

VIRTUAL LABORATORY FOR SUPPORTING COURSE OF INDUSTRIAL AUTOMATION

¹Aditya Tirta Pratama[†], ²Daffa Harindah La Fanny Darwin, ³Tanika Dewi Sofianti

Faculty of Engineering and Information Technology,
Department of Industrial Engineering, Swiss German University
The Prominence Tower Alam Sutera, Jl. Jalur Sutera Barat. No. 15,
Kota Tangerang, Banten, 15143

¹aditya.pratama@sgu.ac.id[†], ²daffahaldwin@gmail.com, ³tanika.sofianti@sgu.ac.id

Abstrak

Perkembangan pesat dalam revolusi industri 4.0 memiliki pergeseran kebutuhan dalam pendidikan. Dosen jurusan teknik industri Swiss German University diharapkan mampu membawa inovasi berbasis teknologi untuk mencapai keberhasilan dalam pembelajaran. Sejak maraknya pandemi Covid-19 di mana segala aktivitas dibatasi oleh protokol kesehatan, kebutuhan transformasi laboratorium fisik menjadi konsep virtual semakin meningkat. Penelitian ini bertujuan untuk menganalisis laboratorium virtual khususnya untuk menunjang kegiatan pembelajaran otomasi industri. Mesin virtual digunakan untuk menduplikasi mesin nyata yang berjalan di lingkungan simulasi. Software open source seperti OpenPLC dan Node-RED digunakan sebagai sarana bagi mahasiswa untuk belajar dan mempelajari tentang otomasi industri. Proyek akhir semester telah dikerjakan oleh sekelompok mahasiswa dengan memanfaatkan laboratorium virtual ini, dan kemudian hasil evaluasi pelaksanaan mata kuliah ini dilakukan berdasarkan respon mahasiswa dari penilaian perkuliahan pada mata kuliah otomasi industri. Selain itu, berdasarkan uji penerimaan pengguna modul Node-RED, 44,4% peserta menilai cukup baik, 44,4% lainnya menilai baik, dan 11,1% peserta menilai sangat baik. Hasilnya, laboratorium virtual dapat secara efektif dan efisien mendukung transfer pengetahuan kepada mahasiswa.

Kata Kunci: laboratorium virtual, otomasi industri, OpenPLC, Node-RED, Industri 4.0

Abstract

Fast developments in industrial revolution 4.0 have necessities in a shifting of education. Lecturers in the industrial engineering department of Swiss German University are expected to bring technology-based innovation to achieve success in learning. Since the rise of the Covid-19 pandemic, where all activities are restricted by health protocol, the need for physical laboratory transformation into a virtual concept has increased. This research aims to analyse a virtual laboratory especially for supporting the learning activity of industrial automation. The virtual machine duplicates the real machine running in a simulated environment. Open-source software such as OpenPLC and Node-RED are used as tools for students to study and learn about industrial automation. A group of students did the final project by utilizing this virtual laboratory and then the final evaluation of course performance was carried out based on the students' responses from the lecture assessment on the course of industrial automation. In addition, based on the user acceptance test of Node-RED training modules, 44.4% of participants consider good enough, another 44.4% consider great, and 11.1% of participants consider excellent. As a result, the virtual laboratory may effectively and efficiently support the knowledge transfer to the students.

Keywords: virtual laboratory, industrial automation, OpenPLC, Node-RED, Industry 4.0

INTRODUCTION

The digital transformation of manufacturing/production and related industries, as well as value creation processes, is known as industry revolution 4.0 or Industry 4.0. Common characteristics of the Industry 4.0 are identified from the increase in digitalization of manufacturing which is driven by four factors such as increased data volume, computational power, and connectivity; the emergence of analytics, capabilities, and business intelligence; the occurrence of new forms of interaction between humans and machines; and improvements in digital transfer instructions to the physical world [1]. In principle, the needs of integration for machines, workflows, and systems by implementing intelligent networks to control each other independently is the essence of Industry 4.0.

Covid-19 has invaded many countries which infected and killed millions of people. When the pandemic of Covid-19 broke out, massive effects were impressed upon the health sector, exhausting the health care system, disrupting the education system, bringing harm to business and economy, and other fields [2]. With the restriction of face-to-face learning as normal, learning from home through certain applications, online lectures/advisories, and online seminars/workshops/trainings are examples of educational services that accelerate the application of education in the Industry 4.0 era. In addition, both students and lecturers are encouraged to understand the

use of digital technology or interactive media to support the teaching and learning activities.

There are several technologies relevant to the future of education such as distance learning, e-learning, virtual laboratories, and dynamics based virtual systems. Technology in the form of advanced applications has been incorporated into various learning activities, including virtual laboratories performance and training students to learn independently [3][4]. A virtual laboratory is a computer-based activity where students interact with an experimental apparatus or other activity via a computer interface [5]. A virtual laboratory can be a pre-practicum tool before students carry out the real practicum in a conventional laboratory. In its use, virtual laboratories have a good impact on student development. Virtual laboratories make it easier for students to connect theoretical and practical aspects [6]. The virtual laboratory developed in this study contains additional material related to industrial automation competencies.

Industrial automation is a course primarily designed for engineering students at advanced undergraduate level, especially in industrial engineering, so they can learn the automation and production systems technologies in modern manufacturing. In this course, students learn the concept and various example of implementation related to automation or robotics such as material handling, quality system, manufacturing system, and manufacturing support system. The main problem of this research is students

cannot conduct the experiments due to limited physical equipment and activities' restrictions during the Covid-19 pandemic. This research will analyse the virtual laboratory for students to learn about PLC as part of the basic element of automation, and Node-RED for students to learn about workflow of IoT in industrial level. PLCs are widely used and important in industrial automation to increase reliability, stability, and performance of production equipment. Meanwhile, the integration of several PLC's and data gathering from the sensors will be handled by Node-RED.

In this section, several prior references will be explained for state of the art.

