Efficiency of Smart Farm System on Enhancement of Pepper Production

Tawatchai Madato[1], Wanida Petlamul[2] and Kuntapon Mahamad[1]*

[1]Faculty of Industrial Technology, Songkhla Rajabhat University, Muang District, Songkhla 90000

[2]College of Innovation and Management, Songkhla Rajabhat University, Muang District, Songkhla 90000

* Corresponding author. E-mail address: kuntapon.ma@skru.ac.th

Received: 16 July 2021; Revised: 6 February 2022; Accepted: 10 February 2022; Available online: 9 September 2022

Abstract

This research presents the Smart Farm System (SFS), networked with the Internet of Things, and its positive impact on the yield and productivity of a pepper crop. The SFS was designed and developed using an ESP32 microcontroller board connected to a BME280 spraying system and also to an SHT10 sprinkler system. The SFS operates continuously and accurately according to set parameters, with the spraying system operating based on temperature and humidity parameters when the temperature is greater than 30 °C and the humidity is less than 80 %RH, and the sprinkler system operating according to soil moisture parameters, when the soil moisture is less than 70%. The results show that, in the comparison of pepper yield of the crops watered under the control of the SFS, for both the spraying systems and the sprinkler system, and a crop watered under the usual general watering process, the mean values of pepper crop yield weights were significantly higher for the SFS-controlled systems. Compared to general watering, the pepper yield weight from the spraying system increased by 49.97% and 24.97% from the sprinkler system. The pepper quality values of average bunch length, bunch diameter, and pepper seed size from both the crop watered by the spraying system and the sprinkler system were all significantly higher than those obtained from the general watering process. User satisfaction with the automated systems for convenience of use, user interface and application, clarity of the instruction manual, material requirements and structure of the devices was high as was the confidence that the systems could generate higher productivity from the pepper.

Keywords: Smart farm system, Internet of Things, Temperature, Humidity, Soil moisture, Pepper

Introduction

Pepper (black pepper, *Piper nigrum* Linn) is the world's most traded spice due to its culinary use, and particularly its medical benefits. Black pepper has been used extensively in health and cosmetics (Bagheri, Abdul Manap, & Solati, 2014), and contains phytochemicals with active properties for preventing certain diseases, such as neurodegeneration in guinea pigs induced to have Alzheimer's disease (Chonpathompikunlert, Wattanathorn, & Muchimapura, 2010). Pepper possesses carminative qualities and mucolytic properties that aid in the treatment of panting, coughing and insomnia, as well as health tonic properties (Palaphan, 2010). Pepper also relieves pain and prevents convulsions in guinea pigs (Bukhari, Pivac, Alhumayyd, Mahesar, Gilani, 2013), depresses inflammation (Tasleem, Azhar, Ali, Perveen, & Mahmood, 2014), and kills breast cancer cells (De Souza Grinevicius et al., 2016). Additionally, it was revealed that a secondary aspect of pepper is that it functions as a pesticide against golden apple snails and insects in the agricultural area (Srivastava & Singh, 2017). According to data on pepper grown in Thailand from 2015 to 2019, the number of households engaged in growing pepper increased from 1,031 to 1,087. Crop yield totalled 1,031 tons in 2020, with most plantation sites in eastern Thailand located in Chantaburi Province. Krabi, Phangnga, Trang, Ranong, Nakhon Si Thammarat, with some regions of Songkhla having the most planted areas in southern Thailand (Office of Agricultural Economics, 2020). Currently, pepper plantation areas are being increased throughout Thailand. Pepper crops are not only grown for domestic use and distribution but comprise an export industry generating millions of baht in income for Thailand annually. Due to pepper's high value in the spice category, farmers who grow pepper can earn a higher income than farmers who grow other economic crops. The price of black pepper is 400 baht per kilogram and white pepper is 1,000 baht per kilogram, both prices showing an upward trend. These factors have encouraged more farmers to be more interested in growing pepper. However, farmers have always faced drought and pest infestations when growing pepper. Due to recent climate change, pest infestations have increased. Additionally, environmental conditions have become more unfavorable for pepper growing. Suitable conditions for growing, blooming, and fruiting of pepper crops include tropical weather with temperatures ranging between 21 – 32 °C with humidity ranging from 60% – 95% (Kandiannan et al., 2011; Chawapradit, 2014; Kandiannan, Krishnamurthy, Gowda, & Anandaraj, 2014). Working within these constraints, farmers must pursue suitable growing conditions to maximize both the quality and quantity of the pepper crop yield.

Agricultural production can be enhanced through modern technology applications that integrate sensor engineering, computer, information, and communication technology, and agricultural knowledge (Atzori, Iera, & Morabito, 2010). Ranokphanuwat (2017) used a smart farm system (SFS) to regulate the functioning of an automatic control system based on the growing stages of vegetables by observing and analyzing the growth of hydroponic vegetables. Morelli et al. (2018) used an SFS in automatic temperature and humidity control systems, assisting farmers in managing their farms extensively by analyzing temperature and humidity data, obtained from measuring systems out in the fields via wireless networking, to plan and achieve farming efficiency and investment-worthy crops to meet consumer demands and profitability. This was consistent with the research conducted by Pettong & Vongkrachang (2020), who studied the use of SFS in producing off-season durians by sending soil moisture data from sensors to control watering requirements and volumes which helped to stimulate the growth of off-season durians and thereby increase the income of the farmers. Mahamad, Kongmon, Petlamul, Petlamul, and Chuwanich (2020) applied SFS to control humidity for lettuce production and found that crops obtained from SFS were 5 times greater than crops from traditional farms. (Mahamad, Mansuriwong, & Petlamul, 2021) found that the yield from a crop of oyster mushrooms was 142% of the yield from a conventionally grown crop when controlled by an SFS

