The virtual laboratory for turning machine operations using the goal-directed design method in the production system laboratory as simulation devices

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Abstract. Virtual laboratory is an interactive learning media that is more effective than conventional media. The implementation and development of the virtual laboratory technology was carried out in the production system laboratory of the Industrial Engineering Department. This is an improvement effort from previous research that still has some shortcomings, especially in aspects of user interaction with the virtual environment. This development is increasingly important because of the frequency of human error when practical activities are running. The development of this virtual laboratory follows the ADDIE model which includes the process of analyzing, designing, developing, implementation, and evaluation. The method for developing virtual laboratories is carried out using the principle of Goal-Directed Design which focuses on user goals. GDD consists of several phases, namely research, modeling, requirements definition, framework definition, refinement, and development support. The output of this method is a virtual laboratory application that has been created with a unity 3D game engine and will be installed on HTC Vive Pro hardware. Evaluation is carried out using a Likert scale by considering aspects of evaluating functional and non-functional requirements. Functional aspects consist of aspects of interaction, visualization, and information. Non-functional aspects consist of aspects of usability, performance, and reliability.

1. Introduction

The development of the world nowadays is in the era of the Industrial revolution 4.0 with a massive role of technology. The technology development has positive impacts in education [1]. The latest technology which often used in educational activities is virtual reality. Diponegoro University as an instrument of Higher Education seeks to adapt to technological developments. One of the efforts taken is to develop a machine training simulation media using virtual laboratory based on virtual reality in the Industrial Engineering Department. The design of the Virtual Laboratory application is carried out in order to improve the quality of learning in the field of the manufacturing process. Based on preliminary research that has been done by observing and filling out the questionnaire, it shows that the frequency of human error in students when operating machines is high. This is due to the lack of students' understanding of how to operate the machine correctly. The analysis shows that conventional machine operation training is not effective. This is because there are various constraints on the resources such as time, machines and operators. Based on the drawbacks of using conventional methods, it is necessary to develop training methods that are more modern and effective. Virtual laboratory based on virtual reality is a technology that can be used to create a modern training media.
The development of a virtual laboratory in the production system laboratory of the Industrial Engineering department was carried out in 2019, but it lacked visualization and interaction. Aspects of functional requirements number four and five relating to aspects of user interaction and virtual environment are not designed according to actual conditions. This is due to limitations on the method and VR Headset used. The development of the virtual laboratory was carried out to improve and enhance the capabilities of the virtual laboratory that had been previously designed. Using the Goal-Directed Design (GDD) method as the design method and the HTC Vive Pro Full kit as the hardware to run the program. The GDD method design based on user needs on the defined persona. The GDD method consists of several stages such as research, modeling, requirements definition, framework definition, and design support [2]. The output of this research is a virtual laboratory based on virtual reality application that has been tested and evaluated by considering several aspects such as interaction, visualization, information, usability, performance, and reliability.

2. Literature Review

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

2.1 Human Computer Interaction Framework

Human-computer interaction (HCI) as a discipline that concentrates on the design, implementation, and evaluation of interactive computer systems for human use with various particular fields of study [3]. There are three key aspects of HCI, which are users, systems and interactions.

2.2 Virtual Laboratory Based on Virtual Reality

A virtual laboratory is a media that supports traditional practice activities. The presence of a virtual laboratory is expected to provide an effective, efficient, and enjoyable training facility so that students can learn independently and flexibly [4]. The virtual laboratory obtains several advantages in its use such as more complete experience, detailed understanding, low cost, and assisting in real-time [5]. The design of the virtual laboratory is carried out by taking into account design strategies such as Goal Oriented, Learning by Doing, Interactive Environment and Flexibility System.

2.3 Goal Directed Design

Goal-Directed Design (GDD) is an interaction design method [6]. The GDD method consists of six phases: research, modeling, requirements definition, framework definition, refinement, and development support [2]. The GDD method is oriented towards the right target users with the persona model identified at the research stage. Hence, it is the research and design phases are frequently. The GDD method bridges this gap by defining user models, building user needs, and translating them into a framework [2]. The Goal-Directed Design method uses a persona in the scenario and develops a design sketch by following the flow through the interface and applying design principles and patterns to construct a solution [6].

