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DESIGN AND DEVELOPMENT OF MULTIPURPOSE EDUCATIONAL AND RESEARCH PLATFORM (MERP) FOR LEARNING CONTROL AND IOT TECHNOLOGIES

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Abstract

Vision TN50 "Transformasi Nasional 2050" is encouraging institutions to produce more talent for digitalization and transformation of Industries. This transformation opens a new domain for the Internet of Things (IoT) technologies. Therefore, students are required to develop their skills and knowledge in the field of advanced automation and robotics. There are many automation or control labs available in the educational institutions that are not equipped with advanced automation, which are required for the Internet of Things (IoT) technologies. This paper presents the design and development of a Multipurpose Educational and Research Platform (MERP) for learning IoT automation technologies. To develop a MERP, four requirements are outlined in this paper; (i) industrial standard controller to be used (ii) integration of the platform with the cloud computing (iii) develop a low-cost platform (iv) suitable for Industrial and Enterprise applications prototyping. To analyse the impact of MERP, students experience is evaluated on this developed platform in International Islamic University Malaysia (IIUM). The evaluation result shows the enormous improvement in student's skills in term of learning new control technologies, especially the Internet of Things (IoT). The proposed platform leverage students to design, control and develop IoT application that is in line with the industry 4.0.

Keywords: Automation and robotics, Control lab, Engineering education, Internet of things (IoT), Learning technologies.

1. Introduction

The number of technologies that appears every day at our home, offices and in our industries are transforming rapidly day by day. With this transformation, devices will interact with each other over the internet, hence, they are named as the Internet of Things (IoT). The term IoT was first made in 1999 by Kevin Ashton in the context of supply chain management and the definition has been expanding into a wide range of applications during the past decade. A diversity of fields brings multiple interpretations of this general concept. However, a simple explanation of this idea is machine perception of the real world and interaction with it [1-3].

In 2011, Germany used the term "Industry 4.0" for the first time as the development of a new German economic policy concept based on high-tech strategies (Mosconi, 2015). This concept initiated the fourth technological revolution based on concepts and technologies, which includes cyber-physical systems, Internet of Things (IoT) and the Internet of Services (IoS) [4, 5].

During the first three industrial revolutions, humans have witnessed and invented mechanical, electrical, and information technologies, which were designed to increase the productivity of the production process. The first industrial revolution increased the efficiency by using hydropower, the machine tools development and use of steam power were increased.

The second industrial revolution offered mass production by electric power (assembly lines). The third industrial revolution further accelerated towards automation systems with the invention of electronics and information technology and now the fourth industrial revolution introduced the cyber-physical systems technology to combine the real world with the information age for future development of industries. Figure 1 displays the first to fourth stages of the industrial revolution [6].

The Internet of Things (IoT) represents the basic concept of integration of all smart devices as part of a major smart project [7]. There are three basic IoT components: (a) The Hardware; it consists of field sensors and actuators, embedded controllers and communication system. (b) The Middleware; pay as you go based cloud computing and storage services for big data analytics and (c) The Presentation; easy-to-understand visualization and interpretation tools that are easily accessible on different platforms and can be designed for a variety of applications [1]. Furthermore, these components can be divided into five layers as shown in Fig. 2. [8].

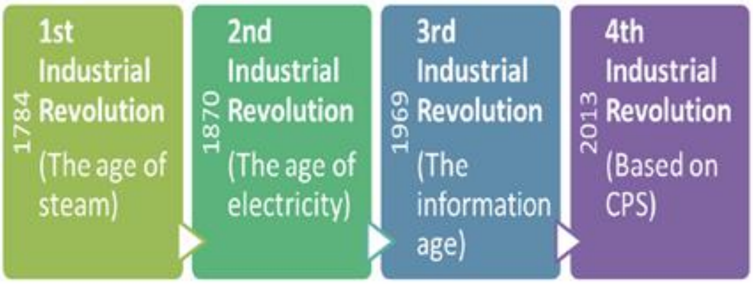


Fig. 1. Four stages of industrial revolutions.

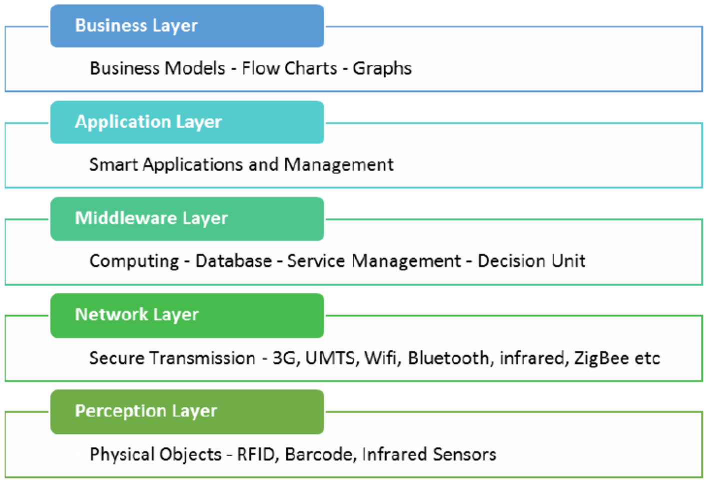


Fig. 2. Architecture of IoT layers.

