Computers and Electronics in Agriculture 156 (2019) 467–474

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Original papers

IoT and agriculture data analysis for smart farm

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A R T I C L E I N F O

Keywords:
Data mining
Knowledge discovery
Wireless sensor networks
Agriculture data analysis
Smart farm
IoTs

A B S T R A C T

In this paper, we propose developing a system optimally watering agricultural crops based on a wireless sensor network. This work aimed to design and develop a control system using node sensors in the crop field with data management via smartphone and a web application. The three components are hardware, web application, and mobile application. The first component was designed and implemented in control box hardware connected to collect data on the crops. Soil moisture sensors are used to monitor the field, connecting to the control box. The second component is a web-based application that was designed and implemented to manipulate the details of crop data and field information. This component applied data mining to analyze the data for predicting suitable temperature, humidity, and soil moisture for optimal future management of crops growth. The final component is mainly used to control crop watering through a mobile application in a smartphone. This allows either automatic or manual control by the user. The automatic control uses data from soil moisture sensors for watering. However, the user can opt for manual control of watering the crops in the functional control mode. The system can send notifications through LINE API for the LINE application. The system was implemented and tested in Makhamtia District, Suratthani Province, Thailand. The results showed the implementation to be useful in agriculture. The moisture content of the soil was maintained appropriately for vegetable growth, reducing costs and increasing agricultural productivity. Moreover, this work represents driving agriculture through digital innovation.

1. Introduction

Advanced technologies can bring benefits to the majority of people. In the recent years, the Internet of Things (IoTs) has begun to play a major role in daily lives, extending our perceptions and ability to modify the environment around us. Particularly the agro-industrial and environmental fields apply IoTs in both diagnostics and control. In addition, it can provide information to the final user/consumer about the origin and properties of the product (Talavera et al., 2017). Thus, this paper aims to apply IoTs for computer aided optimization of agriculture.

In such optimization of agriculture, installing a *Wireless Sensor Network* (WSN) in the field has improved effectiveness and efficiency of the farmers (Capello et al., 2016; Fang et al., 2014; Hashim et al., 2015; Kodali et al., 2014). It can help evaluate field variables such as soil state, atmospheric conditions, and biomass of plants or animals. It can also be used to assess and control variables such as temperature, humidity, vibrations, or shocks during product transport (Pang et al., 2015). Moreover, WSN can be used to monitor and control factors that influence crop growth and yield. They can also be used to determine the optimum time to harvest, which farmer is more suitable for what conditions, detect diseases, control machinery, etc., (Ndzi et al., 2014). In this study, we focus on data consisting of temperature, humidity, and soil moisture in the crop fields. In order to develop a proper system, we require data storage and an approach to discover knowledge from accumulated data, and interactions with the user. A database system will be designed and implemented as a web-based application. The stored data will be used for decision making to control automatic watering of crops. The agriculture data will be analyzed to optimize and modify the environment around, and to predict the water need of crops in the future. As one of the key contributions, this work applied data mining to extract the best value from precise measurements with automatic computerized devices monitoring crops, land, and climate.

Data mining has been applied in agriculture to discover knowledge (Kamilaris et al., 2017; Tripathy et al., 2014). Association rules approach has been mostly used to discover interesting relations between variables in large databases. It helps analyze and establish hidden relationships among the attributes of agricultural data, supporting

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https://doi.org/10.1016/j.compag.2018.12.011
Received 18 June 2018; Received in revised form 7 November 2018; Accepted 5 December 2018
Available online 12 December 2018
0168-1699/

scientific decision-making (Tripathy et al., 2014). Thus, this performed agriculture data analysis by association rules using the Apriori algorithm in the general rules acquisition, while linear regression was applied to model the relationships between several input variables and an outcome variable. In addition, this work aimed to design and implement a WSN system for sensors in the crop field, along with data management interfaced with the user via a smartphone and a web application. The proposed system can support mixed crop farming and help farmers that have anytime and anywhere connectivity with the system.

This article is organized as follows: Section 2 discusses related work, Section 3 presents the proposed diagnostic system, Section 4 shows the agricultural data analysis, Section 5 has results and discussion, and finally, Section 6 concludes the article.

2. Related work

In this section, we discuss relevant prior research pertaining to two aspects. The first involves the application of IoTs, while the second aspect focuses on agricultural data analysis based on IoTs devices.

2.1. Application of IoTs

In the recent years, IoTs have been applied in many studies, as surveyed in (Ojha et al., 2015; Talavera et al., 2017). The applications of technology in the field of agriculture are used to improve crop yields or quality and to reduce costs. The application of WSN in precision agriculture assists the farmers in a statistical manner, helping them make better and well informed decisions (Fang et al., 2014; Kodali et al., 2014).