1. Virtual Laboratory

The virtual laboratory can be used as a supplement to the conventional laboratory to enhance the knowledge of the students [7]. In addition, the virtual laboratory can be more economical compared to conventional laboratory due to elimination of equipment,

staff, maintenance and operating cost [8]. A case study in China showed that virtual laboratory can be used as new pedagogical tool for undergraduate student [9]. By measuring the course outcome, the virtual laboratory can improve the understanding and enrich students' knowledge [10].

2. Industrial Automation

Industrial automation is defined as the use of computer systems and artificial intelligence in place of humans in different industries [11]. Industrial automation provides high quality and flexibility, as well as enhancing the productivity as well as safety of the system. Industrial automation is set of technologies that results in operations of industrial machines and systems without significant human intervention and achieves performance superior to manual operation [12]. Based on ISA-95/IEC-62264, industrial automation can be described in four levels as shown in Figure 1.

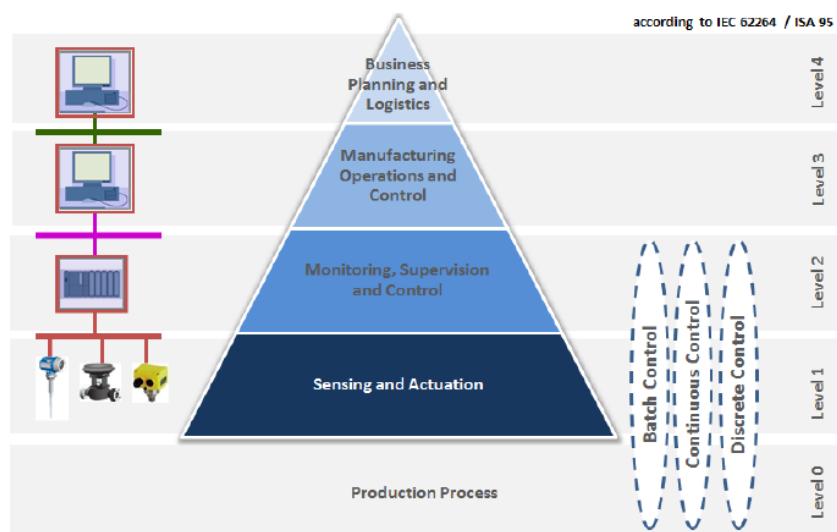


Figure 1. Functional hierarchy according to IEC 62264/ISA 95 [13]

Level 0 is a sensor and actuator that directly interacts with the process of the machine. Level 1 is an automatic control and Level 2 is a supervisory control. Level 3 production control which is responsible for maintenance, production, quality, inventory, etc. Level 4 enterprise is mainly concerned with management functions, sales, marketing, etc

Especially for Level 1 and level 2, communications are commonly connected through either point-to-point cabled solutions (4–20mA current loop) or through fieldbuses (Modbus, Profibus, etc.). Ethernet and serial connections are used to an increasing extent as well. Fieldbuses and Ethernet can give an impression of a standard solution but the data exchange protocol on top of them is often proprietary. Figure 2 shows the diversity of data and interfaces in industrial automation.

3. OpenPLC

OpenPLC is integration of PLCOpen Editor and MatPLC compiler on a complete PLC package, with support of open source hardware and popular SCADA protocol [15]. MatPLC is the most prominent open source PLC. MatPLC behaves like a soft-PLC on POSIX compliant operating systems and is composed of several modules, each of which is executed on a different thread. Although MatPLC became the foundation of an open source PLC, few things are still missing where the program lacks an interface with the programming IDE, a hardware platform to run it with built-in physical I/O and support for ladder logic. One of the tools provided with the MatPLC is the MatIEC Compiler [16]. An Integrated Development Environment (IDE) was developed for IEC 61131-3 framework called PLCOpen Editor [17].

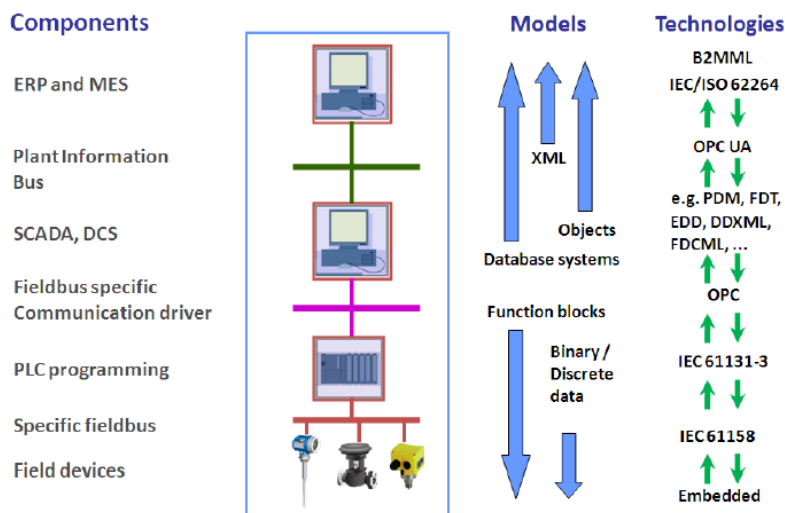


Figure 2. Diversity of data and interfaces [14]

The IDE consists of a Graphical User Interface that allows the development of programs in any of the programming languages defined in IEC 61131-3. Additionally, the IDE also has a backend compiler that can generate IEC 61131-3 Structured Text code out of the user program. PLCOpen Editor was created mainly to allow students to use an IEC 61131-3 programming environment on their own personal computers and practice with the language, without having to pay expensive license deals from existing vendors.

The OpenPLC has many other functions to perform, such as communication over Ethernet for MODBUS-TCP supervisory systems, RS-485 and USB, individual modules control, error messages generation and so on. MODBUS is an industry standard protocol for automation devices. Although, the message format is maintained, there are some variations of this protocol depending on the physical interface it will be used on. As the OpenPLC has Ethernet over TCP-IP, its implementation was supported for the MODBUS-TCP protocol [18].

