Design and Deploy a Wireless Sensor Network for Precision Agriculture

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***Abstract*— This paper describes the design, implementation, and deployment of wireless sensor network for precision agriculture. A wireless sensor network was built to use for precision agriculture in which the farmers can monitor and control the agricultural and environmental parameters such as air temperature, air humidity, light, soil moisture, pH, etc. The collected data is stored and transmitted wirelessly to the farmers, which they can use to control and decide appropriate actions for their farm to manage the production and quality. At the hardware side, the system consists of three components: wireless sensor nodes LAU-WSN, wireless sensor management node LAU-WMN, and a server. Software was built at each node to carry out their tasks. At the software side, we proposed a WSN Management Framework for Precision Agriculture, called MFPA, which consists of 3 modules: data collection module, controller module, and data prediction module. The interaction among these modules ensures that user is provided real time environmental and agricultural information which are used to manage the agriculture field. The deployed system has been working properly and promising to bring significant benefits in the agricultural field. Our experimental results show that the data prediction module with dynamic bayesian network on average can achieve 77.5% and 67.6% accuracy for the temperature prediction, and for the humidity prediction, respectively.**

Keywords—Wireless sensor network; Management framework; dynamic bayesian nework;

I. INTRODUCTION

A Wireless Sensor Networks (WSN) is a network which consists of sensor nodes (for brevity called nodes), equipped with capable sensors of sensing the environment such as temperature sensors, humidity sensors, light intensity sensor, etc... and is capable of wireless communication (wirelessly) to the remaining nodes to form a WSN covering a physical field [2]. The collected data from a sensor node will be transmitted to a base station (or a gateway) via other sensor nodes, and finally through the Internet transmission of data centers for storage, analysis and processing.

Traditional agriculture requires an implementation of a series of a specific task, such as planting, fertilizing, harvesting, with a predetermined schedule. However, agricultural and environmental data can be collected to use for more intelligent decisions such as weather, soil and air quality, monitoring of crop growth and even equipment and labor costs, etc. This is known as precision agriculture (or precision farming). A definition of precision agriculture can be as follows: the technique applying the correct amount of input (water, fertilizer, pesticides, etc ...) in the right place and at the right time to increase production and enhance quality [1].

With precision agriculture, control centers will collect and process data at real time to help farmers make the best decisions concerning planting, fertilizing and harvesting crops. The sensor nodes are placed at the planting place to measure temperature and humidity of the surrounding air and soil. Wireless sensor applications in precision agriculture improve efficiency, productivity and profitability in many agricultural production systems, while minimizing unwanted effects to the location where the plants are. The real-time information collected from the field can provide a solid basis for farmers to adjust strategies at any time. Instead of making decisions based on some hypothetical average conditions or personal subjective experience, which may not exist anywhere in reality, an approach to precision agriculture helps recognize the difference and adjust the optimal management activities.

The contribution of the paper is as follows. First, we proposed WSN system architecture for precision agriculture. Second, we proposed and implemented WSN management framework called MFPA for precision agriculture deployed the system at Long An University of Economics and Industry. Finally, we evaluated the performance of the Data Prediction Module, which employs the dynamic Bayesian network for the two environmental parameter predictions: temperature and humidity.

This paper is organized as follows: Section II describes the related work of wireless sensor network in agriculture; Sections III, IV, V describe the design, implementation and deployment of the system; and Section VI concludes the paper.