Fang et al. (2014) introduced a novel integrated information system (IIS) for regional environmental monitoring and management, based on IoTs, for improving the efficiency in complex tasks. The proposed IIS combines IoTs, Cloud Computing, Geoinformatics (RS, GIS, and GPS), and e-Science for environmental monitoring and management, with a case study on regional climate change and its ecological responses, which is one of the hottest issues in the scientific world. The results showed great benefits from such an IIS, not only in data collection supported by the IoTs, but also in web services and applications based on cloud computing and e-Science platforms. Effectiveness of monitoring and decision-making were obviously improved.

In addition, IoTs was applied in the agro-industrial production chain (Capello et al., 2016; Medela et al., 2013; Li et al., 2013; Ruan and Shi, 2016). Medela et al. (2013) applied IoTs in the agro-industrial production chain. They proposed an innovative architecture based on the concept of IoTs, combining wireless and distributed specific sensor devices with the simulation of climatic conditions, in order to track the evolution of grapes for wineries. Li et al. (2013) presented an information system for agriculture based on IoTs, with a distributed architecture. In that study, tracking and tracing the whole agricultural production process were done with distributed IoTs servers. Moreover, an information-discovery system was designed to implement, capture, standardize, manage, locate, and query business data from agricultural production. Pang et al. (2015) proposed a value-centric business-technology joint design framework to provide information to the final user/consumer about the origin and properties of the product. Capello et al. (2016) applied IoTs for a real-time monitoring service in order to enable the tracing of products from the end consumer back to the field. Ruan and Shi (2016) presented an IoTs framework to assess fruit freshness in e-commerce deliveries, which was a non-traditional retail service that faces unique challenges in transportation, due to product perishability and expensive logistics.

Many studies have attempted to improve the functionality of IoTs (Hashim et al., 2015; Luan et al., 2015). Diedrichs et al. (2014) presented the development of a WSN, based on IEEE-802.15.4, for use in frost characterization in precision agriculture by measuring the temperature. Fourati et al. (2014) proposed a web-based decision support system communicating with a WSN for irrigation scheduling in olive fields. For this purpose, the authors used sensors to measure humidity, solar radiation, temperature, and rain. Hashim et al. (2015) reviewed the control with an electronic device (Arduino) of temperature and soil moisture, and used an Android-based smartphone application for flexibility and functionality. They found advantages in low cost and flexibility for agriculture control in contrast with expensive components such as high-end personal computers. Luan et al. (2015) designed and developed a synthetic system that integrated drought monitoring and forecasting and irrigation amount forecasting into a platform based on IoTs, hybrid programming, and parallel computing. Kanoun et al. (2014), Kaewmard and Saiyod (2014) focused on irrigation systems using WSN for collecting environment data and control of the irrigation system via a smartphone. Kaewmard and Saiyod (2014) provided a long-term sustainable solution for automation of agriculture to get data from vegetable crops, or for environmental measurements. The authors developed a portable measurement technology including soil moisture sensor, air humidity sensor, and air temperature sensors. Chen et al. (2014) proposed systems for monitoring multi-layer soil temperature and moisture in a farmland field using WSN to improve the water utilization and to collect basic data for research on soil water infiltration variations and for intelligent precision irrigation.

Li et al. (2012) proposed an agricultural greenhouse environmental monitoring system based on IoTs, with remote real-time monitoring of environmental information on the greenhouse, combining internet, wireless network and mobile network. Furthermore, Lukas et al. (2015) designed a long-range water level monitoring system for troughs using a WSN based on LoRa transceivers, allowing the cattleman to observe water availability for livestock even when the barn was 1 or 3 km away. Wong and Kerkez (2016) presented a web service and real-time data architecture that includes an adaptive controller that updates the parameters of each sensing node within a WSN based on a previously defined policy. Sarangi et al. (2016) proposed an agriculture support system based on Wisekar to provide automated value-added services that integrate the interoperability of an IoTs web repository with an agricultural advisory call center.

2.2. Agriculture data analysis

The use of IoTs leads to a large-scale or big data that provides valuable information. For this reason, many studies have attempted to turn such data into useful information and knowledge, as surveyed in (Kamilaris et al., 2017). Pahuja et al. (2013) developed an online microclimate monitoring and control system for greenhouses. The system was supported by a WSN for gathering and analyzing plant related sensor data to provide control of climate, fertilization, irrigation, and pests. Tripathy et al. (2014) used data derived from WSN to discover knowledge by data mining. This study focused on leaf spot disease assessing the crop-weather-environment-disease relations, based on wireless sensors and field level surveillance. A classifier was trained to predict the disease. Kehua Xian (2017) proposed a new convenient online monitoring system for IoTs, based on cloud computing. After accumulating enough data from an agricultural IoTs system, modeling of relevant functional requirements was demonstrated to promote the application of large data analysis in agriculture. However, only few studies have applied data mining to extract useful information and knowledge, so this current work will mine the data from IoTs.

