Optimal regulation model of Greenhouse light under limited light resources

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Abstract: In view of the high cost of greenhouse light environment control, a model of greenhouse light optimization controls under limited light resources was proposed to reduce the control cost under the condition of meeting the demand of crop growth. Firstly, with temperature, CO2 and light intensity as input and photosynthetic rate as output, a prediction model of photosynthetic rate based on least squares support vector machine (LS-SVM) was constructed, and the model was verified in practice. Then, based on the proposed prediction model of photosynthetic rate, a database of greenhouse light intensity optimization control model under limited light resources was constructed. According to the total amount of light resources input by users, the optimal light supplement times and unit light supplement amount can be obtained automatically, which can greatly improve the photosynthetic benefits of certain conditions of light resources. The optimal control of greenhouse light under the condition under limited light resources was realized, and the accuracy and intelligent level of greenhouse environmental control were further improved.

1. Introduction

Light is the dominant factor of plant photosynthesis. In the aspect of greenhouse planting, a plant light optimization regulatory model is established to increase the photosynthetic rate of crop considering temperature and CO2 concentration, which is an important part of the intelligent control system of greenhouse. The light optimal regulation model is based on the prediction model of photosynthetic rate, and the traditional prediction model has a variety of problems such as low fitting precision. In recent years, the researchers have studied the photosynthetic rate prediction model, based on the main influencing factors of photosynthesis [1-2]. Different photosynthetic rate models were constructed, which greatly improved the adaptability and accuracy of the prediction model. In the aspect of light regulation, the regulation model with saturation point as the regulation index has been widely used, which can reach the maximum photosynthetic rate, but it will cause the reduction of regulation benefit [3-4]. The light intensity optimization regulatory model based on the discrete curvature algorithm is proposed by Hu J Et al [5-7], which can improve the photosynthetic rate of the crop under the premise of effectively reducing the regulation cost. However, in the actual production practice, the amount of light is not allowed to continuously optimize the above-mentioned theory. So it is advisable for us to explore the light regulation scheme under the limited light resources.

In this study, a prediction model of photosynthetic rate based on least square supports vector machine
(LS-SVM) was constructed, and experiments were designed to verify the model. Eventually, the database of optimal regulation and control model of greenhouse light under limited light resources was constructed based on the prediction model. When the user needs to control the illumination, the corresponding optimal light filling time and unit light filling amount can be automatically obtained by simply entering the total light filling amount, so that Greenhouse light optimization regulation function under limited light resources is realized.

2. Materials and Methods

2.1. Measurement of net photosynthetic rate

The experiment was carried out in the Western Campus training base of Tianjin Agricultural University in December 2019. The experimental materials, cucumber varieties of Jin You No.35, were managed by conventional cultivation and management methods. The environmental factors include temperature, light intensity, and CO$_2$, wherein the temperature is set to 6 gradients (12 °C, 15 °C, 20 °C, 25 °C, 30 °C, 33 °C), the light intensity is set to 8 gradients (200 μmol·m$^{-2}$·s$^{-1}$, 400 μmol·m$^{-2}$·s$^{-1}$, 600 μmol·m$^{-2}$·s$^{-1}$, 800 μmol·m$^{-2}$·s$^{-1}$, 1000 μmol·m$^{-2}$·s$^{-1}$, 1200 μmol·m$^{-2}$·s$^{-1}$, 1400 μmol·m$^{-2}$·s$^{-1}$, 1800 μmol·m$^{-2}$·s$^{-1}$), and CO$_2$ is set to 7 gradients (300 μmol·mol$^{-1}$, 500 μmol·mol$^{-1}$, 600 μmol·mol$^{-1}$, 800 μmol·mol$^{-1}$, 1000 μmol·mol$^{-1}$, 1200 μmol·mol$^{-1}$, 1400 μmol·mol$^{-1}$). This experiment is designed in a nested way of each environmental factor, but test is removed the corresponding maximum light intensity (1700 μmol·m$^{-2}$·s$^{-1}$) under low temperature (12 °C) and the corresponding minimum light intensity (200 μmol·m$^{-2}$·s$^{-1}$) under high temperature (33 °C) conditions.

The robust cucumber plants with little difference in growth condition were selected for the experiment. The measuring equipment is CI-340 portable photosynthetic, which can control the small environment of the Leaf chamber in order to set up different test conditions. In order to avoid the impact on plant "napped the phenomenon" on data collection, tests were carried out between 9:00~11:30 and 14:00~16:30 [8].

This experiment was an instantaneous experiment on single leaf. In order to obtain a sufficiently stable net photosynthetic rate, the same weather was selected for more than 2 consecutive days for measurement, and the leaves clamping to the leaf chamber were fully induced before measurement. Finally, 320 sets of experimental sample sets were formed into temperature, CO$_2$ and light intensity as input and net photosynthetic rate as output.