To adopt and implement these technologies, the Educational and Research Platforms (ERP) are increasingly becoming a key component, especially for engineering laboratories. A wide range of work has been done on ERP in the field of industrial automation and robotics especially in the last decade to improve programming, logical and hardware skills of engineering students. The applicability of these platforms enables students to achieve excellent learning objectives. Many ERP and modern techniques were offered in the field of automation (Control and Robotics), to train or teach the Programmable Logic Controllers or Microcontrollers.

Sanchez and Bucio [9] proposed in improving the Teaching-Learning of Discrete-Event Control Systems using a LEGO Manufacturing Prototype. A major component of this system is Programmable Logic Controller (Siemens Simatic S7-300) and LEGO blocks. Two programming languages (structured-text (ST) and ladder diagrams) are used for learning of this system. Automated Manufacturing System (AMS) implementation with LEGO blocks is shown in Fig. 3, which is a teaching-learning aid in a post-graduate-level first course on the control of Discrete-Event Systems (DESs). Thomas et al. [10] explained that learning substation technology, as development of Substation Automation (SA) platform as shown in Fig. 4, the proposed system based on Intelligent Electronic Devices (IED) and Supervisory Control and Data Acquisition (SCADA) for undergraduate and postgraduate students.

Hwang et al. [11] developed a low-cost training platform on embedded systems using a microcontroller, this multipurpose control platform having several advantages as compared to other commercial embedded system training kits. Open source C/OS-II programming tool is used on the Linux operating system and fundamental library function also developed for different controllable devices. The programming and editing of the controller can be done in C language and in visual programming. Rapid prototyping is possible on this platform, especially for robotics systems.

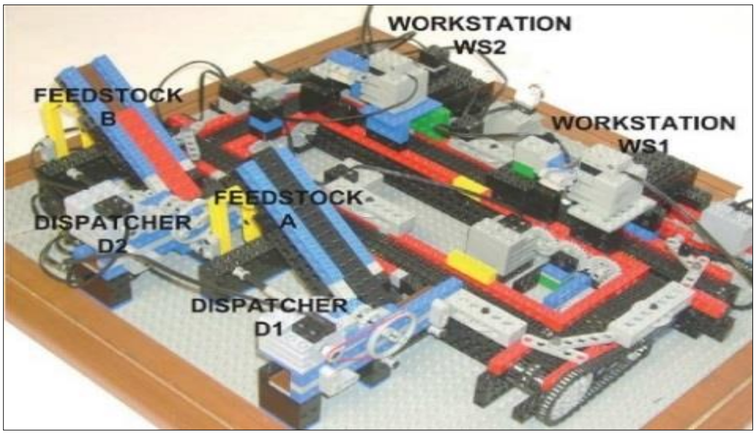


Fig. 3. PLC with LEGO blocks.

Fig. 4. Substation automation system.

For teaching PLC, Gavali et al. [12] developed a technology-based learning system by introducing a new outline for undergraduate engineering students. PLC hardware, interfacing and programming was introduced in lectures. For evaluation, students apply their PLC theoretical knowledge to design and implement the hardware project. Debiec, and Byczuk [13] developed a single board platform based on programmable logic devices like microcontroller as shown in Fig. 5, in which, to teach digital and programmable design techniques.

The researcher uses very good technique to teach students, they allowed them to define their own design problems by this technique has resulted in satisfactory learning outcomes. PLC based educational platform as in Fig. 6, was developed [14] and implemented in education.

The approach was mainly hardware-based development. In addition, platform manuals including presentation materials were prepared. The platform is quite simple and easy to understand the basic concepts of PLC hardware and programming. Similar development approach done by another group [15], had developed multiple IO PLC for enhancement in theoretical understanding and hands-on skill aspect in their learning of PLC.

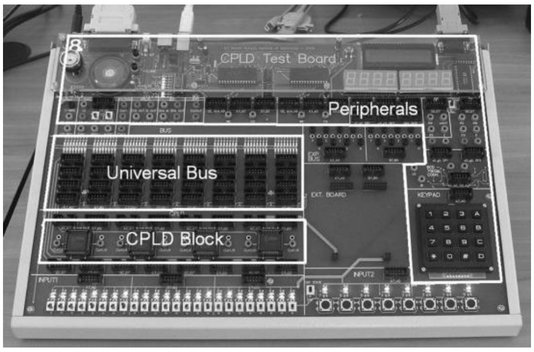


Fig. 5. Single board platform.

Fig. 6. PLC based platform.

Based on studies by Rodriquez-Sanchez et al. [16], a combination of course development and project-based learning was done, the CPBL approach used for Master of Engineering. A good contribution in microcontroller and embedded system course, in which, the "Arduino" open-source platform was used. Four blocks designed for theory and three blocks for practical. The IEC 61160 was the benchmark to implement this course in Engineering Education.

