Hands-on PLC Training Approach for IT Students Using Virtual Reality

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Abstract. The Automation 4.0 needs the integration of Information Technology and the classic automation technology. Most of the IT students lack of the automation technology part where hardware plays an important role. To overcome this, we constructed an approach to create a hands-on PLC training for IT students using Virtual Reality (VR) technology. The pedagogical concept of ADDIE model was implemented in the phase of instructional design. The 3D models of PLCnext learning kit was created using Blender. For interaction purpose, the Unity engine is taken into account. The proposed virtual training system was evaluated in a closed settings. The System Usability Scale (SUS) score suggests that the virtual training system is a good application (68.125).

Keywords: Training · Virtual Reality · PLC · ETAT

1 Introduction

Automation 4.0 is one of the main targets of the industrial transformation plan known as Thailand 4.0 established by Thai government. It should be the answer for the long-term growth of the modern industries in Thailand. Its name reminds the fourth generation of the industry era where the levels of businesses, socials, and infrastructures are digitalized, connected, and integrated. As the pilot area, the Eastern Economic Corridor (EEC) [1] has been set up and developed. The EEC includes 3 provinces of the Eastern part of Thailand namely, Chachoengsao, Chon Buri, and Rayong, which have altogether more than 29 industrial estates [2] that is ready to be invested (approx. 2,345 Hectares and 3,786 factories). The crucial fundamental for the EEC project is to develop qualified professionals and skilled workforce who can create, develop, operate, and maintain the relevant technologies.

In the Automation 4.0 context, the connection of the Information Technology (IT) and the classic automation technology are brought closely together. Their integration make the sense of digital transformation of the Industry 4.0. The essential basis of the Automation 4.0 is therefore the IT and the classic automation. At Faculty of Informatics, Burapha University, the Information Technology is the main target. The students learn

the main concepts of Information Technology such as programming, database management, information technology infrastructure, computer network communication, fundamentals of data preparation and analysis, etc. In terms of workforce capacity building for Automation 4.0, these students have to be equipped with the knowledge of automation technology.

In this work, we aimed to create a learning environment for PLC practical learning activities using Virtual Reality technology in the framework of ETAT Erasmus+ project [3]. The learning materials and the learning methods were designed based on a didactic model called ADDIE model (Analysis, Design, Development, Implement, Evaluation) [4]. The proposed VR training system gives the PLC trainees the experience of PLC training concepts with expensive equipment without owning it. This experience lets the trainees adapt their knowledge to the real PLC later on. The applicability and efficiency of the proposed VR training system are analyzed and discussed.

2   State of the Art

2.1   Virtual-Reality-Enabled Remote Lab with Equipment Connection

In this context, several researchers aimed to develop remote labs with connection to the real equipment. The interaction to these remote labs is realized with Virtual Reality technology. Once a trainee starts a lab activity, a 3D model of an equipment will then connect to the real equipment and it functions according to the trainee's actions.

A work from Avram et al. shows the approach of using Virtual Reality for PLC training [5]. They used virtual reality glasses and gloves to connect the lab setup and the 3D models together. The simulation worked with a specific automation software. In the work, only some parts of the lab setup could be implemented due to the complexity of the virtual reality. Another work from Garcia and Alegria talked about using Virtual Reality for automation training improvement [6]. They presented the so-called Virtual Reality Machine (VRM) that models and emulates the appearance and behaviors of a real machine. The work from Grodotzki et al. described the remote and virtual labs for engineering education 4.0 [7]. They developed a concept of virtual representation of their remote labs for overcoming the limitation of access. Furthermore, the relevant Massive Open Online Course (MOOC) was created for incorporating the remote labs. Shen et al. created a virtual simulation and communication of KUKA robot and PLC [8]. In terms of virtual reality engine, the Unity3D was used. The virtual motion simulation and control of industrial robot were studied over the interconnection between the virtual and real robot. Furthermore, the concept of Augmented Reality (AR) was also used in the training that is related to the real equipment. A work of Kim et al. proposed a hybrid learning system for PLC wiring training using augmented reality technology [9]. They found out that the approach can improve the learning experience of the trainees, especially for a novice who might need more supports at the beginning of the training.