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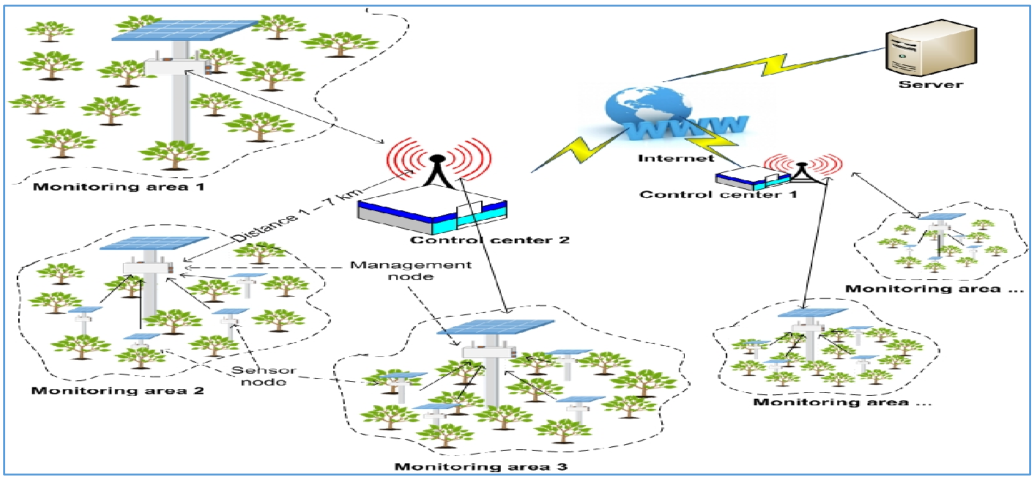

Fig. 1. WSN Architecture for Precision Agriculture

II. RELATED WORK

Using WSN for precision agriculture has been discussed in [1][2][3]. In [1], the authors proposed an open-loop, adaptive, and automatic irrigation controller by using WSN. The proposed system can determine the soil moisture and required level of water to supply in order to maintain adequate moisture level. A microcontroller is used to control the operation along with relay switch and pump. In [2] the authors proposed a WSN used in agriculture for sugarcane crop for Indian climatic conditions. In [3], the authors proposed a precision agriculture sensing system based on wireless multimedia sensor network. These works explores the benefits using of WSN for agriculture.

Wireless sensor networks are used to control for greenhouses in [4] [5] [6]. A greenhouse is a structure covered ground usually used for the growth and development of plants. This structure is associated with the purpose of protecting crops and allowing a better environment to grow. This protection ensures sufficient to provide high quality in crop production. The main function of a greenhouse is to provide a favorable environment than outside. The main factors related to the greenhouse control system: temperature, humidity, CO_2, concentration, radiation, water and nutrients can be controlled by wireless sensor networks.

Smart irrigation system using wireless sensor network is used in [7] [8] for saving water and manpower. Plants need sunlight, nutrients, and water to grow. All agricultural producers have a minimum amount of water required annually to survive and the optimal amount of water required to produce annual maximum. Thus, smart irrigation systems are needed to improve crop yields. Target towards the smart irrigation system is not to use a waterdrop more than required and not a drop of less than necessary for adequate plant growth.

To the best of our knowledge, there is no/little work on wireless sensor network for precision agriculture in Vietnam, especially in Mekong Delta Region, Vietnam. Our system is the first/one of the earliest system is proposed and deployed WSNs for precision agriculture in Mekong Delta Region.

III. WSN SYSTEM ARCHITECTURE FOR PRECISION AGRICULTURE

A. Overall

Fig. 1 describes our overall system. In each area of cultivation, sensor nodes are deployed to monitor environmental parameters such as air temperature, air humidity , light , and the agricutural parameters related to soil conditions, soil moisture, pH,etc. In each region, the sensor node collected, stored and transmitted periodically the data to the management node, and then the data will be sent to the control center and finally to the server via the Internet. Based on the obtained data, farmers can observe and decide appropriate actions to control the health of their farm for production quality assurance. For example , if soil moisture is currently at the level which is lower than the desirable level, they can remotely activate a water pump in the area to improve moisture. Because the system is extendable, it can be implemented on either a small scale area, i.e. a small farm or a large-scale such as the large farm at a level of suburb, or even nation-wide.

B. The details of the system in a monitoring area

Fig. 2 describes the detail of the system in a monitoring area, including sensor nodes and the management node.