Automatic control systems are viewed as a tool that supports in crop production and quality improvement. The Thailand 4.0 Policy (Government Spokesman Bureau, Secretariat of the Prime Minister, 2017) was promulgated to promote and improve the capabilities of farmers and to encourage and provide safe crops for consumers and the environment, leading to a capability in international competition (Shashwathi, Borkotoky, & Suhas, 2012; Masa, Ledóné, & Komarek, 2021). However, it was discovered that automated systems that controlled temperature and humidity conditions in the field were rarely used, although Fletcher, Nyuak, and Yee (2021) investigated a web-based pH monitoring system for liquid fertilizer management, Nyuak, Kedung Fletcher, and Yee (2019) investigated soil moisture and temperature in conjunction with pH. However, SFS for enhancing the quantity and quality of yields in pepper crops were not observed.

This was the impetus for the research described in this paper, the objectives of which were to study the impact on pepper crops yields when humidity, temperature, and soil moisture levels were monitored via an SFS. Using the ESP32, an inexpensive, low power, WIFI and Bluetooth 4.2 BLE board, coupled to sensors in a BME280 spraying system and also an SHT10 sprinkler system. This SFS is low-cost and easy to use system that was implemented for the monitoring and control of watering a pepper crop. Hence, helping farmers save money on time, labor, and resources to produce a quality pepper crop with a high yield thereby providing a regular supply of quality pepper sufficient to meet the demands of the organic agriculture market, and creating a competitive and profitable export market.

Methods and Materials

Pepper, Preparation of Pepper Planting Plot, and Installation of Automatic Watering System

The pepper used in this experiment was 3-year grown by a pepper growing network of producers in Bang Rieng Sub-District, Kuan Neang District, Songkhla Province. The sample crop of 120 pepper trees was grown in 30 concrete pipes with diameter of 50 centimeters and a height of 25 centimeters, in close proximity. Each concrete pipe contained 4 pepper trees and 3-meter cement poles were installed to support the climbing pepper trees. The concrete pipes were arranged in 3 rows with 10 pipes per row and a distance of 2.50 meters between pipes (Figure 1). The pipes were designated into 3 sets of rows, each row consisting of 40 pepper trees. Each row was subject to a different watering regime, each designated as an Experiment. Experiment 1 was general watering as usually performed by farmers, and the plants were watered through a water hose in the morning around 8.00 a.m by an attendant. Experiment 2 used a spraying system for controlling temperature and humidity with the planting pipes covered with a shade net with 60% transparency to reduce the variability of temperature and humidity changes during the experiment. Experiment 3 was an automatic sprinkler system for controlling soil moisture.

Data transmitted by the sensor was processed by the controller for automatic, controlled watering. Simultaneously, the controller would send measurements via a wireless Internet of Things style networked system to display readings to users. These readings and results are saved to a cloud server for further analysis and access as required from a smartphone, as shown in Figure 1.