2.4 Unity 3D Game Engine

Unity 3D is a software that was developed to produce an object or application using 2D and 3D views but is more focused on 3D. Unity 3D can be used to provide tangible effects such as the effects of gravity, collisions, sound, scripts, animations, networks, streaming, memory management, threading, artificial intelligence, and motion animation [7].

2.5 HTC Vive Pro

HTC Vive Pro is a VR Headset that was developed by an American technology company, HTC. HTC Vive Pro Full Kit combines sensors and calculates user movements and translates them into VR system movements in Real-Time [8]. This VR headset is supported by using two controllers used to facilitate user interaction and two base station 2.0 which are used to monitor the room where the user is placed. The controller has input specifications such as multifunction trackpad, grip button, dual-
stage trigger, system button, and menu button. This hardware contains sensors like Steam VR Tracking, G-sensor, Gyroscope, Proximity and IPD Sensor.

2.6 Evaluation Method
Evaluation is a stage in the design process used to validate the design results with the needs, desires, and expectations of users. Evaluation is critical parameter as the feasibility of a design result. In digital products such as virtual reality, there have been a variety of preliminary studies using various aspects in the evaluation phase. Some aspects often used are visualization, user friendly, learnability, usability, interaction, and effectiveness. Nurkertamanda et al used an evaluation method in the form of filling out questionnaires with several respondents consisting of experts and users. Respondents were asked to fill out a questionnaire using the scale of Strongly Agree (SS), Agree (S), Disagree (TS), and Strongly Disagree (STS). The results of the questionnaire are then processed and generalized to approach the conclusions of the evaluation results.

3. Research Design

3.1 Research Objective
This study aims to: (1) identify the user's persona, user’s goal, and user’s requirements; (2) create a virtual laboratory application using Unity 3D; (3) integrate applications with the VR Headset HTC Vive Pro; and (4) evaluating virtual laboratory applications.

3.2 Research Instrument
This research was conducted in Production Systems Laboratory of the Industrial Engineering Department of Diponegoro University. Involve several stakeholders to build the basic framework of design, application development, and evaluation. Stakeholders consist of two categories, users and experts. Users consist of industrial engineering students and production systems laboratory assistants. The experts consisted of three lecturers from the Industrial Engineering department, ergonomics expert, software expert, and virtual reality software development expert. The design of a virtual laboratory involves depicting a complete production system laboratory and providing operating simulations for several turning machine operations. This research is a project carried out by three industrial engineering students which are distinguished by the type of turning machine operations performed. In this research, a turning machine operation consisting of facing operation, conventional operation, contour operation, and threading operation will be carried out.

3.3 Research Method
This study combines the principles of Goal-Directed Design and the principles of ADDIE (Analyze, Design, Develop, Implementation, and evaluation) models [9]. Therefore, this research will be divided into 5 stages of work steps. Each stage will contain design principles which are part of the Goal-Directed Design. This is done to produce virtual laboratory applications based on virtual reality that are in accordance with the needs and rules of product development. The following research schemes will be conducted:

3.3.1 Stage 1: Analyse
The analyse stage consists of the research phase, persona modelling, and requirements definition. The research phase uses ethnographic studies by carrying out several steps aimed at gathering user and system information. The first step undertaken is a review of the development of virtual laboratories that have been carried out previously and several similar studies to gather information about the features, functions, designs, and interactions of virtual reality. Then the user was observed, and the focus group discussion consisted of ten students and five laboratory assistants. This step is carried out to identify user behaviour, user character, goals and motivation, and identify user requirement. The final step in the research phase is conducting interviews with experts to get detailed information in the perspective of virtual reality systems. The Output Research Phase is the pattern of behaviour and
workflow of the user. The results of the Research Phase then become input into the Modelling Phase, modelling virtual laboratory users who are designed based on the information obtained. Output Modelling Phase is the User Model and Domain model that explains the workflow diagram of the persona that has been designed. The end of the analyse phase is defining the functional and non-functional requirements of the person. This phase will compile functional requirements, non-functional requirements, and scenario of the virtual laboratory based on information gathered in the research phase.