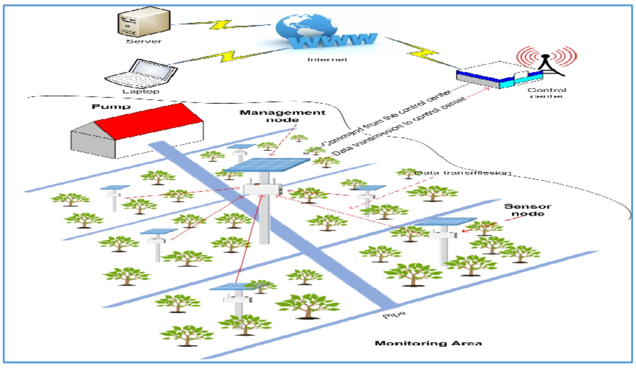

Fig. 2. The model of wireless sensor network at management node

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1) Sensor nodes:

Each sensor node contains sensors which have the ability to sense the environment as air humidity, temperature, pH, light intensity, etc, depending on the type of sensors. In addition, sensor nodes enables to communicate with other sensor nodes in the same coverage area and transmits wirelessly collected data to the management node.

2) The Managemnent Node:

The managemnent node is responsible for the management of sensor nodes in the coverage area and plays as an intermediate node between sensor nodes and the control center, receiving data from the sensor nodes in the region and transfers them to the control center. In addition, the managemnent nodes also have the responsibility of receiving and transmitting commands from the ~~servers~~ to the sensor nodes to take actions requested by the server.

C. Hardware

This describes the hardware of the system built in the monitoring area and,

1) The monitoring area

a. Wireless Sensor nodes (LAU-WSN)

Fig. 3 describes the structure of a wireless sensor node in the system. A sensor node consists of the following four components:

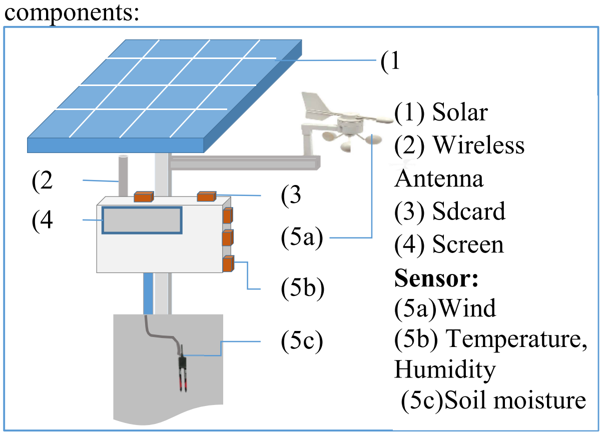

Fig. 3.Structure of sensor node (LAU-WSN)

- Power supply component: this will supply the power of 12V for device operation. Electricity can come from solar energy, batteries...
- Sensors component: includes the following sensors:

  Temperature: collects temperature of the environment.

  Humidity: collects parameters of soil moisture, air humidity.

  pH: pH of water.

- Processing center component: Undertakes data collection from the collective data unit then controls the communication unit to transfer to the field management node, and make the display unit present on the screen.
- Communication component: After the center unit processes and collects data and sends to the communication unit, this communication unit will transfer data to the management node.
- Storage unit: only works ~~of~~ as saving data in a memory card.

b. The management node LAU-WMN

Management node LAU-WMN is the node which receives data from sensor nodes and then transfers to the servers and at the same time taking orders from the servers transferred to the sensor nodes to execute.

Fig. 4 describes the structure of a management node. A management node includes following components:

- The Energy supply component: this will supply the power of 12V for device operation. Electricity can come from solar energy, batteries, …

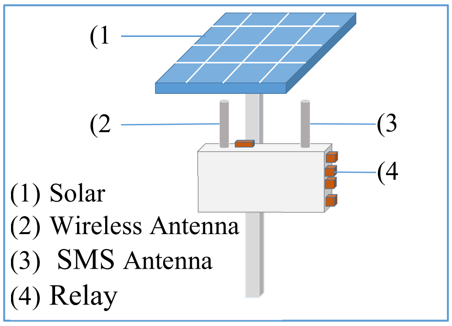

Fig. 4. Structure of the management node LAU-WMN

- The Processing center component: processes information received from the communication unit and returns the data as needed.
- The Communication component: undertakes the task of communication between sensor nodes and the control servers.
- The Control component: does the task of opening and closing devices such as pumps, nebulizers, light, wind turbines

2) Server

At server side, the data is received, stored and displayed to the users, which provide the information about the health of the current system. The server can also perform the actions to the WSNs to manage the field. The data will be stored and analysed in order to provide the farmers/ users an overall perspective on the area they monitor and support them with a number of actions.

