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PAPER

Assessing AI Applications of Energy Management in Manufacturing: A Case Study of Engineers' Training Course in Thailand

Sasithorn Chookaew (✉), **Suppachai Howimanporn**

King Mongkut's University of Technology North Bangkok, Bangkok, Thailand

sasithorn.c@fte.kmutnb.ac.th

ABSTRACT

The application of technology for energy management in manufacturing is a critical issue gaining increasing attention, particularly in energy consumption in industrial plants. Many studies have proposed methods to improve energy efficiency and achieve savings, yet the most advanced technologies are often complex to transfer and require specialized engineering expertise. Additionally, traditional training methods must enhance their ability to effectively bridge the gap between academic knowledge and real-world industrial applications. This study explores integrating artificial intelligence (AI) technology in energy management through training courses focused on appropriately adjusting the pressure in compressed air systems (CAS). Specifically, the Adaptive Nereo-Fuzzy Inference System (ANFIS) was used to analyze data from these systems and manage energy consumption across different operating conditions. The study involved 34 engineers who participated in these training courses. A paired samples t-test was conducted to assess changes in engineers' understanding before and after the training, revealing a significant improvement. Overall, the engineers perceived the training as beneficial and responded positively.

KEYWORDS

artificial intelligence (AI), energy management, engineering education, learning factory

1 INTRODUCTION

Today, the need to apply optimization technology to reduce energy waste in industrial manufacturing plays a crucial role as energy consumption is distributed across various machines, equipment, and processes, which are complex systems. These systems should monitor energy usage in real time, identify inefficiencies, and automatically adjust energy-consuming systems to optimize usage according to demand and operational conditions [1]. As the demand for global energy consumption continues to rise, the need for innovative, sustainable, and efficient energy management

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solutions has never been more critical. Energy management is the key to saving energy, which is the process of monitoring, controlling, and conserving energy in the industrial sector. It is a critical way to reduce energy consumption and associated costs [2]. Primarily, energy savings in compressed air systems (CASs) can account for up to 10% of the total electricity consumption in industrial plants [3–4]. CASs refer to air kept under more significant pressure than atmospheric pressure. They are an essential medium for the transfer of energy in industrial processes. CASs are primary energy consumers in the industrial sector, accounting for around 10% of the electricity consumed in the European Union and China. By contrast, the United States, Malaysia, and South Africa account for 9% of total energy consumption [5]. Many studies have attempted to propose a methodology for developing the energy management of CASs. For example, Thabet [6] proposed real-time sensing and machine learning to increase CAS efficiency using algorithms that automatically detect energy inefficiencies and decide suitable troubleshooting procedures. Sanders [7] proposed new intelligent techniques to save energy in CASs with real-time ambient sensing through artificial intelligence (AI) and knowledge management to improve efficiency in energy-intensive manufacturing automatically. In addition, improving energy efficiency in industry is difficult due to the high complexity of industrial energy systems. The journey toward energy efficiency has some challenges. One critical barrier is promoting staff training in energy management, as there is a need for more awareness and understanding of energy efficiency practices and their benefits [8]. Therefore, proper energy management with new technology can help engineers connect knowledge with real-life practice. By learning how to manage their energy levels, engineers can upskill using technology to benefit their careers [9].

This study presents energy management with AI training courses that focus on reducing energy consumption in compressors by considering real-time circumstances and predicted needs. The role of AI in these courses is to interpret the real-time performance information delivered by sensors in the trainer platform and then act automatically to save energy in the pneumatic process in industrial manufacturing. In this, an experiment was conducted in a training course to explore the potency of this study based on the research questions as follows:

RQ1: Can AI in energy management training courses be used to enhance engineers' understanding of energy management?
RQ2: What are engineers' perceptions of AI in energy management?

