JIT Mahasarakham University, Thailand
http://jit.it.msu.ac.th

Journal of Applied Informatics and Technology, 7(1), 27-40.

Research Article

Smart Greenhouse System Based on Internet of Things using Information Flow Diagram and MQTT Connectivity

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Received:
30 March 2024
Revised:
27 April 2024
Accepted:
12 May 2024

Keywords:

Smart Greenhouse, Internet of Things, Technology Acceptance Model, Message Queue Telemetry Transport

Abstract: Technological advancements have driven the rapidly changing digital era, making the Internet of Things (IoT) adaptable in several study fields. Efficiently designing and developing smart greenhouse systems may enhance precision agriculture by enabling automated and accurate operations. This study concentrates on the architectural design of a smart greenhouse monitoring system. It employs Message Queue Telemetry Transport (MQTT) as a protocol to facilitate data communication between devices within the IoT system over extensive distances. This protocol works in conjunction with applications that use the Information Flow Diagram (IFD) architecture for the user interface. Additionally, the protocol evaluates the efficiency of using the smart greenhouse system with a mobile application. By assessing farmers' acceptance of the proposed IoT system, 35 farmers explored the adoption of IoT technology for farming based on the Technology Acceptance Model (TAM) model. The evaluation of the results of the hypothesis test was analyzed using the critical ratio value, with a required limit of 1.96 at the 95% confidence level. We can conclude that all the hypotheses were acceptable.

1. Introduction

Currently, technology plays a critical role in the ongoing global digital transformation (Ghobakhloo, 2020). It is essential in various areas of daily life and work. The Internet of Things (IoT) is another technology that has played a significant role, is becoming a revolutionary step in the modern world, and is pursuing cost-effective resources (Li *et al*., 2014; Laghari *et al*., 2021; Promput, Maithomklang, & Panya-isara, 2023). Specifically, we focus on data connection, factor control, and automation of data collection to boost productivity in the industrial and agricultural sectors. Labor can be managed in the agricultural sector by through the application of innovation and technology. In a value-based economy, driven by innovation, modern farmers earn by enhancing their skills and utilizing cutting-edge agricultural technologies to transfer from traditional agriculture to modern precision farming. This technology has been continuously utilized in precision farming, and there is ongoing research into the application of the Internet of Things in agriculture (Ahmed *et al*., 2019), including chicken farming (Masriwilaga *et al*., 2019), mushroom cultivation (Mahmud *et al*., 2018), control and monitoring for agriculture (Padalalu *et al*., 2017), and automatic watering systems (Patil & Shah, 2019).

Nevertheless, there is a growing need among farmers for precision farming or smart farming systems that can effectively enhance productivity across multiple farms. There are many advantages to intelligent systems, such as the ability to analyze data. Automatic displays are convenient and easy to use for status monitoring, environment management, etc. The challenge in system development is its compatibility with a variety of devices. The design and development of applications are crucial for managing a diverse range of environments. We have studied the design concepts using information flow diagrams to understand and communicate the process (Rukhiran & Netinant, 2020a; Rukhiran & Netinant, 2020b).

The Technology Acceptance Model (TAM) (Davis & Venkatesh, 1996; Venkatesh & Davis, 2000) is a theory that says and represents that the theory was developed from the Theory of Reasoned Action (TRA), a study about the acceptance and decision-making of new technologies or innovations by consumers. Many researchers have applied the concept of TAM to study the adoption of applications in various contexts, such as library information systems (Rafique *et al*., 2020), medical technology (Rahimi *et al*., 2018), and describing the ICT acceptance behavior of agriculture professionals (Alambaigi & Ahangari, 2016). We tested the acceptance of IoT technology, sensors, and remote-control devices to evaluate smart farm applications. The farmers were evaluated based on the principles of technology acceptance for the studied system. This assessment involves comparing the usefulness and ease of use between traditional farm systems and smart farm systems.

The objectives of this study are to investigate the adoption and utilization of IoT technology in precision agriculture, specifically in smart greenhouse systems. The application can improve efficiency, user experience, and acceptance of IoT technology for farmers. The authors concentrate on crafting the IoT system architecture and developing applications for smart greenhouse systems, which aid in automating control and monitoring environments. They used information flow diagrams (IFDs) for the design process, user interface, and user interaction of the web application. In addition, the TAM is used to examine the farmers' satisfaction with the system. Therefore, developing a user interface design application for a smart greenhouse on a handheld device can support the needs of farmers.