IV. WSN MAMANGEMENT FRAMEWORK FOR PRECISION AGRICULTURE

In this section, we present the WSN Management Framework for Precision Agriculture called MFPA in detail. To address the scalability issue, MFPA uses hierarchical management architecture. MFPA consists of 3 modules: Data collection, Controller, and Data Prediction Modules.

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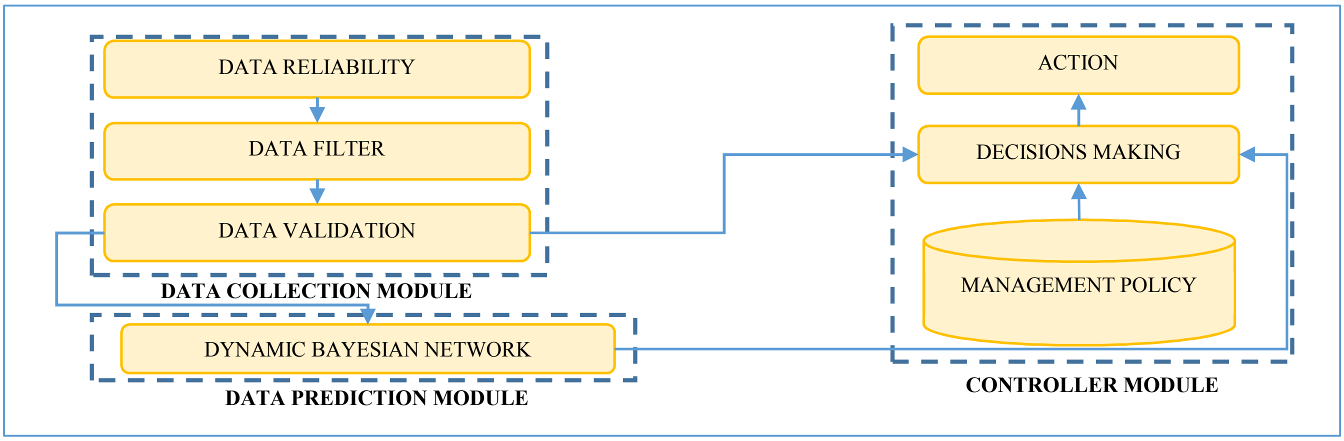

Fig. 5. WSN Management Framework for precision agriculture

A. Data collection module:

The data collection module is responsible for environmental and agricultural data management, which consists of three components: data reliability, data filter and data validation. The data reliability is responsible for ensuring the delivery ratio. In our system, a light-weight energy-efficient end-to-end transport protocol is used to ensure the delivery of the data collection. The data filter component is responsible for filtering the noise before passing the data to the data validation. The data validation component is responsible for running the algorithm valid data, which WSNs collect in period.

B. Controller module:

The controller module is responsible for decision making and action performing. It consists of three components: decision making, action, and management policy components.

- Management policy component: The management policy Component stores the management policies defined by the core module.
- The action component is responsible for performing the action assigned by the decision making module.
- Decision making component: Based on the information from the data collection module, the policies defined in management policy component, and the data prediction module, the decision making component determines appropriate actions to be executed and passes the request to the action component.

