Comparative Study on Implementation of 3D Virtual Simulator System for Manufacturing Facilities Programming Education

Hyeon-Ho Seo, Koo-Rack Park, Dong-Hyun Kim

Abstract: *Background/Objectives: The Fourth Industrial Revolution has introduced the widespread automation of facilities in production manufacturing sites through PLC(Programmable Logic Controllers). While this has led to the construction of smart factories, technology for operating manufacturing facilities is insufficient, and there is an urgent need for PLC programming education. In this regard, this paper presents a virtual simulator model for PLC programming education that uses a simulator technique.*

Methods/Statistical analysis: Extending beyond factory automation, PLC is a key component of building smart factories and plays an integral role in manufacturing. However, most platforms for PLC education are represented in 2D, contributing too many difficulties in education and training. Moreover, PLC education is not realistic in places other than large-scale educational institutions. The development of 3D virtual facility simulators using physical engines has increased with improvements in PC performance. This trend has facilitated the implementation of systems using simulators for PLC programming learning, in which manufacturing facilities can be operated without huge costs.

Findings: A type of controller widely used in the product manufacturing industry, PLC is a very effective system in terms of production cost and has proven reliable as well. This paper presents a virtual facility simulator comprising a physical engine. It consists of a simulator for displaying the correct answer for training and a simulator for displaying program written by the operator. The middleware is also configured to communicate the information of the correct answer program and inspection program to the virtual facility simulator and unique memory area. The start trigger function is embedded to enable the correct answer module and inspection module to start operation simultaneously, while the PLC Integrated Development Environment (IDE) is equipped with emulator functionality to enable program practice and testing even without a PLC. The model operates through a repeater that transmits signals between the test response module and the PLC emulator through a signal transmission module. This not only alleviates existing economic problems but also improves educational effectiveness in various aspects such as accessibility through online education, time-saving, and level of interest.

Improvements/Applications: Amidst active discussions on engineering education, future studies should investigate mounting the correct answer module in not only PLC education simulators but also simulators of various other devices.

Index Terms: *PLC Programming, Ladder Diagram, 3D Virtual Simulator, Physical Engine, Middleware.*

I. INTRODUCTION

Recently, researchers have discussed the various objectives of engineering education and suggested directions for teaching methods in real classrooms and simulation environments[1,2]. Virtual learning environments, a representative educational method, enable smooth communication when teaching and providing educational materials and are widely used in higher education[3]. In addition, computer-based educational programs have gradually expanded to complement and replace traditional educational methods in schools, while computer-based virtual simulations have been used for various purposes in engineering education[4]. With the development of web standards promoting the development and practical use of various methods for remote and electronic learning, virtual simulations have proved helpful to researchers and students who lack resources and time[5]. Hyundai introduced automation systems for many facilities in its manufacturing sites based on programmable logic controllers (PLC).

Extending beyond factory automation, PLC has become a key component of building smart factories and plays an integral role in manufacturing. However, most platforms for PLC education are represented in 2D, contributing to many difficulties in education and training. Moreover, PLC education is not realistic in places other than large-scale educational institutions. However, the development of 3D virtual facility simulators using physical engines has increased with improvements in PC performance. This technology can be used to verify PLC programs or monitor virtual facilities in environments very similar to reality. This paper proposes a system for PLC programming learning that uses a simulator technique to eliminate large cost burdens. The proposed system can reduce the cost of education and is expected to provide an environment for self-learning PLC programming by expanding access to education from offline to online.

II. RELATED WORKS

2.1 PLC

A type of controller widely used in the product manufacturing industry, PLC is a very effective system in terms of production cost and has proven reliable and flexible as well. Generally, a PLC program is written through ladder diagrams or other programming methods through a computer or portable console. The input/output port can also be extended [6]. In addition, various tasks can be programmed or reprogrammed, allowing the manufacturer to flexibly adapt to future changes [7].

The Integrated Development Environment (IDE) of PLC is a tool that can debug, compile, and download the program written in the ladder diagram to the PLC of the manufacturing company. Even if the PLC does not exist, an embedded IDE with emulator functionality must be used so that the ladder logic can be executed and compiled. In addition, it is necessary to enable access to the internal memory of the emulator to read the information of the input/output device, connecting with the 3D virtual simulator to verify the PLC program.