The world's largest successful distance learning university "The Open University" has developed a course for learning IoT in 2011 [17]. This course was designed for those students who had no programming experience in computing. The hardware SenseBoard, visual programming software Sense and cloud service are used for this online course. It was a great development for learning basics of IoT. For learning IoT and Wearable Technology a hackathon workshop was conducted in Ireland [18] for promoting a career in the field of computer science. All participants learned programming skills in the previous session. Students developed their prototypes based on given hardware like Raspberry Pi, Arduino, basic Sensors and servos. Twenty-one (21) students participated in this event. It was an effective experience for students and a great motivation for learning modern technologies. For teaching the Internet of Things (IoT) in university curricula [19] developed a low-cost and open-source platform. Arduino UNO as hardware and ThingSpeak as Cloud Computing was used in this platform. During the development of this platform, all layers of IoT discussed to best possible way to teaching IoT Technology to students.

Development of platforms and curriculum for learning control and IoT technologies can be categorized into two groups [9-19]. Firstly, PLC, microprocessor and microcontroller are used for teaching control logic and programming languages by soft (development in curriculum) and hard (development of platforms) techniques. The existing control engineering labs already consist of standard control platforms according to this category, but these platforms are lacking in the latest control and IoT application integration. Secondly, for teaching IoT skills small-scale open component kits consisting of basic I/O with Raspberry Pi or Arduino were used, which are not to the educational and industrial standard. In this study, a low-cost centralized training platform is developed for learning and implementing all types of controlling and IoT applications, which fulfils the educational and industrial requirement.

2. Hardware Design and Implementation

The design of the developed MERP for control lab took care to incorporate all requirements for learning the new control technologies for undergraduates and also for the postgraduate students to design, implement and test their research. It was essential to provide an advanced control feature in the design of MERP. The system design and implementation are described as follows.

2.1. System hardware

The core component of the control-engineering platform for teaching and learning software and hardware logic concepts is a controller. Siemens Simatic IoT2020 was used, which belongs to the Simatic IoT2000 Series. This family offer a robust, compact and flexible solution with a focus on the IoT environment. The key features are, high degree of ruggedness, compact design (Din-Rail / Wall mount), Ethernet and USB interfaces, internal interfaces for Arduino compatible Shields and Mini PCIe card, freely programmable interfaces and maintenance-free operation is possible. The Simatic IoT2020 can be a program with high-level programming languages with open source software's like, IDE, Python and eclipse, It operates on Linux (Yocto V2.1) based operating system and hardware designed for the reliable 24/7 operation even in harsh condition [20].

Two power supplies, 12 and 5 VDC are used in this platform. The first power supply is to power up the controller and second for IO Connectivity. Raspberry Pi USB Dongle is used with Controller for internet connectivity, major features are BCM43143 chipset with 802.11b/g/n, 150Mbps maximum throughput. According to RS Components Ltd. [21], in the main panel, 8 channel relay module is used, which is connected to output Indicator lamps and ports. Relay shield is used for Motor control application panel. This shield is mounted inside the Controller. The basic temperature sensor (LM35), Light Dependent Resistor (LDR), Potentiometer and a Servo Motor are used on the main panel. One 3-phase circuit breaker and four magnetic contactors are used for three-phase induction motor control application. Push button, indicator lamps, IO connectivity ports and project boards are used to fulfil the basic operator interface requirement of the educational platform.

2.2. Schematic design

After the selection of components, the circuit was designed according to the advanced-learning requirement of control logic and IoT technologies. The platform was divided into two parts. First, is the main panel and second is the application panels (motor control and project board). The details are given as follows.

2.2.1. Main panel

The schematic design of the main panel is shown in Fig. 7, AC voltage is the main power of panels. Through a power switch is connected to power supplies (12 and 5 VDC). The 12 VDC supply is connected with 12VDC ports, digital output indicator lamps and powering up the Simatic controller. A 5 VDC supply is connected with 5 VDC ports and digital input push buttons. An 8 channel relay module is connected at pin no 8-13, 18 and 19 of the Simatic controller and relay outputs are connected with output ports and indicator lamps in parallel. Pin no 0-4 and 7 are used as digital input signals, which are coming from input ports and push buttons. Pin No 5 and 6 are used as analogue output (PWM) and A0-A3 used for analogue input.

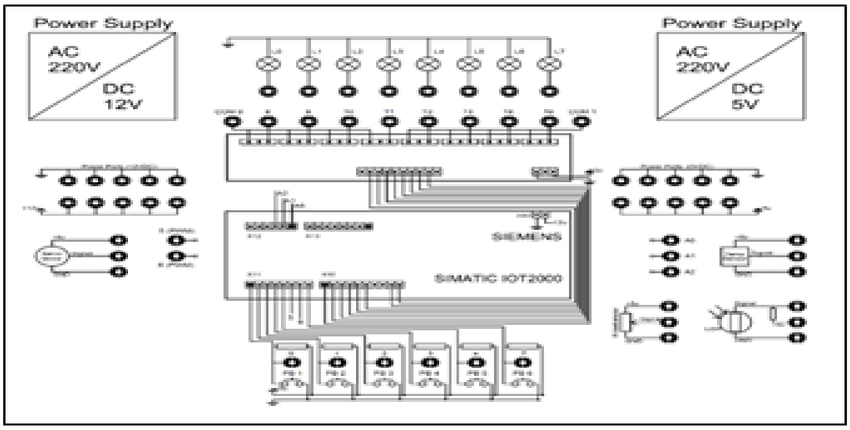


Fig. 7. Schematic diagram of main panel.