C. Data prediction module:

In order to assist the decision making, the data prediction module is responsible for data prediction. In our framework, we used a Dynamic Bayesian network (DBN) for predicting parameters. DBN [9][10] is a belief network that represents the stochastic process of a set of random variables over time:

Let $X = \{X_1, X_2, X_3, \dots X_n\}$ be the set of features whose values change over time.

$$X[t] = [X_1[t], X_2[t], \dots . X_n[t]]^T$$

Xi[t] be a random variable representing the value of Xi at time t for $0 \le t \le T$. A DBN is a probabilistic network defined as a pair $(B_0, B_{\rightarrow})$ represents the joint probability distribution over all possible time series. Where B0 (G0, P0) is a DAG G0 contains initial state of Bayesian network, consists of variables in X[0] with probability prior distribution P0(X[0]. Transition Bayesian network $B_{\rightarrow}(G_{\rightarrow}, P_{\rightarrow})$ is DAG $G_{\rightarrow}$ with transition probability $P_{\rightarrow}$(X[t+1] | X[t]). DBN theory is generally based on two assumptions. First, the process is Markovian X,i.e. P(X[t+1]|X[0],...,X[t])=P(X[t+1]|X[t]). The other assumption is that the process is stationary, i.e. the transition probability $P_{\rightarrow}$ (X[t+1]|X[t]) is independent of t. The transition probability is computed following:

$$P_{\rightarrow}(X[t+1] \mid X[t]) = \prod_{i=1}^{n} P_{\rightarrow}(X_i[t+1] | Pa(X_i[t+1]))$$

Where $Pa(Xi[t+1]) \subseteq \{X[t+1], X[t\ ]\}$

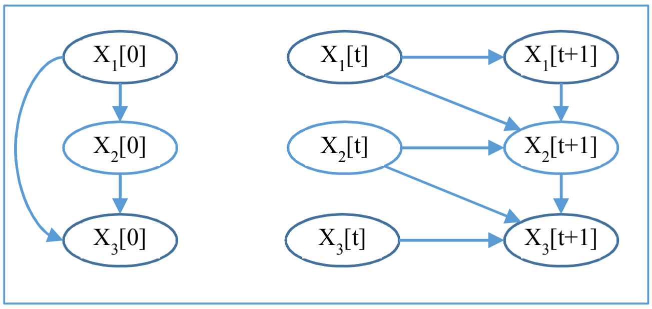

Fig. 6. Dynamic Bayesian Network (n=3)

The joint probability distribution is

$$P(X[0], \dots, X[T]) = P_0(X[0]) \prod_{t=0}^{T-1} P_{\rightarrow}(X[t+1] | X[t]).$$

Each Xi is assumed to have r_i possible values. Let $\{i_1, i_2, \dots., i_{|Pa(X_i)|}\}$ denote the indices of the parents of node i. The number of possible parent states in node i is

$$s_i = r_{i_1}.r_{i_2} \dots .r_{i_{|Pa(X_i)|}}$$

Denote φ_{ijk} $=P_{\rightarrow}(X_i[t+1] = \{k\} | Pa(X_i[t+1]) = \{j\})$, with $k \in \{1, 2, \dots, r_i\}$ is value k th in state {k} and $j \in$

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$\{1, 2, \ldots, s_i\}$ is state j th correspond to the parents of the ith node.

Given a network structure $\mathcal{M}$, the global parameter is $P(\varphi/\mathcal{M}) = \prod_{i=1}^{n} P(\varphi_i/Pa(X_i))$, where $\varphi_i = \{\varphi_{ijk} \,|\, j \in \{1, 2, \ldots, s_i\}, k \in \{1, 2, \ldots, r_i\}\}$, and the local independence is defined $P(\varphi_i/Pa(X_i)) = \prod_{j=1}^{s_i} P(\varphi_{ij}/Pa(X_i))$, where $\varphi_{ij} = \{\varphi_{ijk} \,|\, k \in \{1, 2, \ldots, r_i\}\}$. Furthermore, we perform predicting via to find the highest scoring $\hat{x}_i = agr\ max_{x_k} P(\varphi_{ijk}/Pa(X_i) = j)$. We predict value in slice t + 1 from sets of value parents in slice t and t +1 and recursive in data prediction to predict for the next day, with n = 48, X_i is average value of data separated by half an hour.

V. IMPLEMENTATION AND RESULTS

A. Implementation detail:

At the server side, the software was implemented in a high - level programming language C# on PC. The LAU-WSN and LAU-WMN were built by using MSP430G2553 for processing, module wireless nfr24L01 for communicating, sensor modules SHT11 for sensing temperature and humidity, light sensor LDR12mm-10K/2M, and soil moisture sensor FC-28. The gateway connects to PC in serial port by using module FT232.