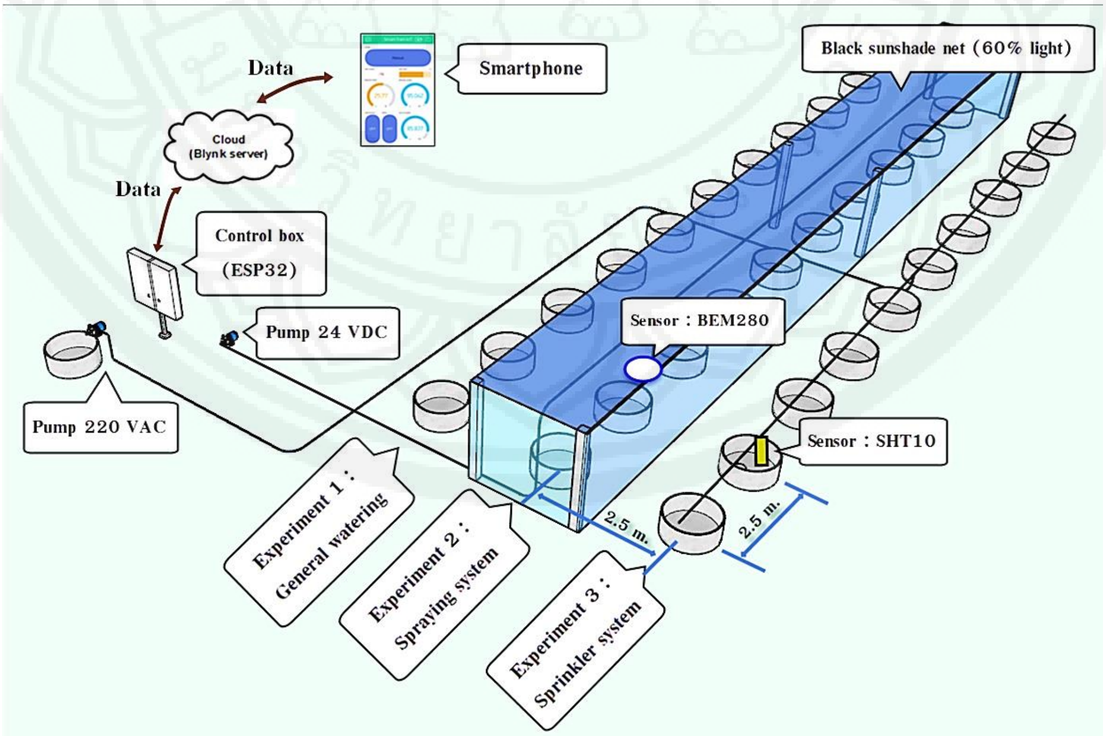

Figure 1 Pepper planting plot and installation of the system

To grow and maintain the pepper plants, the same methodology was performed for each of the 3 experiments. First, 1.50 kilograms of chemical fertilizer was added, per pole, 3 times per year The first application of fertilizer was a 15-15-15 formula to support the development of the stems. The second application of fertilizer was an 8-24-24 formula to accelerate blooming, and the third application was a 12-12-17+Mg formula to nourish the pepper fruits. Each of the three applications of fertilizer included an additional 2 kilograms per pole of organic fertilizer. Root rot was eliminated by adding 200 grams of *Trichoderma* sp. per pole every 2 months.

Design and Development of Control System for Smart Farm System

In this research article, the control system was designed and developed to be operated in both manual control and automatic mode to maintain the temperature and humidity at the specified values. This control program was written by using Arduino IDE on the ESP32 microcontroller board (Jasungnuen, 2019) and the Blynk application which is a free application designed to support operations on a microcontroller. The ESP32 could be connected from a smartphone with both Android and IOS systems. Users were able to pull real-time data from the sensors and the results were displayed via smartphone as required. The control system designed in this research included operation and command processes needed to configure and set the temperature and humidity, and soil moisture, values. The operational diagram is shown in Figure 2.

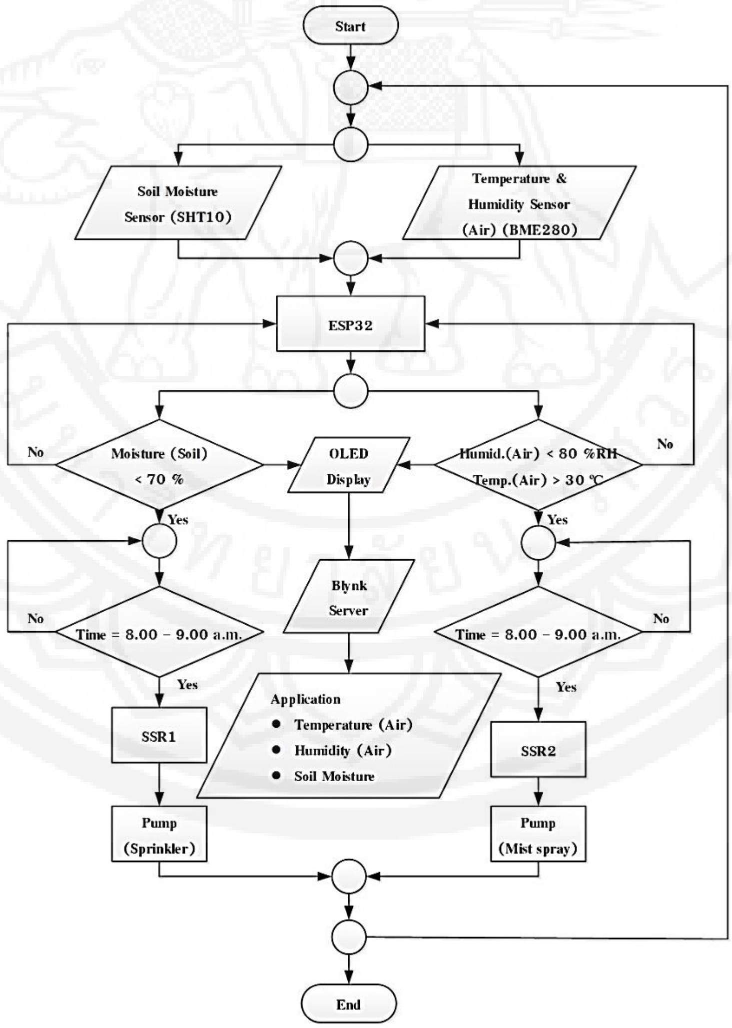

Figure 2 Diagram on functionality of automatic control system

The ESP32 is a microcontroller used to develop control systems in these experiments. (Figure 2). It is a low cost, adaptable, with low power consumption, that has support for WIFI and Bluetooth 4.2 BLE connectivity with rapid data transmission. The BME280 is an accurate temperature and humidity sensor, while the SHT10 is an accurate soil moisture sensor. They were controlled by the ESP32 microcontroller in the control system and could measure a wide range of temperatures and humidity. The microcontroller board received the measured data from the sensors and displayed the results via the Blynk application, allowing users to verify and adjust the values as needed.

In Experiment 2, the BME280 sensor measured and transmitted the temperature and humidity data to the ESP32. The system was conditioned to operate when the temperature was greater than 30 °C and the humidity was less than 80 %RH., which are suitable conditions for pepper growth (Kandiannan et al., 2011; Chawapradit, 2014). This system was programmed to read and gather data from 8:00 a.m. to 9:00 a.m., as this is the optimal period to water the plants (Singnan & Vangkapun, 2016). The solid-state relay (SSR2) would be activated by the system in response to the set conditions, turning the 24 VDC water pump and mist spray system on or off according to the temperature and humidity levels being reached.