2.2.2. Application panels

The motor control panel is the first application of MERP. Four (4) Channel Arduino Relay Shield V3.0 is used with Simatic controller. A shield is connected with four magnetic contactors for Star, Delta, forward and reverse operation. Three (3) push buttons are used for forward, reverse and stop operation and four (4) indicator lamps for a star, delta, forward and reverse status. The lamps are connected with the Normally Open (NO) contacts of Magnetic Contactor (MC) for indication of the MC status. The second application panel consists of two project boards and Simatic controller for student self-prototyping.

2.3. Layout design

The hardware developed on the acrylic sheet and these sheets (main, motor control and project board) mounted on aluminium and steel stand. Din-Rail was used to mount the Simatic IoT2020 Controllers, circuit breaker, and magnetic contactors, wire duct used to cover the wiring of the motor control panel. The developed platform is shown in Fig. 8.

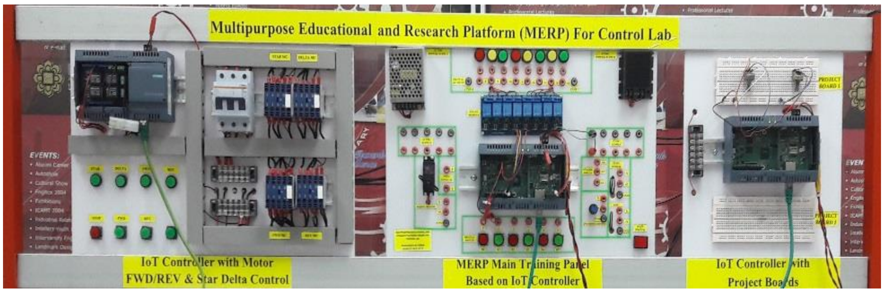


Fig. 8. Developed Multipurpose Educational and Research Platform (MERP).

2.4. Features of developed MERP

A comprehensive comparison of the Developed Multipurpose Educational and Research Platform (MERP) with other related platforms in the market/institutions is shown in Table 1. The platform type, controller type, controller compliance with industry, target audience, development approach and development cost are highlighted. MERP is the latest development in education, which give all features relates to the Internet of Things (IoT) field.

Table 1. Comparison of developed MERP with related platforms.

Ref.	Development title	Platform type	Controller type	Industrial standard	Target audience	Development approach	Low-cost development
		i. Controller ii. IoT	i. IED ii. PLC iii.Microcontroller iv. Microprocessor v. Arduino vi. Raspberry Pi	i. Yes ii. No	i. Research ii. Master iii. Degree iv. Diploma v. Training	i. Hardware ii. Course contents	i. Yes ii. No
[9]	**Discrete-event control system**	i	ii	i	ii	i	ii
[10]	**Substation automation laboratory**	i	i	i	ii, v	i	ii
[11]	**Rapid prototyping platform**	i	iii, iv	ii	iii	i	ii
[12]	**PLC education**	i	ii	i	iii	ii	ii
[13]	**Single laboratory board**	i	iii, iv	ii	iii	i	i
[14]	**PLC platform**	i	ii	i	iii	i	ii
[15]	**PLC module for education**	i	ii	i	iv	i	ii
[16]	**Embedded systems course**	i	v	ii	ii	i, ii	i
[17]	**Educating the Internet-of-Things**	i, ii	v	ii	v	i	i
[18]	**An IoT and wearable technology Hackathon**	i, ii	vi	ii	v	i	i
[19]	**Internet of Things in university curricula**	i, ii	v	ii	iii	i, ii	i
	MERP for learning control and IoT technologies	i, ii	iv	i	i, ii, iii	i, ii	i

3. Course Design and Implementation

The Industrial Automation (MCTE 3373) three credit hours and Mechatronics Lab II (MCTE 3103) one credit hour are compulsory for students in Bachelor of Mechatronics Engineering, International Islamic University Malaysia [22]. The MCTE 3373 covers the basic concepts, components and terms of industrial sensors, robotics, pneumatic logic, sequence control, industrial networks, CNC machines, PLC, DCS and SCADA system. In addition, in MCTE 3103 students implement the classical control systems, instrumentation, pneumatic based control and PLC based exercises. According to current curriculum and lab equipment, there is no contents and platform where students can learn advanced control industry applications like; IoT, IIoT and Industry 4.0. To introduce modern technology in engineering degree by developed platform course contents are prepared and mentioned in this section. The main objective of the developed contents based on MERP is to deliver the hands-on experience to students from the physical layer (sensor, actuator) to cloud computing layer. This advanced skills and knowledge will lead to achieving the country vision of digitalization and transformation also creates further research contribution in this field. Breakdown of objectives is shown in Table 2.

