

An Intelligent Drip Irrigation Innovation for The Sustainable Development of Large Bird's Eye Chili Farming Communities

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Abstract

This study aimed 1) to develop an intelligent drip irrigation system for large bird's eye chili production in order to enhance the potential of large-scale chili farming communities, and 2) to transfer knowledge and raise awareness of the importance of technology in developing the intelligent drip irrigation system for large bird's eye chili production to strengthen the capacity of large-scale chili farming communities. The target group consisted of 32 farmers from large-scale chili farming communities, selected through purposive sampling. To evaluate the system's performance and the success of the knowledge transfer and technology awareness, the Black Box Testing method was employed, with five experts serving as evaluators. Additionally, the results of the satisfaction assessment regarding the knowledge transfer were analyzed using descriptive statistics, specifically mean and standard deviation.

The research findings are:

1. The developed system for knowledge transfer and promoting technological Awareness comprising a NodeMCU ESP microcontroller that controls sensors detecting temperature, humidity, water flow, water usage rate, and electricity consumption, as well as reporting environmental data from the cultivation area and handling system errors such as lack of water flow through a developed web application-achieved an overall efficiency at the highest level ($\bar{x} = 4.71$, S.D. = 0.50)
2. The evaluation of participants' satisfaction with the training on knowledge transfer regarding the development of the intelligent drip irrigation system for large bird's eye chili production indicated that overall satisfaction in all aspects was at the highest level ($\bar{x} = 4.72$, S.D. = 0.57)

Keywords: Intelligent Drip Irrigation Innovation, Large Bird's Eye Chili, Farmer Community

Introduction

Chili peppers belong to the Solanaceae family, alongside tomatoes, eggplants, potatoes, tobacco, and petunias. They possess high nutritional value, particularly high amounts of vitamin A and vitamin C (Department of Agriculture, 2019). They can be utilized either as fresh produce or dried and processed into various food products such as chili paste,

curry paste, chili sauce, dipping sauce, and pickled chilis. They are also used as flavor-enhancing ingredients in snacks and instant noodles. Chili colorants, chili oil (oleoresin), and chili extracts (capsaicin) can be utilized in the pharmaceutical and dietary supplement industries (Kasetkaona et al., 2020). Chili is also a crucial economic vegetable crop. There are several varieties of chilis in Thailand, including large-fruited bird's eye chili, spur chili, garden bird's eye chili, banana pepper, and bell pepper. Regarding the chili import and export situation in 2018, there was an increase in the importation of chilis and chili products. This was due to the prices of imported chilis being cheaper than those produced domestically, particularly those from India and China. Additionally, the export volume in 2018 increased from the previous year, with exports destined for countries such as Singapore and Malaysia (Office of Agricultural Economics, 2019). Currently, the market is continuously expanding, and prices remain at a favorable level. For example, cultivating approximately 1 rai of chilis can generate an average income of 60,000-100,000 THB. Farmers can grow chilis year-round, but the most optimal period is between October and February. This allows the harvest to occur during the dry season, which is convenient for sun-drying. The ideal temperature range for chili growth is between 24 and 29 degrees Celsius (Department of Agricultural Extension, 2018). To secure high market prices, planting must be done during April-May and August-September, which are the most challenging periods for chili cultivation.

In Khan Rai Subdistrict, Sirindhorn District, Ubon Ratchathani Province, the majority of farmers prefer to cultivate chilis. The produce can be distributed to various provinces, especially in the southern region, and exported to Malaysia and Indonesia. Consequently, most farmers engage in chili cultivation as a primary source of household income. A problem survey conducted by the research team revealed that cultivating a 3-rai chili plot in Khan Rai Subdistrict requires farmers to spend 4 to 6 hours manually watering the crops. Furthermore, it was found that over 90% of these farmers lack the knowledge and skills to apply technology and innovation to alleviate their farming workload. Therefore, the research team developed the concept of creating an intelligent drip irrigation system for large bird's eye chili production. This system is intended to serve as a learning plot and demonstration site, acting as a district-level agricultural learning prototype center for the community. It aims to demonstrate the application of innovation and technology to enhance the efficiency of large bird's eye chili production for the fresh produce market. Furthermore, this initiative is driven by the Bio-Circular-Green (BCG) Economy Model (National Science and Technology Development Agency [NSTDA], 2021) within a Smart Farm framework, utilizing Internet of Things technology (Jaidee et al., 2021) to assist farmers in reducing labor time during cultivation. The time saved through the use of technology can be redirected towards generating alternative income, ultimately resulting in an increase in the farmers' household income.

Objectives

1. To develop a drip irrigation system for large bird's eye chili production.
2. To transfer knowledge and raise awareness of the importance of technology in developing an intelligent drip irrigation system for large bird's eye chili production.

Literature Review

The objective of this research is to develop an intelligent drip irrigation system for large bird's eye chili production, aiming to enhance the capacity of chili farming communities

in large-scale plots. The research team studied relevant theories and literature to establish a conceptual foundation, which guided the analysis and the formulation of the research framework. The details are presented sequentially as follows:

Botanical Characteristics and Production of Large Bird's Eye Chili

Large bird's eye chili (*Capsicum frutescens*) belongs to the family Solanaceae. It is a perennial herbaceous plant with an erect stem, reaching a height of approximately 0.5-1.2 meters, depending on the variety and cultivation practices. This chili type has a taproot system that penetrates deeply and spreads well in soils with good drainage. The leaves are simple, with pointed tips and smooth surfaces. Flowers are solitary, borne in the leaf axils, and are white to pale green in color. The fruits are slender and elongated with pointed tips, green at the immature stage and turning red when fully mature. A distinctive characteristic of large bird's eye chili is its strong pungency and its ability to be harvested continuously several times within a year. However, chili growth is highly sensitive to soil moisture and ambient temperature; therefore, an appropriate irrigation system can significantly improve both yield and fruit quality (Department of Agricultural Extension, 2020).