In Experiment 3, the soil moisture control system was designed and developed with SHT10 sensors connected to ESP32 microcontroller board. The system was conditioned to operate when the soil moisture was less than 60% (Peng et al., 2010) and was programmed to read and gather data from 8:00 a.m. to 9:00 a.m. The system activated the solid-state relay (SSR1) in response to the set condition, resulting in the 220 VAC water pump operating automatically. However, if the systems overran the designated watering parameters, the entire control system shut down the 220 VAC water pump or the 24 VDC misting spray pump as appropriate. The electrical circuit designed and developed for the SFS is illustrated in Figure 3.

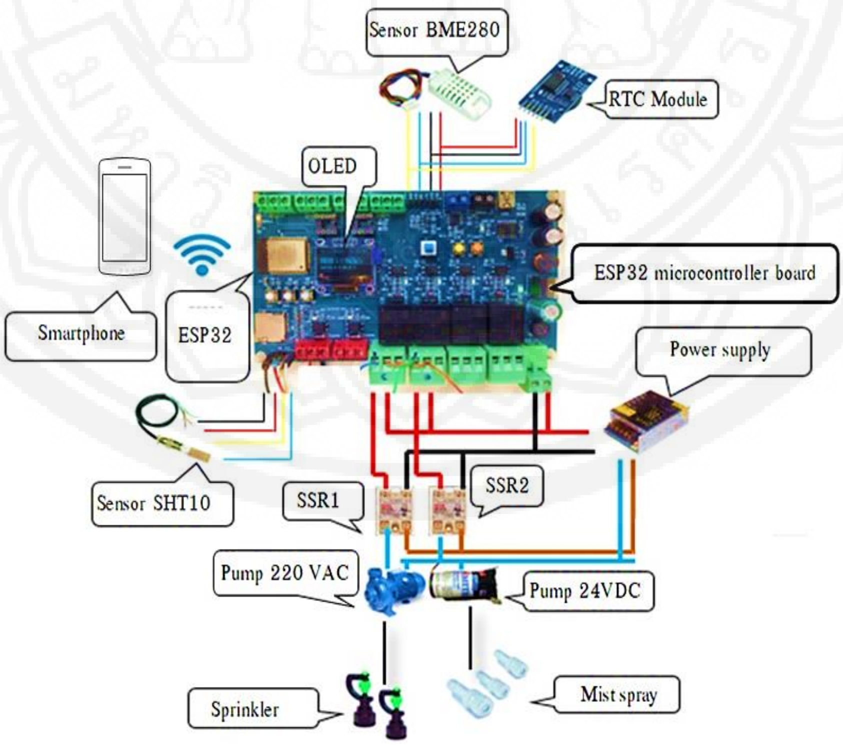

Figure 3 Design of electrical circuit of SFS with ESP32 microcontroller board

The system was also able to be operated manually in case of any error in the internet signal by simply pressing the button located in front of the control cabinet.

The Blynk application was used to validate the measurement data collected from the BME280, SHT10 sensor, and ESP32 microcontroller board, and it could store the data on the Blynk server as backup. All recorded data was stored as comma-separated value files (.CSV, thus allowing it to be analyzed using Microsoft Excel® spreadsheets) with storage for 1 year. The files could be transmitted to email addresses. The application and data storage format are shown in Figure 4.

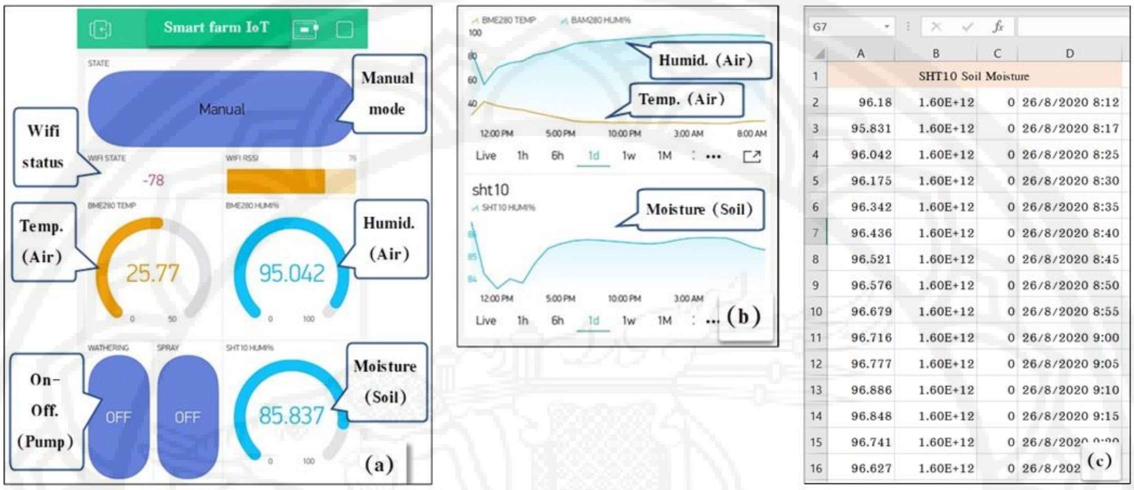

Figure 4 Data display and data storage of system (a) Graphic user interface (b) Trend graph (c) Database