2 BACKGROUND AND MOTIVATION

2.1 Application of AI in industrial manufacturing

Artificial intelligence is a developed computer system or machine that can perform tasks that typically require human intelligence. It is a cognitive science technology related to image processing, natural language processing, robotics, and machine learning [10–11]. Previous studies have confirmed that AI education is an essential concept and competency for students in new generations in many fields and levels [12–13], especially in higher education that focuses on the curriculum and the creation of an AI-ready workforce covering the essential 21st-century competencies identified as workforce and government needs worldwide [14]. Some studies have generated course offerings based on challenge-based learning, physical and virtual practice labs, and mixed teaching methodologies to accommodate the digital transformation and demands of Industry 4.0 and to educate and prepare the new generation of students [15]. In addition, some researchers have tried to develop a conceptual understanding of AI through a literacy course at a university [16]. The true power of AI education lies in its connection with the industrial sector. This connection can facilitate fruitful collaboration and knowledge exchange between academia and industry, leading to valuable research partnerships, internship opportunities, and industry-driven curriculum development. This symbiotic relationship ultimately benefits not just educational institutions but also the industrial sector, underscoring the crucial role of industry professionals in shaping the future of AI education [17–18]. Conversely, integrating AI technologies into industrial operations can help improve and streamline various industries' processes. Furthermore, AI teaching in the industrial sector can help employees adapt to and leverage AI technologies, ensuring a skilled workforce capable of utilizing AI to its full potential. Companies can benefit from increased efficiency, reduced costs, predictive maintenance, and enhanced safety [19]. AI can also facilitate the development of smart factories and automated systems, thereby improving productivity and competitiveness.

The use of industrial AI in process optimization in manufacturing is gaining rapid traction, enabling more innovative and efficient data-driven decision-making by leveraging historical and real-time data. In developed countries, the power industry has started using AI technologies to connect with smart meters, smart grids, and Internet of Things (IoT) devices to improve efficiency, energy management, transparency, and the usage of renewable energies [20]. Thus, AI plays a crucial role in industrial manufacturing, as it can optimize production processes by analyzing real-time data and identifying improvement areas. This increases efficiency and reduces operational costs [21]. This novel technology is transformed into advanced manufacturing by summarizing the latest progress in critical enabling technologies (e.g., production processes) and transitioning toward digitalization with the implementation of sensors that provide real-time data that can now be monitored remotely with IoT technology and AI and IoT, which can monitor production processes and reduce high maintenance costs [22–23].

Artificial intelligence also enables predictive maintenance and allows manufacturers to detect potential equipment failures before they occur, thus minimizing disruptions to the production line. AI-powered robotics can handle repetitive tasks precisely and quickly, leading to higher productivity. Integrating AI into industrial manufacturing can lead to cost savings, improved quality control, and enhanced overall performance. The main emphasis is energy consumption prediction and optimization problems [24]. For energy saving, many studies have proposed an intelligent manufacturing management system based on data mining in AI energy-saving resources [25]. The commercial application of AI is energy saving in a team, energy cost savings in buildings, and demand reduction in factories [26].

2.2 Energy management of compressed air systems

Compressed air systems refer to air kept under more significant pressure than atmospheric pressure in a pneumatic system. Pneumatics is how air pressure feeds and moves something in industrial manufacturing. It puts compressed air into operation by moving applications, especially tools and machinery used in engineering. It is an essential medium for energy transfer in industrial processes, is an effective solution for balancing this mismatch, and is therefore suitable for future electrical systems to achieve a high penetration of renewable energy generation [27]. Industrial manufacturers rely on compressed air with specific pressure, flow, and purity requirements. These requirements can be met with careful planning, offering significant cost-saving opportunities. Compressed air is a costly utility, but manufacturers can make substantial savings by implementing strategies to reduce air system operating costs, such as considering compressor controls. The ultimate goal of any compressor control system is to efficiently match the compressed air supply to demand, thereby optimizing energy usage and reducing costs. Effectively managing energy in CASs can start by conducting regular audits to identify and address any leaks, inefficiencies, or areas of improvement and by considering investing in energy-efficient equipment. Factory CASs have more than one compressor; therefore, controlling multiple units in concert increases energy efficiency and pressure stability. Running multiple units independently often results in unstable pressure and wasted energy, such as running more machines than necessary or running compressors at higher pressures than needed. Optimizing air pressure and implementing a system to monitor and control compressed air usage is also important. It is also essential to provide personnel with training to understand the importance of energy management and know how to operate the system efficiently [28]. Energy management in CASs involves learning about the efficient and sustainable use of energy resources. It provides studies on energy conservation with energy-efficient technologies. It aims to prepare individuals to make informed decisions about energy use and to develop strategies for reducing energy consumption and environmental impact.

3 APPLICATION OF ARTIFICIAL INTELLIGENCE TECHNOLOGY ON ENERGY MANAGEMENT TRAINING COURSE

We have developed the AI for the energy management professional training course to promote engineers' understanding of energy efficiency and savings and the use of AI for decision-making. Figure 1 shows the structure of the professional training course consisting of the AI of things for energy management, which focuses on the activity of using a programmable logic controller (PLC) to control industrial equipment as energy management in a compressed air system learning kit with an AI algorithm (i.e., an Adaptive Nereo-Fuzzy Inference System (ANFIS)) to manage energy in the manufacturing process.