Water Requirements and Growth Factors of Chili

Water is a crucial factor directly affecting plant growth. Insufficient water supply can result in growth retardation, leaf yellowing, and leaf drop, whereas excessive water can cause root rot and soil-borne fungal diseases, severely reducing crop yield. Crop water requirement (ET_{crop}) refers to the amount of water needed to compensate for water loss through evapotranspiration. In other words, it is the quantity of water required by plants for optimal growth (Sumitr Khunchat, 2018). Different crops have different water requirements. For example, vegetable crops generally require about 3-5 mm/day, fruit trees about 3 mm/day, sweet corn approximately 5-8 mm/day, and rice about 10 mm/day. These values can be used to calculate daily irrigation needs or to estimate the total water resources required. For instance, vegetable cultivation on an area of 1 rai (1,600 m²) requires approximately 4.8-8.0 cubic meters, or 4,800-8,000 liters, of water per day (Office of Agricultural Product Promotion and Management, 2016). Irrigation is an agricultural engineering technology developed to facilitate farm management, improve water use efficiency, reduce labor requirements, and minimize crop damage caused by water stress. Nowadays, irrigation systems are widely adopted, especially in fruit orchards, vegetable farms, and field crops. Water plays an essential role in photosynthesis, nutrient dissolution and uptake, plant cooling through transpiration, and ultimately determines crop productivity. Water requirements vary according to crop type, variety, and growth stage; therefore, irrigation must be properly managed to meet crop needs. Chili generally requires about 600-900 mm of water per production cycle, with optimal soil moisture maintained at approximately 60–80% of field capacity. The most critical stages for water demand are flowering and fruit setting.

Smart Technology and Embedded IoT Systems Internet of Things

The Internet of Things (IoT) is a technology that connects various devices via the Internet, enabling automatic data transmission and remote control. The main components of an IoT system include sensors, microcontrollers, communication modules, and data storage platforms (Atzori, L., Iera, A., & Morabito, G., 2010). In agriculture, IoT has become a key part of Precision Agriculture, such as using sensors to measure soil moisture, temperature, or light intensity and sending the data to a control system to automatically irrigate crops. This improves irrigation efficiency, reduces labor, and minimizes unnecessary resource use (Digital Government Development Agency, 2021). A smart irrigation system for large chili peppers using IoT can report real-time soil moisture status, send alerts via applications, and

automatically adjust water supply based on collected data, effectively supporting digital-era farming. Gubbi et al. (2013) stated that the Internet of Things (IoT) consists of four main layers: the Sensing Layer, Network Layer, Data Processing Layer, and Application Layer, where devices are connected via the Internet to automatically collect and transmit data. Vermesan et al. (2014) explained that the IoT architecture links physical devices with digital systems. Data collected from devices is sent to the cloud for analysis and response, accessible through user-interactive applications. The integration of IoT, GIS, and remote sensing in precision agriculture enables the monitoring and decision-making based on real-time data from farmland. This integration focuses on three technologies:

1. IoT Uses field sensors to collect environmental data, such as moisture, temperature, and soil pH.
2. GIS (Geographic Information System) Visualizes farmland data on maps and performs spatial analysis.
3. Remote Sensing Utilizes satellite or drone imagery to monitor crop health and field trends. Combining IoT with GIS and remote sensing improves agricultural efficiency in planning, risk assessment, resource management, and yield optimization. These technologies support precise, site-specific decision-making.

Smart Farm

Smart Farm refers to the use of digital technologies and automated systems to manage agricultural operations. It relies on data from sensors, the Internet of Things (IoT), Artificial Intelligence (AI), Big Data analytics, and remote control systems to increase production efficiency, reduce costs, and promote sustainable agriculture. Wolfert et al. (2017) stated that Smart Farming is an agricultural approach that leverages information technology and IoT devices to enhance productivity and reduce costs by analyzing sensor data for decision-making in farm management. Zhang Q. (2019) explained that Precision Agriculture is a methodology that utilizes digital technologies, such as IoT, AI, and Cloud Computing, to manage farming at a site-specific level. This approach reduces the use of resources such as water, fertilizer, and labor while improving yield and quality sustainably, and According to Klerkx et al. (2019), a Smart Farm consists of the following main subsystems 1) Sensing System Uses sensors to measure various parameters, including soil moisture, temperature, sunlight, pH, and nutrient levels. 2) Connectivity System Transmits data from the farm via wireless networks, such as LoRa, NB-IoT, or Wi-Fi. 3) Analytics System Utilizes software or AI to analyze data for yield prediction, disease alerts, or crop planning.

Unstructured Databases (NoSQL)

An unstructured database, or NoSQL, is a database capable of storing information that does not need to follow a tabular format, such as JSON, XML, or Key-Value data. Unlike traditional SQL databases, which require a well-defined schema, NoSQL databases are suitable for smart irrigation systems that require real-time data processing, large volumes of information, and flexible data structures that can be adapted according to usage (MongoDB Inc., 2023). NoSQL databases commonly use formats similar to JSON and BSON for data exchange. In application development, NoSQL databases are often integrated with JSON and BSON data formats (Panupong Boonrom, 2023)

Related Research

Piyawat Maksri et al. (2020) developed a research project on an automated irrigation control system using soil moisture sensors. The study aimed to design an automated watering system for small-scale greenhouses by utilizing a microcontroller to regulate the system's operation based on real-time soil moisture levels. By installing sensors within the cultivation area and using the microcontroller for data processing, the findings indicated that this system significantly enhanced plant growth and improved water efficiency.