3.3.2 Stage 2: Design.

The Design Stage consists of the Framework Definition and Refinement phases. The Framework phase designs the information obtained at the analyse stage into several design frameworks, Interaction Framework (IF), Visual Design Frame (VDF), and Industrial Design Framework (IDF). Interaction framework will model the interaction between the user and the system by using several diagramming tools such as use case diagrams, activity diagrams, and sequence diagrams. The design of the framework is based on scenarios and work patterns of users when interacting with work systems in the production system laboratory. VDF defines design guidelines related to visualization of real environments in a virtual environment. Some things to consider include the colour, dimensions, widget treatment, and material properties of various elements of the virtual environment. IDF is carried out to model the equipment related to turning machine operations into a 3D form. The output refinement Framework phase is a design framework that matches the behaviour patterns and actual environmental conditions. The output of this phase will be refined in the refinement phase. The refinement phase will produce a final framework design from the virtual laboratory as input to Software Development at the develop stage.

3.3.3 Stage 3: Develop

This stage contains the final phase of the principle of Goal-Directed Design, Development Support. At this stage a virtual laboratory application will be made based on the final framework design. Making an application is done using the Unity 3D game engine. The output from this stage is the application of a virtual laboratory turning machine based on virtual reality.

3.3.4 Stage 4: Implementation

This stage is a step to integrate virtual laboratory software with HTC Vive Pro hardware. This process is carried out by performing an installation which is followed by a trial of the tool by users and experts. Each respondent will try to use a virtual laboratory to conduct an evaluation at a next stage.

3.3.5 Stage 5: Evaluation

The evaluation model is carried out by considering the aspects design. Evaluation aspect for developing virtual laboratory consists of two parts, such as functional needs aspects and non-functional needs aspects. The following are aspects that will be evaluated:

Evaluation aspects of functional needs consist of interaction aspects, visualization, and information. Interaction, an aspect that evaluates the suitability of interactions in a virtual laboratory application with actual interactions in the real world. Visualization, aspects that appraise the level of visualization from various content, assets, and graphics in a virtual laboratory application. Information, aspects that appraise the level of information availability required by users in using virtual laboratory applications. The evaluation aspects of non-functional needs consist of usability aspects, performance, and reliability. Usability, aspects that appraise the level of user’s convenience to learn, understand, operate, and interact with virtual laboratory applications [10]. Performance, an aspect that evaluates the pace of response for virtual laboratory applications. Reliability, the aspect for evaluating the level of system completeness in providing services when it’s needed by users and the reliability of virtual reality applications in running tasks in the system that mainly related to errors that occurs.

Evaluation is carried out by respondents consists of users and experts. users consist of ten industrial engineering students and five assistant of production system laboratory. Expert respondents consisted of three Industrial Engineering department lecturers, ergonomics expert, software expert, and virtual
reality development expert. The evaluation steps begin with conducting a virtual laboratory trial. Then Respondents are asked for completing questionnaires with a total of about 30 questions. The questionnaire refers to evaluation aspects that have been determined before. The questionnaire was filled out using a Likert scale that consists of Strongly Agree (SA), Agree (A), Neutral (N), Strongly Disagree (SD), and Disagree (D). Data processing is done by calculating the number of respondents’ choices that consists of Strongly Agree (SA), Agree (A), Neutral (N), Strongly Disagree (SD), and Disagree (D) in each aspect of assessment. The results of the calculation then processed to an aspect answers proportion into diagrammatic form to make contain information reading easier. 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 the assessment aspects. The assessment aspect that fulfill users goals and requirements are an aspect that has a higher response proportion of the Agree (SA) and Agree (A) than the total proportion of answers Neutral (N), Strongly Disagree (SD), and Disagree (D).

4. Conclusion
This research is aimed for developing a virtual laboratory based on virtual reality by using the goal-directed design 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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