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A Simulation Study on an Artificial Neural Network based Automatic Control System of a Plant Factory

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Abstract

This paper proposes a framework to design an automatic control system of a plant factory based on artificial neural network (ANN) and presents the simulation results of the proposed system. The proposed system can collect information of crop cultivation environment and monitor it in real-time by using various environment sensors. Installed wire or wireless sensor nodes, based on the sensor network, collect the growing condition's information such as temperature, humidity, CO_2, and the control system is to monitor the control devices by using ANN. The proposed automatic control system provides that users can control all equipments installed on the plant factory directly or remotely and the equipments can be controlled automatically. The simulation results show the application possibility of the proposed system in a plant factory.

Keywords: *Automatic Control System, Artificial Neural Network, Plant Factory*

1. Introduction

A Plant factory is a closed growing system which enables a farmer to achieve constant production of vegetables all year around. The facility utilizes artificial control of light, temperature, moisture, and carbon dioxide concentrations and so on [1]. The developed concept of a plant factory receives attention and in contrast with previous attempts it appears that the concept will be successful now. This is also thanks to the worries of customers regarding food safety and the low level of self-sufficiency. The plant factory is a closed growing system, in which throughout the year a constant production of high quality vegetables can be achieved. Artificial control of growing conditions, such as light, temperature, moisture, carbon dioxide concentration and the possibility to add culture solutions are added advantages because of theses growers can plan their production better. The closed growing systems only use artificial light. Hygienic conditions are an absolute requirement. The system is regarded to be a way to increase food production by cultivating in more than one layer and all year round. The food processing industry and the restaurant sector strongly demand a stable supply of high quality vegetables all year round [2, 3].

The agricultural crop production in a plant factory is attracting increasing attention and agricultural crop environment is also controlled automatically. The essential characteristic of the plant factory system is not only its productivity, but also its ability to produce a stable amount of clean and safe agricultural production. It is believed that plant factories will play an essential role in future agriculture. Commercial plant factories are being established, although problems of profitability still exist [2].

Recently, the remarkable technologies have developed for a plant factory such as computer integrated systems for automatic control in a plant factory. In a plant factory, it is very important technique to control the agricultural crop environment because it is to gain higher

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yields and better quality of plants. But it is difficult to control the agricultural crop environment automatically because of its complexity and uncertainty of complicated environment factors. The basic descriptions of the plant factory control problem are presented in References [4, 5, 6]. Kim suggested an expert system for automatic control of greenhouse environment [7].

Artificial neural network (ANN) is analytic techniques modeled on the learning processes of the human cognitive system. ANN was applied for prediction and classification studies in the sciences and engineering applications and so on. Garver presented that ANNs are superior to the conventional statistical applications [8]. Bishop has demonstrated how ANN outperforms the multiple regression models [9]. The application models of ANN are ranged from product cost estimation [10] to financial analysis [11]. The abilities of ANN such as nonlinear learning and noise tolerance make them particularly useful in situations and make them useful at solving problems without the clearly represented procedures [12, 13, 14, 15].

This study attempts to design a framework of an artificial neural network (ANN) based automatic control system for a plant factory. The proposed control system can collect the growing condition's information of crop cultivation environment such as temperature, humidity, CO_2 and illuminance and monitor it in real-time by using various environment sensors [16, 17]. Installed wire of wireless sensor nodes based on the sensor network, collect, and the control system is to monitor the control devices by using ANN [18]. The proposed automatic control system provides that users can control all equipments installed on the plant factory directly or remotely and the equipments can be controlled automatically. Simulation results show that the proposed system developed in this paper can achieve both accuracy and reliability.

2. Research Background

2.1. Control system of a plant factory

As mentioned above, a plant factory is a closed growing system which enables a farmer to achieve constant production of crops all year around. That is to say, a plant factory allows crops such as vegetables and fruits to be produced in an industrial manner. A plant factory can produce crops of consistent quality and guarantee a steady year-round harvest, resulting in stable prices. These characteristics are quite similar to those of a factory in the industrial domains. In addition, crops are grown in trays in multilayer cultivation shelves, with artificial lights installed above and nutrient solutions supplied directly to their roots Instead of being planted in the ground.