Al-Obaidi et al. (2020) developed research on designing an automated irrigation system to control water quantity using the Arduino Uno R3 microcontroller and soil moisture sensors. The system controls irrigation and schedules water delivery based on the type of plant, aiming to reduce costs such as water and labor expenses while increasing agricultural productivity. This proposed system is a sustainable solution for enhancing water use efficiency in agricultural areas according to plant needs. The system operates using a drip irrigation method, with the irrigation sensors connected to the Arduino Uno R3, allowing real-time monitoring via a computer. It also allows selection of plant types according to the system's program based on soil conditions and root zone moisture. The automatic irrigation system for farmers helps determine the required water quantity at scheduled times, reports the water status for each agricultural plot, and allows tracking of soil moisture levels and pump operation. It includes a database on plants and displays suitable water quantities for different plant types.

Rossy et al. (2020) developed research on the design and implementation of an automated tomato irrigation system using IoT with the ESP8266 microcontroller. The system considers factors such as the required soil moisture, air conditions, and temperature necessary for growing tomatoes, which should be between 60% and 80% humidity and temperatures between 24°C and 28°C. The research team utilized IoT technology to develop an innovative agricultural technology solution to address issues and enhance irrigation precision based on soil moisture levels and air temperature. The system, which includes ESP8266, soil moisture sensors, and DHT11, can be controlled remotely via an internet connection. The program is integrated with the Telegram Messenger application to receive data from the sensors and automate tomato watering. Experimental results showed that the soil moisture sensors functioned well, accurately reading soil moisture levels, and the temperature sensors provided suitable air temperature readings. Users receive all sensor data through the Telegram Bot, which sends notifications, allowing farmers to easily monitor and control tomato irrigation remotely. The system also manages and tracks the condition of tomato cultivation.

Garg et al. (2018) B conducted research titled IoT-Based Smart Agriculture Design for Optimal Management. The primary objective was to develop an agricultural system capable of maximizing the efficiency of resource management, including water, fertilizer, and energy. This was achieved by integrating Internet of Things (IoT) technology with data mining techniques and advanced communication protocols. The researchers designed a prototype consisting of sensor nodes for field data collection, a control unit for analysis and decision-making, and a cloud system for remote data storage and access. The system features real-time internet communication, along with security measures and data recovery protocols in case of system failure. The findings indicate that this developed system enhances farm management efficiency, reduces resource waste, and provides accurate agricultural forecasting while reducing labor demands and remaining adaptable for remote farming areas.

Boonrom et al. (2024) developed an "IoT-Based Adaptive Drip Irrigation System for Tomato Cultivation" following the five stages of the SDLC (Systems Development Life Cycle) model: 1) Problem Study and Planning, 2) Analysis, 3) System Design, 4) Development and Testing, and 5) Evaluation. The system enables moisture control within the cultivation plot based on settings configured via a web application. Command data for board control is stored in a NoSQL cloud database, ensuring rapid response times for electrical device control. Cultivation data is collected periodically in the cloud and migrated daily to a relational database. This stored data includes temperature, moisture, electricity consumption, and daily water usage throughout the harvest cycle. This information is intended for further analysis and processing into agricultural information to be shared with farmers.

Additionally, the system features an error-handling mechanism: if no water flow is detected, the web application notifies the user via the Line API and automatically shuts down the water pump.

Research Methodology

This research focuses on the development of a smart drip irrigation system for large bird's eye chili production. The research team proceeded according to the following steps:

1. Feasibility Study and Site Analysis

After conducting field research on the factors affecting the growth and irrigation of large bird's eye chilies in Ubon Ratchathani Province, it was found that most local farmers still rely on traditional, imprecise irrigation methods, such as manual hose watering or furrow irrigation. While some farmers utilize drip tapes, they still rely on manual observation to determine water needs. This lack of precision leads to over-watering or under-watering, which hinders plant growth and results in the waste of labor and water resources. Furthermore, during the dry season or dry spells, the absence of an efficient control system leads to a significant reduction in crop yield. Consequently, the analysis and planning phase consists of three key steps: 1) Designing a drip irrigation system tailored to the farmers' specific plots 2) Developing and installing an intelligent control system utilizing embedded systems technology and 3) Conducting field testing to evaluate water-use efficiency and overall productivity.

2. Study of Embedded IoT System Principles

The study focuses on the operating principles of the NodeMCU ESP8266, which is a small microchip or can be referred to as an embedded “microcontroller brain” with built-in Wi-Fi capability. It is low-cost, manufactured by Espressif Systems, and is widely used in IoT devices and smart home applications. A key feature of the ESP8266 is that it can be programmed directly, and it provides up to 4 MB of program memory. It operates at a voltage range of 3.3-3.6 V. When used with other sensors that operate at 5 V, a voltage divider circuit is required to prevent damage to the module. In addition, the operating principle of the YF-S201 Water Flow Sensor module is described. This module is used to measure the water flow rate. In general, its working principle involves detecting water flow based on changes in pressure or the movement of water inside a pipe. The sensor module contains an internal rotor (impeller) that rotates as water flows through it, allowing the measurement of water flow. The sensor must be installed on a water pipe to detect and measure the flow of water passing through the pipe.