OpenPLC Runtime and OpenPLC Editor are the two components that make up OpenPLC. The Runtime is portable software made to work on everything, from an 8-bit AVR in an Arduino board to a 64-bit Xeon in a server rack, or from the smallest microcontrollers to robust cloud servers. It is in charge of carrying out the PLC programs that are written using the OpenPLC Editor. Currently, OpenPLC Runtime can be

supported on the platform of ESP8266, Arduino family, UniPi Industrial Platform, and so on. In addition, all Linux & Windows versions are targeted only as generic soft-PLC [19].

4. Node-RED

Node-RED is an open source flow-based development tool for the integration of IoT hardware devices, APIs (application programming interfaces) and online services developed by IBM Emerging Technology [20]. Node-RED is a free JavaScript-based tool, built on Node.js platform, which provides a visual browser-based flow editor. The system contains nodes that are represented by appropriate icons. It can operate in two ways: drag, drop and wire up nodes, or import JavaScript code. Node-RED enables developers to wire up input, output and processing nodes in order to create flows for data processing, controlling things, or sending alerts [21]. It works on the following principle: it enables the connection of web services or customizes nodes to one another or to things, in order to perform functions such as sending sensor data via e-mail or to services like Twitter, easily performing complex analysis, etc.

The minimum general specification for running Node-RED in general can be described as follows: at least 1st generation of Raspberry Pi, 512 MB of memory, few GiB storage, and network connection. Node-RED

can run in Debian-based operating system, RPM-based operating system, and Windows [22].

5. LMS

E-learning makes use of computer and internet technologies to reach and engage more individuals, particularly those who are unable to attend traditional classroom instructions due to their location or circumstances. E-learning focused more on developing human cognitive skills through knowledge sharing and applying knowledge or method to solve the problems [23].

The Learning Management System (LMS) is an online platform that connects educators and learners. The LMS itself helps in easy exchange of classroom materials and activities. It's also a platform that enables teachers and students to engage outside of the classroom, via forums, to have discussions that otherwise take up time that could be spent learning and teaching [24]. The Learning Management System (LMS) is a software program that is used for educating, training, monitoring, reviewing, providing educational materials, and overall management [25].

Moodle is the most popular and preferred open-source LMS. Moodle has a high rate of acceptance in the community and in many institutions and has a wide variety of active courses, available in many languages [26][27]. A recent study that determined the

effect of LMSs on students' performance in educational measurement and evaluation recommends that LMSs such as Moodle should be learnt and used by lecturers [28].

The basic requirements for Moodle are as follows: 200MB disk space for the Moodle code, plus as much as you need to store content. 5GB is probably a realistic minimum, processor of 1 GHz (min), 2 GHz dual core or more recommended, memory of 512MB (min), 1GB or more is recommended. 8GB plus is likely on a large production server. Moodle is primarily developed in Linux using Apache, PostgreSQL/MySQL/MariaDB and PHP. Meanwhile, if it is installed in a Windows with php5.5 onward, the Visual C++ Redistributable for Visual Studio 2012 is required [29].

RESEARCH METHOD

System Description

The fundamental requirement of e-Learning platforms is to make contents accessible on the web and give to students a privileged communication channel with didactic tutors and teachers [30]. Figure 3 shows the system structure of the virtual laboratory. The students from each group can access the virtual machine for web-based applications from their home or anywhere as long as the internet connection is available. Each group consists of 4 or 5 students, and they can access the virtual machine simultaneously.

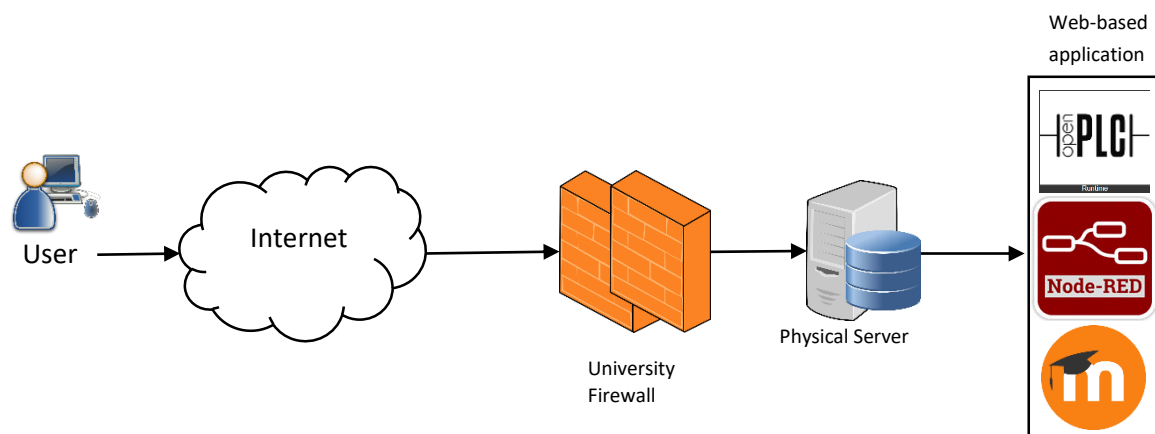


Figure 3. System Structure of Virtual Laboratory

In this virtual laboratory, the hardware for physical server must be reliable, especially in server uptime. The hardware of physical server is using HPE ProLiant ML110 Gen10 4108, with Xeon Silver 1.8 GHz, 8 cores, 16 GB RAM, and 2 TB storage. This server is connected to the internal university network with firewall in a separated machine to protect the system security from external attacks and preserve the performance of virtual server. VMware® is used as the virtualization framework of the server which supports 64-bits architecture and using hardware CPU virtualization provided by Intel®.