Accuracy Test of Sensors for Measuring Temperature and Humidity, and Soil Moisture of Developed SFS

The finished SFS was installed in the pepper planting plots for Experiment 2 and Experiment 3, as shown in Figure1. The efficiency of the developed system, as well as display via the Blynk application connection, were monitored, as illustrated in Figure 5. From 8:00 to 9:00 a.m., three replications of air temperature and humidity measurements, as well as soil moisture values, were taken from both the SFS and standard measuring meters in the same site. The mean value was calculated from the acquired data and converted to an error percentage (%) for evaluating the operational effectiveness of the developed SFS (Noonak & Suesut, 2012), applying Equation 1.

$$\%\text{error} = \frac{|E_{mea} - E_t|}{E_t} \text{x } 100 \quad (1)$$

where E_{mea} is measured value

E_t is the actual value measured by the standard measuring tool

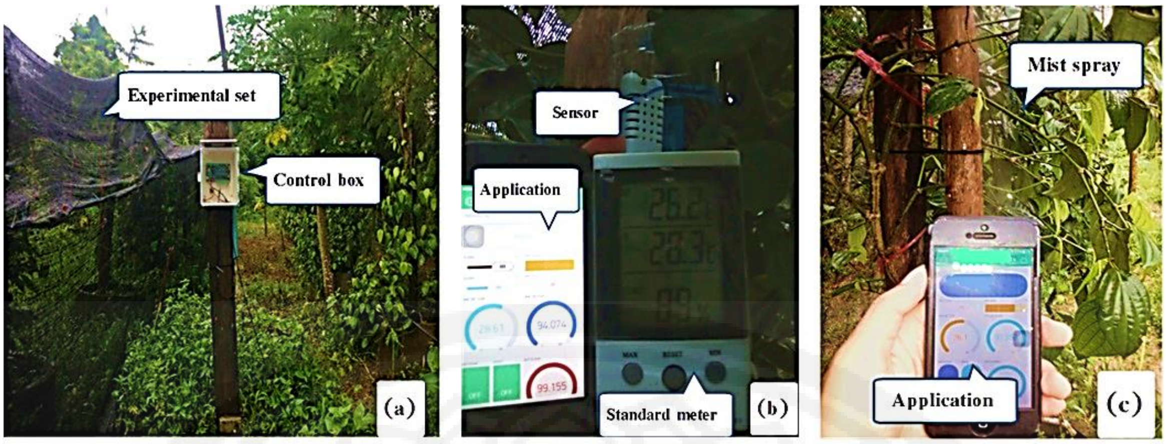

Figure 5 Accuracy test of sensors for measuring temperature and humidity of developed control system (a) Planting plot for testing spraying system (b) Comparison between the value obtained from the sensor and standard meter (c) System operational test

The Efficiency of the SFS for Improving Pepper Production

After installing and testing the accuracy of operation of SFS, the system then was set to be operated continuously for 30 days to harvest all pepper bunches (immature-mature) based on the usual harvest method of farmers for crops intended to be distributed in the form of dried and fresh pepper products or for adding value by processing as white pepper. The mean of the weights of the total fresh pepper, bunch length of the fresh pepper, size of the fresh pepper seeds, and the density of pepper seeds per bunch were recorded for each of the three experiments and compared. The analysis of variance of the experimental data was compared to the Fischer's Least Significant Difference (LSD) between the means of each experiment.

The Satisfaction Assessment of Users for Pepper Production

Assessment of the satisfaction of users towards the SFS in pepper growing. A cohort of 32 farmers in the Herbal Plants Farmers Network in Bang Reang Sub-District, Kuan Neang District, Songkhla Province were sampled after they had used the SFS in their pepper growing activities. This was conducted by holding training sessions on the system. User satisfaction was assessed by using a Likert rating scale of 5 levels. Mean and standard deviation were calculated from the responses (Siljaru, 2005).

Results

Results of Accuracy Test of Sensors

Air temperature and humidity, and soil moisture, were recorded every 10 minutes between 8 am and 9 am daily. Both the BME280 sensor used in Experiment 2 and the SHT10 sensor used in Experiment 3 recorded similar values to those measured by the standard meter (Figure 6).