2. Materials and Methods

2.1 The IoT Architecture Diagram Design

The conceptual design of smart greenhouse systems using IoT for research purposes employs a 4-layer architecture. This architecture is utilized to design components of the IoT (Madato, Petlamul, & Mahamad, 2022) concept, integrating with technology to communicate data between IoT devices for control or data exchange using the widely adopted Message Queue Telemetry Transport (MQTT) protocol. This includes environmental monitoring, such as detecting changes in rainfall and weather conditions and providing real-time plant care information to farmers in India (Mukherji *et al.*, 2019). MQTT, being a reliable and secure protocol for data transmission, utilizes small-scale management, facilitates low-cost productivity enhancements, and offers high convenience. Hence, it is suitable for future smart farm technology (Yoon *et al.*, 2020). Farmers can utilize this concept to develop plant care control systems in small-scale greenhouse environments using IoT technology.

The smart greenhouse systems have been developed to support the implementation and application of environmental condition monitoring and control systems, as shown in Figure 1. The applications and data logging layer retrieves data from the data logging component for analysis, visualization, and generating insights for decision-making through mobile applications. The data storage and processing layer enables tracking temperature, humidity, soil moisture, and soil PH data. The communication layer connects to Wi-Fi for wireless connectivity between the perception layer and other layers. MQTT is a lightweight messaging protocol that facilitates communication between the perception and application layers. The perception layer consists of IoT sensors and devices, such as the Raspberry Pi 3 Model B+, relay, temperature sensors, and humidity sensors.

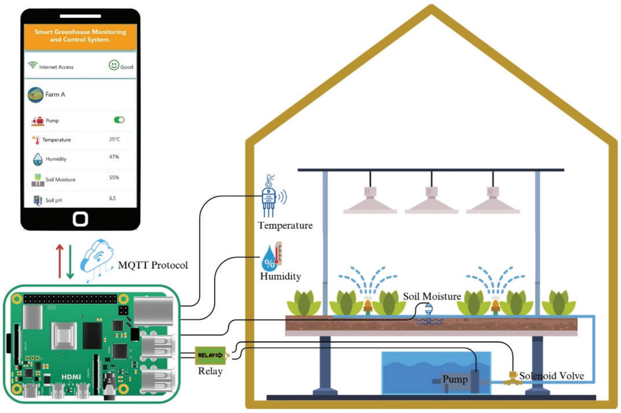
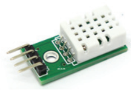


Figure 1. Architecture diagram for smart greenhouse farming

Table 1. Hardware information for a smart greenhouse

Model	Description	Images
Raspberry Pi 3 Model B+	The microcontroller signal-board computers (SBCs) are for connecting all devices and sensors.	
Relay module (12 V, 1 channel)	The relay module uses a control signal.	
SHTC3 Temperature and Humidity Sensor	The digital sensors detect pressure, humidity, and temperature.	
Soil Moisture Sensor Module	The module detects soil moisture levels.	
Soil pH Sensor	The digital sensor for the soil pH meter.	

In this paper, we study various sensors employed in designing and developing an IoT architecture for smart greenhouse systems for environmental detection. Our system uses the Raspberry Pi 3 Model B+ as the control unit for connecting all devices and sensors, which are programmed using a C++ instruction set to enable wireless connectivity at 2.4 GHz frequency to establish communication for sending data to applications with the MQTT protocol. The sensor devices used include a relay module (12 V, 1 channel), a SHTC3 temperature and humidity sensor, a soil moisture sensor module, and a soil pH sensor. The features of these sensors are shown in Table 1.

2.2 Data Transfer using MQTT Protocol

The MQTT is an IoT communication protocol that operates on top of the Transport Control Protocol (Dinculeană & Cheng, 2019). The system architecture is demonstrated in practice using Raspberry Pi connections to an application that is able to communicate with the PIN I/O of a board, as illustrated in Figure 3. MQTT connectivity enables the seamless transmission of sensor data from IoT sensors (such as the SHTC3, soil moisture, and soil pH sensors) to mobile devices, allowing users to monitor and analyze the greenhouse's environmental parameters through a mobile application in real-time.