B. Software GUI at the server

At the server side, the data is received, stored and displayed for the users, which provide them the health of the current system. As shown in Fig.7, the users can view real-time information of the monitoring area such as temperature, humidity, soil moiture, etc.

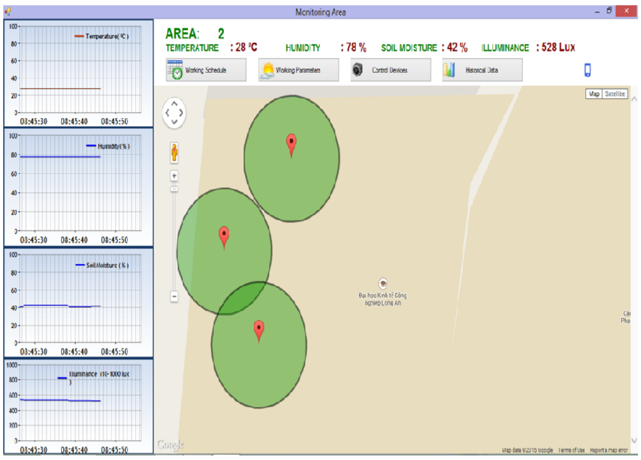

Fig. 7. Information Interface monitoring area

From the PC, the software allows users to either perform an action or perform a list of actions to be scheduled in advance for managing their field. Fig.8 show an example of time scheduling for irrigation.

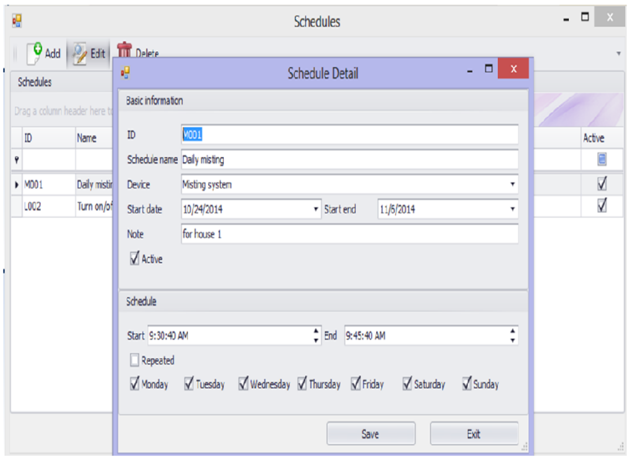

Fig. 8. An interface of time scheduling for irrigation

C. The Evaluation of Data Prediction module

In this section, we describe how we evaluate the data prediction module. Specifically, we evaluate the two important environmental parameters: the temperature and humidity.

1) Experimental setup

In order to evaluate the data prediction module, the sensor data was collected at the 30 minutes sampling rate (equivalent to 48 measurement per day). In our experiment, we only evaluate the two attributes for environmental information: the temperature and the humidity. We collected the temperature and humidity data from 1/10/2014 to 01/04/2015 for our evaluation, which contains approximately 8,646 measurements.

2) Evaluation metrics:

In order to evaluate the accuracy of the prediction module, the RMSE (Root Mean Square Error) and the MAE (Mean Absolute Error) are calculated. The MAE and the RMSE are quantifying how close the predictions to the target value are. While the MAE is an average of the absolute error, the RMSE indicates square of the absolute error, emphasizing on how large the difference between the predicted and actual values is. We compare the actual value $x_i[t]$ to the predicted value $\hat{x}_i[t]$. The RMSE of a day tth is calculated as following:

$$RMSE[t] = \sqrt{\frac{\sum_{i=1}^{n} (\hat{x}_i[t] - x_i[t])^2}{n}}$$

The MAE of day tth is calculated as following:

$$MAE[t] = \frac{1}{n} \sum_{i=1}^{n} |\hat{x}_i[t] - x_i[t]|$$

The Accuracy (ACC) is calculated as following:

$$ACC = \frac{number\ of\ true\ prediction}{number\ of\ true\ prediction\ + number\ of\ false\ prediction}$$

ACC showed the percentage of the true prediction. In our experiment, we assume that the allowed error for temperature measurement and humidity measurement is ±1^{0}C and ±5%, respectively.