3. Research methodology

3.1. The real-situation test area

This work will demonstrate real installations at 3 points (villages). The three example villages are located apart from each other and have differences in farming. The first example village has lime cultivation

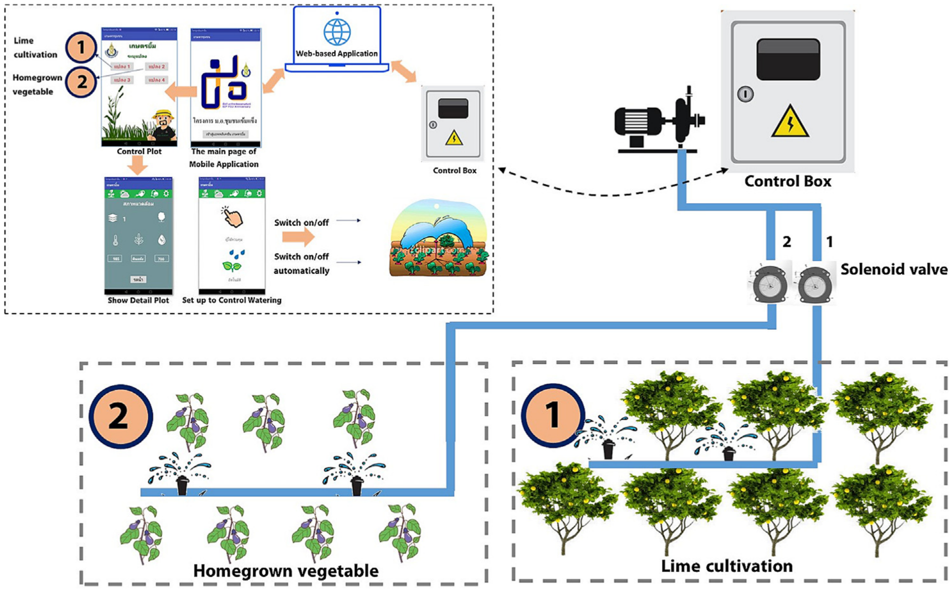

Fig. 1. The model for the first example village.

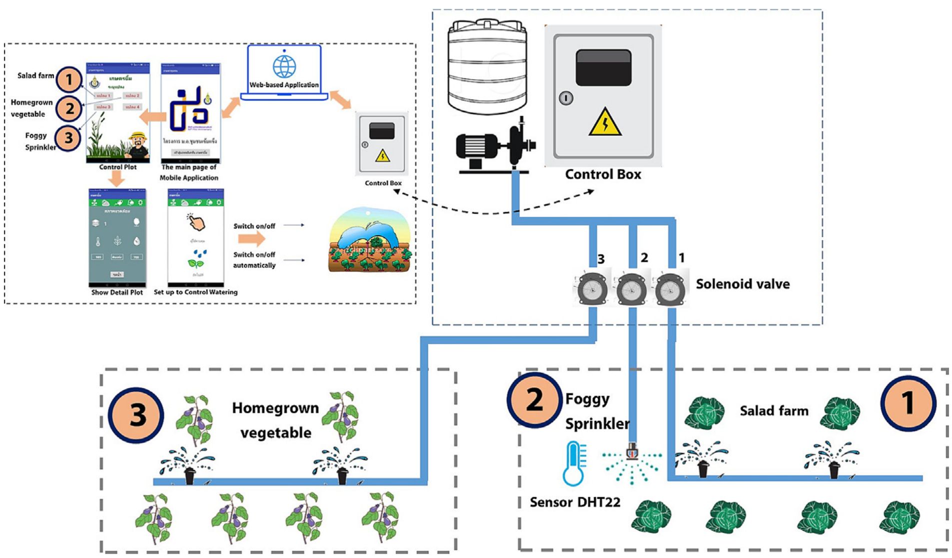

Fig. 2. The model for the second example village.

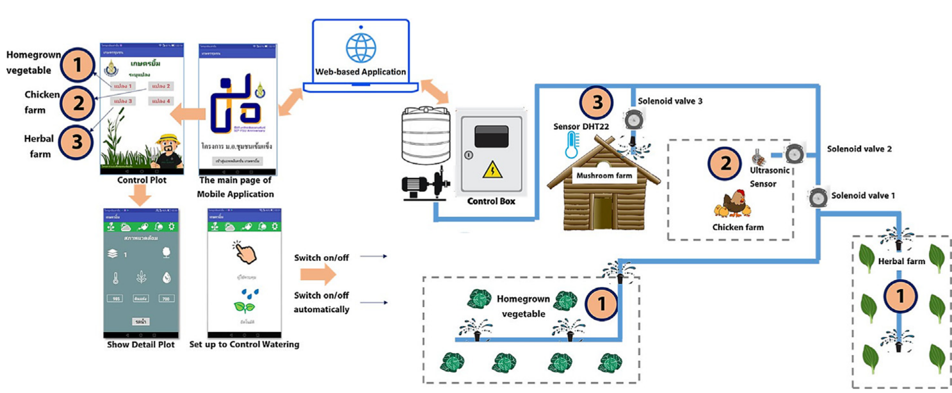

Fig. 3. The model for the final example village.