2.3 The Smart Greenhouse System on the Web Application

The architectural design has been introduced to facilitate the utilization of sensors, networks, monitoring systems, data aggregation, and decision-making systems. In collaboration with IoT, data flow diagrams have been devised to improve the user experience of the web application for the intelligent subsoil decomposition system (Rukhiran & Netinant, 2020a; Rukhiran & Netinant, 2020b). Additionally, soil temperature monitoring in agricultural areas (Khan *et al*., 2022) and the regulation of temperature and humidity in greenhouses via cloud platforms and mobile apps enable effective data visualization, analysis, and real-time device control (Zaguia, 2023). These systems serve various purposes, such as environmental management, light adjustment, and maintaining optimal temperature and humidity levels conducive to plant growth (Rukhiran, Chomngern, & Netinant, 2023; Sofwan *et al*., 2020).

The smart greenhouse development is based on the System Development Life Cycle (SDLC) model, (Rhodes, 2012), which defines the development process. The working system can support the cultivation of various types of plants. The system can adapt to the

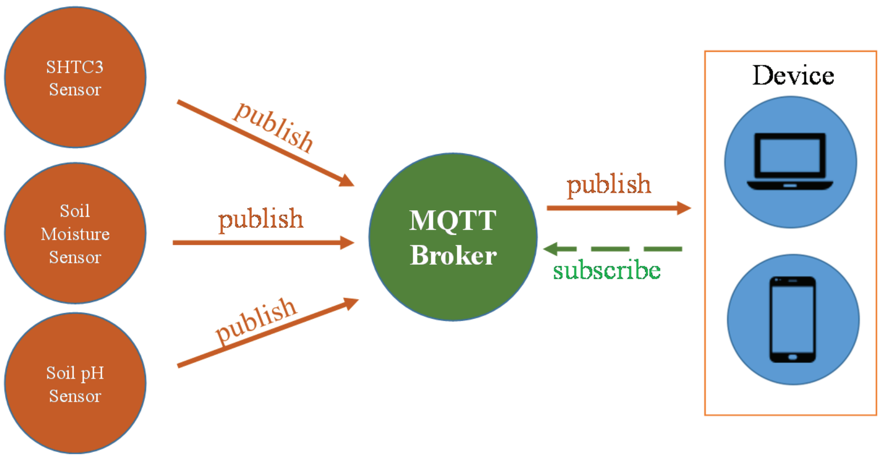


Figure 2. MQTT connection through IoT sensors

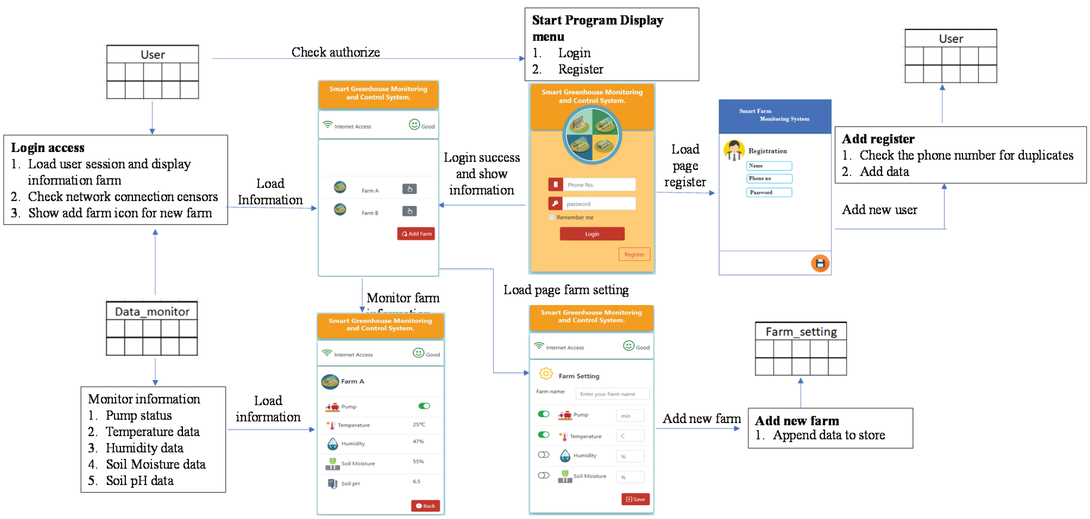


Figure 3. The information flow diagram smart greenhouse for this research

unique environment as needed. The smart greenhouse system uses data flow using the principles of the IFD shown in Figure 4, which consists of four primary components: the user interface, data, processes, data flow, and database.