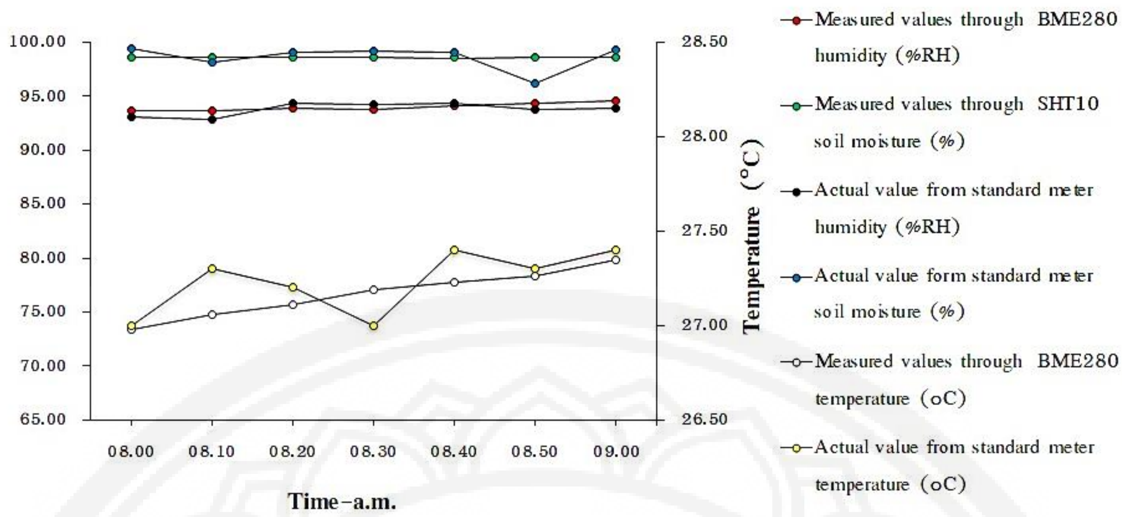

Figure 6 Temperature and humidity measured by sensors of developed control system compared to value measured by standard meter

As illustrated in Figure 6, the sensors used to measure temperature and humidity, and soil moisture in the developed automatic control system were both efficient and accurate. When the error percentage was calculated as given in equation 1, it was discovered that the temperature and humidity values detected by the BME280 sensor in experiment 2 had an average error percentage of 0.42 and 0.56. In experiment 3, the average error percentage of the soil moisture value detected by the SHT10 sensor was 0.87 (Table 1).

Table 1 Error percentage of temperature and humidity, and soil moisture measured by control system compared to the standard meter during the period 8 am to 9 am.

8 am to 9 am	Measured values through sensor: Sensor BME280		Measured values through sensor: Sensor SHT 10	Actual value from standard meter (Elitech)		Actual value form standard meter (Landtek)	(%) Error in Sensor BME280 set		(%) Error in Sensor SHT10 set
	Temperature (°C)	Humidity (%RH)	Soil moisture (%)	Temperature (°C)	Humidity (%RH)	Soil moisture (%)	Temperature (°C)	Humidity (%RH)	Soil moisture (%)
Average	27.17	94.00	96.60	27.23	93.79	98.63	0.42	0.56	0.87

The data in Table 1 demonstrates that the SFS continuously measured the temperature and humidity, and soil moisture accurately, consistent with the standard meter. Additionally, results could be displayed on a smartphone. It can be confidently stated that the SFS developed in this project efficiently and effectively collected and used the recorded data for its purpose (Kitsawang, 2016).

Results of Study on Efficiency of SFS for Improving Pepper Production

The pepper crop data collected from the three experiments are detailed in Table 2.

Table 2 Mean of pepper yields collected for each of the three experiments

	Pepper Crops			
Experiments	**Pepper Bunch Length (cm.)**	**Pepper Bunch Diameter (cm.)**	**Size of Pepper Seed (mm.)**	**Pepper Quantity (kg./rai) /1**
General watering	12.05	1.10	4.00	18.69c
spraying system	18.70	1.55	6.50	28.03a
sprinkler system	15.30	1.25	5.50	23.36b
F test				*
CV (%)				12.43

/1 Means followed by the small letter in the same column and row are not significantly different by Fischer's Least Significant Difference (LSD) test at 95% ($P<0.05$)

Table 2 demonstrates that the mean of the pepper crops in Experiment 2 (the spraying system) was the highest in all dimensions, with a pepper bunch length of 18.70 cm., a pepper bunch diameter of 1.55 cm., and a pepper seed size of 6.50 mm., followed by Experiment 3 (sprinkler system) with a pepper bunch length of 15.30 cm, a pepper bunch diameter of 1.25 cm., and a pepper seed size of 5.50 mm. Experiment 1 (hand watering) yielded the lowest pepper crops, with a pepper bunch length of 12.05 cm, a pepper bunch diameter of 1.10 cm, and a pepper seed diameter of 4.00 mm. These findings indicate that spraying resulted in the highest pepper yields and pepper seeds of best quality and abundance. Pepper yields from Experiment 2 (28.03 kg/rai) and Experiment 3 (23.36 kg/rai) were significantly higher ($p<0.05$) than those from Experiment 1 (18.69 kg/rai). Experiment 2 yield was 49.97% greater than from Experiment 1, and Experiment 3 was 24.97% greater.

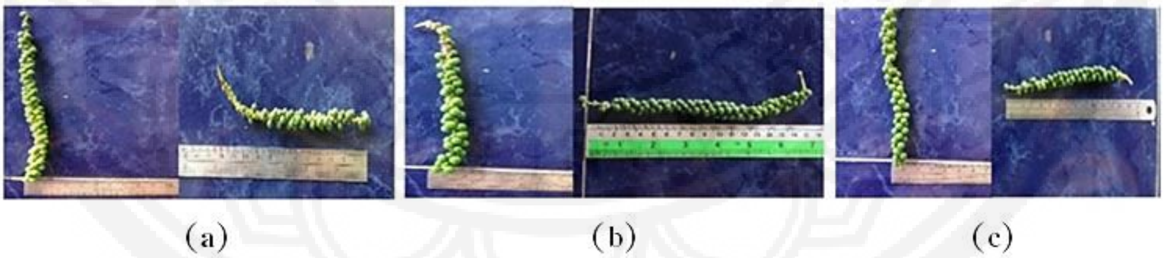

Figure 7 Comparison of fresh pepper fruits from different irrigation systems (a) general watering (b) Spraying system (c) sprinkler system

Similarly, the bunch length and seed size of fresh pepper from both Experiments 2 and 3 were substantially larger than from Experiment 1. These bunch lengths (15.30 cm and 12.05 cm) were also larger than the bunch length indicated in ecotype data, of only 5-15 cm with a pepper seed diameter of approximately 4-6 mm (Changthom, 2014). As a result, these different irrigation systems have varying effects on pepper growth and yields providing quantitative data in terms of weight and qualitative data in terms of size.