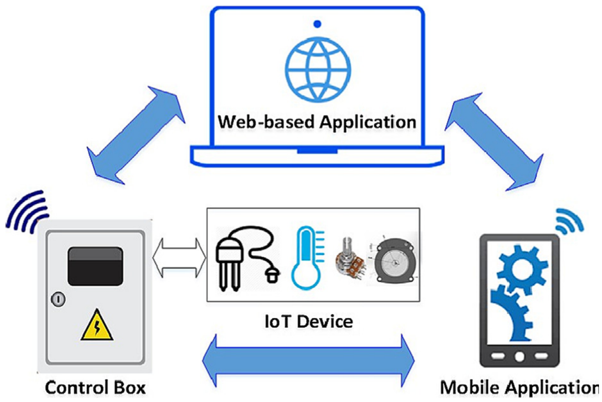

Fig. 4. An overview of the system.

and homegrown vegetables. The second example village has a salad farm and homegrown vegetables. The final example village has an integrated farming system with salad farm, chicken farm, mushroom farm, and herbal farm. The three example villages are represented by the models in Figs. 1–3.

All the example villages showed that IoTs can be used to support and help farmers with any type of agriculture. Moreover, the farmers can spend the time saved on other activities for increased income. The real-time information from IoTs devices in each village was used to control on-off switching of water sprinklers, automatically. Initially, we collected IoTs information for 5 months (170 days) and performed yield analysis with these data. The obtained IoTs information consists of temperature, humidity, and soil moisture, and was collected every 20 min, but for analysis the daily averages were used. Moreover, recorded the yields of lime cultivation and homegrown vegetables to determine relationships between IoTs information and the agricultural products.

3.2. Design and overview of the system

This work aims to design and implement systems with sensors in the crop field and data management by using a smartphone with web application. The three components are hardware, web application, and mobile application, as shown in Fig. 4.

Referring to Fig. 4, the first component was designed and developed in control box form. This control box is designed to control the IoTs devices and obtain data from the crops. The control box and IoTs devices used in this work are shown in Table 1.

The second component discussed is the web-based application. This component involves managing the real-time information from IoTs devices in each village. The web-based application allows an administrator to manipulate the conditions for water need of each crop. In addition, the details of information from IoTs devices can be viewed by an administrator to manage each kind of agriculture. These data were analyzed to predict the water need of crops in the future. The web-based application to manipulate IoTs data from each installation and the details of any crop are shown in Fig. 5.

The final component was used by farmer on a mobile phone. The mobile application was designed to control watering after the data had been analyzed. The mobile application provided two modes, such that farmers can control watering manually, or the proposed system can automatically turn on/off watering based on IoTs information, as shown in Fig. 5.

We summarize the formal mechanisms in the proposed system with the system architecture shown in Fig. 6. This system architecture consists of 3 parts i.e. environmental data acquisition layer, data and communication layer, and application layer. The environmental data acquisition layer is designed to collect data on environmental factors from the sensors and device control. The next layer transports all of the gathered sensor data to collect it into a server. The application layer uses the accumulated data to monitor and control the crop and for data management.

Table 1
Deployment parameters.

Parameter	Value	Voltage
nodeMCU	–	135–215 mA
Temperature and Humidity	DHT22	2.5 mA
Relay Module ×5	1 Channel	5.0 mA
Solenoid	Plastic 1/4	1.3 mA
Achitecture	Crop field	–

3.3. Implementation

The proposed system is implemented with three parts i.e. control box, web-based application, and mobile application. The control box keeps electronic devices in a waterproof box, as shown in Fig. 7. The control box could be located anywhere in farm or near the farm, having the soil moisture sensors, solenoid valve, DHT22 sensor, and an ultrasonic sensor connected to the control box. In this study, IoTs is applied to the soil moisture sensors to measure the humidity of crop soil and to control switching on-and-off water sprinklers automatically. The solenoid valve was used to control water flow with on/off action. The DHT22 sensor was used to control the humidity of mushroom farm. Ultrasonic sensor was applied to measure the level of water in the chicken farm.

The second part is a web-based application that gets agriculture information from NodeMCU. It accesses the internet via WiFi connection. The web-based application was implemented to manage agricultural plots and to manage watering of crop, or to analyze what is suitable watering. Fig. 8 provides an example web page presenting the water need and IoTs information from each installation. Moreover, this part involves the agriculture data analysis that is explained in Section 4.

The final part was implemented in order to interface with the farmer. The mobile application is used to control on-off switching of the electrical system by the farmer. This application has 2 modes; automatic and manual. The automatic system was activated when IoTs devices were detected with defined values of field sensors without user input. The farmer can take over the control and turn the water on or off with the mobile application. Fig. 9 is an example of the mobile application to control watering. The main functions of the application are monitoring watering, set-up of crop details in each plot, and notifications via LINE application.