The course content, which is designed to meet the goals of the MERP, is shown in Table 3. This session has three modules, the first module starts with the revision of controllers like, microcontroller, Programmable Automation Controller (PAC) and Programmable Logic Controller (PLC), then cover the introduction to industry 4.0, IOT, IIOT cloud/web services, big data, analytics and IoT communication protocols concept in detail like Message Queue Telemetry Transport (MQTT), which is an application layer protocol designed for resource-constrained devices. It uses a topic-based publish-subscribe architecture. This means that when a client publishes a message M to a particular topic T, then all the clients subscribed to the topic T will receive the message M [23]. In the second module Simatic IoT controller programming, configuration and Machine to Machine (M2M) communication are included. The third module covers the IoT web and mobile application design and development. All modules are synced with each other, which gives a clearer picture to students on how they can design and implement the IoT projects and applications.

All subjects of Mechatronics Engineering (MCTE) degree in IIUM is reviewed carefully and proposed the developed contents with a related subject. The module 01 (Lecture part: introduction to technology and tools) will be integrated into the "Industrial Automation (MCTE 3373)" and module 02 and 03 (Practical part: software and hardware) will be integrated into the "Mechatronics Lab II (MCTE 3103)". The modules are proposed to third year (sixth (VI) semester) students.

Table 2. MERP course objectives.

No.	Objectives
1	To provide an understanding of 4^{th} industrial revolution in detail, which includes IoT and IIoT to have a better understanding of their academic subjects by applying real-time industrial applications step by step.
2	To provide an essential skill of IoT controller, web and mobile application to design, program and implement the IoT and IIoT projects.
3	To provide students the ability to start working and building their own real-world projects.

Table 3. Course content to teach IoT on MERP (Module 01).

Topic	Description
1. Introduction to:	Controllers Industry 4.0 IoT and IIoT Cloud and web services Big data and analytics
2. IoT communication protocols	MQTT.Org [24]
Module 02	
1. IoT controller programming **2. Machine to Machine (M2M) communication**	Node-RED [25]
Module 03	
1. Development of IoT mobile application	MQTT Dash [26]
2. Development of IoT cloud/web application	IO Adafruit [27] ThingSpeak [28]

3. Evaluation in Engineering Education

To evaluate the validity of the developed MERP a survey was conducted. For the authentic survey feedback, different evaluation techniques were adopted. Rodriquez-Sanchez et al. [16], Byrne et al. [18] and Kaluz et al. [29] inspired the formulation of this survey questionnaire (rated questions), where about same types of survey questions were asked for an evaluation of engineering/technical lab development. It had four major sections. All students filled the first section prior to the session and second, third and fourth section after the session. The first two sections were pre and post questioners to measure the skill level difference before and after the session. The first and second section named Teaching Evaluation Questionnaires (TEQ). Students were asked about their basic skills like sensor, actuator and programming skills in first two questions and three questions asked about IoT skills like, IoT communication protocols, IoT web application development and IoT mobile application development.

The third section belongs to the Self-Assessment Questionnaire (SAQ). These questions were adopted for targeted and basic evaluation for two objectives. First, to inspect the quality of hands-on experience and second to analyse the level of convincing in learning IoT. Fourth section related to Questionnaires Regarding Improvement (QRI). In this section, three questions were asked from students i) their satisfaction with performing the analogue and digital IO related tasks ii) the issues in designing of IoT software and hardware applications iii) overall usefulness of MERP features. The responses in this section are observed for future development and improvements in MERP. Students also provided feedback comments like positive support and problems they faced in the session, also some suggestions are taken into account for future improvement in MERP.

5. Observation and Result Analysis

The evaluation was provided by 67 students participating in workshops and Engineering Degree Lab. The workshops were conducted four times and demonstrated two times in Mechatronics Lab II during semester 1 2017/2018. There are eleven students on average per session. The students in this study were fourth-year Bachelor of Engineering and a few from Master of Engineering at the International Islamic University Malaysia (IIUM).

5.1. Teaching evaluation questionnaires (TEQ) (Pre and post)

To analyze the TEQ, a statistical technique Paired Sample t-Test was conducted to evaluate the impact of MERP for learning modern technology. The Paired-Samples t-Test compares two means that are from the same individual, object, or related units. The two means typically represent two different times (e.g., pre-test and post-test with an intervention between the two-time points) or two different but related conditions or units (e.g., left and right ears, twins). The purpose of the test is to determine whether there is statistical evidence that the mean difference between paired observations on a particular outcome is significantly different from zero. According to Kent State University [30], the Paired Samples t-Test is a parametric test. In this study, the same TEQ questionnaires were asked before and after the workshop/lab sessions.

According to the results shown in Table 4, the hypothesis can be accepted (confidence higher than 95%). It can be confirmed that student's skills in TEQ3, TEQ4 and TEQ5 are significantly higher than TEQ1 and TEQ2. The mean (M) difference for the first two questions was between 0.39-0.63, and for the last three questions, it was 2.39 to 2.45. The evaluation result related to IoT skills (TEQ3, TEQ4 and TEQ5) showed a highly significant increase as compared to IO and programming skills (TEQ1 and TEQ2), the mean differences shown in Fig. 9 indicating that students are fully hands-on on the advanced technology and also improved their skills in I/O and programming by this platform.