However, one big drawback of this approach is that an equipment is limited to an access at a time. Once it is taken, no other connections can be established. They have to wait until the equipment is released to be used.

2.2   Virtual-Reality-Enabled Hands-on Training

This type of training concentrates on practical training based on Virtual Reality technology without connecting to any real equipment. The great benefit of this type of training is the multiple access. Multiple trainees can access an engineer-related content with virtual reality at the same time. The limitation of the system depends on how the system is constructed. If the training system delivers the training contents over the Internet, the server performance and the bandwidth of the Internet connection play a big role. If the training contents of the system is installed on a computer, the performance of computer itself is the main criterion.

In the work of Boonmee et al., the Virtual Reality training environment for Electrical Vehicle (EV) was conceptualized and implemented [10]. They used the didactic model called ADDIE for content creation and evaluation. The results showed that the trainees accepted the training system. An approach from Kim and Kim aimed to create virtual interaction based PLC training system [11]. They created virtual sensors, virtual actuators, virtual PLC, and virtual network for training system simulation. The system was applied into a real training class at a university's training center. The results showed that the training system is accepted and can be applicable for training programs.

Although, the training method of using Virtual Reality technology is useful and it provides new real experiences of hands-on training to the trainees with less cost than real up-to-date equipment, the training materials themselves catch less concern. Only small number of researchers was talking about creating training materials using any standardized didactic concept. A well-known didactic concept can be helpful when creating meaningful training materials.

2.3   Virtual Contents with Specific Didactics

Creating training materials based on a well-known didactic model can bring more benefit to the trainees in terms of flattening the learning curve and easier to understand. An elaborate training content may be concise and get to the point. This can help to reduce training time.

In the approach of training material creation for engineering education, some works are done concerning some didactic models. The work of Yu et al. aimed to use the ADDIE model interactive system based on Virtual Reality [12]. According to the model, they got the feedback and evaluated the system for improvement. Another work of Pérez-Ramírez and Ontiveros-Hernández described experiences of training system development [13]. The factors of using virtual reality as a training tool were discussed. Comprehensive training data can be collected and evaluated. In addition, the work of Boonmee et al. [10] mentioned above also took the ADDIE model into account. The system was planned using elaborate instructional design for content preparation, which let the system gained the high score of the overall satisfaction.

3   The Proposed PLC Virtual Training System

3.1   Overview of the System

The proposed PLC Virtual Training System consists of 2 main parts, namely 1) the computer and the virtual reality devices, and 2) the VR Learning System for PLC. The first

part includes a high-performance computer set that equipped with high computational power and a VR-enabled graphic card chipset. This is a crucial criterion for experiencing VR content smooth and effective virtual object rendering and representation. For specific VR devices, some specific out-ports on the graphic card may be required. In our approach, the HTC Vive CE 2018 is used. This set includes VR glasses, base stations, and controllers. The second part is the VR Learning System for PLC training. This part is to develop 3D models used in the virtual environment and represented the real equipment and functionality for the training. The Blender is used for 3D models creation where the Unity is used to create interactions and behaviors of the objects. All the developed elements are then connected together over the platform called SteamVR. Figure 1 depicts the overview of the PLC virtual training system.
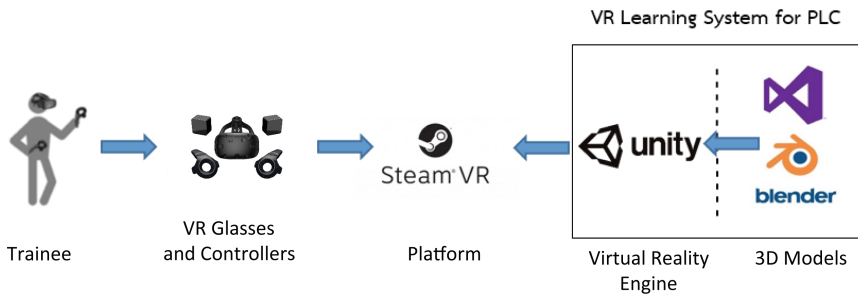

Fig. 1. Overview of the PLC virtual training system

The system is designed to be a single user system. A trainee with a set of VR device and a computer can access the system that is installed on that computer. Once wearing the VR glasses and Controllers, and connected to the SteamVR platform, a trainee will immerse into the PLC lab setup virtual environment. He/she will be guided through the training environment according to the didactic concept based on ADDIE model design as described in the next section.