4. Agriculture data analysis

Data mining was applied to extract important and useful knowledge from large data on crops, obtained with IoTs. The knowledge discovery processes are discussed in (Han and Kamber, 2006). Data mining refers to extracting knowledge from large amounts of data. This paper divides data mining into 4 steps as follows.

1. *Data pre-processing:* This is an important step in the knowledge discovery process, because the quality of knowledge depends on the quality of data. In the real world, data tend to be dirty, incomplete, and inconsistent. Thus, this step can help improve the accuracy and efficiency of the subsequent mining. This step includes data cleaning, data integration, and data transformation. This work used the large amounts of data from IoTs devices on temperature, humidity, and soil moisture, to predict yields, and data for the first example village are shown in Fig. 10. We converted the IoTs information to discrete format in order to support data modeling.
2. *Data reduction:* This step can encode the data to a smaller reduced representation. The integrity of the original data was preserved in

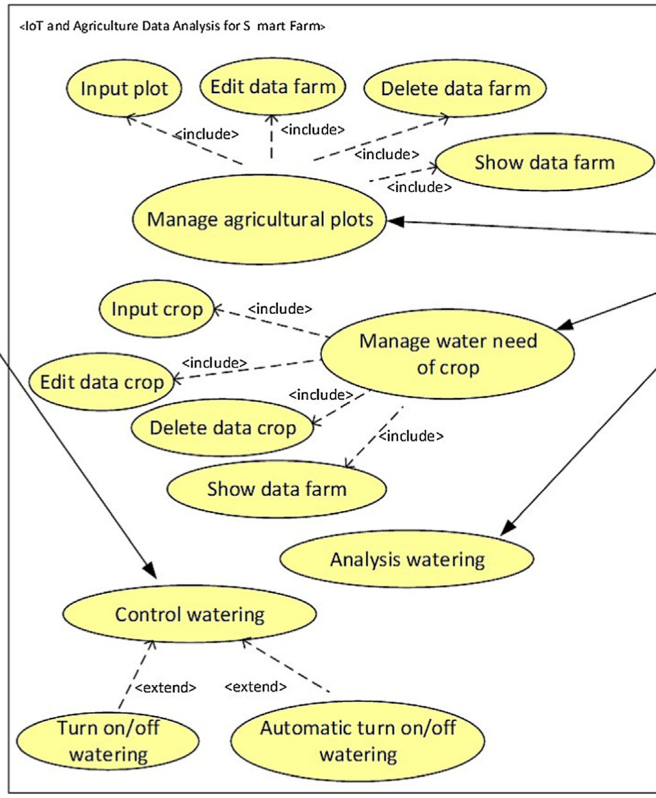

Fig. 5. Use case diagram to show the process with web-based and mobile application.

order that mining the reduced data should be more efficient yet produce the same (or almost the same) analysis results. This work used numerosity reduction, where nonparametric methods for storing reduced representations of the data include histograms. We used equal-width histograms with uniform width buckets and 3 buckets for low, middle, and high level.

3. *Data modeling/discovery:* This step extracts knowledge from the prepared data. Mostly, data modeling/discovery applies intelligent methods to identify patterns in the data. The analysis tools can include classification, clustering, association, and so on. Association rules are the data mining technique applied in this work. Association rules are if/then statements that help discover relationships between subjectively unrelated agriculture data. They were used to find relationships among temperature, humidity, and soil moisture, as well as yields of lemons and homegrown vegetables. There are two basic criteria that association rules use, support and confidence, and they represent relationships and rules as frequently true if/then patterns. In this work the minimum support

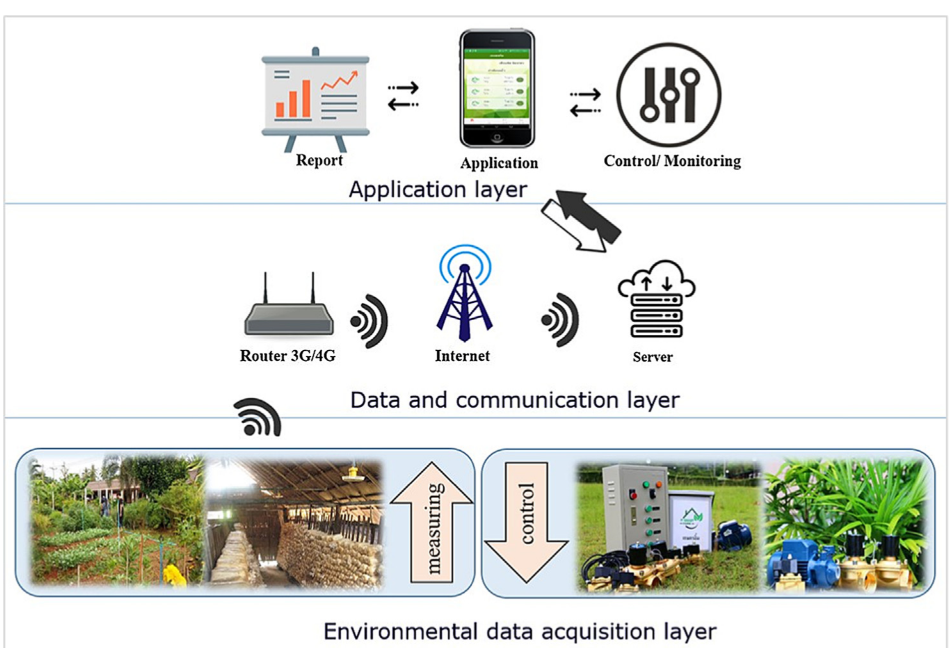

Fig. 6. The architecture of the control system.