An IFD shows the overall system components and data collection. Users can access the system via a login page, register, and access various parameters, such as pump control, and monitor the temperature, humidity, and moisture content of the air and soil.

2.4 Experimental Design

To assess the implementation of the smart greenhouse system, we designed a research questionnaire to gauge farmers' willingness to adopt the system. This involved examining various aspects of technology acceptance, namely: 1) perceived ease of use; 2) perceived usefulness; 3) behavioral intention; and 4) actual system use, which influences users' intentions to use it and the likelihood of continued usage in the future (Davis, Bagozzi, & Warshaw, 1989). The TAM framework guides the identification of these constructs and the formulation of questionnaire items. The TAM factors were categorized into four sections: perceived usefulness (PU) (consisting of 5 items), perceived ease of use (PEU) (comprising 5 items), behavioral intention (BI) (including 3 items), and actual system use (ASU) (comprising 3 items).

2.5 Hypotheses Model

The current research model for this study is adapted from the TAM. The proposed framework has four variables that suggest the following hypotheses:

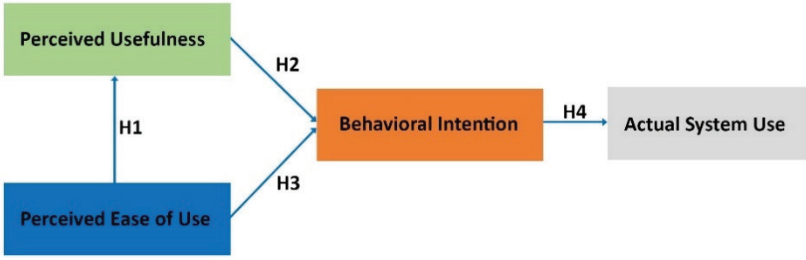


Figure 4. Research model

H1: Perceived ease of use has a positive effect on perceived usefulness

H2: Perceived usefulness of use has a positive effect on behavioral intention

H3: Perceived ease of use has a positive effect on behavioral intention

H4: Behavioral intention has a positive effect on actual system use

By testing these hypotheses within the context of the smart greenhouse application, researchers can gain insights into the relationships between perceived ease of use, perceived usefulness, behavioral intention, and actual system use. This model provides a structured approach to understanding user acceptance and adoption, contributing to the development and improvement of technology in agricultural practices, as shown in Figure. 4.

2.6 Respondents

Sampling for research according to Arikunto, if the subject was less than 100 people all the sampling should be taken (Jiang & Yuan, 2017). The respondents in this study were chosen via simple random sampling. Specifically, by selecting 35 farmers with greenhouses near Rajamangala University of Technology Tawan-ok, Bang Phra campus as sampling objects.

2.7 Questionnaires and Data Collection

A questionnaire was designed based on variables from the TAM framework. The questionnaire design used a five-point Likert scale, with values from 1 (strongly disagree) to 5 (strongly agree). The collection of data occurred between October 15 and December 20, 2023. Research data were collected by giving the smart greenhouse system to farmers to try, then giving them questionnaires after trying out the system.

3. Results and Discussion

3.1 Evaluation of Measurement Model

The test of the measurement model is an evaluation of the validity and reliability of the instrument. Following the recommendations of Bagozzi and Yi, none of the 15 items were removed from the analysis because all standard item loading values had a statistical limit of 0.5. The loading values of 0.754 to 0.984 were significant and showed great dependability. The instrument's accuracy, consistency, and dependability were evaluated.

The average variance extracted (AVE), which measured the proportion of variance captured by the latent variable, was above 0.50 and ranged from 0.753 to 0.892.

The composite reliability (CR), which assesses the internal consistency of the instrument, exceeded 0.70 and ranged from 0.913 to 0.965.

These findings indicate high data reliability. Additionally, Cronbach's alpha coefficient, which measured internal consistency, exceeded 0.70 and ranged from 0.905 to 0.967, as recommended by Cronbach.

Table 2 shows that all research variables are valid and reliable.