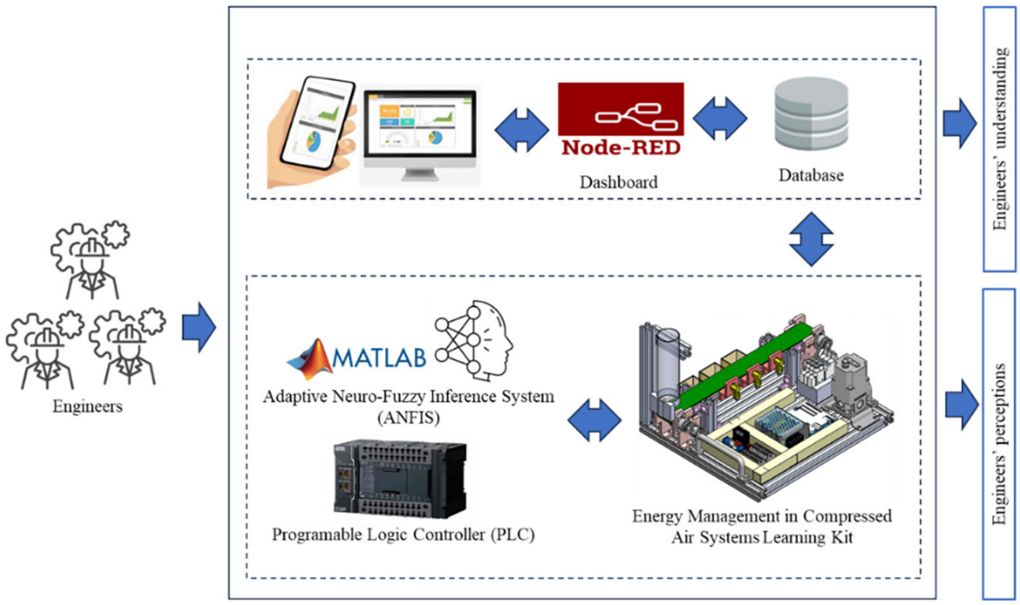

Fig. 1. Conceptual framework of training process

According to this training, it is processed when dealing with input data from many devices, which requires enough data for training. It can operate with a scenario related to AI, particularly in adjusting pressure to save energy in manufacturing, which uses data to generate effective machine learning or AI models. Therefore, we prepared the data set for engineers to use training data in this training activity. Figure 2 shows the screenshots of the MATLAB program that uses the Neuro-Fuzzy designer for the Adaptive Nereo-Fuzzy Inference System.