Results of Analysis on Satisfaction of Users Towards SFS in Pepper Growing

The satisfaction assessment results from the 32 participating farmers revealed that they were satisfied with the SFS at the highest level. The overall satisfaction (4.60 and SD=0.53) was shown in Table 3.

Table 3 Results of assessment on satisfaction of users towards SFS in pepper growing

Opinion	$\overline{X}$	S.D.	Satisfaction level
1. Materials and device structure	4.41	0.61	High
2. Convenience of use	4.72	0.46	Highest
3. User interface and application	4.66	0.55	Highest
4. Instruction manual	4.63	0.49	Highest
Mean	4.60	0.53	Highest

The highest average satisfaction level was at 4.72 (Convenience of use), followed by 4.66 (User interface and application), and 4.63 (Instruction manual), while the highest satisfaction level was at 4.41 (Materials and device structure) as detailed in Table 4. The satisfaction results indicated that this SFS provided sufficient pepper yield. It is particularly convenient to use and the operation of the system is easy to understand. According to the developed automatic system of pH monitoring (Fletcher et al., 2021), as well as the investigation of soil moisture, temperature, and pH (Nyuak et al., 2019), these studies were aimed at farmers in order to increase pepper yields using simple method.

Comments from the participating farmers also provided additional information from an interview that *"utilization of this automatic watering system could help reduce the duration of maintenance and watering, enabling farmers to have more time to do other things." Since most farmers are older people, it also helped reduce the exploitation of labor. "*

Conclusion and Suggestions

Three modes of watering were tested, two of which were controlled by the SFS system with separate watering schemes based on a sprinkler system and a spray system. The third system was general watering.

The yields from the crops that had been watered under SFS control were higher in quality and greater in quantity, both results being significantly better than the yield from the crops of general watering. The results indicate that the automated SFS is able to overcome the variability in weather conditions that affect the growth of pepper plants by a method of controlled watering that comprehends temperature, humidity and soil moisture conditions, and maintains a consistent environment for plant growth and pepper seed yield. Farmers can use the findings as guidelines for applying SFS to pepper crops at all growth stages. If farmers collect data on a continuous and long-term basis, that data can be utilized to enhance the SFS performance, aid in resolving problems, as well as upgrading and extending the system and responding to all farmer expectations. Enhancement of the system will allow the SFS to be used in a variety of agricultural fields other than pepper growing due to the assemblage of high-accuracy BME280 and SHT10 sensors and a high-quality and adaptable ESP32 microcontroller board which can be constructed at a cost that is well within the reach of farmers.

We are confident that our findings provide beneficial information to the farming community, and the importance of this research to individual farmers and the rural and rural products exports sectors will lead to more research in this vital field of agricultural automation.

Acknowledgments

This research is supported on operations and tools by Department of Industrial Electrical Technology, Faculty of Industrial Technology, Songkhla Rajabhat University. Mr. Roy I. Morien of the Naresuan University Graduate School edited the text for correct English expression and grammar.

References

Atzori, L., Iera, A., & Morabito, G. (2010). The internet of things: A survey. *Computer Networks*, *54(15)*, 2787-2805.

Bagheri, H., Abdul Manap, M. Y. B., & Solati, Z. (2014). Antioxidant activity of *Piper nigrum* L. essential oil extracted by supercritical CO_2 extraction and hydro-distillation. *Talanta*, *121*, 220-228.

Bukhari, I. A., Pivac, N., Alhumayyd, M. S., Mahesar, A. L., Gilani, A. H. (2013). The analgesic and anticonvulsant effects of piperine in mice. *Journal of Physiology and Pharmacology*, *64(6)*, 789-794.

Changthom, C. (2014). *A textbook on the wisdom of pepper production in Chanthaburi*. Chanthaburi: Great Unity Media Limited Partnership.

Chawapradit, P. (2014). *Information on suitable environment for growth and yield of pepper. Office of Agricultural Product Promotion and Management Department of Agricultural Extension.* Retrieved from http://www.agriman.doae.go.th/home/t.n/t.n1/5vagetable_Requirement/004_Pepper.pdf

Chonpathompikunlert, P., Wattanathorn, J., & Muchimapura, S. (2010). Piperine, the main alkaloid of Thai black pepper, protects against neurodegeneration and cognitive impairment in animal model of cognitive deficit like condition of Alzheimer's disease. *Food and Chemical Toxicology*, *48(3)*, 798-802.

De Souza Grinevicius, V. M. A., Kviecinski, M. R., Santos Mota, N. S. R., Ourique, F., Porfirio Will Castro, L. S. E., Andreguetti, R. R., … Pedrosa, R. C. (2016). Piper nigrum ethanolic extract rich in piperamides causes ROS overproduction, oxidative damage in DNA leading to cell cycle arrest and apoptosis in cancer cells. *Journal of Ethnopharmacology*, *189*, 139-147.