3. Study of the Operating Principles of Firebase and Relational Database Systems

Firebase Realtime Database is a NoSQL cloud database that stores data in JSON format and enables real-time data synchronization across all connected devices automatically within milliseconds. It supports offline operation, where data is stored locally and automatically synchronized once the device reconnects to the internet. In addition, Firebase provides Security Rules that allow customized conditions for both read and write access to data. It supports multiple platforms, including Android, iOS, web applications, as well as ESP8266 devices. The study also examines the operating principles of relational databases. A relational database stores data in the form of tables, consisting of multiple tables that are related to each other. Each table is divided into rows, and each row is further divided into columns. In this research, a relational database is used to store daily statistical data, such as humidity and temperature values, and to generate statistical graphs for reporting results to users based on the collected data.

4. System Analysis Process

The research team collected data and analyzed existing problems in order to develop a web application for controlling a smart drip irrigation system for the production of large-fruited bird's eye chili. The objective is to enhance the potential of farming communities cultivating chili in large-scale plots. The analysis process consists of the following steps:

Analyze the smart drip irrigation system for the production of large-fruited bird's eye chili to enhance the potential of farming communities engaged in large-scale chili cultivation.

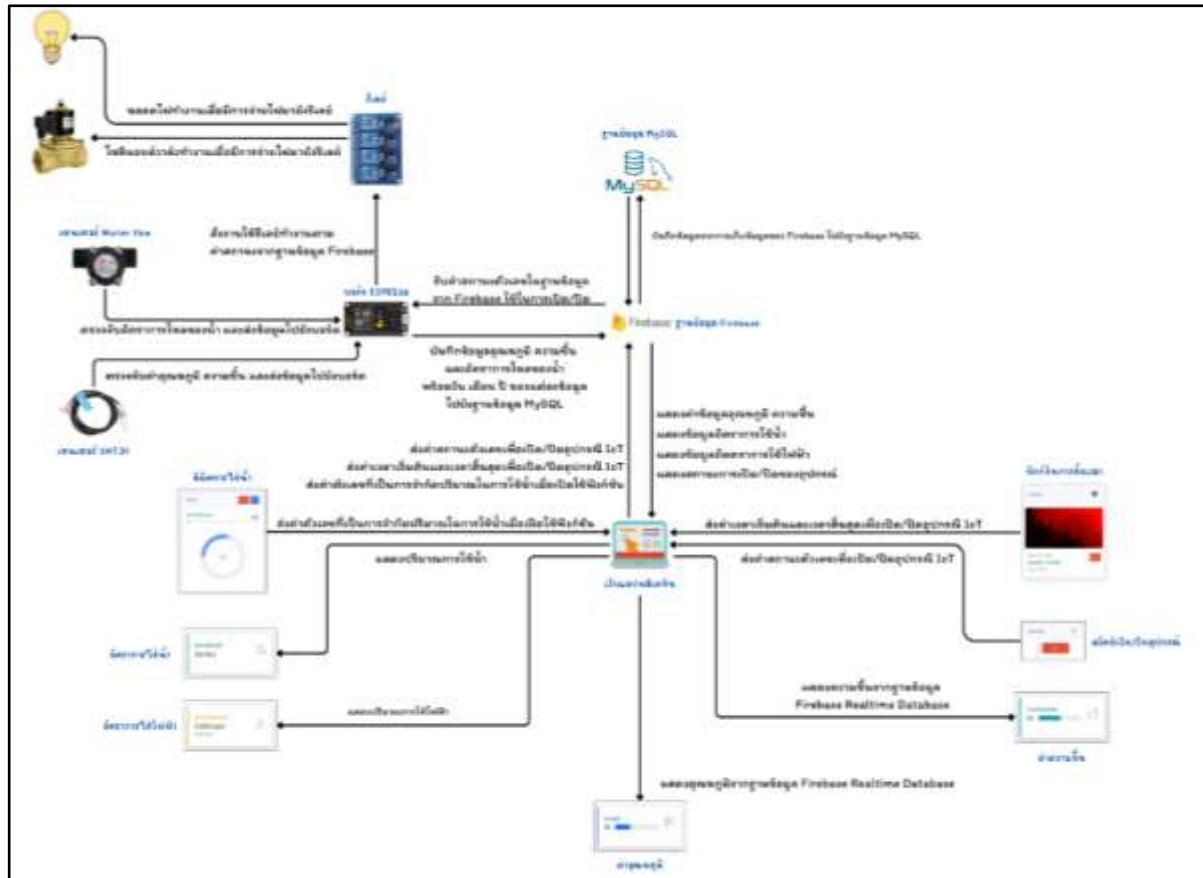


Figure 1: Smart Drip Irrigation System for The Production of Large-Fruited Bird's Eye Chili to Enhance The Potential of Farming Communities Engaged in Large-Scale Chili Cultivation

Based on Figure 1, the operation of the irrigation control system begins when the user accesses the web application developed by the research team. The system sends status values in the form of numeric commands (1, 0) to Firebase to control the water on/off operation. Subsequently, the ESP8266 board retrieves the numeric status data from the Firebase database and acts as a command transmitter to activate a 4-channel relay module. The relay supplies power to the operating devices, including light bulbs and electric solenoid valves.

The solenoid valves then control the opening and closing of water for the operation of mist sprayers and drip irrigation emitters, according to the commands issued through the developed web application. For the sensors that monitor temperature, humidity, and water flow rate, data are collected every 30 minutes and temporarily stored in Firebase Firestore.