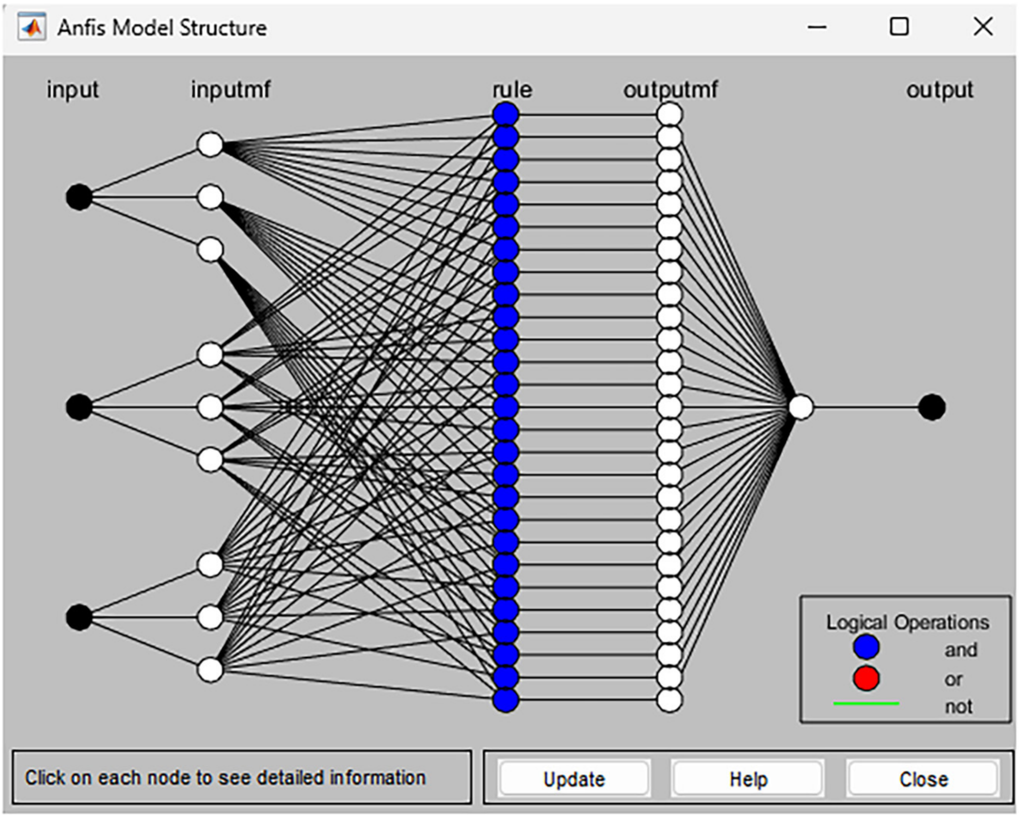

Fig. 2. The screenshots of the ANFIS model in MATLAB program

4 METHODOLOGY

4.1 Participants

In this study, we used a convenience sampling method. We recruited the participants as volunteers from the cooperation of many industrial enterprises in Thailand. The participants were 34 engineers, comprising 27 men and seven women, aged 20–55. They graduated with a bachelor's degree in a major in mechatronics, mechanical, and electrical engineering. We obtained voluntary and informed consent from the participants before involving them. They received information about the research purpose, procedures, risks, benefits, and their right to withdraw from the study at any time. The demographic information of the participants is shown in Table 1.

Table 1. Demographics of the participants

Demographics		Frequency	Percentage (%)
Gender	Male	27	79
	Female	7	21
Age (years)	20–30	10	29
	31–40	6	18
	41–50	11	32
	Over 50	7	21
Positions	Engineer	17	50
	Senior Engineer	2	6
	Supervisor Engineer	10	29
	Engineering Manager	2	6
	Business Owner	3	9
Work experiences (years)	Under 1	4	12
	1–5	7	21
	6–10	10	29
	Over 10	12	36

4.2 Instruments

The understanding assessment, designed by seven experienced industrial sector experts and an instructor with more than 10 years of experience in teaching-related fields, focused on the engineers' post-training understanding. The test measured engineers' understanding of energy management using AI technology and consisted of 30 multiple-choice questions in the pre- and post-tests, with items in the two tests being different. The test was evaluated and scored out of 30, with the achievement tests demonstrating a reliable Cronbach's alpha of 0.75. In addition, the engineers' perceptions assessment of AI in energy management consisted of 15 items.

4.3 Procedures

This study adopted a one-group pre- and post-test design to examine whether the engineers' understanding levels were significant after participating in a training course. The engineers attended the training course for about 12 hours and completed it in two days. On the first day, the engineers were given an introduction and overview, and they took a pre-test to measure their prior knowledge, which was completed in 30 minutes. Afterward, the trainer presented and demonstrated the training kit so participants could understand how to save energy. Then, they learned that integrating AI into PLC programming involves adding ANFIS algorithms and data processing capabilities, as shown in Figure 3a. After that, they performed the learning activities based on scenario learning, which involved energy consumption problems in industrial manufacturing and a subsequent solution-finding process to save energy with AI technology and test the performance testing of adjusting the pressure in each situation, as shown in Figure 3b. They must apply their knowledge to solve problems and conduct discussions during this process. After performing the training activities, all the engineers took post-tests in 30 minutes.

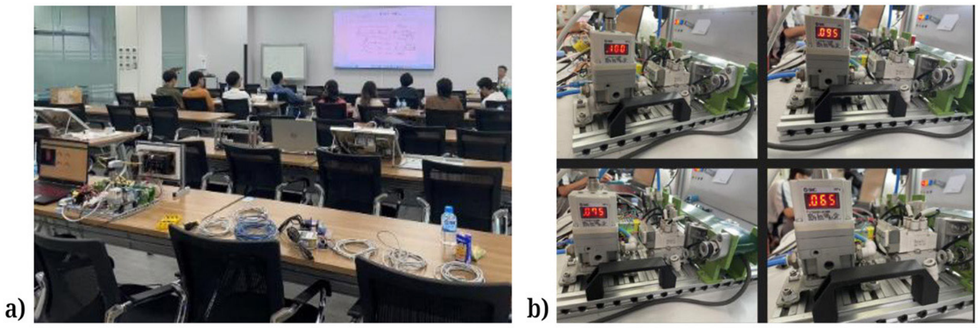

Fig. 3. The training activities of artificial intelligence in energy management

5 RESULTS

RQ 1: Can AI in energy management training courses be used to enhance engineers' understanding of energy management?