2.2 PHYSICAL ENGINE

In addition to the development of computer graphics, various types of technology are being developed to enhance the realism of products in the digital contents market, such as 3D games and movies. Researchers are actively studying methods to maximize realism through physics-based simulations [8, 9, 10]. The 3D virtual simulator applies a physical engine based on the 3D modeling data of the actual facilities to operate in the same way as the real world. Processors with different processing speeds can be synchronized by configuring the shared memory area between the PLC emulator and the virtual facilities. The use of 3D factory simulation software has recently expanded as a simulation analysis tool for production systems.

Workers, machinery, facilities, and raw materials that make up the actual production system are arranged in the 3D space, building a virtual manufacturing site for simulation [11].

2.3 SHARED MEMORY

In distributed asynchronous storage systems, the emulation of read-write shared memory is an active field of research in distributed computing theory [12]. Inter-process communication (IPC) is a technology that exchanges data between different processors; there are various techniques, including pipes, message queues, shared memory, and sockets. Among these technologies, shared memory, in which the memory area is directly accessed to share data, has very fast operation speeds because the two processors share memory directly without an intermediary, unlike other IPC techniques. In this paper, we classify the input / output signals of data exchanged between the 3D virtual simulator and the middleware and assign access rights to prevent collision between the two modules. (The 3D virtual simulator consists of the physical engine, while the middleware was written through the .Net Framework.)

III. THE PROPOSED SYSTEM

3.1 SYSTEM CONFIGURATION

[Figure 1] below shows the overall configuration of the proposed system for automation facility programming. It consists of largely three parts. First, the virtual facility simulator consisting of the physical engine comprises a simulator to display correct answers and a simulator to display the program created by the operator.
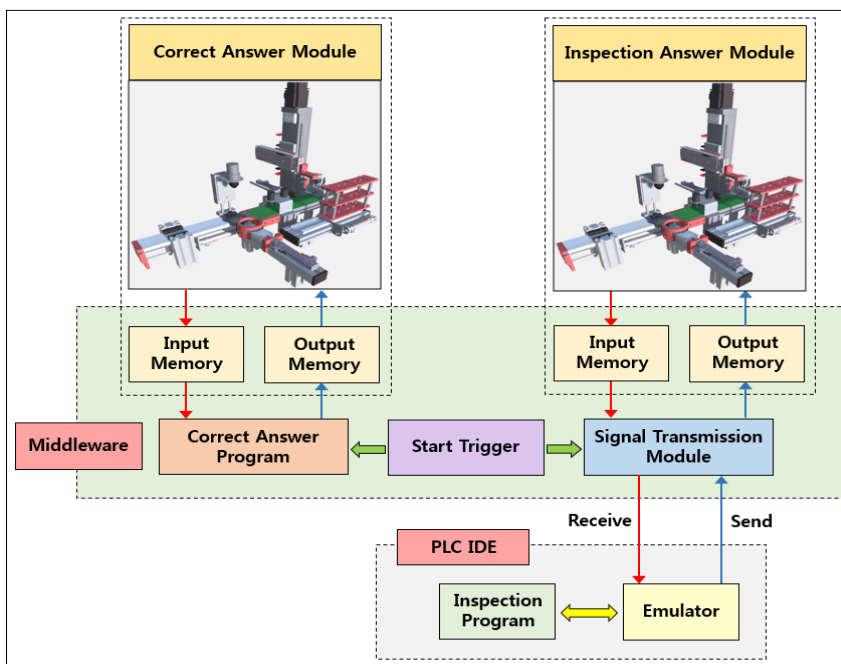

Figure 1. System Configuration Diagram

Second, the middleware transmits information of the correct program and the inspection program to the memory area to be shared with the virtual facility simulator. In addition, the start trigger function is embedded to enable the correct answer module and inspection module to start operation simultaneously.

Third, the PLC IDE includes emulator functionality to enable practicing and testing without the PLC.