Figure 4 shows the configuration of the virtual machine on the physical server. On VM-1, the openPLC and Node-RED are only one session, therefore each group must access the VM-1 according to the determined schedule. Students can also install the

openPLC and Node-RED on their own laptops. VM-2 is the ELMS and multiple students can access the materials, assignments, quizzes, and so on with a maximum of 30 students accessing at the same time. VM-3 was specially dedicated for other tools (e.g. statistics, discrete event simulation, system dynamics, agent-based simulation, etc.). VM-3 is not utilized in this research.

Virtual machine is used as an efficient and isolated duplication of a real machine. In the virtual machine, Linux Debian 10 64-bit, Apache, MySQL/MariaDB and PHP are installed. Then, all web-based applications (OpenPLC, Node-RED, and Moodle) are installed and configured in the virtual machine. Figure 5 shows the system layer of the virtual laboratory.

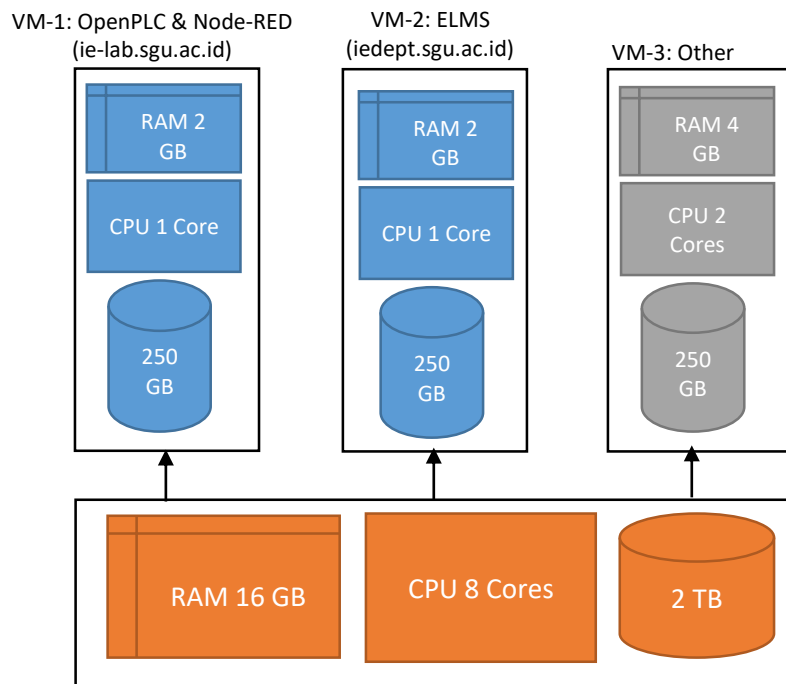


Figure 4. System Structure of Virtual Laboratory

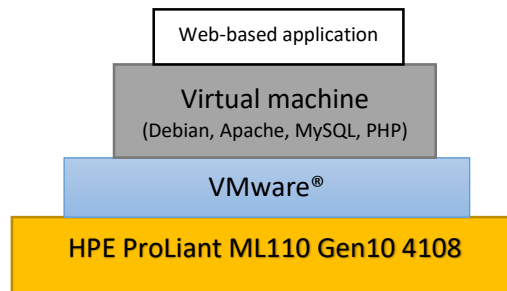


Figure 5. System layer of the virtual laboratory

RESULT AND DISCUSSION

Implementation of virtual laboratory was done by dividing the students into several groups. Each group will try to explore and integrate the application of OpenPLC and Node-RED as part of Industrial Internet of Things (IIoT), then documented in the form of experiment modules. The runtime of OpenPLC will be deployed at the virtual server, and can be used by students for

executing their PLC program. Figure 6 shows the dashboard of OpenPLC Runtime.

For developing and simulating the PLC program by using ladder logic diagram, OpenPLC Editor can be used and run in each student's PC/Laptop. Students will collaborate in each group for developing the PLC program. Figure 7 shows the example of input and output in the OpenPLC Editor, while Figure 8 shows the example of ladder programming used in the OpenPLC Editor.

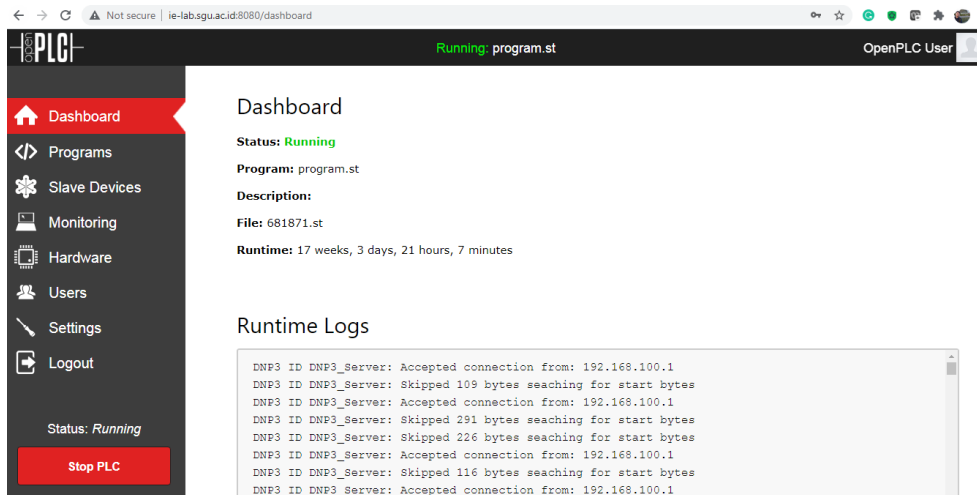


Figure 6. OpenPLC dashboard

#	Name	Class	Type	Location	Initial Value	Option	Documentation
1	Pushbutton2	Local	BOOL				PB2
2	Pushbutton3	Local	BOOL				PB3
3	Pushbutton4	Local	BOOL				PB4
4	Pushbutton5	Local	BOOL				PB5
5	Emergency	Local	BOOL				Emergency
6	Relay	Local	BOOL				coil 1
7	LED3	Local	BOOL				LED3
8	LED4	Local	BOOL				LED4
9	Pushbutton1	Local	BOOL				PB1
10	LED1	Local	BOOL				LED
11	LED2	Local	BOOL				LED2
12	LED5	Local	BOOL				LED5
13	LED6	Local	BOOL				LED6
14	TON0	Local	TON				
15	TOF0	Local	TOF				