At 11:00 PM each day, the data are transferred to a MySQL database for storage in a relational database system, after which the data stored in Firebase Firestore are deleted.

System Design Process

Based on the study of problems and system development planning, the research team designed a smart drip irrigation system for the production of large-fruited bird's eye chili to enhance the potential of farming communities engaged in large-scale chili cultivation. The system design was divided into the following parts:

1. Design of the overall system operation.
2. Design of the greenhouse for tomato cultivation to study the smart drip irrigation system for the production of large-fruited bird's eye chili to enhance the potential of farming communities engaged in large-scale chili cultivation.
3. Design of the operating principles of the smart drip irrigation system for the production of large-fruited bird's eye chili to enhance the potential of farming communities engaged in large-scale chili cultivation.
4. Design of the overall workflow of the smart drip irrigation system for the production of large-fruited bird's eye chili to enhance the potential of farming communities engaged in large-scale chili cultivation.
5. Design of the web application for the smart drip irrigation system for the production of large-fruited bird's eye chili to enhance the potential of farming communities engaged in large-scale chili cultivation.

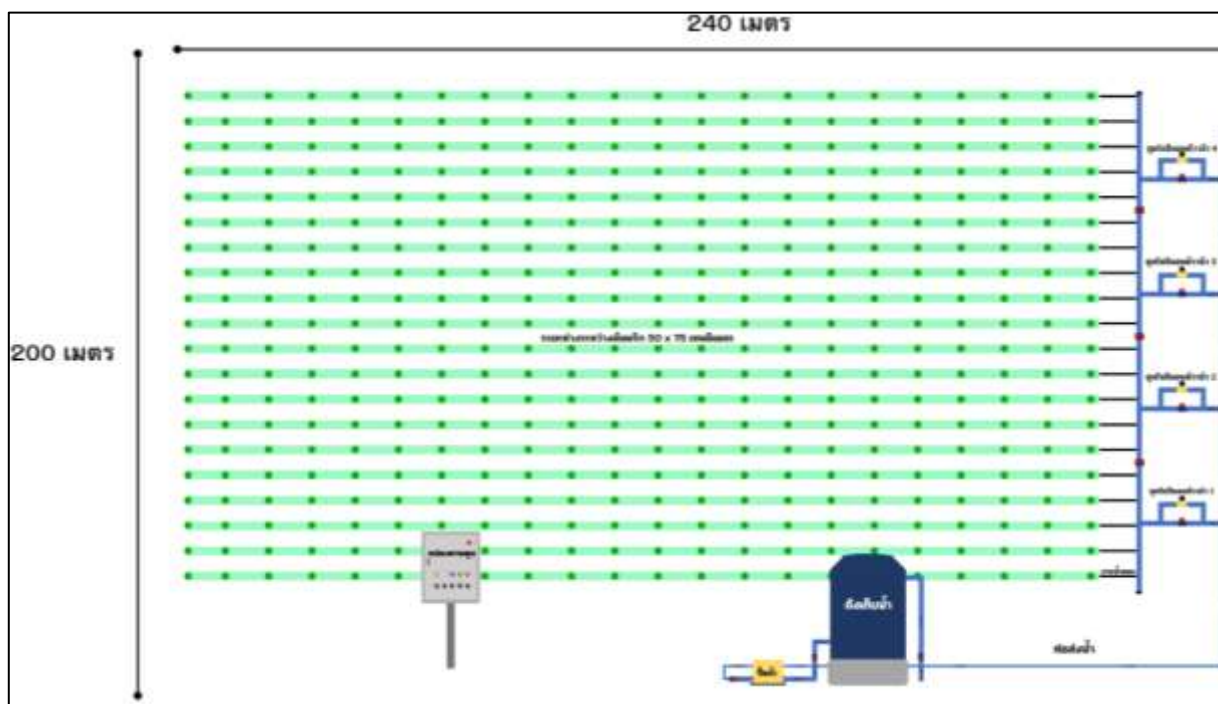


Figure 2: Design Illustrates a Large-Fruited Bird's Eye Chili Cultivation Plot with a Total Area

From Figure 2, the design illustrates a large-fruited bird's eye chili cultivation plot with a total area of 3 rai, covering dimensions of 200 × 240 meters. The layout includes the installation of control boxes and a water pump, as shown in the figure. The placement of solenoid valves was designed to ensure that the irrigation system can supply water in quantities appropriate to the needs of the chili plants. The planting spacing was specified at

50 × 75 centimeters, which is considered optimal. Based on this spacing, the cultivation area consists of 20 rows of chili plants. A total of four solenoid valve points are used, with each valve controlling four rows of plants.