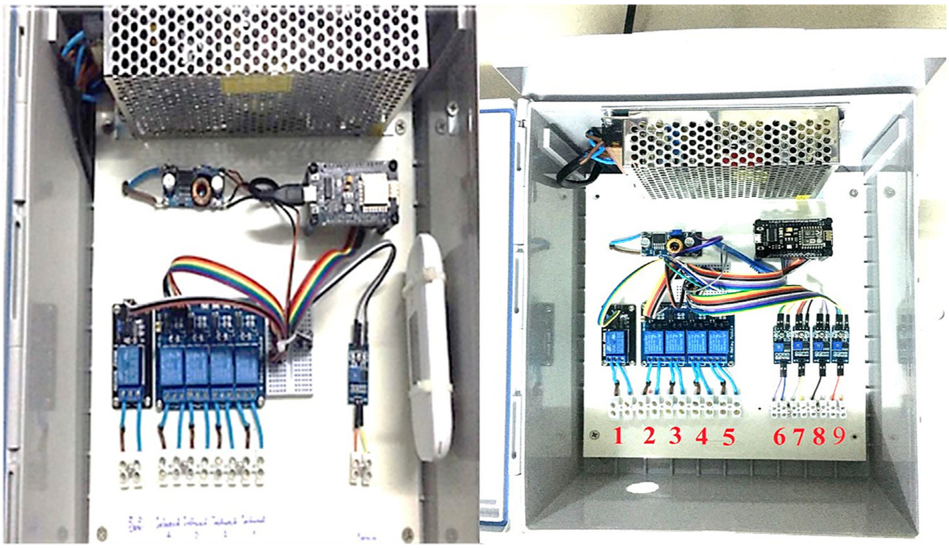

Fig. 7. The control box design for installation.

was 0.75 and confidence was better than 90%.

The Apriori algorithm available in Weka 3.6.9 (http://www.cs.waikato.ac.nz/ml/weka/) was used to extract association rules from data. In addition, we applied linear regression to model the relationship between several input variables and an outcome variable. The model type is shown in Eq. (1),

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_\rho x_\rho + \epsilon, \tag{1}$$

where y is the outcome variable,

x_j are the input variables, for $j = 1, 2, \ldots, \rho - 1$,
β_0 is the value of y when each x_j equals zero,
β_j is the change in y based on a unit change in x_j for $j = 1, 2, \ldots, \rho - 1$, and
ϵ is a random error term that represents the difference in the linear model and a particular observed value for y.

The outcome variables are products of lime cultivation and homegrown vegetables (each has its own model), while the input variables are temperature, humidity, and soil moisture. The R environment was used to fit the models at 95% confidence level, shown in Eqs. (2) and (3) for products of lime cultivation (*Prod_Lemon*) and for homegrown vegetables (*Prod_Veg*), respectively,

$$Prod\_Lemon = 0.89 * Temp + 0.07 * DHT - 0.02 * Humidity - 25.87, \tag{2}$$

$$Prod\_Veg = 0.16 * Temp + 0.10 * DHT - 0.04 * Humidity - 7.29. \tag{3}$$

4. *Solution analysis:* This step involved an analysis of the results from data modeling/discovery. The solution in our work will be discussed with the real implementation.