3.2 SYSTEM PROCESS

As shown in [Figure 2], the correct answer program and PLC program start operation simultaneously by the trigger signal embedded in the middleware and deliver the input and output signals to the two virtual facility modules through the shared memory, respectively.
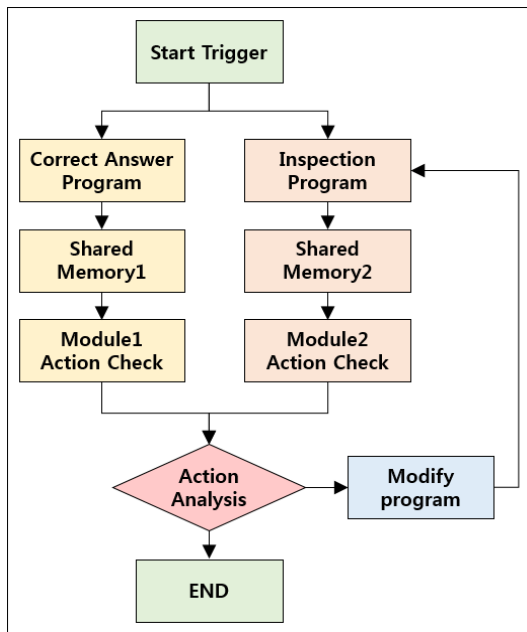

Figure 2. System Process

At this time, when the operation order and operation timing of the two virtual facilities differ, the learner can visually confirm this fact in real time and correct the program based on the current analysis results, reflecting this in the PLC.

3.3 MIDDLEWARE CONFIGURATION

[Figure 3] below shows the configuration of the middleware used in the system.
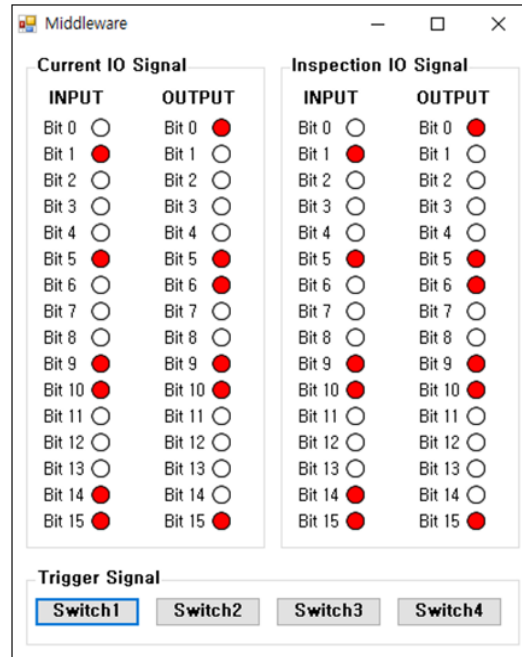

Figure 3. Middleware Configuration

It enables access to the shared memory of each module, allowing the learner to visualize the data in the shared memory. Additionally, the two modules can be activated simultaneously through the trigger switch embedded in the middleware, allowing operation analysis to be smoothly conducted.

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3.3.1   SIGNAL TRANMISSION MODULE

As shown in [Figure 4], the signal transmission module transmits signals between the inspection answer module and the PLC emulator through a repeater.
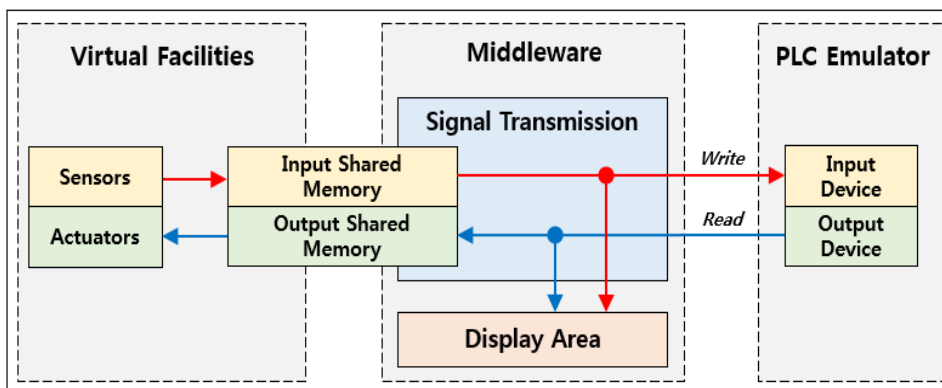
Figure 4. Signal Transmission Module Configuration

The transmitted signal unit is based on 16-bit (1WORD) size data, which is commonly used in PLCs. The uses of input and output are classified into different blocks. The signal transmission module first reads the memory area in which the sensor signal is stored among the shared memory blocks of the virtual facility simulator and displays it in 1-bit units in the middleware. At the same time, the input signal of the virtual facility simulator is transmitted to the input device area of the PLC through the API function provided by the PLC emulator. Afterwards, the data read from the output device of the PLC is visibly displayed in the middleware, and the data is transmitted to the actuator memory area to be read by the virtual facility simulator.