In a plant factory, the facility utilizes artificial control of light, temperature, moisture, and carbon dioxide concentrations and so on. This method produces crops in closed environments in which all the important elements needed for plant growth artificially controlled. A plant factory is a closed growing environment in which air conditioning and lighting sources such as fluorescent lamps and light-emitting diodes, or LEDs, are used to replace natural ventilation and sunlight. In addition, temperature and humidity are also carefully adjusted so that the effects of detrimental weather conditions can be eliminated.

As a result, it is important to develop an automatic control system of a plant factory. The control system is to collect information of crop cultivation environment and monitor it in real-time by using various environment sensors. In this paper, we proposed the architecture of control system of a plant factory as shown in Figure 1.

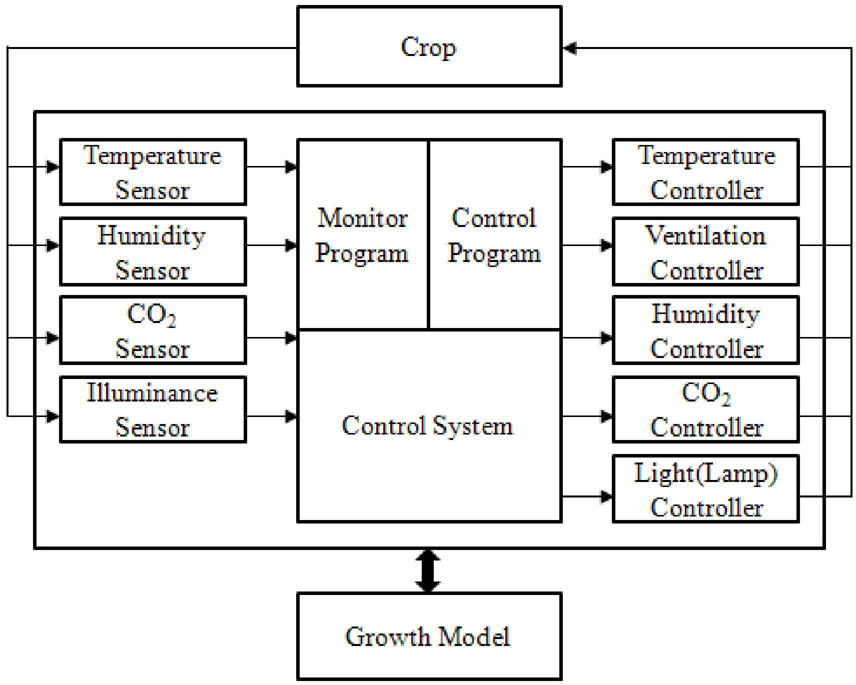

Figure 1. The proposed control system of a plant factory

As shown in Figure 1, the proposed control system of a plant factory consists of four sensors, control parts and five controllers. Especially, we consider four important environmental factors for the control system such as illuminance, temperature, humidity and CO_2 concentration. The information of crop cultivation environment was gathered by installed wire of wireless sensor nodes, based on the sensor network and the control commands delivered to environmental factors' controllers. And then the actuators of equipments connected controllers were operated [7].

The proposed control system is to monitor the control devices by using ANN. The proposed automatic control system based on ANN provides that users can control all equipments installed on the plant factory directly or remotely and the equipments can be controlled automatically.

2.2. Artificial neural network (ANN)

ANN is the information processing system that has specific performance characteristics common to biological neural networks [19]. ANN comprises some layers with numerous simple processing elements called nodes or neurons as shown in Figure 2. Each node in a layer is connected to other nodes with associated weight. These weights between nodes and nodes represent information utilized by the net to solve a problem. ANN generally consists of some layers such as one input layer, one or several hidden layers, and one output layer [20]. Each layer has nodes that are connected to other nodes in an adjacent layer. Each node is a processing unit containing a summation function and an activation function. A weight returns a mathematical value for the relative strength of connections for transferring data from one layer to another layer. The input layer can be considered the model stimuli and the output layer is the input stimuli outcome. The hidden layer determines the mapping relationships between input and output layers.