Figure 7. Example input and output in the OpenPLC Editor

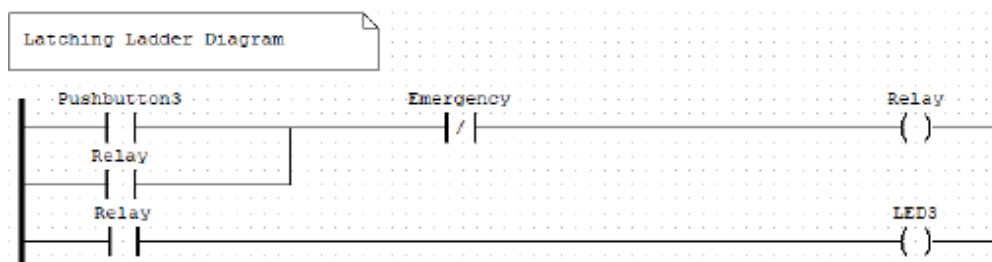


Figure 8. Example of ladder programming in the OpenPLC Editor

An experiment module on communication between Node-RED and MQTT was developed by each group of the students. In this module, the HMI of Node-RED will be used to display the condition from the sensor.

Figure 9 shows the Node-RED editor windows which contain four main components: header, palette, workspace, and sidebar.

The header on the top contains the deploy button, main menu, and user menu if

the user authentication is enabled. The palette in the left contains the available nodes that can be utilized by the user. The workspace in the middle is the area where the flows are created, and sidebar at right side is used to bring information about the palette or flows that currently being developed, and displays

message to debug nodes within the flow, as well as log messages from the runtime.

The dashboard board can be developed by utilizing and configuring the Node-RED palettes in the workspace. Figure 10 shows an example of user interface from Node-RED for indicating or changing the gauge.

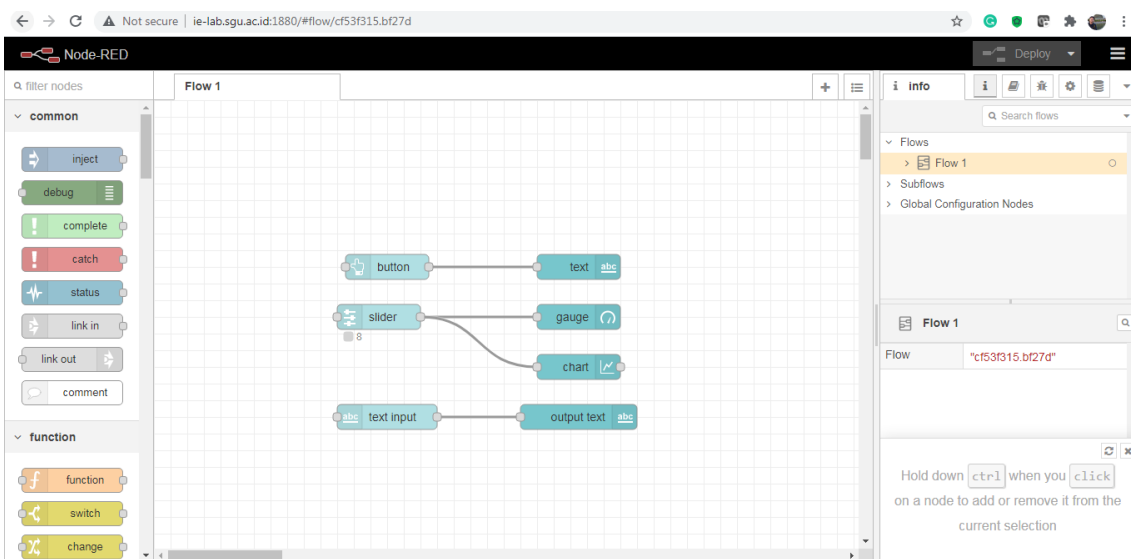


Figure 9. Node-RED editor window

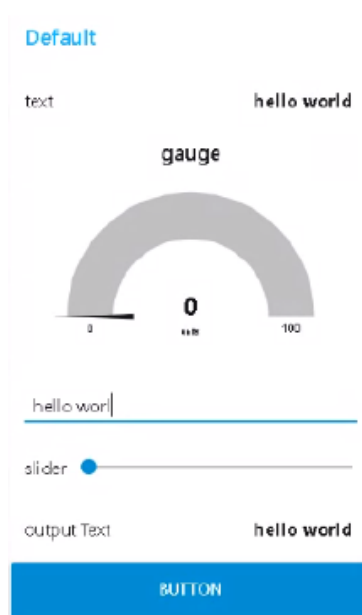


Figure 10. Example of Node-RED human machine interface

In addition, LMS (Learning Management System) has been prepared to support students learning Node-RED. Table 1 shows the topics on Node-RED E-learning that can be separated into three main courses: Beginner, Intermediate, and Advanced.

Figure 11 shows that the visual of the LMS dashboard where students have access to e-learning. Students can access and study the available Node-RED modules. The modules are delivered in text with some explanations of

the content.

For instance, a topic that explains about the palettes and flows of the Node-RED by showing an example of figures of the palettes or flows, so that students can see the visual configuration of the Node-RED's palettes and flows in the workspace. In addition, a short-answer quiz is given to test students' understanding about the learning content that they have learned from the provided learning content in the LMS.