2.2. Construction of Photosynthetic Rate Prediction Model Based on LS-SVM

The main factors affecting the photosynthetic rate of cucumber are temperature, light intensity and CO$_2$. The establishment of photosynthetic rate model is to seek the relationship between temperature ($x_1$), light intensity ($x_2$) and CO$_2$ ($x_3$) and photosynthetic rate ($y$). In this study, LS-SVM algorithm, which is referred to reference [9-10], was used to build the photosynthetic rate prediction model.

2.3. Construction of Optimal Decision Model of Greenhouse light under Limited light intensity Resources

Based on the above, this study put forward greenhouse light intensity idea of optimizing control under limited light resources, which is to find the optimal supply light time for the day of the greenhouse with the corresponding the number of supply light. With the photosynthetic rate increment after light supplement as the evaluation index, the limited light resources were instantiated to establish the optimal regulation model database of light intensity.

Divide 1 d with $\Delta t$ as the step length and set it as 1.0 h, 1.5 h, 2.0 h, 3.0 h and 4.0 h, so as to divide 1 d into 24, 16, 12, 8 and 6 time periods. The limited light intensity resources were set as $PPFD \cdot T$ (light intensity * time), the interval of $PPFD$ was set as 100-2400 μmol·m$^{-2}$·s$^{-1}$, the fixed step size was 50 μmol·m$^{-2}$·s$^{-1}$, and T was set as 1h. The limited light intensity resources were evenly divided
into each $\Delta t$ to obtain the amount of supplementary light $\Delta PPFD = PPFD / \Delta t$ in this time period. The environmental factor parameters ($T, CO_2, PPFD$) in the above time period and those after light supply ($T, CO_2, PPFD + \Delta PPFD$) were obtained respectively, and they were taken as input parameters of the photosynthetic rate prediction model to obtain the photosynthetic rate without light supplement ($P_{n1}$) and the photosynthetic rate after light supplement ($P_{n2}$). Calculating the photosynthetic rate of increment in the corresponding time period, the maximum increment obtained by optimization and the corresponding regulation period are summarized into the regulation model database.

Then, five sets of data corresponding to different time intervals under the given condition under limited light resources were found to obtain the maximum photosynthetic rate increment and corresponding time period as the regulation scheme under the condition under limited light resources. In order to clearly describe the research content of this part, the optimal decision-making process of supplemental light under the condition under limited light intensity resources is drawn, as shown in Figure 1.

When the facility is supplying light, the total amount of light compensation is remotely controlled by the operator through the control panel on the control panel. This data represents continuous supplying light for $Y$ h with the light intensity of $X$, so that based on the above model database, the time period and unit amount of supplying light can be automatically obtained to achieve the optimal light supplying strategy combining temperature and CO$_2$ parameters.

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**Fig 1. Optimization process of light supplement decision under limited light resources**
3. Results & Discussion

3.1. Evaluation and validation of LS-SVM model

Programming with Matlab2018B is based on the data obtained in this experiment, and the early 320 groups of data were randomly sorted. The first 257 groups of data were taken as the input of the prediction model, accounting for 80% of the total data, and the remaining 63 groups of data were tested for the prediction model.

$\gamma$ is a tunable parameter for controlling the degree of sample penalty. $\sigma_2$ is the parameters of the radial base nuclear function. The optimal modeling parameter $\gamma$ and $\sigma_2$ [11] are obtained through the grid search. To calculate $\gamma = 283.589, \sigma_2 = 0.2161457$. The model each parameter is determined to call the trainlssvm function of the LS-SVM toolbox for the construction of the photosynthetic rate prediction model.

3.1.1. Model assessment. In the LS-SVM toolbox of MATLAB, the simlssvm function is called to perform model verification and the predicted results were inverse normalized with the actual samples. The results show that $\text{MAE}=0.6514 \, \text{mol m}^{-2} \cdot \text{s}^{-1}$, $R^2=0.9685 \, \text{mol m}^{-2} \cdot \text{s}^{-1}$, $\text{MSE}=0.8902 \, \text{mol m}^{-2} \cdot \text{s}^{-1}$; The error between the predicted results and the actual data is shown in Figure 2, it can be seen that the error of the photosynthetic rate prediction model based on LS-SVM is small, even if the maximum error is maintained within $3.5000 \, \text{mol m}^{-2} \cdot \text{s}^{-1}$. Accordingly, It can better predict the trend of crop photosynthetic rate.

![Fig.2 Prediction error of LS-SVM](image)

3.1.2. Model verification. In order to verify the actual prediction effect of the model, predictive model verification tests were carried out in the Greenhouse of Tianjin Agricultural University West Campus Training Base. The test was conducted from 09:00 to 16:00 in March 8, 2020. Environmental parameters are collected through the solar greenhouse remote intelligent monitoring system. The system saves the environmental sensor data every 3 minute and records it as a sample. The changes of environmental parameters in the greenhouse on that day are shown in Fig. 3.
The environmental parameters which read by Matlab were used as input data of the photosynthetic rate prediction model to predict the photosynthetic rate. CI-340 portable photosynthesize was used to measure the photosynthetic rate of cucumber in the same greenhouse. The comparison and error between the actual photosynthetic rate and the predicted photosynthetic rate were shown in Figure 4.