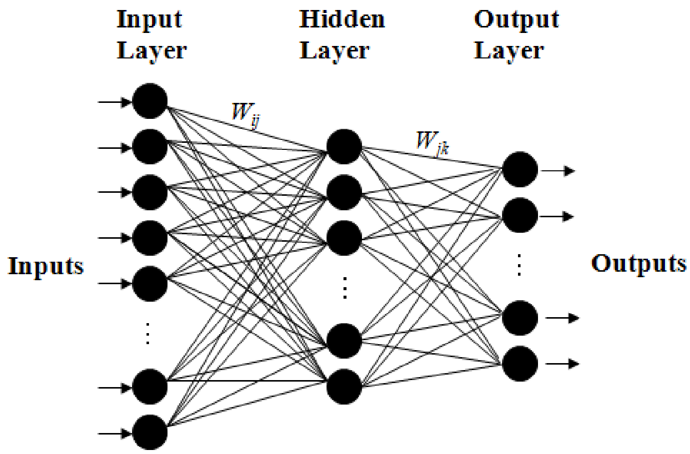

Figure 2. The architecture of ANN

ANN can be classified into several categories based on supervised and unsupervised learning methods. A back-propagation neural network (BPNN) is a neural network that uses a supervised learning method and feed-forward architecture. The learning process in a BPNN differs from traditional feed-forward neural networks because a BPNN uses an activation function for the hidden unit and not the input value and it has the gradient of the activation function [21]. The output of a BPNN is compared with the target output and an error is computed for an each training iteration. This error is then back propagated to the neural network and utilized to adjust the weights, thereby minimizing the mean squared error between the network's training output and the actual output. Eventually, the BPNN model yields training output that is similar to the actual output [21, 22].

In this study we adopt the BPNN for designing an automatic control system of a plant factory.

3. Design the ANN based Automatic Control System

In this study, we adopt the BPNN model which is one of the most widely used ANN models. The BPNN architecture comprises one input layer, hidden layers and one output layer. The BPNN parameters include a number of hidden layers, a number of hidden nodes, an activation function, learning rate, momentum and so on. These parameters of BPNN have significant impact on ANN performance. In most cases, one hidden layer is sufficient to calculate arbitrary decision boundaries for outputs [23]. Therefore, we set one hidden layer of BPNN. In order to determine the number of nodes in the hidden layer, we performed trials and errors. After performing some trials and errors, the final number of nodes in the hidden layer was determined. The activation function is mathematical formula that determines the output of a processing node. In this study, we adopted a sigmoid function for the activation function where $f(x)=1/(1+e^{-x})$ and output value in the interval [0, 1]. For setting the learning rate and momentum, we also performed trials and errors.

The final structure of our BPNN model is proposed in Figure 3. As shown in Figure 3, the BPNN architecture comprised one input layer, hidden layers and one output layer. The input nodes consisted of four nodes such as temperature, humidity, CO_2 and illuminance and the output nodes comprised five nodes such as temperature, ventilation humidity, CO_2 and illuminance control values.