5. Results and discussion

The proposed system can use IoT devices to collect data on humidity

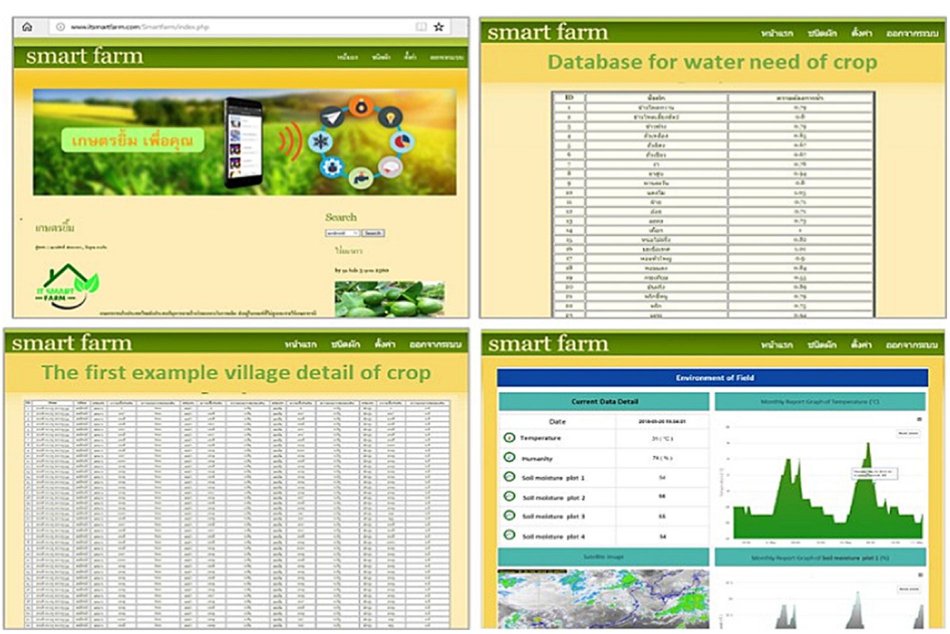

Fig. 8. An example web page presenting water need and IoT information from each installation.

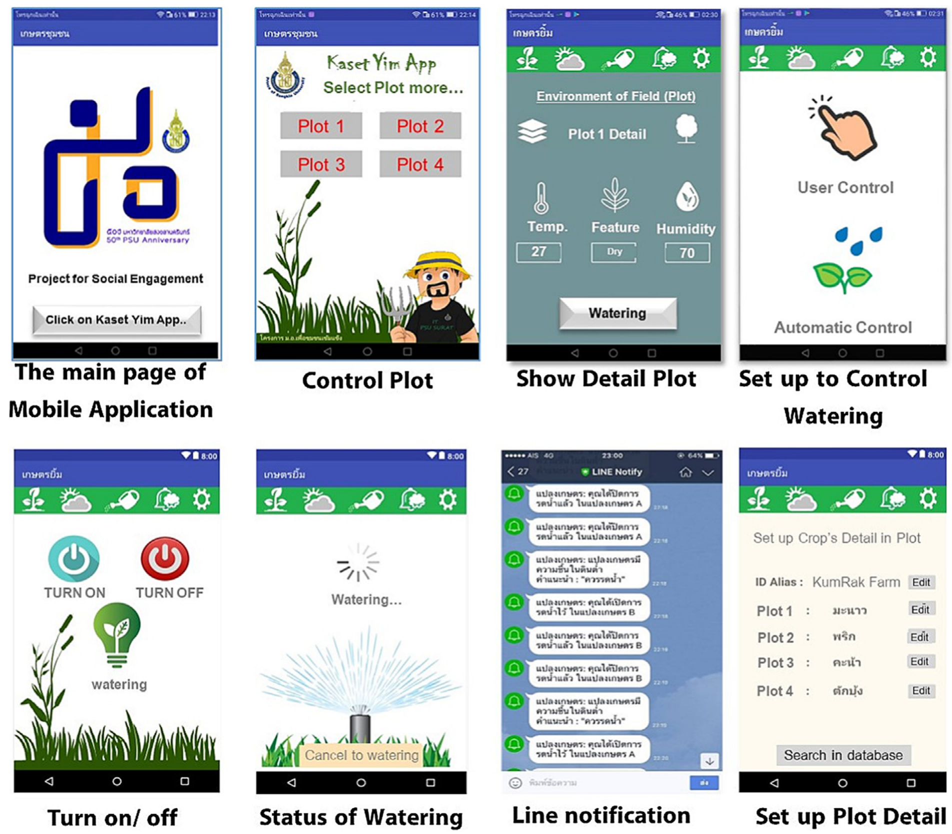

Fig. 9. An example of mobile application to control watering.

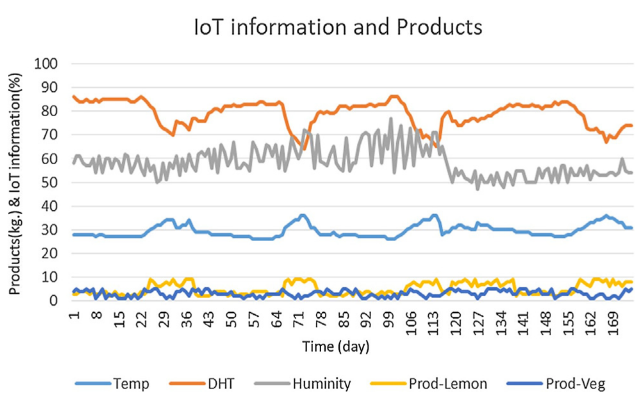

Fig. 10. IoT information and products from the first example village.

derived from the DHT22 sensor, soil moisture derived from soil moisture sensor, and temperature derived from web service of the Thai Meteorological Department Homepage (https://www.tmd.go.th/). This information can be displayed on a mobile device to the farmer, and is used by automatic on/off control of watering. Moreover, the farmer can manually turn on/off the watering. The functional status of on-off switching and time stamps can be notified via LINE Application. Further, an administrator can manipulate the obtained IoTs information and control the data from each installation. The admin can also mine the data to discover knowledge. This knowledge is applied to optimize the farming by season. From data modeling/discovery, the knowledge results showed that if the product of homegrown vegetables is high (more than 4 kg./day) and lime cultivation is high (more than 6 kg./day) then the temperature will middle level (between 29 °C and 32 °C), and if the product of lime cultivation is high (more than 6 kg./day) then the humidity will middle level (between 72% and 81%). The knowledge discovery from real data is illustrated in Fig. 11. We found that the knowledge discovery represented the real data well.