Table 2. Convergent validity and reliability of constructs

Constructs	Items	Loadings	AVE	CR	Cronbach' alpha
Perceived Usefulness (PU)	PU1	0.907	0.753	0.938	0.930
	PU2	0.754			
	PU3	0.945			
	PU4	0.809			
	PU5	0.910			
Perceived Ease of Use (PEU)	PEU1	0.771	0.848	0.965	0.967
	PEU2	0.925			
	PEU3	0.954			
	PEU4	0.955			
	PEU5	0.984			
Behavioral Intention (BI)	BI1	0.918	0.778	0.913	0.905
	BI2.	0.890			
	BI3.	0.836			
Actual System Use (ASU)	ASU1	0.967	0.892	0.961	0.958
	ASU2.	0.966			
	ASU3:	0.898			

Table 3. Overall results goodness of fit model

Fit Model	Recommended	Actual
Chi-square	p > 0.05	0.075
X^2/df	< 2.00	1.391
CFI	≥ 0.95	0.975
GFI	≥ 0.95	0.997
AGFI (Adjusted)	≥ 0.95	0.987
RMSEA	< 0.05	0.014
SRMR	< 0.05	0.003

3.2 Overall Conformity Evaluation (Overall Goodness of FIT Model)

Table 3 presents a summary of the overall model fit measurements. In addition to the chi-square, X^2/df, CFI, GFI, AGFI, RMSEA, and SRMR values are checked (Diamantopoulos, Siguaw, & Siguaw, 2000; Bollen, 1989; Kaplan, 2009; Hu & Bentler, 1999).

The overall results for the goodness of fit model were as follows: The chi-square value was significant ($p = 0.075 > 0.05$); the X^2/df, a calculation of the chi-square value divided by the degree of freedom (df), = 1.139 < 3, thus fulfilling the criteria for goodness of fit; the RMSEA = 0.014 < 0.05 and the SRMR = 0.003 < 0.05 meet the absolute goodness of fit requirement; the CFI = 0.975 ≥ 0.95, GFI = 0.997 ≥ 0.95 and AGFI = 0.987 ≥ 0.95 all meet the incremental fit measures.

3.3 Analysis of the Structural Model

The application of the structural model produces the output in the form of path coefficients and R-squared. The value of R-squared (R2) was determined to identify the ability to explain the four research variables. If the value of R2 is close to 1, it indicates the independent variable explains a large portion the variance in the dependent variable (Imam, 2012). The test results showed that the R2 value of the perceived usefulness variable was 0.761, the behavioral intention variable was 0.498, and the actual system use was 0.541. While the perceived ease of use variable was 0.

The path coefficient describes the positive or negative relationship between two latent variables and the magnitude of the influence one latent variable has on the other. The CR value is obtained by dividing the estimated parameter value by the

Table 4. Coefficient calculation results

Hypothesis	Estimate	SE	CR	Description
H1: Perceived ease of use → Perceived Usefulness	1.253	0.510	5.621	Acceptable
H2: Perceived Usefulness → Behavioral Intention	1.791	0.239	4.327	
H3: Perceived ease of use → Behavioral Intention	1.920	0.182	4.877	
H4: Behavioral Intention → Actual System Use	0.358	0.101	4.974	

estimated standard error (SE) value. The aim of the hypothesis test was to analyze the critical ratio (CR) value, then compare it to the required limit of 1.96, and use a 95% confidence level to determine if a relationship is significant. According to Table 4, it could be concluded that hypotheses H1, H2, H3, and H4 were acceptable.

4. Conclusions

In this paper, the study highlights the significance of the IoT smart greenhouse system architecture, which acts as a foundational framework for integrating diverse components. The perception layer acquires crucial environmental data through sensors like temperature, humidity, soil moisture, and pH sensors. Efficient and reliable data transmission between the perception and application layers is ensured by the communication layer through MQTT connectivity. The application layer provides a user interface, empowering users to monitor, control, and analyze the greenhouse environment via a mobile application. The findings underscore the seamless integration of IoT devices and web applications into the design and operation of smart greenhouses. Key elements such as the main menu, data storage, and database, automatically updated according to the information flow diagram (IFD), contribute to establishing an appropriate and consistent natural environment. These findings resonate with Terence & Purushothaman's (2020) research on smart farming architecture, leveraging IoT for remote monitoring and control to reduce labor intensity and optimize resource utilization. Addressing user acceptance factors and ensuring the perceived usefulness and ease of use of the IoT smart greenhouse system can enhance its adoption and successful implementation. This research utilizes a microcontroller that is compatible with wireless networks, specifically Wi-Fi, to establish connections with devices. This feature enhances the accessibility and usefulness of the system.