Table 4. t-test results for TEQ pre and post questionnaires.

Skills	M pre	M post	M diff	N	95% Confidence interval of the difference		t	Sign
					M lower	M upper		
Sensor and actuator skills	3.03	3.66	0.63	67	0.438	0.816	6.62	0.000
Programming skills	3.19	3.58	0.39	67	0.229	0.547	4.88	0.000
IoT communication protocols Skills	1.13	3.57	2.43	67	2.237	2.628	24.83	0.000
IoT Web application development skills	1.13	3.52	2.39	67	2.213	2.563	27.27	0.000
IoT Mobile application development skills	1.12	3.57	2.45	67	2.261	2.634	26.21	0.000

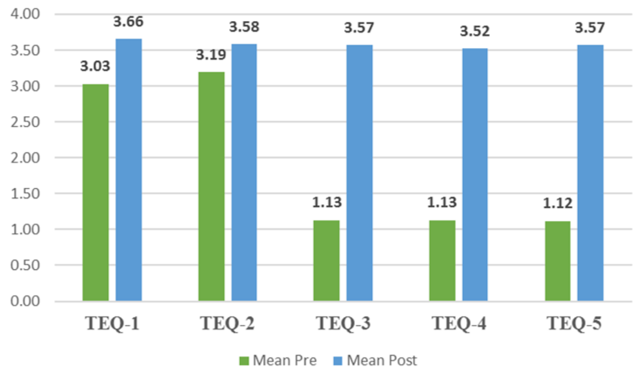
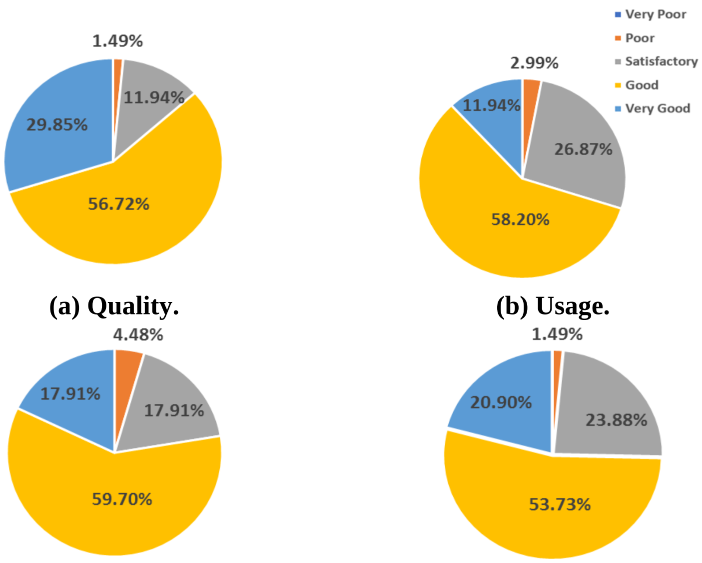


Fig. 9. Pre and post mean difference of Teaching Evaluation Questionnaires (TEQ).

5.2. Self-assessment questionnaires (SAQ)

The SAQ survey results are shown in Fig. 10. It indicates a good effect of Quality, Usage, Learning and Convenience positive effect of remote experimentation in the courses. In all questions positive feedback was given, 55-60% of the participants rated Good, in term of level of interactivity and overall technical quality of MERP, 30% response was Very Good. In Usage and level of convenience for learning advanced skills, around 25% students rated satisfactory. Less than 5% students rated Poor and none of them given feedback as Very Poor. The overall results of SAQ indicated that participants feel that they are now able to work on this technology.



(a) Quality. (b) Usage.

(c) Learning. (d) Convenience.

Fig. 10. Results of Self-Assessment Questionnaires (SAQ).

5.3. Questionnaires regarding improvement (QRI)

The students feedback for improvement is shown in Fig. 11. Students were able to perform Analog and Digital IO's task without having technical issues and, they are able to design and program IOT Applications without having Software and hardware issues due to its advanced interactivity features. Most of the student's responses were "good" in the first two questions (QRI-1 and QRI-2) and "Very Good" in the third question (QRI-3). Only 3% percent response was poor in QRI-2 and 1.5% in QRI-3.

Students suggestions have been collected in the survey. The most common issue the students stated is the short-time. They want to practice / hand-on more on this platform and technology. After getting few comments about short time in the first session, a pre-requestee guideline for software and application installation was prepared and emailed to all participants prior to session/lab, in result they got some more time for practice. Most of the comments shown a positive learning experience.

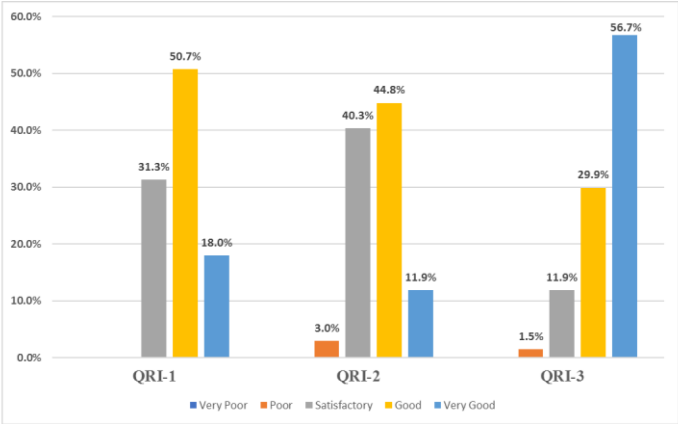


Fig. 11. Results of Questionnaires Regarding Improvement (QRI).