From an economic perspective, this proposed system was considered an investment because of its low cost of approximately 93.27 US Dollars per field. We focused on the first example village. The lime cultivation productivity improvement indicates payback within 2 months. In addition, the increased productivity means that the farmer can spend more time on other tasks. In addition, this study has been carried out in a mixed crop environment with three example villages. Each village had different crops and purposes of agriculture. Knowledge discovery can be applied to suggest a control strategy for watering when the farmer would like to have mixed crops.

6. Conclusion

IoTs was applied in agriculture to improve crop yields, improve quality, and reduce costs. For these reasons, we proposed WSNs application to watering crops, in this paper. We designed and implemented a system to control environmental factors in the crop fields. The system had the three parts hardware, web application, and mobile application. The first part was designed and implemented in control box form. This control box included hardware and electronic control system to connect to sensors and obtain data on crops. The control box was designed for real-life testing. The implemented design connected to and received IoT information from any field in this study. The second part was the web-based application designed and implemented to manipulate details of crop data and field information. In this step, large-scale data from IoT is stored and utilized in data analysis. As one key contribution, this work applied data mining by association rules to discover useful information on effects of environment and climate. The results showed that suitable temperature for high productivity of homegrown vegetables and lemons was between 29 °C and 32 °C. Moreover, suitable humidity for high productivity of lemons was within 72–81%.

The final part was to control the crop watering with a mobile

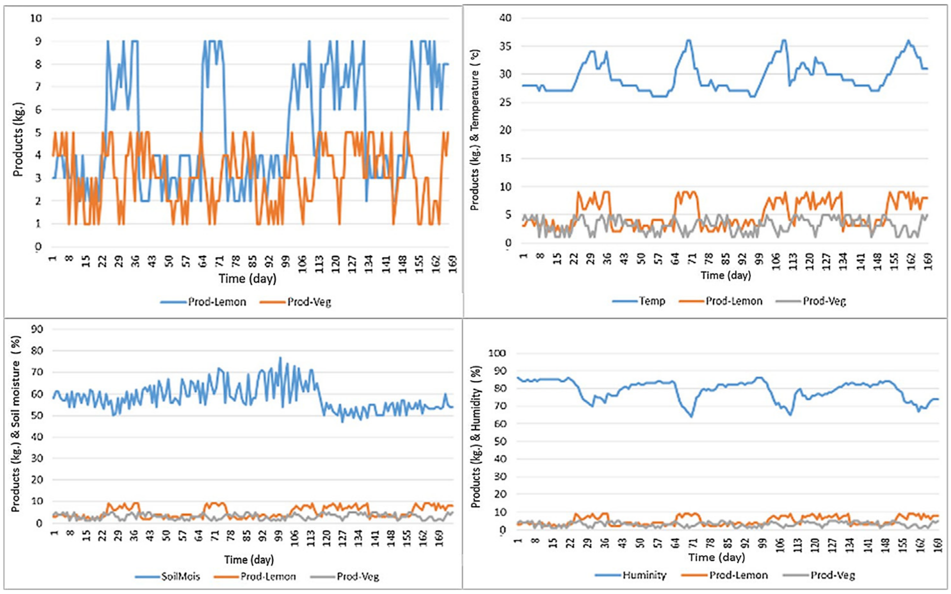

Fig. 11. Comparison of IoT information with productivity.

application on a smartphone. This allowed for both automatic and manual functional control to the user. The user can use the automatic function based on data from soil moisture sensors for watering. However, manual control was possible in the functional control mode. The system sent notifications through LINE API of the LINE application.

The developed system was installed in Makhamtia District, Suratthani Province, Thailand. The results showed clear benefits to agriculture. The moisture content in the soil was appropriately controlled for the vegetables, reducing costs and increasing agricultural productivity. This case study shows high potential for digital technology applications in agriculture.

Acknowledgments

The authors are deeply grateful to the Faculty of Science and Industrial Technology, Prince of Songkla University, Surat Thani campus, Thailand. This research was financially supported by Research and Development Office, Prince of Songkla University, under grant No. X601128. The authors also gratefully acknowledge the helpful check the language in English of Assoc. Prof. Dr. Seppo Karrila.

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.compag.2018.12.011.

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