To answer the research question, we used the paired samples t-test to determine whether there was a significant difference in the engineers' understanding scores before and after the intervention. Table 2 shows the engineer had an understanding of energy in the pneumatic system with a pre-test score of 2.50 (SD = 1.12) and a mean post-test score (M = 4.21, SD = 0.76, t = 7.43, p = 0.000); an understanding of energy efficiency and savings with a mean pre-test score of 2.74 (SD = 1.36) and a post-test score of 3.71 (SD = 1.07, t = 4.74, p = 0.000); an understanding of calculating energy savings with a mean pre-test score of 2.91 (SD = 1.58) and a post-test score of 7.85 (SD = 1.48, t = 15.93, p = 0.000); and an understanding of using AI for decision-making with a mean pre-test score of 5.85 (SD = 1.57) and a mean post-test score of 6.62 (SD = 1.11, t = 2.56, p = 0.015).

Table 2. Results of paired samples t-test of engineers' understanding scores (N = 34)

Topic	Pre-Test	Post-Test	df	t	Sig.
	M (SD)	M (SD)			
Understanding of energy in the pneumatic system	2.50 (1.12)	4.21 (0.76)	33	7.43	0.000*
Understanding of energy efficiency and savings	2.74 (1.36)	3.71 (1.07)	33	4.74	0.000*
Understanding of calculating energy savings	2.91 (1.58)	7.85 (1.48)	33	15.93	0.000*
Understanding of using AI for decision-making	5.85 (1.57)	6.62 (1.11)	33	2.56	0.015*

RQ 2: What are engineers' perceptions of AI in energy management?

Table 3 displays the engineers' perceptions toward applying AI in energy management, encompassing three dimensions based on 15 questions [29]. The results indicate that, after completing the training course, participants had the following mean perceptions: awareness of AI (M = 4.79, SD = 0.42), advantages of using AI (M = 4.45, SD = 0.68), and application of AI (M = 4.75, SD = 0.45).

Table 3. Results of the engineers' perceptions of artificial intelligence

Items	Mean	S.D.
Awareness of AI		
1. AI can help save energy effectively.	4.82	0.38
2. AI can work with more confidence than human experience.	4.79	0.40
3. I have high expectations regarding the application of AI in energy management.	4.85	0.35
4. I have good knowledge and understanding of this AI energy management system.	4.82	0.38
5. I have a positive perception of AI energy management systems.	4.68	0.53
Advantages of using artificial intelligence		
6. AI can improve industrial processes to be more precise and efficient.	4.38	0.59
7. AI has no limitations on space and time to work.	4.47	0.70
8. AI can effectively reduce energy consumption.	4.44	0.69
9. AI has no emotional exhaustion or physical limitations.	4.47	0.70
10. AI can analyze energy usage in real-time.	4.47	0.70
Application of Artificial Intelligence		
11. AI is easy to apply in energy management.	4.53	0.50
12. AI is developed by experts with relevant experience.	4.82	0.38
13. AI can analyze energy usage accurately.	4.79	0.47
14. AI can be used to provide advice in unexpected situations.	4.76	0.42
15. AI can be applied to many other forms of energy management.	4.82	0.38

Notes: 1.00–1.80 = Strongly Disagree, 1.81–2.60 = Disagree, 2.61–3.40 = Not agree, 3.41–2.60 = Agree, 4.21–5.00 = Strongly Agree.

Findings show that the participants' perceptions toward the application of AI for saving energy are positive; they think that AI technologies can quickly analyze large volumes of data and make real-time decisions. In energy usage, AI can optimize energy consumption by adjusting usage based on demand and identifying inefficiencies that would be difficult for humans to spot. People see this as a powerful tool to save money on energy costs. Some examples of the participants' insights, as revealed in interviews, included:

Engineer 1: "I found using AI for energy saving is easy if we understand the concept or problem, something new, and want to improve it. [...] We can apply this idea to several industrial sectors."

Engineer 2: "[...] I think AI systems can sometimes be difficult for average users to understand and manage. Many people might worry about the learning curve of using these systems or feel overwhelmed by the technology. However, after this training, I understand how to apply them in energy decision-making."