3.3.2 CORRECT ANSWER PROGRAM

The correct answer program is a virtual emulator that operates inside the middleware with a separate thread. It shares data with the virtual facilities that display the correct answer and is pre-mounted with a correct answer algorithm.
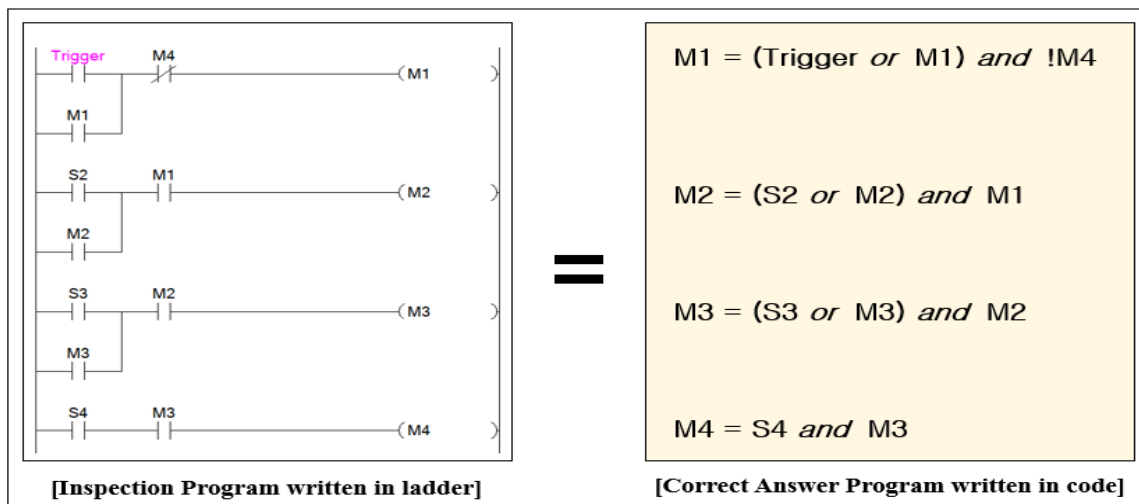
Here, the correct answer algorithm can be written in various languages. However, as the ladder configuration used in the PLC differs, the correct answer program must be converted to ladder code in order to operate the two virtual facilities equally.

[Figure 5] below shows an example of translating a program written in ladder into PC language.

$$M1 = (Trigger \ or \ M1) \ and \ !M4$$

$$M2 = (S2 \ or \ M2) \ and \ M1$$

$$M3 = (S3 \ or \ M3) \ and \ M2$$

$$M4 = S4 \ and \ M3$$

[Inspection Program written in ladder]   [Correct Answer Program written in code]

Figure 5. LADDER Language Conversion Example

IV. RESULTS AND DISCUSSION

[Figure 6] below shows the 3D virtual simulator used in the experiment. It reproduces based on the MPS system drawing used for the national qualification skill test. The experimental group received education with both the correct answer module and the inspection answer module mixed, while the control group only used the inspection answer module.
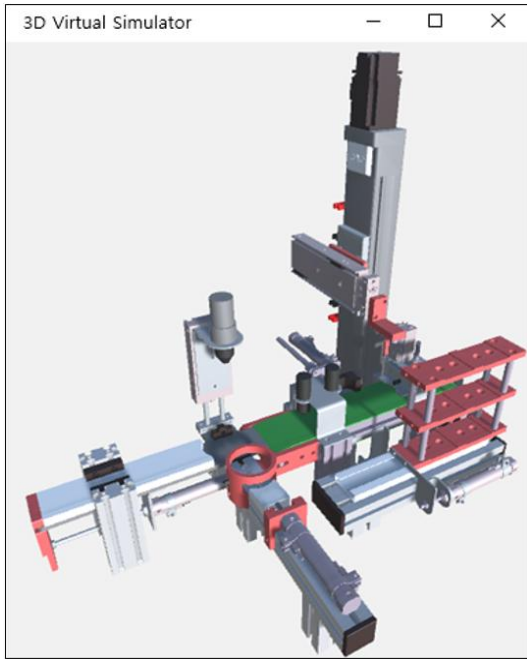
Figure 6. 3D Virtual Simulator with MPS System