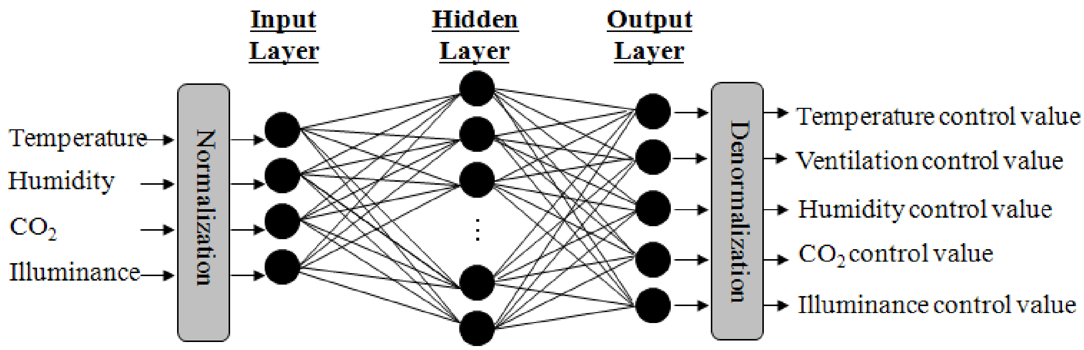

Figure 3. The architecture of the proposed ANN model

4. Simulation Results of ANN based Automatic Control System

4.1. Data collection

Controlled environment in a plant factory offer a way to achieve the high productivity, but it is hard to optimize all environmental parameters to genetic yield potential [24]. We collected the simulation data of a plant factory for lettuce. The productivity of lettuce is in a combination of high temperature, high light, proper humidity and elevated CO_2. We gathered the historical data of temperature, illuminance, humidity and CO_2 concentration for cultivating lettuce in a plant factory during six months. For example, the temperature(°C) of day and night was gathered 23/18, 26/21, 29/24, 32/27 and 35/30 and relative humidity (%) was between 60 and 90. The CO_2 concentration ($\mu ml \cdot m^{-2} \cdot s^{-1}$) was between 500 and 1,200 and the illuminance of light (PPF; photosynthetic photon flux density) was between 300 and 1,000. In addition, the controllers' values of temperature, ventilation, illuminance, humidity and CO_2 concentration according to the condition of temperature, ventilation, illuminance, humidity and CO_2 concentration were also collected.

The data set is randomly split into two subsets: 80% of the data is used for training set and 20% of the data (holdout) is used for testing set.

4.2. Simulation results

This study refers to the following three test appraisal benchmark data, which are "mean absolute error'', ''root squared error'' and "coefficient of determination'' as follows:

(1) MAPE (mean absolute percent error).

$$MAE = \sum_{i=1}^{n} \left| T_i - E_i \right| / n \quad (1)$$

T is real value.

E is the estimated value.

N is the number of data

We can learn the diversion rate between the real value and the estimated value by MAE value. The smaller the value is, the smaller the diversion rate is leading to better results.

(2) RMSE (root mean squared error)

$$RMSE = \sqrt{\sum_{i=1}^{n} (T_i - E_i)^2} / n \tag{2}$$

The smaller the value is, the smaller diversion rate is, yielding better results.

(3) r^2 (coefficient of determination)

$$r^2 = SSR/SST = (SST-SSE)/SST = 1-SSE/SST, \ 0 \le r^2 \le 1 \tag{3}$$

SST: total sum of squares.

SSR: sum of squares due to regression.

SSE: sum of squares due to error.

We can understand the matching degree between the estimated values and the real values by r^2). The closer to 1 the value is, the better the result is.

The structure of the proposed BPNN consists of three layers such as one input layer, one hidden layer and one output layer. The number of nodes in the hidden layer is critical to BPNN model performance. There is no precise formula to determine the number of node in the hidden layer. In this study, the range of nodes in the hidden layer was between $2N + 1$ and $OP(N + 1)$, where N is the number of input nodes and OP is the number of output nodes [25]. Since N is 4 and OP is 5 in this case, the bound of neurons in the hidden layer is [9, 25]. Subsequently, some experimental networks (4-9-5, 4-14-5, 4-19-5 and 4-24-5) were performed where the 4-9-5 network has 4 nodes in the input layer, 9 nodes in the hidden layer and 5 nodes in the output layer. The RMSE, r^2 and MAPE results indicate that the 4-9-5 network superior to other networks as sown in Table 1. In this network model, the learning rate was 0.7 and momentum was 0.3 by trials and errors. Therefore, 9 nodes are finally assigned into hidden layer.

Table 1. Simulation results of the BPNN models

Model	RMSE	MAPE	r^2
4-9-5	**0.055*(0.235**)**	**1.650(9.512)**	**0.95(0.850)**
4-14-5	0.086(0.261)	2.422(10.025)	0.920(0.825)
4-19-5	0.075(0.250)	3.052(11.152)	0.935(0.840)
4-24-5	0.105(0.275)	3.421(11.337)	0.895(0.810)

* Training dataset, ** Testing dataset

In order to evaluate the performance of the proposed automatic control system, we simulated the daily temperature changes during 2 weeks in May. The simulation results of daily temperature changes during 2 weeks were shown in Figure 4. The maximum temperature of day was set at 32°C and the minimum temperature was set 18°C. The temperature changes in plant factory by the automatic control system were between 24°C and 28°C, so the change ranges were satisfactory.