3.2 Instructional Design

Since our approach is to train IT students about PLC using Virtual Reality technology, we then concentrated on hardware and basic concepts of PLC programming. From the observation phase of Analysis in ADDIE model, we gained the insight that the IT students lack the knowledge of common procedure used in PLC programming. The concept of functional interaction between hardware configuration and programming in PLC has to be emphasized. Hence, in the Design phase, a storyboard is used to layout the concept and pedagogic plan. The key interactions of the practical training have to be realized and taken into account. The correct movement of hands and head will support the long-term memory of the trainees. The step-by-step instruction created a very easy to follow steps in self pace tempo. This allows trainees with different needs to follow the training materials individually. Figure 2 shows the instructional design of the approach.

After entering the system, a trainee has possibilities to acquire basic knowledge of PLC from watching the video tutorial or reading information from the boards. For the
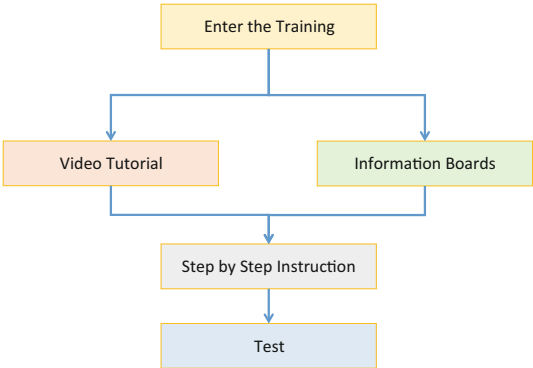
Fig. 2. Instructional design of the proposed training virtual system.

PLC technology, we provide the information of the PLCnext technology for its benefit of current technology in Automation 4.0. After basic knowledge, a trainee will enter the step-by-step instruction section. He/she has to select the right hardware device and configure it properly. Then, he/she has to do the basic PLC programming, which is a Function Block Diagram (FBD) programming in this case. After the programming, the trainee has to put it into the PLCnext and interact with the Inputs of the virtual learning kit. The results of the PLCnext programming can be then observed from the Outputs of the learning kit.

3.3   3D Models

The 3D models in this training system consist of 2 types; 1) the PLCnext-related training 3D models and 2) the environment 3D models. The original PLCnext learning kit as shown in Fig. 3 is used as a real device. All Inputs and Outputs of this PLCnext were created and the basic functionalities were assigned.

Fig. 3. The original PLCnext learning kit

Figure 4 shows the 3D model of PLCnext in virtual environment. The important and relevant components of the controller were created in 3D models using Blender. The 3D model of PLCnext has to look realistic as much as possible for giving the trainees the maximum experience in the VR environment.
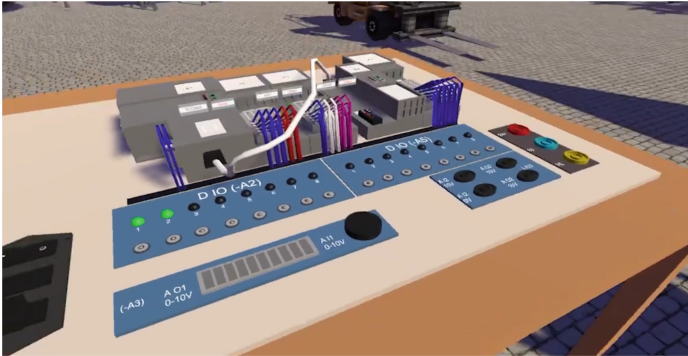

Fig. 4. The 3D model of PLCnext in virtual environment.

Other 3D models for room setup and environment were also created. This includes tables, power outlets, and boards.

3.4   Training Environment and Setup

This virtual training environment is implemented using Unity engine for interactions and functionalities. Once enter the system (Fig. 5), the trainee can navigate throughout the area using teleport function on the controllers. For preventing some uncomfortable effects or motion sickness, it is recommended to use teleport instead of walking around so much.

Fig. 5. Portal for entering the virtual training system.