5.4. MERP outcomes

The impact of developed MERP in engineering added and shown in Table 5. In which, the reader can easily understand that MERP is fulfilling the Pillars (Layers) of IoT. Additionally, the MERP outcomes based on course objectives are also visible in the breakdown of Modules, Topics and IoT Layers.

All participants successfully implemented the 3-phase induction motor IoT application. Star-delta starting and forward / reverse operation can be done on “Motor control panel” of MERP. After learning the Node-Red nodes and flows, MQTT communication protocol, MQTT Dash and AdaFruit IO. The participants developed the node-red program for the aforementioned operation. By this program, the induction motor can be controlled form physical push buttons, IoT mobile application “MQTT” Dash and IoT web application “Adafruit IO” through MQTT communication protocol. The status can be monitored through physical status lamp on panel, MQTT Dash and Adafruit IO.”

Table 5. MERP outcomes and pillars/layers of IoT.

No.	IoT pillars / layer	MERP module’s	Major topic	MERP outcomes in-line with course objectives
1	**Perception**	Module 01	Introduction to: Controllers, Industry 4.0, IoT and IIoT, Cloud and web services, Big data and analytics	Understanding of industry 4.0
		Module 02	Working with: sensors, actuator and controller	Essential IoT skills
2	**Network**	Module 01	Introducing the IoT communication protocols	Understanding of industry 4.0
		Module 02	Machine to Machine communication with MQTT	Essential IoT skills
3	**Middleware**	Module 03	Working with: IO Ada Fruit, ThingSpeak and MQTT dash	Essential IoT skills
4	**Application**			
5	**Business**			
Final IoT Project		Project	3-phase induction motor control application.	Ability to start developing real-world projects

6. Conclusions

This paper shows the successful development of low-cost and open-source Multipurpose Educational and Research Platform for learning Control and IoT automation technologies. The result has shown the enormous improvement in students learning skill through this platform. Students developed and implement real-time industrial prototype on MERP. Moreover, the prototype has been integrated with IoT mobile and cloud applications. This developed platform allows full access to industrial grade physical, control, communication and cloud layer. However, all these layers are not compatible with existing teaching platform. The MERP teaching platform unlocks new control technologies that allow to develop and implement small scale industrial IoT application, which meets the future demand of Industry 4.0.

Abbreviations

AMS	Automated Manufacturing System
CPBL	Combined Project Based Leering
DCS	Distributed Control System
DES	Discrete Event System
ERP	Education and Research Platform
IEC	International Electrotechnical Commission
IED	Intelligent Electronic Devices
IIoT	Industrial Internet of Things
IoT	Internet of Things
I/O	Input/Output
LDR	Light Dependent Resistor
M	Mean
MCTE	Mechatronics Engineering
MERP	Multipurpose Education and Research Platform
MQTT	Message Queue Telemetry Transpor
M2M	Machine to Machine
PLC	Programmable Logic Controller
PWM	Pulse Width Modulation
QRI	Questionnaires Regarding Improvement
SA	Substation Automation
SCADA	Supervisory Control and Data Acquisition
SAQ	Self-Assessment Questionnaires
TEQ	Teaching Evaluation Questionnaires
VDC	Volt Direct Current

References

1. Gubbi, J.; Buyya, R.; Marusic, S.; and Palaniswami, M. (2013). Internet of things (IoT): A vision, architectural elements, and future directions. *Future Generation Computer System*, 29(7), 1645-1660.
2. Gluhak, A.; Krco, S.; Nati, M.; Pfisterer, D.; Mitton, N.; and Razafindralambo, T. (2011). A survey on facilities for experimental internet of things research. *IEEE Communication Magazine*, 49(11), 58-67.
3. Falkenberg, R.; Masoudinejad, M.; Buschhoff, M.;Venkatapathy, A.K.R.; Friesel, D.; Hompel, M.T.; Spinczyk, O.; and Wietfeld, C. (2017). PhyNetLab:

An IoT-based warehouse testbed. *Proceedings of the Federated Conference on Computer Science and Information Systems (FedCSIS)*. Prague, Czech Republic, 1051-1055.