Through comparative calculation, MAE=0.967 7 μmol·m⁻²·s⁻¹, MSE= 0.932 7 μmol·m⁻²·s⁻¹, and the maximum error is less than 1.8 μmol·m⁻²·s⁻¹. The data showed that the photosynthetic rate prediction model constructed in this study has a high accuracy and can provide guidance of the prediction of crop photosynthetic rate for greenhouse.

3.2. Data analysis of the decision-making model of greenhouse supplemental light optimization under the condition under limited light intensity resources

In order to build the regulation database of the above model by Matlab according to the above ideas, the environmental parameters from March 1, 2020 to March 31, 2020 in the greenhouse of the training base on the west campus of Tianjin Agricultural University were obtained through the remote intelligent monitoring system of the solar greenhouse. In this study, the data was taken as an example to analysis forms March 9, 2020. According to the above ideas, 235 sets of data were constructed in the regulation database of this time. Since they could not be enumerated one by one, a total of 15 sets of data in segments were given under the three sets of available supplementary light resources with a total amount of 1000×1, 1800×1 and 2400×1 (μmol·m⁻²·s⁻¹·h⁻¹).

It can be seen from Table 1 that the higher photosynthetic efficiency can be obtained at 00:00 ~ 04:00 in the early hours.
Table 1 Light supplement regulation scheme under limited resources

| Optimal supplying time | Duration of light compensation (h) | Increment of photosynthetic rate ($\mu$mol·m$^{-2}$·s$^{-1}$) | Light supplement per minute ($\mu$mol·m$^{-2}$·s$^{-1}$·min$^{-1}$) | Total light supplement ($\mu$mol·m$^{-2}$·s$^{-1}$) |
|------------------------|-----------------------------------|-------------------------------------------------|-----------------------------------------------------|----------------------------------|
| 00:00-01:00            | 0                                 | 1                                               | 1 203.571                                           | 1 000.00                         |
| 00:00-01:30            | 1.5                               | 1                                               | 1 491.513                                           | 666.67                           |
| 02:00-04:00            | 2                                 | 1                                               | 1 675.162                                           | 500.00                           |
| 00:00-03:00            | 3                                 | 1                                               | 1 877.077                                           | 333.33                           |
| 00:00-04:00            | 4                                 | 1                                               | 1 974.07                                            | 250.00                           |
| 00:00-01:00            | 0                                 | 1                                               | 1 261.062                                           | 1 800.00                         |
| 00:00-01:30            | 1.5                               | 1                                               | 1 916.65                                             | 1 200.00                         |
| 00:00-02:00            | 2                                 | 2                                               | 2 296.136                                           | 900.00                           |
| 00:00-03:00            | 3                                 | 2                                               | 2 808.810                                           | 600.00                           |
| 00:00-04:00            | 4                                 | 3                                               | 3 122.749                                           | 450.00                           |
| 00:00-01:00            | 0                                 | 1                                               | 811.463                                              | 2 400.00                         |
| 00:00-01:30            | 1.5                               | 1                                               | 1 970.056                                           | 1 600.00                         |
| 02:00-04:00            | 2                                 | 2                                               | 2 553.479                                           | 1 200.00                         |
| 00:00-03:00            | 3                                 | 3                                               | 3 267.558                                           | 800.00                           |
| 00:00-04:00            | 4                                 | 3                                               | 3 743.432                                           | 600.00                           |

During this period of time, due to greenhouse is covered by insulated cotton, the intensity of light in the greenhouse is 0 $\mu$mol·m$^{-2}$·s$^{-1}$. Thus, the data shows the reasons for supplying light in this time may be related to the temperature and CO$_2$. Temporal temperature and CO$_2$ change data visualization as shown in Fig. 5.

Combined with the drawing, it can be analyzed that in the early morning of 00:00 ~ 04:00, the concentration of CO$_2$ in a higher range ($\geq$ $1 100$ $\mu$mol·mol$^{-1}$), and temperature (17 °C ~ 20 °C) is within the growth section of the cucumber [12]. Thus, supplying light can get higher photosynthetic benefits during the above period.

4. Conclusions
In this study, an optimal control model of greenhouse light intensity under limited light resources was proposed. The database of greenhouse illumination optimal control model under limited light resources is based on the proposed photosynthetic rate prediction model using LS-SVM algorithm, which can automatically optimize the light compensation time and unit light compensation according to the total amount of light resources input by the user. Under certain light resources conditions, the photosynthetic
rate can be improved to the maximum extent by this study. However, CO2 concentration will be reduced during photosynthesis in practical application, which is not taken into account in the light intensity optimization control model constructed in this study. In order to solve this problem, gas fertilizer generator is used to dynamically adjust CO2 concentration on actual production. Meanwhile, the photosynthetic rate of crops is also affected by the environmental parameters such as temperature and humidity in Greenhouse. In the future, our research group based on the existing research will combine other environmental parameters to study multi-dimensional environmental factor coupling regulation model, the accuracy and intelligent level of intelligent agricultural facilities regulation will be further improved.

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