Fletcher, K., Nyuak, A., & Yee, T. P. (2021). Ph monitoring for liquid fertilizer management in black pepper farming. *International Journal of Innovation and Industrial Revolution*, *3(6)*, 1-12.

Government Spokesperson Bureau, Secretariat of the Prime Minister. (2017). Thailand 4.0 driving the future towards security, prosperity, and sustainability. *Thai Khu Fah Online Journal*, *33*, 1-43.

Jasungnuen, N. (2019, August 6). *ESP32 Part 1 Get to know the board to learn IOTs first* [Video file]. Retrieved from https://www.youtube.com/watch?v=e0T2p-A2LZg

Kandiannan, K., Parthasarathy, U., Krishnamurthy, K. S., Thankamani, C. K., Srinivasan, V., & Aipe, K. C. (2011). Modeling the association of weather and black pepper yield. *Indian Journal of Horticulture*, *68(1)*, 96-102.

Kandiannan, K., Krishnamurthy, K. S., Gowda, S. J. A., & Anandaraj, M. (2014). Climate change and black pepper production. *Indian Journal of Arecanut, Spicies and Medicinal Plants, 16(4)*, 31-37.

Kitsawang, P. (2016). Real-time alarming system of dangerous leakage current at distribution transformer via digital signal processing. *The Journal of Industrial Technology, 12(3)*, 1-13.

Mahamad, K., Kongmon, A., Petlamul, M., Petlamul, W., & Chuwanich, S. (2020). Application of smart farm technology for pesticide residue-free vegetable fields system: A case study of Boromarajonani College of Nursing, Songkhla. In S. Siwawat (Ed.), *CreTech 2020 Multidisciplinary to drive economy and social: Proceedings of the 8th international conference on creative technology held in Grand Pacific Sovereign Resort and Spa Cha-am, Phetchaburi Province, Thailand, 5-7 August 2020* (pp. 39-46). Bangkok: Rajamangala University of Technology Krungthep.

Mahamad, K., Mansuriwong, P., & Petlamul, W. (2021). Application of smart farm system to enhance phoenix oyster mushroom production. *ASEAN Journal of Scientific and Technological Report, 24(3)*, 47-57.

Masa, N., Ledóné, H. D., & Komarek, L. (2021). Impact of precision monitoring system on vegetable cultivation in raral areas. *Review on Agriculture and Rural Development, 10(1-2)*, 3-8.

Morelli, B., Howell, J., Watson, J., Lucero, S., Kanesin, Y., Kim, C., & Ratliff, L. (2018). *In IoT trend watch 2018*. London: IHS Markit.

Noonak, N., & Suesut, T. (2012). *Measurement and Measuring Tools. Applications in the food industry.* Bangkok: Faculty of Engineering King Mongkut's Institute of Technology Ladkrabang.

Nyuak, A., Kedung Fletcher, K., & Yee, T. P. (2019). Web based monitoring system for pepper farming. In MNNF Publisher, *Leading towards creative & innovation: Proceedings of an international invention, innovative & creative (InIIC) conference 2019, 27 April 2019* (pp. 39-46). Malacca, Malaysia: MNNF Publisher.

Office of Agricultural Economics. (2020). *Pepper: Number of growing households 2003-2020.* Retrieved from http://www.oae.go.th/assets/portals/1/fileups/prcaidata/files/holdland%20pepper63.pdf

Palaphan, M. (2010). *Cultivation of pepper.* Bangkok: Thanat Printing.

Peng, Q., Liang, Y., Chen, C., Zhu, J., Wei, Z., Jia, W., & Wu, Y. (2010). Effects of soil moisture on growth and pepper fruit quality in greenhouse during fruiting stage. *Journal of Northwest A & F University-Natural Science Edition, 38(1)*, 154-160.

Pettong, W., & Vongkrachang, S. (2020). The development of soil moisture control system based on wireless communication technology for Off- Season Durian production in Nopphitam District, Nakhon Si Thammarat Province, Thailand. *Naresuan University Journal Science and Technology, 28(1)*, 38-48.

Ranokphanuwat, R. (2017). Greenhouse hydroponics automation system using IoT technology and deep learning tool. *Journal of Information Science and Technology, 8(2)*, 74-82.

Shashwathi, N., Borkotoky, P., & Suhas, K. (2012). Smart farming: A step towards techno- savvy agriculture. *International Journal of Computer Applications, 57(18)*, 45-48.

Srivastava, A. K., & Singh, V. K., (2017). Biological action of *Piper nigrum* – the king of spices, *European Journal of Biological Research, 7*, 223-233.

Siljaru, T., (2005). *Research and Data Collection Statistic with SPSS and AMOS* (4th ed.). Bangkok: V Inter Print.

Tasleem, F., Azhar, I., Ali, S. N., Perveen, S., & Mahmood, Z. A. (2014). Analgesic and anti-inflammatory activities of *Piper nigrum* L. *Asian Pacific Journal of Tropical Medicine, 7(1)*, S461-S468.

Singnan, T., & Vangkapun, W. (2016). Irrigation control with soil moisture sensor. In S. Saowakoon (Ed.), *RSC 2016 Rajamangala Surin Conference: Proceedings of the 8th Rajamangala Surin National Conference held in Rajamangala University of Technology Isan Surin Campus, Surin Province, Thailand, 22-23 December 2016* (pp. A99-A106). Bangkok: Rajamangala University of Technology Isan Surin Campus.