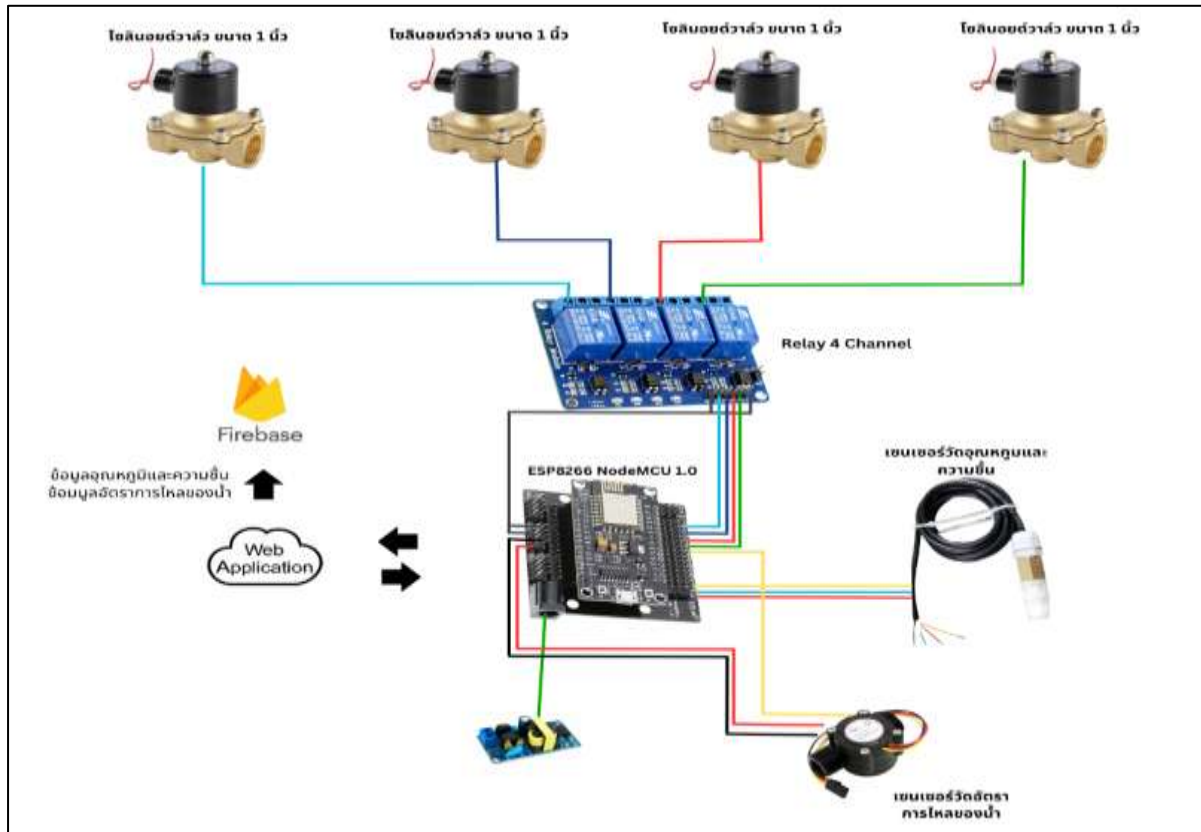


Figure 3: Connection Between The Database System and The System for Data Collection of The Smart Drip Irrigation System for Large-Fruited Bird's Eye Chili Production.

From Figure 3, the design illustrates the connection between the database system and the system control box in order to collect data on temperature and humidity from sensor devices, as well as operational status data such as water flow status, irrigation duration for each operation (solenoid time duration), and the amount of water used in each cycle through the web application. All of these data are stored in the Firebase database.

System Development and Testing Process

The development phase was carried out according to the system design. The development process was divided into four stages as follows:

Stage 1: Development of the chili cultivation plot according to the design, with a total cultivation area of 3 rai.



Figure 4: Mulching The Cultivation Beds with Plastic Film, Planting Chili Seedlings, and Arranging Rows for Irrigation.

From Figures 4, the images show a large-fruited bird's eye chili cultivation area covering 3 rai. The planting beds were prepared with rows for cultivation and covered with plastic mulch to prevent weed growth. The spacing between rows was set at 75 centimeters, and the spacing between chili plants was 50 centimeters, which is considered appropriate for optimal chili growth and development.



Figure 5: Installation of solenoid valves and connection of electrical wiring to the solenoid valves.

From Figures 5, the images show the routing of electrical wiring from the control box to the solenoid valve locations. Electrical wires with a diameter of 1.5 millimeters were used and threaded through 16-millimeter PE pipes to serve as insulation and to prevent electrical leakage hazards.

Stage 2: Programming and Development of the Database System for System Operation Control

The programming phase involved developing control programs using the Arduino IDE to manage the operation of solenoid valves via the NodeMCU 1.0 ESP8266 for drip irrigation control. The system controls irrigation, regulates soil moisture, monitors water flow, reports temperature and humidity data from sensors, and transmits water usage information to the web application. The MQTT protocol is used as an intermediary for data communication

between the control box and the cloud database. PHP and Python programming languages were employed for system control and application development. For database system development, a MySQL database was used to store daily data on temperature, humidity, and irrigation rates. This database operates as an online real-time database. The developed web application serves as an intermediary for connecting the NodeMCU ESP8266 device to receive data from the SHT30 sensor, which is used to measure temperature and humidity. The sensor transmits data to the web application, which is then used to control soil moisture and drip irrigation in the chili cultivation plot. The system's operational status at any given time is stored in the cloud database. The cloud database is also used as an intermediary to calculate daily irrigation rates. The microcontroller control board was programmed to receive data from the NodeMCU ESP8266, including temperature and humidity values from the SHT30 sensor, as well as irrigation duration for each cycle. These data are used to calculate water consumption in the drip irrigation system for the chili cultivation plot, based on the water flow rate per minute and the duration of each irrigation cycle.

System Evaluation

The system evaluation was conducted using a performance assessment questionnaire for the smart agricultural irrigation system based on the Internet of Things (IoT). Five experts were invited to evaluate the performance of the system. The evaluation results were analyzed using statistical methods to summarize the performance of the developed system.

The arithmetic mean ($\bar{x}$) and the standard deviation (S.D.) were calculated for each evaluation aspect in order to determine the level of system performance and quality.