A trainee can watch the tutorial video or read the information for the boards. This step can be skipped for experienced trainees. For step-by-step training, a trainee has to look to his/her right and pick up a correct device and bring it to the PLCnext Learning Kit table. After that the desired FBD programming can be pickup and put into the PLCnext for programming simulation. In this approach, the 2 basic functions of AND and OR blocks are used for the testing purpose. Figure 6 shows the tables where the devices and FBD programming locate.
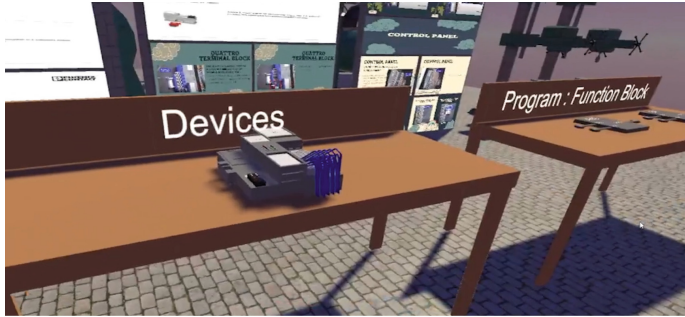

Fig. 6. Tables where devices and FBD locate.

The essential information for learning PLCnext programming is placed on the device and on the boards. A trainee has a possibility to touch the right button for getting the information. Figure 7 depicts the information pop-up and boards.

Figure 8 represents a basic FBD programming for PLCnext. In this case, the OR block is used with simple 2 Inputs and 1 Output. After putting this into the PLCnext controller, a trainee can then interact with the Inputs to see the results (Fig. 9).

For the training, a trainee has a task to assembly the necessary devices and then do the simple PLC programming. During this task, he/she can acquire information on the information board or learn from the instructional videos. After device assembly and programming, a trainee can test his/her programming by interacting with the input devices (switches) and see the output (LEDs) as a result. This instruction will let a trainee, i.e. an IT student in this case, understand the PLC programming procedure and how to evaluate the output of the system.

4   Results and Discussion

This virtual PLC training system has been tested by 16 students in major computer science and information technology. The evaluation is done in 2 parts; the training and Automation 4.0 related questions and the System Usability Scale (SUS) test. The evaluation was conducted under the controlled conditions. The students were first asked with the basic questions, trained with the virtual training system, and then answered the SUS questions.

The results of the basic questions show that most of the students participated in this virtual training system test are confident with their programming skill (68.8% admitted
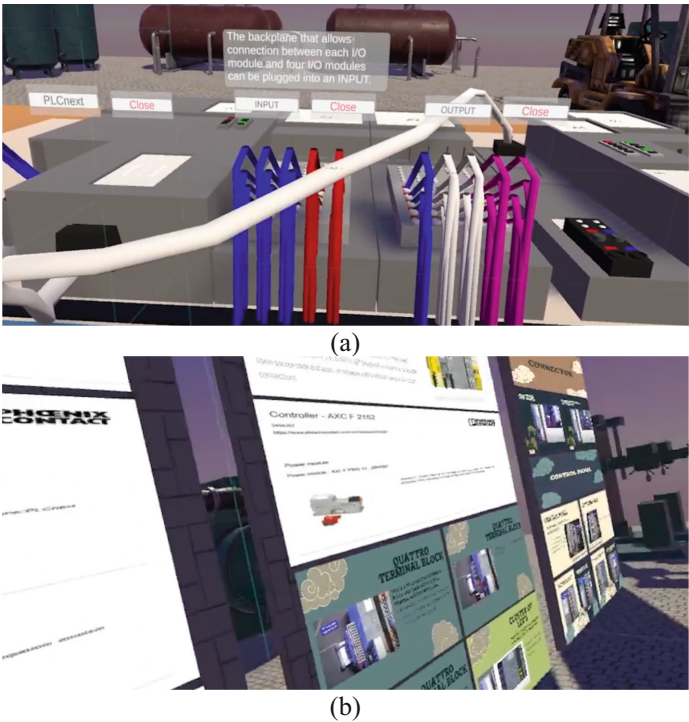
(a)

(b)