Table 1. Course Divisions for the Node-RED E-learning

Beginner	Intermediate	Advanced
Introduction to Node-RED		
Installing Node-RED on some systems such as Linux, Windows, and Raspberry Pi	Applying Dashboard on Node-RED	Communication Protocol Programming such as MODBUS-TCP and MQTT
Understanding the fundamental knowledge of Node-RED		
Creating a simple model based on the previous chapter: Understanding the fundamental knowledge of Node-RED		

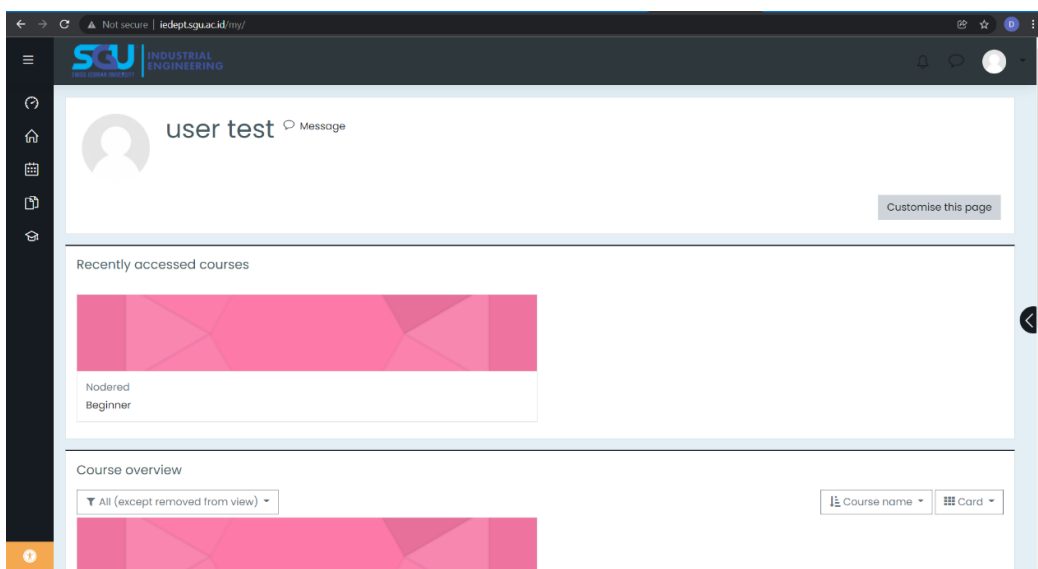


Figure 11. Visual of the LMS dashboard as a student

Table 2. Lecturer assessment on course of Industrial Automation

Respondent	Q01	Q02	Q03	Q04	Q05	Q06	Q07	Total Score
1	4	4	4	4	4	5	4	4.14
2	4	4	4	4	4	4	4	4.00
3	4	4	4	4	4	4	4	4.00
4	5	5	5	4	5	5	4	4.71
5	5	5	5	5	5	5	5	5.00
6	4	3	3	4	4	3	4	3.57
7	4	3	4	5	3	5	4	4.00
8	1	1	1	1	1	3	1	1.29
9	4	3	4	3	3	4	3	3.43
10	4	3	3	3	4	4	3	3.43
11	5	5	5	5	5	5	5	5.00
Average	4.00	3.64	3.82	3.82	3.82	4.27	3.73	
Total Score Average								3.87

Note:

- Q01. Attendance/punctuality in class
- Q02. Clear and understandable explanation
- Q03. Class control (ability to manage the class)
- Q04. Teaching materials provided
- Q05. Prompt feedback (quizzes, assignment)
- Q06. The usage of proper English Language
- Q07. Online learning teaching method

*)Scale 1-5

Lecturer assessment is used by the Department of Industrial Engineering – SGU as an evaluation instrument to assess lecturer performance. Lecturer assessment is used to figure out how the students respond to the course of Industrial Automation which is associated with the implementation of the virtual laboratory, There are 11 students who participated in the lecturer assessment with the results as seen on Table 2.

Based on Table 2, the highest total score (5.00) is given by two students, while the lowest total score (1.29) is given by one student. The average of total score for the

Industrial Automation course is 3.87. Since the implementation of virtual laboratory is part of group project, then Q05 and Q07 can be interpreted as the impact of the implementation for this course. In Q05, the highest score and the lowest score are 5 and 1 respectively, with an average of 3.82. In Q07, the highest score and the lowest score are 5 and 1 respectively, with an average of 3.73.

Furthermore, a user acceptance test has been used to review the virtual laboratory through a survey or questionnaire. The questionnaire is based on the e-learning platform's user experience such as the well-

being of the design, attractiveness, simplicity, and the overall quality of the e-learning platform. There are nine respondents for the questionnaire with 62.5% of the respondents from the Department of Mechanical Engineering with concentration in Mechatronics and 37.5% of the respondents from the Department of Industrial Engineering. The purpose of well-being of the design is to show how good the design of the e-learning for the user to navigating the platform, as shown in Figure 12.

The nine responses are quite varied. Five out of nine (55.6%) are answered on the scale of four which is slightly good, then the three out of nine (33.3%) are answered on the scale of five that is good. One out of nine

(11.1%) is answered on the scale of six which is terrific. To sum up how well the design is, the design of the platform looks good for the user.

The attractiveness of platform must be measured to pique the user interest to navigating the e-learning platform, as shown in Figure 13. According to the Figure 13, one out of nine (11.1%) replied that the attractiveness of the design is slightly bad, two out of nine (22.2%) replied slightly good for the attractiveness of the design, followed by the six out of nine (66.7%) replied good for the attractiveness of the design. Therefore, the attractiveness of the e-learning design platform looks good for the user.