Research Finding

The research team organized the presentation of the results of the development of the smart drip irrigation system for the production of large-fruited bird's eye chili to enhance the potential of farming communities engaged in large-scale chili cultivation in accordance with the research objectives, as follows:

Part 1: Results of the development of the smart drip irrigation system for the production of large-fruited bird's eye chili to enhance the potential of farming communities engaged in large-scale chili cultivation.

1. The web application interface for system control in the smart drip irrigation system for large-fruited bird's eye chili production.

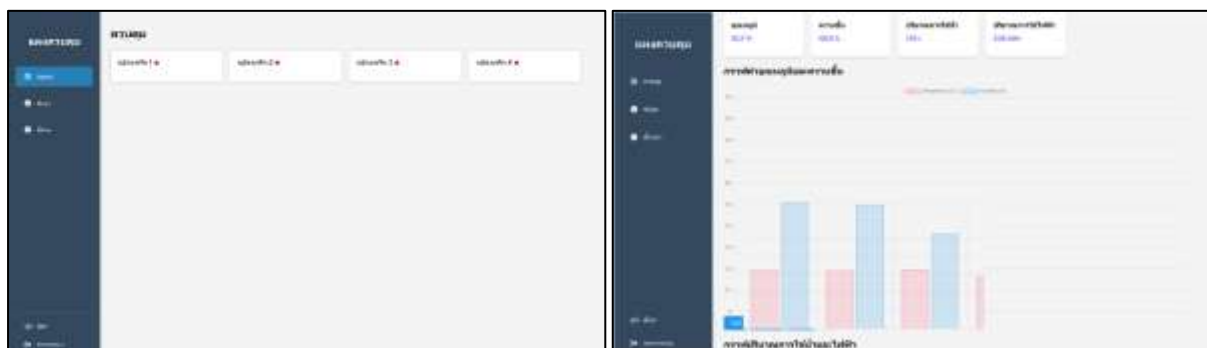


Figure 6: Interface Displaying Operational Data of The Smart Drip Irrigation System for Large-Fruited Bird's Eye Chili Production.

From Figures 6, the web application pages of the smart drip irrigation system for large-fruited bird's eye chili production display information about the chili cultivation plots in each area. This allows the web application to control water distribution, manage irrigation to the cultivation plots, enable automatic irrigation to maintain appropriate moisture levels, and schedule irrigation times for each day of the week.

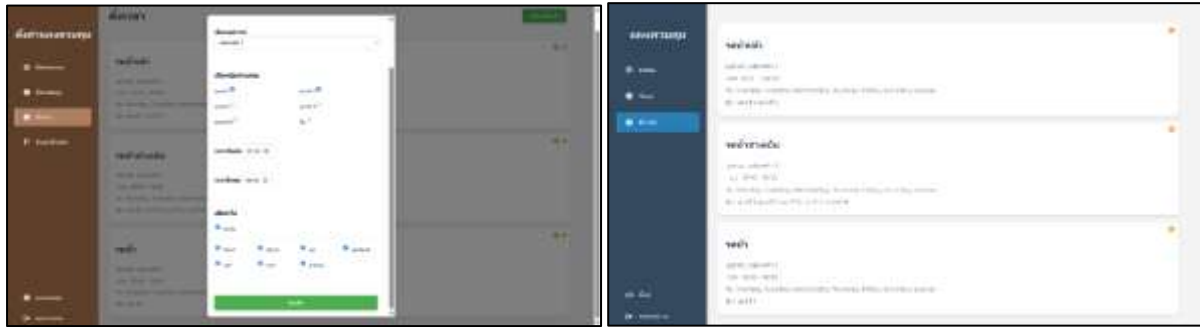


Figure 7: The Web Application Interface for Scheduling and Time-Based Control

Based on Figure 7, the page shows the system scheduling interface of the web application used to control the smart agricultural plot. The system allows multiple schedules to be created. For each schedule, users can specify a schedule name, set the start time and end time, and select the days for operation. The system enables users to choose both active days and excluded days as required. In addition, the system allows scheduling of various devices for on/off control and status settings. After the scheduling configuration is completed, the system can be edited. The available editing options include modifying the schedule name, start time, end time, selected days, device activation time, and enabling or disabling the operational status.

2. Results of the development of the device control box for the smart drip irrigation system for large-fruited bird's eye chili production.



Figure 8: device control box for the smartdrip irrigation system for large-fruited bird's eye chili production to enhance the potential of farming communities engaged in large-scale chili cultivation.

Based on Figure 8, the results of the development of the device control box for the smart drip irrigation system for large-fruited bird's eye chili production to enhance the potential of farming communities engaged in large-scale chili cultivation are presented. The control box consists of the following components: ESP8266 board, which controls

the operation of sensors for measuring temperature and relative humidity, as well as the solenoid valves by managing the opening and closing of water supply.

Part 2: Results of the Evaluation of the Smart Drip Irrigation System Performance for Large-Fruited Bird's Eye Chili Production to Enhance the Potential of Farming Communities Engaged in Large-Scale Chili Cultivation, as Evaluated by Five Experts

For system testing, a performance evaluation of the smart drip irrigation system for large-fruited bird's eye chili production was conducted after the system had been tested by five experts. The experts then evaluated the overall system performance in four aspects, as follows:

Table 1: Results of The Evaluation of System Functionality in Meeting User Requirements (Functional Requirement Test)

Evaluation Items	Performance and Quality		
	$\bar{X}$	S.D.	Interpretation
1. The system can effectively control the cultivation plot, including manual on/off control of the drip irrigation system and lighting	4.80	0.45	Very High
2. The system can effectively use the water usage limitation function	4.60	0.55	Very High
3. The system can provide alerts when irrigation is activated but water does not flow	4.60	0.55	Very High
4. The system can effectively report temperature, relative humidity, electricity consumption rate, and water usage rate	4.80	0.45	Very High
5. The system enables fast and efficient control	4.80	0.45	Very High
Overall Average	4.72	0.49	Very High

From Table 1, the results of the evaluation of the system in terms of meeting user requirements show an overall mean score of 4.72 and a standard deviation of 0.49. These results indicate that the developed system demonstrates very high performance in fulfilling user requirements.