4. Lasi, H; Kemper, H.-G.; Fettke, P.; Feld, T.; and Hoffmann, M. (2014). Industry 4.0. *Business and Information Systems Engineering*, 6(4), 239-242.
5. HuanNing, N.; and Hong, L. (2015). Cyber-physical-social-thinking space based science and technology framework for the Internet of Things. *Science China Information Sciences*, 58(3), 1-19.
6. Zhou, K.; Liu, T.; and Zhou, L. (2015). Industry 4.0: Towards future industrial opportunities and challenges. *Proceedings of the International Conference on Fuzzy Systems and Knowledge Discovery (FSKD)*. Zhangjiajie, China, 2147-2152.
7. Roblek, V.; Mesko, M.; and Krapez, A. (2016). A complex view of industry 4.0. *SAGE Open*, 6(2), 1-11.
8. Khan, R.; Khan, S.U.; Zaheer, R.; and Khan, S. (2012). Future internet: The internet of things architecture, possible applications and key challenges. *Proceedings of the 10th International Conference on Frontiers of Information Technology. Islamabad, India,* 257-260.
9. Sanchez, A.; and Bucio, J. (2012). Improving the teaching of discrete-event control systems using a lego manufacturing prototype. *IEEE Transactions in Education*, 55(3), 326-331.
10. Thomas, M.S.; Kothari, D.P.; and Prakash, A. (2011). Design, development, and commissioning of a substation automation laboratory to enhance learning. *IEEE Transactions in Education*, 54(2), 286-293.
11. Hwang, K.-S.; Hsiao, W.-H.; Shing, G.-T.; and Chen, K.-J. (2011). Rapid prototyping platform for robotics applications. *IEEE Transactions in. Education*, 54(2), 236-246.
12. Gavali, A.B.; Patil, S.A.; and Koli, A.R. (2016). Technology-based learning system in programmable logic controller education. *Proceedings of the IEEE Eighth International Conference on Technology for Education (T4E)*. Mumbai, India, 264-265.
13. Debiec, P.; and Byczuk, M. (2011). Teaching discrete and programmable logic design techniques using a single laboratory board. *IEEE Transactions in Education*, 54(4), 652-656.
14. Navrapescu, V.; Chirila, A.O.; Deaconu, A.S.; and Deaconu, I.D. (2015). Educational platform for working with programmable logic controllers. *Proceedings of the 9th International Symposium on Advanced Topics in Electrical Engineering (ATEE).* Bucharest, Romania, 215-220.
15. Burhan, I.; Azman, A.A.; and Talib, S. (2015). Multiple input/outputs programmable logic controller (PLC) module for educational applications. *Innovation and Commercialization of Medical Electronic Technology Conference (ICMET)*. Selangor, Malaysia, 39-43.
16. Rodriquez-Sanchez, M.C.; Torrado-Carvajal, A.; Vaquero, J.; Borromeo, S.; and Hernandez-Tamames, J.A. (2016). An embedded systems course for engineering students using open-source platforms in wireless scenarios. *IEEE Transactions in Education*, 59(4), 248-254.

17. Kortuem, G.; Bandara, A.K.; Smith, N.; Richards, M.; and Petre, M. (2013). Educating the Internet-of-Things generation. *Computer*, 46(2), 53-61.
18. Byrne, J.R.; Sullivan, K.O.; and Sullivan, K. (2017). An IoT and wearable technology hackathon for promoting careers in computer science. *IEEE Transactions in Education*, 60(1), 50-58.
19. Dobrilovic, D.; and Zeljko, S. (2016). Design of open-source platform for introducing Internet of Things in university curricula. *Proceedings of the IEEE 11th International Symposium on Applied Computational Intelligence and Informatics (SACI)*. Timisoara, Romania, 273-276.
20. Siemens. (2016). SIMATIC IOT2000 extension module. Operating instructions. Nunberg, Germany.
21. RS Components Ltd. (2018). Raspberry Pi USB Wireless Adapter. Retrieved April 5, 2018, from http://za.rs-online.com/web/p/wireless-adapters/8920012/.
22. International Islamic University Malaysia. (2018). Department of mechatronics engineering. Retrieved Mar 12, 2018, from http://www.iium.edu.my/mechatronics/index.php?option=com_content&view=article&id=95&Itemid=78.
23. Thangavel, D.; Ma, X.; Valera, A.; Tan, H.-X.; and Tan, C.K.-Y. (2008). Performance evaluation of MQTT and CoAP via a common middleware. *Proceedings of the IEEE Ninth International Conference on Intelligent Sensors, Sensor Networks and Information Processing (ISSNIP)*. Singapore, 1-6.
24. MQTT.Org. (1999). MQTT v3.1.1 now on oasis standard. Retrieved March 12, 2018, from http://mqtt.org/.
25. Node RED. (2018). Node-RED. Flow-based programming for the Internet of Things. Retrieved March 25, 2018, from https://nodered.org/.
26. Google Play. (2018). MQTT Dash (IoT, Smart Home). Retrieved March 25, 2018, from https://play.google.com/store/apps/details?id=net.routix. mqttdash.
27. IO Adafruit. (2018). Internet of things for everyone. Retrieved March 29, 2018, from https://io.adafruit.com/.
28. ThingSpeak. (2018). Understand your things. Retrieved March 29, 2018, from https://thingspeak.com/.
29. Kaluz, M.; Garcia-Zubia, J.; Fikar, M.; and Cirka, L. (2015). A flexible and configurable architecture for automatic control remote laboratories. *IEEE Transactions on Learning Technologies*, 8(3), 299-310.
30. Kent State University. (2018). Paired samples t test. Retrieved August 30, 2018, from https://libguides.library.kent.edu/SPSS/PairedSamplestTest/.