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# Precise control and prediction of the greenhouse growth environment of *Dendrobium candidum*

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ABSTRACT

*Objective:* *Dendrobium officinale* is a perennial epiphytic herb of the Orchidaceae family. It has very strict needs with respect to growth environment and climatic conditions. In order to precisely control the artificial growth environment of *Dendrobium candidum*, a monitoring system was designed and implemented using a Programmable Logic Controller (PLC) and Supervisory Control and Data Acquisition (SCADA) system.
*Methods:* A platform was created for precise control using a Siemens S7-200CPU224 PLC and different sensors of various environmental parameters as the control unit and SCADA-configured software as the core of the monitoring unit. We here used 4 indexes, soil temperature, soil moisture, humidity, and light, as prediction parameters and established a three-layer feed-forward fuzzy optimization neural network model.
*Results:* The system not only allows prediction of the optimal environmental parameters for the growth of *Dendrobium candidum*, real-time monitoring, and intelligent control but also escapes the shortcomings of traditional back-propagation (BP) neural networks, which suffer from slow convergence, shock, and poor generalization. The current model's average prediction error is less than 2.5%. It also provides a theoretical basis and decision support for the precision control of planting projects and relevant environment forecasting. The climate in the test area is hot and rainy in summer and colder and drier in winter. The annual precipitation is concentrated in spring and summer, peaking twice, in May and October. The subtropical high temperature was recorded in August, which has little rainfall and is prone to drought. Winter features both cold and warm air and some rainy days, but not as much overall precipitation as summer.

## 1. Introduction

*D. candidum* is widely favored by customers and researchers due to its unique medical health care functions (Li et al., 2011; Guo, 2014) such as a significant improvement in immune function, an anti-aging effect, the stimulation of saliva secretion, an anti-fatigue effect and tolerance to hypoxia. Establishing a precise control system for the artificial greenhouse environment of *D. candidum* and predictive research are of great significance for the effective control of the growth of artificially cultivated *D. candidum*, as well as for the improvement of herb quantity and quality.

In recent years, many studies have been conducted on the intelligent control technology of artificial greenhouse cultivation environments in China (Shi et al., 2013; Gao and Xiong, 2014). The growth environment of *D. candidum* has been roughly controlled using WiFi, Zigbee, monochip computers or hardware modules of PLC, coupled with sensors and controllers (Sun, 2006; Tan and Jiang, 2007; Wang et al., 2013; Dong, 2015; Huang et al., 2015; Jia et al., 2015). However, *D. candidum* is an epiphytic perennial herb of orchidaceae and is very demanding with respect to the growth environment and climatic conditions. In its natural environment, *D. candidum* usually grows at an altitude of 800–1600 m, a relative humidity of 60–75%, a forest light transmittance of about 60%, a growing season temperature of 20–25 °C, a night temperature of 10–13 °C, a temperature difference between day and night within 10–15 °C and an annual rainfall of 1100–1500 mm. In addition, frost can easily damage seedlings of *D. candidum* when the temperature is below 10 °C, and these plants will begin to wither when the temperature is lower than 5 °C. And parameters such as temperature, humidity and light are largely inert (Sun et al., 2005; Guo et al., 2007; Wang, 2016), resulting in problems such as weak regulation of the controller, a long duration of regulation, and serious delays.

An intelligent system was developed for monitoring the parameters of the *D. candidum* growth environment using the Siemens S7-200CPU224 Programmable Logic Controller (PLC) and Supervisory

*Abbreviations:* BP neural networks, back-propagation neural networks; PLC, Programmable Logic Controller; SCADA, Supervisory Control and Data Acquisition

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Control and Data Acquisition (SCADA, a data acquisition and monitoring control system) software KINGVIEW. The system consists of various sensors, the PLC controller, a host computer and other hardware equipment. The sensors were used to collect environmental parameters. The data transmission was completed using an RS-485 bus, and the switch control of the environment was achieved through the PLC controller. Based on the above equipment, real-time dynamic monitoring and regulation of the environmental parameters were realized. The control system has a distributed control structure with fully independent subsystems that do not interfere with each other. This ensures the reliability and safety of system operation and allows room for future expansion of the extended interface and lays a strong foundation for later enlargement of the iron *Dendrobium* planting project.

A back-propagation (BP) neural network is a feed-forward neural network with a strong non-linear capacity and high prediction accuracy. A common three-layered BP neural network includes an input layer, hidden layer and output layer. Each layer consists of a number of neurons that can perform various operations, and the neurons are connected to those in the next layer. A BP neural network can be trained by simulating an animal's neural excitation and information transmission suppression, which can contribute to the effective prediction of the neural network. In order to overcome the shortcomings of the traditional BP neural network, such as low convergence speed and tendency to local minima, fuzzy control theory was applied, and an adaptive step size algorithm was used to train the feed-forward artificial neural network so as to reduce the training time of the BP neural network and improve the convergence efficiency and network stability.