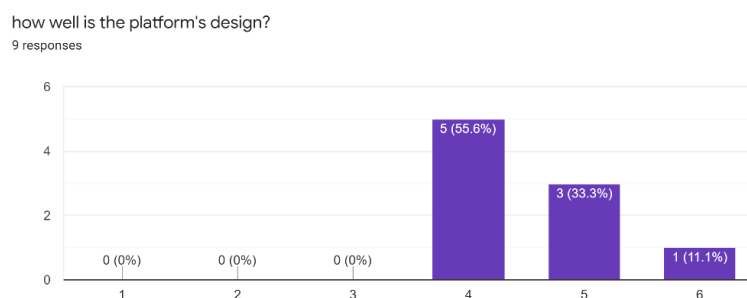


Figure 12. Result of the E-learning's Platform Well-being Design

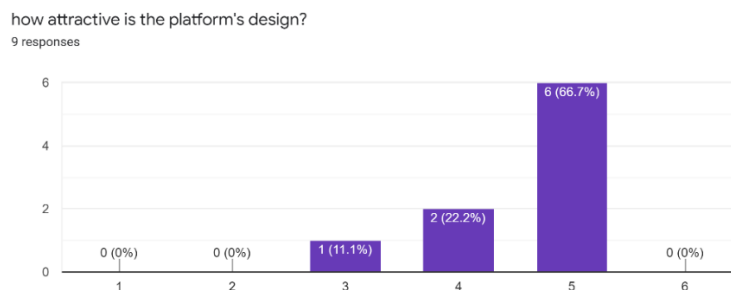


Figure 13. Result of E-learning Platform's Design Attractiveness

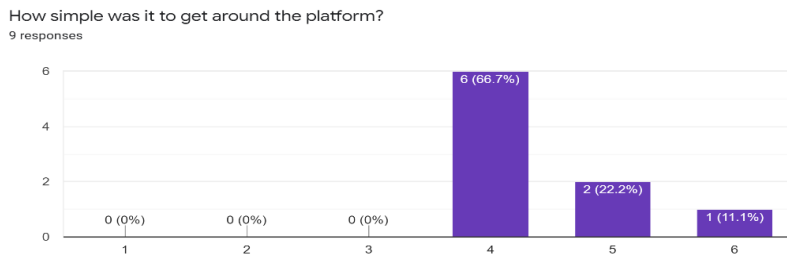


Figure 14. Result of E-learning's Platform Simplicity.

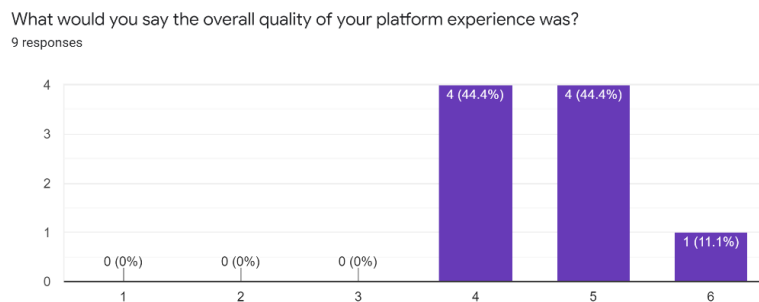


Figure 15. Result of the E-learning Platform's Overall Quality

The simplicity is imperative for the user's experience to use the e-learning platform without trouble. The simplicity's result of the e-learning platform can be seen in Figure 14.

Figure 14 shows that the e-learning platform is simple to use for the nine responses. Six out of nine (66.7%) responded that the simplicity of the e-learning platform is slightly good, then the two out of nine (22.2%) responded that the e-learning platform's simplicity is good, followed by the one out of nine (11.1%) responded that the simplicity of the e-learning platform is terrific. Therefore, the simplicity of the e-learning platform is simple to use for the responses so that the user can explore the e-learning platform without trouble.

Figure 15 shows the overall quality of the e-learning platform's experience. The scale

begins from one to six which leads from poor to terrific result. the four out of nine responses (44.4%) answered that the overall quality is slightly good, and four out of nine responses (44.4%) answered good for the overall quality. Then the one out of nine (11.1%) answered terrific for the overall quality of the e-learning platform. Moreover, the overall quality of the e-learning platform for the user experience is good and decent to explore inside the platform.

CONCLUSION AND RECOMMENDATION

In this paper, the e-learning experience using virtual laboratory is presented as part of Industrial Automation course. The virtual laboratory was implemented as part of a group project, so that students can try to explore and integrate the applications related to industrial automation.

This research has been completed, in that it interpreted the results of the lecturer assessment and user acceptance test. The lecturer assessment indicates that students respond positively to the course of Industrial Automation which is associated with the implementation of the virtual laboratory. Meanwhile, the user acceptance test indicates the modules for industrial automation has been a success for the overall result. The e-learning is accepted and it successfully supports knowledge sharing to the learners effectively and efficiently. The user acceptance test was done to measure how effective and efficient the e-learning system is for knowledge sharing. The questionnaire was constructed, which is about the well-being of the design, attractiveness, simplicity, and overall quality. The results showed that e-learning is successful in facilitating good quality learning to the students. Overall, the participants are satisfied with the e-learning performance and they think that e-learning is useful and effective for their study. In general, e-learning can be implemented and used by any organization as a standardized learning source and platform.

During the discussion and feedback from students, CodeSYS can be used as an alternative for learning and simulating the PLC program, since OpenPLC is an open source software with limited support. Codesys is a development environment for programming controller applications according to the international industrial standard IEC 61131-3.

In addition, the palettes of Node-RED need more exploration and can be used for many applications related to the Internet of things (IoT). For example, how Node-RED can communicate with various protocols, such as OPC-UA, http, udp, etc. Developing other modules that can integrate the Dobot Magician arm robot with Node-RED that can work together with Vision Kit or Conveyer Belt Kit can also be conducted as further improvement.