In the future, we aim to develop an intelligent system to control and monitor greenhouse temperatures. Once a farmer selects a crop type, we will create a database to automatically store the best environmental conditions for growing that crop. Additionally, we plan to improve the efficiency of control equipment compatible with 5G signal networks, enabling remote farming operations.

5. Acknowledgments

The authors gratefully acknowledge the generous support of the Department of Mechatronics and Robotics Engineering, School of Engineering and Innovation, Rajamangala University of Technology, Tawan-ok (RMUTTO).

References

Ahmed, M., Rahaman, M. O., Rahman, M., & Kashem, M. A. (2019). Analyzing the quality of water and predicting the suitability for fish farming based on IoT in the context of Bangladesh. In *International Conference on Sustainable Technologies for Industry 4.0 (STI)* (pp. 1-5). IEEE. https://doi.org/10.1109/STI47673.2019.9068050

Alambaigi, A. & Ahangari, I. (2016). Technology acceptance model (TAM) as a predictor model for explaining agricultural experts behavior in acceptance of ICT. *International Journal of Agricultural Management and Development (IJAMAD)*, *6*(2), 235-247. https://doi.org/10.22004/ag.econ.262557

Bollen, K. A. (1989). *Structural equations with latent variables*. New York : John Wiley & Sons. https://doi.org/10.1002/9781118619179

Davis, F. D., Bagozzi, R. P., & Warshaw, P. R. (1989). User acceptance of computer technology: A comparison of two theoretical models. *Management science*, *35*(8), 982-1003. http://www.jstor.org/stable/2632151

Davis, F. D. & Venkatesh, V. (1996). A critical assessment of potential measurement biases in the technology acceptance model: three experiments. *International journal of human-computer studies*, *45*(1), 19-45. https://doi.org/10.1006/ijhc.1996.0040

Diamantopoulos, A., Siguaw, J. A., & Siguaw, J. A. (2000). *Introducing LISREL: A guide for the uninitiated*. Cornell University, USA: Sage.

Dinculeană, D. & Cheng, X. (2019). Vulnerabilities and limitations of MQTT protocol used between IoT devices. *Applied Sciences*, *9*(5), 848. https://doi.org/10.3390/app9050848

Ghobakhloo, M. (2020). Industry 4.0, digitization, and opportunities for sustainability. *Journal of cleaner production*, *252*, 119869.vhttps://doi.org/10.1016/j.jclepro.2019.119869

Hu, L. T. & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling: A Multidisciplinary Journal*, *6*(1), 1-55. https://doi.org/10.1080/10705519909540118

Imam, G. (2012). *Aplikasi analisis multivariat dengan program IBM SPSS 20*. Semarang : Badan Penerbit Universitas Diponegoro.

Jiang, G. & Yuan, K. H. (2017). Four new corrected statistics for SEM with small samples and nonnormally distributed data. *Structural Equation Modeling*, *24*(4), 479–494. https://doi.org/10.1080/10705511.2016.1277726

Kaplan, D. (2009). *Structural equation modeling: Foundations and extensions*. Los Angeles: SAGE.

Khan, A. A., Faheem, M., Bashir, R. N., Wechtaisong, C., & Abbas, M. Z. (2022). Internet of things (IoT) assisted context aware fertilizer recommendation. *IEEE*, *10*, 129505-129519.https://doi.org/10.1109/ACCESS.2022.3228160

Laghari, A. A., Wu, K., Laghari, R. A., Ali, M., & Khan, A. A. (2021). A review and state of art of internet of things (IoT). *Archives of Computational Methods in Engineering*, 1-19. https://doi.org/10.1007/s11831-021-09622-6

Madato, T., Petlamul, W., & Mahamad, K. (2022). Efficiency of smart farm system on enhancement of pepper production. *Naresuan University Journal: Science and Technology (NUJST)*, *30*(4), 53-65. https://doi.org/10.14456/nujst.2022.35

Mahmud, M. A., Buyamin, S., Mokji, M. M., & Abidin, M. Z. (2018). Internet of things based smart environmental monitoring for mushroom cultivation. *Indonesian Journal of Electrical Engineering and Computer Science*, *10*(3), 847-852. http://doi.org/10.11591/ijeecs.v10.i3.pp847-852

Masriwilaga, A. A., Al-hadi, T. A. J. M., Subagja, A., & Septiana, S. (2019). Monitoring system for broiler chicken farms based on Internet of Things (IoT). *Telekontran: Jurnal Ilmiah Telekomunikasi, Kendali dan Elektronika Terapan*, *7*(1), 1-13.