Engineer 3: "[...] AI algorithms can offer energy-saving recommendations based on an industrial process's usage patterns. This can add value to the enterprise, making the energy-saving process more relevant and easier to implement."

The summary showed that the engineers perceived the training courses as beneficial and responded positively. The training courses provided them with practical skills and knowledge directly applicable to their future careers. This hands-on experience could give them a competitive edge in the job market. However, this course is too short to allow students to participate in the activities; they need more time to learn more about the complex concepts of AI. In addition, training courses often offer opportunities for networking and building connections within the industry, which can be invaluable for future job prospects.

6 CONCLUSION

This study is a testament to the power of collaboration between academics and industry establishments. We introduced AI technology in energy management training courses, which leverage ANFIS to learn data and predict energy use in various pneumatic system scenarios. This study is crucial because it provides a practical way to develop technological knowledge and disseminate innovations that benefit a wide range of establishments. This study opens up exciting avenues for future research to explore additional factors and conditions for organizing the learning environment, thus potentially revolutionizing AI competency development in factory learning settings and engineering education. This finding is consistent with [30], which states that focusing on manufacturing is important because it aims to reduce consumption, save resources, and achieve sustainable development. Integrating AI represents a scientific application of knowledge widely used in energy management systems. For instance, an AI-powered system has optimized energy consumption in smart buildings by enabling real-time energy management and implementing demand response strategies to reduce energy costs and improve the overall efficiency of smart building operations [31]. Beyond smart buildings, similar AI-driven approaches have also been employed in industrial settings. Such an integrated AI in the energy management framework enables the timely forecasting of abnormal electricity consumption and provides reliable data to support production scheduling, allowing industrial enterprises to optimize operations based on peak and off-peak electricity pricing [32]. The experiment demonstrated the immediate benefits of the training courses and highlighted areas for future improvement. Although the engineers' understanding increased and their perception of the course was positive, their feedback suggested potential enhancements in the design of the learning activities.

A significant limitation of our study is engineering training requires new technology to cover professional knowledge systems but has limited time to learn. However, continuing education programs in engineering are typically short-term and ad hoc rather than cyclical. Consequently, this approach is deemed insufficient for adequately preparing employees for new or different work demands [33]. Instead, this voluntary education enhances employee knowledge and skills [34]. In addition, the training course should enhance career progression and provide valuable insights for professionals and employers navigating the evolving landscape of career growth [35].

This process is not only beneficial. It is essential for industrial staff to ensure that valuable information, skills, and best practices are passed on from experienced employees to new hires or existing team members to enhance operational efficiency, safety standards, and overall productivity within the industrial setting. In future studies, we plan to implement this course in the industrial sector through a knowledge transfer process using new technology across many platforms. In addition, future research considers using a larger sample size to enhance the validity of our study by including an experimental and control group, which would allow for a more robust comparison and clearer interpretation of the intervention's effects.

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9 AUTHORS

Sasithorn Chookaew is an Associate Professor in the Division of Mechatronics and Robotics Engineering, Department of Teacher Training in Mechanical Engineering, Faculty of Technical Education, King Mongkut's University of Technology North Bangkok (KMUTNB), Thailand. She obtained her Bachelor of Science degree in Technology Education in 2005 and her Master of Science degree in Computer and Information Technology in 2008, both from King Mongkut's University of Technology Thonburi (KMUTT), Thailand. In 2015, she earned her Doctor of Philosophy (Ph.D.) in Science and Technology Education from Mahidol University, Thailand. Her research interests include technology-enhanced learning, the application of technology in engineering education, AI education, STEM education, personalized

learning, professional development and training, and educational robotics (E-mail: sasithorn.c@fte.kmutnb.ac.th).

Suppachai Howimanporn is an Associate Professor in the Division of Mechatronics and Robotics Engineering, Department of Teacher Training in Mechanical Engineering, Faculty of Technical Education, King Mongkut's University of Technology North Bangkok (KMUTNB), Thailand. He received his Bachelor of Engineering in Electrical Engineering and Master of Engineering in Control Engineering from King Mongkut's Institute of Technology Ladkrabang, Thailand, in 1999 and 2004, respectively. He earned his Doctor of Engineering in Mechatronics from the School of Engineering and Technology, Asian Institute of Technology (AIT), Thailand in 2014. His research interests include intelligent control systems, robotics, industrial automation, and artificial intelligence (E-mail: suppachai.h@fte.kmutnb.ac.th).