who were distinguished by the type of turning machine operation. In this study, turning machine operations consist of boring operations, drilling operations, reaming operations, and tapering operations.

3.3. **Research Method**

This research uses the Requirements Engineering method which is used to design the needs and design of the virtual laboratory that will be made and consists of four phases, namely beginning with requirements elicitation, requirements documentation, requirements validation and negotiation, and requirements management. The following research schemes will be conducted as shown in Figure 1.
3.3.1. Elicitation requirements. In the requirements elicitation phase, there are two activities namely observation and interview. At the observation stage, to see the user's behavior and the actual situation of the laboratory directly in carrying out work processes that occur and identifying and seeing potential hazards that might occur, as well as identifying and looking at the preferences, errors, and frequency of users in carrying out a process. At the interview stage or interviews conducted on experts and users. Interview the user to identify the goals and motivations of the user, identify the needs, desires, and expectations of users, get the user's aspirations, identify the level of problems and frustration of users. User interviews were conducted with ten students and five laboratory assistants. Interviews with experts were conducted to obtain detailed information related to the field of expertise needed in designing a virtual laboratory. Interviews of experts were carried out on ergonomists, software experts, virtual reality experts.

3.3.2. Requirement documentation. In the requirements documentation phase in this study using the results of the requirements elicitation phase. In this phase, the needs and information that must be produced by the application both functional and non-functional needs have been obtained. These needs are obtained based on observations that have been made in the previous stage. In this phase, the user model and domain user are created. The user model is a model of the user that will be the basis for designing a Virtual laboratory. In this phase also a confession of needs has been determined which is translated into a design that is following the principles of interaction. At this stage, it produces an interaction framework in the form of sequential and more detailed steps. Use cases are also used to model learning that must be done by the practitioner. Activity diagrams are used to frame the application activation process. Sequence diagrams are used to create information exchanging interactions between users and systems. After that, the design of the framework is made with visuals that are determined by
several things related to the color, type, widget treatment, and overall dimensions, as well as the material properties of the interface used to achieve the goals of the user following predetermined needs. Then the existing design is made into 3 dimensions related to the work operation of the turning machine and a virtual environment will be made according to the actual conditions of the laboratory.

3.3.3. **Requirements validation and negotiation.** In the requirements validation and negotiation phase, the validation of the requirements that have been determined, and the refinement of the design concept that has been done are carried out. The framework that has been created will be evaluated and converted into the final design form used in the virtual laboratory. If there is a part that is not following the output of the previous stage, it will be revised from the part that is not appropriate.

3.3.4. **Requirements management.** This phase is the last phase of the requirements engineering method. In this phase, a learning application is made on the working of a lathe in the form of a virtual laboratory based on virtual reality. The software used in designing virtual laboratories is to use Blender and Unity 3D. making applications based on the final design that has been generated from the previous phase.

3.3.5. **Application and hardware integration.** The application design that has been done previously will produce virtual laboratory software. Integration needs to be done between software and hardware devices HTC Vive Pro Full Kit in the world of virtual reality. The results of the installation will then be used for the trial process as an initial step in the evaluation process of the virtual laboratory product.

3.3.6. **Evaluation.** The evaluation phase carried out with aspects that see the aspects used in the design. The aspects of evaluation consist of functional and non-functional aspects. Functional aspects include visualization, interaction, and information. While the non-functional aspects consist of aspects of performance, reliability, and reusability.

   Evaluation is carried out by respondents consisting of users and experts. Users consist of ten industrial engineering students and five production system laboratory assistants. The experts consist of lecturers from the undip industrial engineering department, ergonomics experts, and software experts. The evaluation begins with conducting a virtual laboratory trial. Then the respondent is asked to fill out a questionnaire that refers to the evaluation aspects that have been determined. The questionnaire was filled out using a Likert scale consisting of Strongly Agree (SA), Agree (A), Neutral (N), Strongly Disagree (SD), and Disagree (D). Data processing is done by calculating the number of answer choices from respondents consisting of Strongly Agree (SA), Agree (A), Neutral (N), Strongly Disagree (SD), and Disagree (D) on each aspect of the assessment. The calculation results are then processed into a proportion of answers to each aspect into diagrammatic form to facilitate the reading of the information contained. Analysis of the evaluation results is based on the results of data processing. The analysis is done by comparing the proportion of answers from each aspect of the assessment. The assessment aspect is considered to have fulfilled the user goals and requirements if it has a higher proportion of the responses of the Agree (SA) and Agree (A) compared to the total proportion of the Neutral (N), Strongly Disagree (SD), and Disagree (D) answers.

4 Conclusion
This research is intended to develop a virtual reality-based virtual laboratory using the requirements engineering method in the production system laboratory. This development is based on the lack of interaction aspects in previous research. The development of virtual laboratory applications is oriented towards user goals in defining functional and non-functional requirements. Applications that have been installed in the HTC Vive Pro are used to conduct virtual laboratory evaluations by users and experts.

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