In this comparative study, we conducted experiments for two groups: the experimental group consisting of vocational education students who received training using the proposed system, and the control group in which the participants were trained through the system excluding the correct answer module functionality. Each group comprised 20 participants.

We conducted a pre-evaluation before training to compare the homogeneity of the two groups, which included an overview of the automation system, the basics of electricity, and an evaluation of mathematical ability. The results of the pre-evaluation of the two groups are shown in [Table 1] below.

Table 1: Pre-evaluation results of the two groups

Group	Number of members	Mean	Standard deviation
Control group	20	20.25	9.93
Experimental group	20	20.5	9.89

Second, four hours of programming education using the same curriculum and two evaluations were conducted for the two groups at intervals of 5 days.

As shown in [Table 2] and [Table 3], the experimental group showed higher average scores than the control group in both evaluations; in particular, the experimental group showed a distribution in a relatively high score group compared to the control group.

Table 2: Mean and SD of first and second evaluation for each group after training

Group	Number of members	First evaluation		Second evaluation	
		Mean	Standard deviation	Mean	Standard deviation
Control group	20	65.20	14.63	71.90	15.50
Experimental group	20	79.25	12.84	79.25	12.44

Table 3: Mean score distribution of first and second evaluation for each group after training

Score range	First evaluation		Second evaluation	
	Control group	Experimental group	Control group	Experimental group
40-49	3	0	1	0
50-59	4	2	3	1
60-69	5	3	5	4
70-79	4	6	5	6
80-89	3	5	2	4
90-100	1	4	4	5
Sum	20	20	20	20

V. CONCLUSION

In recent years, many modern manufacturing sites have adopted facilities using PLC-based automation systems. Though a key component in building smart factories, PLC training is difficult to implement. This paper proposed a system for PLC programming education that uses simulators to avoid large expenses. A variety of previous studies have introduced techniques for simulating and monitoring virtual facilities using physical engines and PLC emulator functionality.

We combined these methods with educational techniques to implement 3D virtual simulation, through which we expect to improve education on various fronts, from economic feasibility and students' level of interest to accessibility and time savings through online education. The experimental results of the proposed virtual simulator show that the experimental group is more effective than the control group, which did not use the correct answer module.

This result indicates that in PLC virtual simulation education, systems equipped with a correct answer module are more effective. Future studies should investigate mounting the correct answer module in not only PLC educational simulators but also simulators of various other devices.

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AUTHORS PROFILE

Hyeon-Ho Seo Received the B.S. Mechatronics Engineering in 2013. Master's Course in IT Convergence at Kongju National University, Cheonan, Korea. Currently, he is working as a software team leader at METIS corporation. His research interests include Computer Simulation, Multimedia Application, Smart Factory, Computer Vision System and IT Convergence.

Koo-Rack Park Received the B.S. in Electronic Engineering from Chung-Ang University, Seoul, South Korea, in 1986 and the M.S. in Computer Science and engineering from Soongsil University, Seoul, Korea, in 1988. He received Dr. Degree of Computer Science from Kyonggi University, Suwon, Korea, in 2000. Currently, he is a Professor in the Department of Computer Science and Engineering at Kongju National University, Cheonan, South Korea. His research interests include Multimedia, Electronic Commerce, Simulation, Crime Prediction, Predictive Modelling, and IT Convergence.

Dong-Hyun Kim Received the B.S. in Electronic Engineering from Chung-Ang University, Seoul, South Korea, in 1986 and the M.S. degree in Computer Multimedia Engineering from Kongju National University, Gongju, South Korea, in 2005. He received the Ph.D degree of Computer Engineering in 2010 from the Kongju National University, Cheonan, South Korea. His research interests include Image Processing System, Geographic Intelligence, Computer Simulation, and Multimedia Application.