Fig. 7. (a) Pop-up Information on device, (b) PLCnext technology information board.
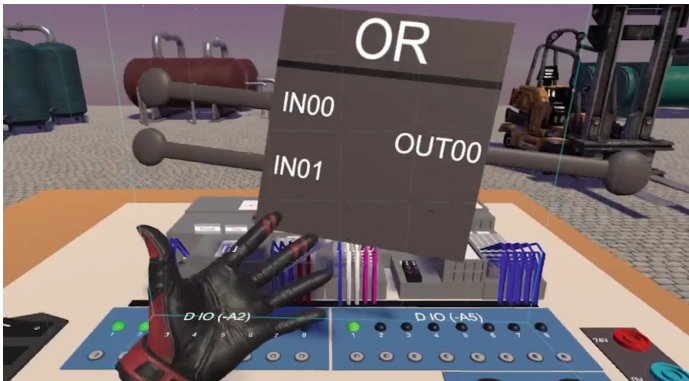

Fig. 8. Basic FBD programming for PLCnext.

better than average). 87.5% of the students know the basic of PLC but never do programming it. They do want to improve their Automation 4.0 skill for better chances in the employment market. The most interesting topics for them are, amongst others, programming, system administration, process data analysis, and PLC programming. For VR experience, 62.5% of the participated students used to use a VR device set. All of
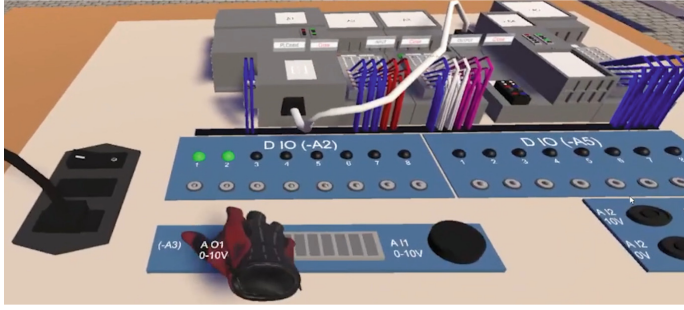
Fig. 9. Outputs testing of the basic programming.

them want to use a VR-enabled training system for better training experiences and they think a training with a VR system will improve their skills significantly.

The SUS test is a well-known method for usability measuring [14]. The method is quick and requires less cost for conducting. Furthermore, this method is tested and reliable. The SUS questionnaire includes 10 questions with 5 points on a scale of Strongly Agree (5), Agree (4), Neutral (3), Disagree (2), and Strongly Disagree (1). The total score of SUS is 100. The average score is 68. The SUS score calculation can be done using following equations:

$$X = \text{(Sum of the points for all odd-numbered questions)} - 5 \tag{1}$$

$$Y = 25 - \text{(Sum of the points for all even-numbered questions)} \tag{2}$$

$$\text{SUS Score} = (X + Y) * 2.5 \tag{3}$$

The SUS score of the proposed virtual training system for PLC training is 68.125. This score can be interpreted as Good. In this context, the virtual training system is understandable and suitable for real training in a classroom. However, a complete in classroom evaluation is still necessary to be conducted.

A qualitative evaluation based on interviews showed that most of the IT students confused with the VR equipment at first. However, after a short introduction, they could master the system professionally. After the training, most of them understand more about PLC programming procedure and they are more familiar with the devices.

5   Conclusion and Outlook

The key finding in our work is the elaborate approach of creating a hands-on PLC virtual training system for IT students who happen to familiar with programming and computer network communication. The clear structured training materials according to the pedagogical ADDIE model have improved the learning effectiveness of the students. The lack of practical activities with PLC devices was overcome with the realistic 3D models of PLCnext and environment. A trainee can practice his/her assignment as often

as he/she wishes. Not only can this virtual training system reduce the cost of buying expensive and up-to-date equipment, but also user-friendly and intuitive. Along with ADDIE model for instructional design, a virtual training system is recommended for the blended learning as well as reskill or upskill method.

The outlook of this work is to conduct the evaluation of the virtual training system for PLC training in a classroom. Other evaluation methods such as vital sign monitoring via non-invasive devices such as pulse tracking, heart rate tracking, eye tracking, etc. or activity log analysis of the user interaction with the learning contents can be considered. Furthermore, the 3D models of other devices and their functionalities have to be created for a complete training program.

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