Mukherji, S. V., Sinha, R., Basak, S., & Kar, S. P. (2019). Smart agriculture using internet of things and MQTT protocol. In *2019 International Conference on Machine Learning, Big Data, Cloud and Parallel Computing (COMITCon)* (pp. 14-16). IEEE. https://doi.org/10.1109/COMITCon.2019.8862233

Padalalu, P., Mahajan, S., Dabir, K., Mitkar, S., & Javale, D. (2017). Smart water dripping system for agriculture/farming. In *2017 International Conference for Convergence of Technology (I2CT)* (pp. 659-662). IEEE. https://doi.org/10.1109/I2CT.2017.8226212

Patil, V. B.& Shah, A. B. (2019). Automated watering and irrigation system using Arduino UNO. *International Journal of Innovative Science and Research Technology*, *4*(12), 928-932.

Promput, S., Maithomklang, S., & Panya-isara, C. (2023). Design and analysis performance of IoT-based water quality monitoring system using LoRa technology. *TEM Journal*, *12*(1), 29-35. https://doi.org/10.18421/TEM121-04

Rafique, H., Almagrabi, A. O., Shamim, A., Anwar, F., & Bashir, A. K. (2020). Investigating the acceptance of mobile library applications with an extended technology acceptance model (TAM). *Computers & Education*, *145*, 103732.https://doi.org/10.1016/j.compedu.2019.103732

Rahimi, B., Nadri, H., Afshar, H. L., & Timpka, T. (2018). A systematic review of the technology acceptance model in health informatics. *Applied clinical informatics*, *9*(03), 604-634. https://doi.org/10.1055/s-0038-1668091

Rhodes, D. L. (2012). The systems development life cycle (SDLC) as a standard: Beyond the documentation. In *SAS Global Forum*, (184), 1-5.

Rukhiran, M., Chomngern, T., & Netinant, P. (2023). Insights from a dataset on behavioral intentions in learning information flow diagram capability for software design. *Data in Brief*, *49*, 109307. https://doi.org/10.1016/j.dib.2023.109307

Rukhiran, M., & Netinant, P. (2020a). Mobile application development of hydroponic smart farm using information flow diagram. In *2020-5th International Conference on Information Technology (InCIT)* (pp. 150-155). IEEE. https://doi.org/10.1109/InCIT50588.2020.9310780

Rukhiran, M., & Netinant, P. (2020b). IoT architecture based on information flow diagram for vermiculture smart farming kit. *Tem Journal*, *9*(4), 1131-1137. https://doi.org/10.18421/TEM94-03

Sofwan, A., Sumardi, S., Ahmada, A. I., Ibrahim, I., Budiraharjo, K., & Karno, K. (2020). Smart greetthings: Smart greenhouse based on internet of things for environmental engineering. In *2020 International Conference on Smart Technology and Applications (ICoSTA)* (pp. 1-5). IEEE. https://doi.org/10.1109/ICoSTA48221.2020.1570614124

Terence, S. & Purushothaman, G. (2020). Systematic review of internet of things in smart farming. *Transactions on Emerging Telecommunications Technologies*, *31*(6). https://doi.org/10.1002/ett.3958

Venkatesh, V., & Davis, F. D. (2000). A theoretical extension of the technology acceptance model: Four longitudinal field studies. *Management science*, *46*(2), 186-204. https://ssrn.com/abstract=4062393

Yoon, H. W., Kim, D. J., Lee, M., Weon, C., & Smith, A. (2020, August). L & M farm: A smart farm based on LoRa & MQTT. In *2020 International Conference on Omni-layer Intelligent Systems (COINS)* (pp. 1-6). IEEE. https://doi.org/10.1109/COINS49042.2020.9191387

Zaguia, A. (2023). Smart greenhouse management system with cloud-based platform and IoT sensors. *Spatial Information Research*, *31*(5), 559-571. https://doi.org/10.1007/s41324-023-00523-3