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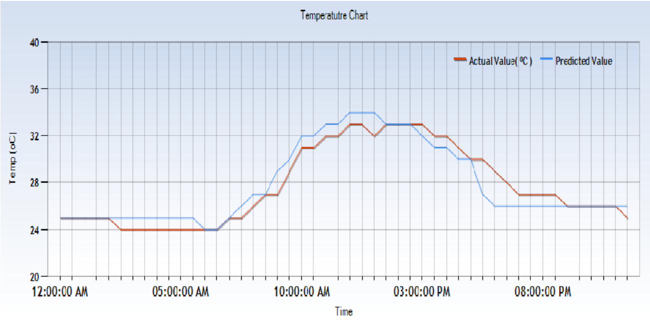
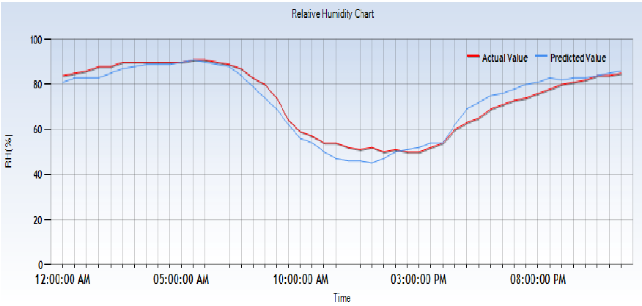
3) Experimental results:

Fig. 9 showed the comparison between the actual and the predicted values of the temperature and humidity on 03/03/2015. The results show that the prediction values with the DBN on 03/03/2015 are very close to the actual values.



(a)



(b)

Fig. 9. The comparison betweeen the actual values and the predicted values for temperature (a) and humidity (b) on 03-03-2015

TABLE I. ACTUAL AND PREDICTED VALUES FOR TEMPERATURE FROM 01/10/2014 TO 01/04/2015

	1st month	2nd month	3rd month	4th month	5th month	6th month
MAE	1.1512	1.0421	1.0756	0.9982	08966	0.6330
RMSE	1.5705	1.5578	1.5667	1.3847	1.2534	0.9758
ACC (%)	70.20	73.28	75.23	76.64	79.14	90.44

Table I and Table II showed the actual and the predicted temperatures and humidity during the entire period from 01/10/2014 to 01/04/2015. We observed that the average ACC for the entire period is 77.5% for the temperature, and 67.6% for the humidity, respectively. The results showed that the the data prediction module with DBN achieved considerable performance. The result may also due to the fact that the system was deployed and tested in the dry season. Thus, the weather condition is not much fluctuated. Moreover, we also observe that the trend for the accuracy prediction increases when more training data was obtained. For example, the ACC significant increases from the 1st month to the 6th month, from 70.2% to 90.44% for the temperature, and from 54.21% to 79.63% for the humidity, respectively.

TABLE II. THE ACTUAL AND PREDICTED VALUES FOR HUMIDITY FROM 01/10/2014 TO 01/04/2015

	1st month	2nd month	3rd month	4th month	5th month	6th month
MAE	6.0156	4.8075	4.5224	4.4309	4.1619	4.8767
RMSE	7.8051	6.6903	6.0046	6.7362	5.6228	3.5772
ACC (%)	54.21	66.22	66.83	67.07	71.77	79.63

VI. CONCLUSION

This paper describes the design, implementation, and deployment of wireless sensor networks for precision agriculture at Long An University of Economics and Industry. The system has been deployed and operated, which promises to bring significant benefits to the agricutural field. We also evaluated the performance of the prediction module, which on average achieved 77.5% for the temperature, and 67.6% for the humidity, respectively. Our system will enable the farmers easily to access and control the agricultural production, whereas saving the input materials, improving efficiency, productivity and profitability in farming production system.

In the future, we will test the prediction module in the rainy season to evaluate the performance of the system.

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