REFERENCES

- [1] S. Maria, D. C. Darma, S. Amalia, Y. P. Hakim, and T. Pusriadi, "Readiness to face industry 4.0," *International Journal of Scientific & Technology Research*, vol. 8, no. 9, pp. 2363–2368, 2019.
- [2] "Advice for the public on covid-19," *World Health Organization*. [Online]. Available: <https://www.who.int/emergencies/diseases/novel-coronavirus-2019/advice-for-public>. [Accessed: 25-July-2021].
- [3] A. Paolini, "Enhancing Teaching Effectiveness and Student Learning Outcomes.," *Journal of effective teaching*, vol. 15, no. 1, pp. 20–33, 2015.
- [4] J. Ramírez-Romero, D. Rodriguez, and S. Rivera, "Teaching using a synchronous machine virtual laboratory," *Global Journal of Engineering Education*, vol. 22, no. 2, pp. 123–130, 2020.
- [5] P. A. Hatherly, "The virtual laboratory and interactive screen experiments,"

- Connecting Research in Physics Education with Teacher Education, pp. 1–7, 2016.
- [6] M. E. Ahmed and S. Hasegawa, “An instructional design model and criteria for designing and developing online virtual labs,” *International Journal of Digital Information and Wireless Communications (IJDIWC)*, vol. 4, no. 3, pp. 355–371, 2014.
- [7] E. Tisserant, L. Bessard, and M. De Sousa, “An open source IEC 61131-3 integrated development environment,” in *2007 5th IEEE International Conference on Industrial Informatics, 2007*, vol. 1, pp. 183–187.
- [8] W. D. Sasongko and I. Widiastuti, “Virtual lab for vocational education in Indonesia: A review of the literature,” in *AIP Conference Proceedings, 2019*, vol. 2194, no. 1, p. 020113.
- [9] R. Wang, C. Liu, and T. Ma, “Evaluation of a virtual neurophysiology laboratory as a new pedagogical tool for medical undergraduate students in China,” *Advances in Physiology Education*, vol. 42, no. 4, pp. 704–710, 2018.
- [10] W.-J. Shyr, “Multiprog virtual laboratory applied to PLC programming learning,” *European Journal of Engineering Education*, vol. 35, no. 5, pp. 573–583, 2010.
- [11] E. Lavrov, A. Zolkin, T. Aygumov, M. Chistyakov, and I. Akhmetov, “Analysis of information security issues in corporate computer networks,” in *IOP Conference Series: Materials Science and Engineering, 2021*, vol. 1047, no. 1, p. 012117.
- [12] A. I. Omer and M. Taleb, “Architecture of industrial automation systems,” *European Scientific Journal*, vol. 10, no. 3, 2014.
- [13] I. Standard, “62264-3: 2016; Enterprise-Control System Integration—Part 3: Activity Models of Manufacturing Operations Management,” *International Organization for Standardization: Geneva, Switzerland, 2016*.
- [14] T. Bangemann et al., “State of the art in industrial automation,” *Industrial Cloud-Based Cyber-Physical Systems: The IMC-AESOP Approach*, pp. 23–47, 2014.
- [15] T. Alves and T. Morris, “OpenPLC: An IEC 61,131–3 compliant open source industrial controller for cyber security research,” *Computers & Security*, vol. 78, pp. 364–379, 2018.
- [16] M. de Sousa and A. Carvalho, “An IEC 61131-3 compiler for the MatPLC,” in *EFTA 2003. 2003 IEEE Conference on Emerging Technologies and Factory Automation. Proceedings (Cat. No. 03TH8696)*, 2003, vol. 1, pp. 485–490.
- [17] E. Tisserant, L. Bessard, and M. De Sousa, “An open source IEC 61131-3 integrated development environment,” in *2007 5th IEEE International Conference on Industrial Informatics, 2007*, vol. 1, pp. 183–187.

- [18] T. R. Alves, M. Buratto, F. M. De Souza, and T. V. Rodrigues, "OpenPLC: An open source alternative to automation," in IEEE Global Humanitarian Technology Conference (GHTC 2014), 2014, pp. 585–589.
- [19] Open Source PLC Software. "1.1 OpenPLC Overview – OpenPLC." Openplcproject.com, 5 Oct. 2022, openplcproject.com/docs/openplc-overview/.
- [20] "Home," Node RED Programming Guide. [Online]. Available: <http://noderedguide.com/>. [Accessed: 25-July-2021].
- [21] G. Gardašević, H. Fotouhi, I. Tomasic, M. Vahabi, M. Björkman, and M. Lindén, "A heterogeneous IoT-based architecture for remote monitoring of physiological and environmental parameters," in Internet of Things (IoT) Technologies for HealthCare: 4th International Conference, HealthyIoT 2017, Angers, France, October 24-25, 2017, Proceedings 4, 2018, pp. 48–53.
- [22] "Node red minimum configuration," Node-RED Forum, Aug. 11, 2020. [Online]. Available: <https://discourse.nodered.org/t/node-red-minimun-configuration/31416>. [Accessed: Feb. 23, 2023]
- [23] B. Ghirardini, E-learning methodologies: A guide for designing and developing e-learning courses. Food, 2011.
- [24] N. A. Adzharuddin, L. H. Ling, and others, "Learning management system (LMS) among university students: Does it work," International Journal of e-Education, e-Business, e-Management and e-Learning, vol. 3, no. 3, pp. 248–252, 2013.
- [25] I. A. Khan, "Electronic learning management system: Relevance, challenges and preparedness," Journal of Emerging Technologies and Innovative Research, vol. 7, no. 5, pp. 471–480, 2020.
- [26] A. Al-Ajlan and H. Zedan, "Why moodle," in 2008 12th IEEE International Workshop on Future Trends of Distributed Computing Systems, 2008, pp. 58–64.
- [27] S. Sergis, P. Vlachopoulos, D. G. Sampson, and L. Pelliccione, "Implementing teaching model templates for supporting flipped classroom-enhanced STEM education in Moodle," Handbook on Digital Learning for K-12 Schools, pp. 191–215, 2017.
- [28] B. C. Oguguo, F. A. Nannim, J. J. Agah, C. S. Ugwuanyi, C. U. Ene, and A. C. Nzeadibe, "Effect of learning management system on Student's performance in educational measurement and evaluation," Education and Information Technologies, vol. 26, pp. 1471–1483, 2021.

- [29] “Documentation,” Installing Moodle - MoodleDocs. [Online]. Available: https://docs.moodle.org/401/en/Installing_Moodle. [Accessed: 13-Feb-2023].
- [30] G. Totkov, “Virtual learning environments: towards new generation,” in *CompSysTech*, 2003, pp. 8–16.