In this paper, a *D. candidum* cultivation base in Jingshan, Hangzhou, was used as the study site, and a large-scale *D. candidum* greenhouse control and prediction system was established based on PLC and SCADA for real-time monitoring and intelligent control of the soil temperature, air humidity, soil moisture, carbon dioxide concentration and light intensity of the artificial environment of *D. candidum*. In addition, a multilayer feed-forward BP neural network model was established to predict and evaluate the light, air humidity, soil temperature and soil moisture of the cultivation environment. During training, using numerous training data as the "teacher", cultivation data collected from consecutive time points were imported into the neural network. The general rule of changes in the cultivation prediction parameters with time was found using the neural network, thereby realizing simultaneous output of the prediction parameters. The results show that the adaptive step size BP neural network improved using the fuzzy method (FABPM-BP) has fast convergence speed, high prediction accuracy and good stability, which can provide a reliable basis for the control and prediction of the growth environment of *D. candidum*.

## 2. Material and methods

### 2.1. System design

The main environmental factors affecting the growth of *D. candidum* were selected as the basic monitoring and control items, namely, temperature, humidity, carbon dioxide concentration and light intensity. The overall design of the control system is shown in Fig. 1. The system is mainly composed of the data acquisition unit, actuators, PLC unit and configuration unit. With PLC as the core controller, and PC and KINGVIEW software as the monitoring module, the system actuators were controlled by the communication between the two through serial ports. In the design, parameters such as the temperature, humidity, carbon dioxide and lighting were collected regularly by sensors, converted into digitals through an A/D converter, and then input into the PLC controller. The hardware control cabinet is shown in Fig. 2.

In the system, parameters were mainly collected by different kinds of sensors, and actuators were controlled by the internal program of the PLC to turn the related equipment on or off so as to adjust the corresponding parameters. As a result, the parameters were controlled within the range of preset values to ensure optimal environmental conditions for the growth of *D. candidum*.

A Siemens S7-200 series CPU224 was adopted as the control system. It is a small-scale programmable controller produced by Siemens that integrates 14 inputs/10 outputs of digital quantity and 2 inputs/1 output of analog quantity. It is featured by high reliability, strong anti-interference capability, excellent function, small size, low energy consumption, and expansion (Sun, 2006). A GM2 wall-mounted sensor was used as the humidity sensor and has a low cost, high precision, fast response speed, low environmental requirements and is easy to install. A GM-LUX model light collector was used as the light sensor, and an LM393 gas sensor was used as the carbon dioxide sensor.

### 2.2. Strategies of parameter control

The control system controlled the temperature, humidity, carbon dioxide concentration and light in the growth environment of *D. candidum*. Considering the safety and reliability of the system in an actual application, two operational modes (automatic and manual) were adopted in the greenhouse. In automatic mode, PLC control was implemented periodically according to the program settings. In manual mode, users could manually override the actuators in case of emergency.

Among the parameters, temperature and humidity interacted with each other. In the system, the air conditioning unit, heating system, fan system and sprinkler system were jointly adjusted to maintain the temperature and humidity within a specific range. In automatic mode, when the detected real-time temperature was higher than the set temperature, the air conditioning unit was switched on via PLC command, and the fan was in the forward rotation to withdraw indoor high-temperature air and therefore improve the cooling efficiency. When the detected temperature was lower than the set value, the heating system turned on, and the fan was in a reversed rotation. If the detected value was within the range of the set value, the system was in standby mode. Humidity control was divided into humidification and dehumidification. The function of humidification mainly depended on the sprinkler system. The water in sprinkler system was either from cooled vapor inside the heating pipe or from the water pipe. When the water of the cooling box was not available for the sprinkler system, tap water was used. When the concentration of carbon dioxide inside the greenhouse failed to meet the requirement, the carbon dioxide compensator turned on. When the greenhouse light intensity was lower than the set value, the sunshade and LED light source were switched on; when the light intensity was higher than the set value, the sunshade was closed.

### 2.3. Determination of the optimal parameters

In order to improve the quality and quantity of *D. candidum*, precise control can be used to simulate a suitable growth environment. However, many factors determine the growth of plants, and it is difficult to determine the best growth environment. Experimental methods are generally used for a rough determination of a good growth environment.

It is believed in this study that high-quality *D. candidum* is cultivated in an appropriate growth environment. Under this precondition, the *D. candidum* cultivation experiment was carried out, and the data of the changing environment were accurately recorded during the experiment. In addition, the yield and quality of all *D. candidum* were evaluated. Based on the data of the portion of *D. candidum* with high yield and quantity, the optimal growth environment for *D. candidum* was determined using least squares fitting.

Based on a 24-hour cycle, the diurnal curve of the best environmental parameters of *D. candidum* in the seedling acclimatization period of the spring season are shown in Fig. 3, and the specific environmental parameters are shown in Table 1.