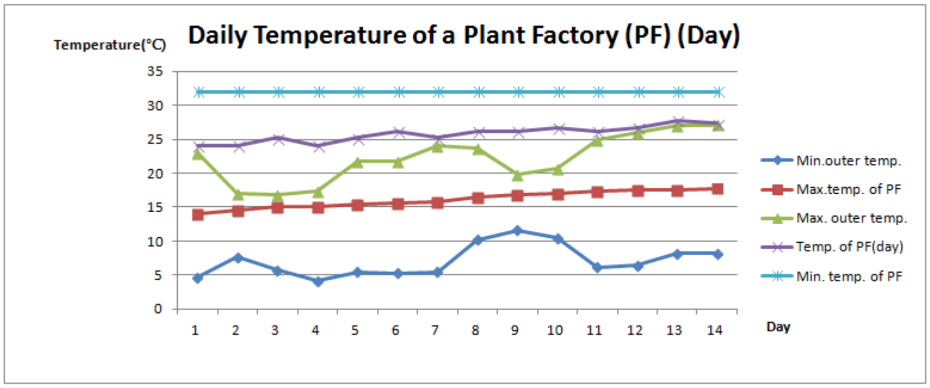

Figure 4. The simulation results of daily temperature of a plant factory

4.3. Discussion of simulation results

From the simulation results of the BPNN model is generalize the learning pattern of data. The values of RMSE, MAPE and r^2 are sufficient to apply to the automatic control system of a plant factory. The proposed model offers a measure of both the training and testing error, and allows the possibility of performing several iterations to improve the accuracy. Of course, the users can train different iterations to change the learning conditions such as stopping condition, the number of hidden layers, the number of nodes, the number of runs, learning parameters and momentum and so on.

This study presented the intelligent control systems for agricultural production in a plant factory. Environmental factors such as humidity, temperature, CO_2 concentration and light intensity of the plant factory are maintaining according to plant growth and these factors need to be monitored and maintained for an automated control system [3]. The proposed control system in this paper was applicable to the automatic control system consisting of wire or wireless network, and remote monitoring via Internet. Sensors of environmental factors are installed for monitoring environmental conditions and network has been deployed for data acquisition from these sensors and communicated the equipments' controllers and actuators. The proposed control system provides an efficient control system that facilitates plant growth by varying light, temperature, CO_2 and humanity intensities according to these factors' conditions and growing requirements.

5. Conclusions

The plant factory is a closed growing system which enables a farmer to achieve constant production of vegetables all year around. The facility utilizes artificial control of light, temperature, moisture, and CO_2 concentrations and so on. The agricultural crop production in a plant factory is attracting increasing attention and agricultural crop environment is also controlled automatically. The essential characteristic of the plant factory system is not only its productivity, but also its ability to produce a stable amount of clean and safe agricultural production. Recently, the remarkable technologies have developed for a plant factory such as computer integrated systems for automatic control in a plant factory. In a plant factory, it is very important technique to control the agricultural crop environment because it is to gain higher yields and better quality of plants. But it is difficult to control the agricultural crop environment automatically because of its complexity and uncertainty of complicated environment factors.

This paper presented a framework to design an automatic control system of a plant factory based on artificial neural network with back-propagation. The proposed system can collect information of crop cultivation environment and monitor it in real-time by using various environment sensors. Installed wire or wireless sensor nodes, based on the sensor network, collect the growing condition's information such as temperature, humidity, CO_2, and the control system is to monitor the control devices by using ANN. The proposed automatic control system provides that users can control all equipments installed on the plant factory directly or remotely and the equipments can be controlled automatically. Simulation results demonstrate that the proposed system can achieve both accuracy and reliability.

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