Table 2: Results of The Evaluation of System Performance in Terms of Operation According to Specified Functions (Function Test)

Evaluation Items	Performance and Quality		
	$\bar{X}$	S.D.	Interpretation
1. Accuracy of data storage	4.80	0.45	Very High
2. Accuracy of data presentation	4.60	0.55	Very High
3. Accuracy of notifications	4.80	0.55	Very High
Overall Average	4.73	0.48	Very High

From Table 2, the results of the evaluation of the system in terms of operating according to the specified functions show an overall mean score of 4.73 and a standard

deviation of 0.48. These results indicate that the developed system demonstrates very high performance in performing its designated functions.

Table 3: Results of The Evaluation of Ease of Use (Usability Test)

Evaluation Items	Performance and Quality		
	$\bar{X}$	S.D.	Interpretation
1. Appropriate use of text colors	4.80	0.45	Very High
2. Appropriate use of background colors	4.80	0.45	Very High
3. The wording displayed on the screen is clear and easy to understand	4.80	0.45	Very High
4. Clarity of the text displayed on the screen	4.60	0.89	Very High
5. Overall layout and alignment of the system are appropriate	4.60	0.55	Very High
6. The developed system is easy to use	4.80	0.45	Very High
Overall Average	4.73	0.54	Very High

From Table 3, the results of the evaluation of the system in terms of ease of use show an overall mean score of 4.73 and a standard deviation of 0.54. These results indicate that the developed system demonstrates very high performance in terms of ease of use.

Table 4: Results of The Data Security Evaluation (Security Test)

Evaluation Items	Performance and Quality		
	$\bar{X}$	S.D.	Interpretation
1. System Access Security	4.60	0.55	Very High
2. Data Security in the System	4.80	0.45	Very High
Overall Average	4.70	0.50	Very High

From Table 4, the results of the evaluation of the system's data security show that the overall mean score is 4.70 with a standard deviation of 0.50. This indicates that the developed system demonstrates high effectiveness in terms of data security and is rated at a very good level.

Table 5: Results of The Overall System Performance Evaluation Across All Aspects

Evaluation Items	Performance and Quality		
	$\bar{X}$	S.D.	Interpretation
1. Accuracy of data storage	4.80	0.45	Very High
2. Accuracy of data presentation	4.60	0.55	Very High
3. Accuracy of notifications	4.80	0.55	Very High
Overall Average	4.73	0.48	Very High

According to the system evaluation results shown in Table 6, the overall system evaluation across all aspects has a mean score of 4.71 and a standard deviation of 0.50. This indicates that the developed system demonstrates very high overall performance.

Conclusion

The development of an intelligent drip irrigation system for the production of large-fruited bird's eye chili, aimed at enhancing the potential of large-scale chili farming communities, was conducted in accordance with the five stages of the System Development Life Cycle Model. These stages consisted of: (1) problem study and system development planning, (2) system analysis, (3) system design, (4) system development and testing, and (5) system evaluation. The intelligent drip irrigation system for large-fruited bird's eye chili production was evaluated for its efficiency by experts. The evaluation results indicated that the overall performance of the system was at the highest level. This was because the system was able to control soil moisture in the cultivation plots based on predefined settings through a web application. The system could record control commands sent to the control board via the web application and store them in a cloud database, which is a non-structured (NoSQL) database, enabling rapid control of electrical devices. In addition, cultivation data were continuously stored in the cloud database at different time intervals, and at specified times the data were transferred and stored daily in a relational database. The data stored in the relational database included temperature, humidity, electricity consumption, and daily water usage throughout the entire cultivation cycle until harvest. These data can later be analyzed and processed into information for use in agricultural academic studies and for dissemination as cultivation guidelines for farmers. Furthermore, the system was equipped with an error control mechanism for situations in which there was no water circulation in the system. This function operated through the developed web application by notifying users via the LINE application and automatically shutting down the water pump. The findings of this study are consistent with the research of Khemchat Cheychom (2019) and Parichat Rungruangnattakun (2019), who investigated approaches to the development of smart agriculture models and found that the adoption of smart farming practices can reduce labor burdens and long-term costs for farmers. The results are also in line with the studies of Weerasak Fongngoen et al. (2018) and Ornpan Saetang et al. (2017), who conducted research on the design and development of temperature and humidity control systems suitable for mushroom growth. Their studies revealed that uneven mushroom yields were caused by inappropriate temperature and humidity conditions, and that maintaining suitable environmental control in cultivation facilities resulted in more uniform mushroom production.

Suggestion

The smart drip irrigation system for the production of large-fruited bird's eye chili, aimed at enhancing the capacity of farming communities cultivating chili in large plots, cannot yet be used in cultivation areas where electricity is not available. If the system is further developed, an environmental control system can be designed to operate using solar energy in combination with grid electricity, in order to ensure suitability for cultivation areas according

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