Greenhouse Microclimate Control Strategy to Reduce Costs Based on Improved NSGA-II Optimal Method

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***Abstract*—Environmental parameters such as temperature, light, water, gas, and fertilizer in a controlled environment are important components of the greenhouse microclimate.**

In general, temperature and humidity are highly dependent on individual factors, and indeed it is difficult to control multiple targets simultaneously. This paper proposes an improved non dominant classification genetic algorithm II (NSGA-II) to solve this problem. The method of adaptive mutation can be set in the holding solution diversity, while still maintaining a high speed to obtain a Pareto optimal solution. Original crossover method has the global search capability is not big enough limitations, it is replaced with arithmetic crossover method, but also can make the diversity of knowledge is maintained. For improved multi-objective optimization algorithm simulation test, simulation and data analysis found: Pareto optimal distribution of cutting-edge solution set more reasonable, and its efficiency with better performance indicators have improved

***Index Terms*—Greenhouse microclimate control, Improved NSGA-II, Pareto optimization, Cost minimization.**

I. INTRODUCTION

Greenhouses can create the best growth conditions for crops by changing the growth environment. Improving the temperature and humidity of crops and controlling pests and diseases are important measures to improve agricultural productivity and quality [1,2]. Through the analysis of the greenhouse model, the greenhouse system is a multi-input and multi-output system, which is characterized by nonlinearity and strong coupling [3-5]. Combining the characteristics of the system and the effective control of the greenhouse environment, the purpose of optimizing the growth environment of crops requires consideration of external climatic conditions, indoor control actuators and the impact of the crop itself [6,7]. So in order to adjust the internal environment of greenhouse, we use the control method based on the greenhouse environment model [8-10]. The greenhouse environment system is a MIMO system. which is characterized by nonlinearity and strong coupling [3-5]. Combining the characteristics of the system and the effective control of the greenhouse environment, the purpose of optimizing the growth environment of crops requires consideration of external climatic conditions, indoor control actuators and the impact of the crop itself [6,7]. When you need to build an accurate model of the greenhouse climate, which is an important parameter in the control system [15], you need to consider the interaction of multiple elements [16,17]. Through a large number of studies on models and control optimization methods, researchers found that, according to user needs and data clustering [18,19], if NSGA-II algorithm is adopted in greenhouse climate control system, the efficiency and performance of the system can be improved in all aspects. In [20], for the control of temperature and humidity, they obtained the proportional integral differential (PID) control parameters of the control system with the help of NSGA-II algorithm. As a kind of genetic algorithm and non-dominant sorting, the advantage of NSGA-II algorithm is that it can find the optimal solution space, so it is a famous control system optimization algorithm. In[21], they used NSGA-II method to gain Pareto optimal solution set of power supply controller. However, researchers pay more attention to the performance of the controller than the production cost and economic profit.

In this paper, We conduct research from two aspects, the first is the optimization for multiple goals, and the second is the economic cost reduction that is rarely mentioned in other similar academic papers. Since temperature and humidity are two important factors in the greenhouse environment, this article will study how to establish a greenhouse environment model about temperature, humidity and energy consumption, improve traditional multi-objective optimization algorithms, and analyze the effects of external weather and internal environmental variables on greenhouse humidity. Influence, and explore the law of material and energy changes in the greenhouse.Through the method, the overall performance can be improved to the maximum and the production cost can be reduced to the maximum.

The paper is organized as follows. The second plate, Describing models for temperature, humidity, and energy consumption that take into account the greenhouse environment. The third part present he objective and constraint functions. The fourth part shows the result of simulation and the conclusion of comparison. The last of part, Summarizing the full text, we draw conclusions and look forward to the future.

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II. System Description Problem Formulation

A. Abbreviations and Acronyms Greenhouse Temperature Models

Temperature variation is physical state changes that involves the exchange of energy and the exchange of materials [22]. The energy balance equation is as follows: [23]:

$$Q_{\mathrm{a}} = Q_{\mathrm{heat}} + Q_{\mathrm{rad}} - Q_{\mathrm{con}} - Q_{\mathrm{ven}} - Q_{\mathrm{tran}} \qquad (1)$$

In the formula, Q_{a} is the change in the total energy of the air, which is caused by the change in ambient temperature Q_{heat} is Heat per unit area supplied to heating devices; Q_{rad} is absorbed total energy of solar radiation per unit of greenhouse area; Q_{con} is Exchange heat from greenhouse roofing material; Q_{ven} is Heat exchange energy loss through ventilation; Q_{tran} is the latent heat of vaporization of water and gas in the greenhouse and the evaporation of the product. Greenhouse energy calculations and variable descriptions are as follows:

(1) Total variation of air energy:

$$Q_{\mathrm{a}} = \rho \cdot \mathrm{C}_{\mathrm{p}} \cdot \mathrm{V} \cdot \frac{d\mathrm{T}_{\mathrm{in}}(t)}{dt} \qquad (2)$$

Where ρ is the density of air, C_{p} is the specific heat of air, V is the overall volume of the greenhouse, and $T_{\mathrm{in}}(t)$ is the temperature of the air in the greenhouse.

(2) The formula for solar radiant energy is as follows

$$Q_{rad} = A_{\mathrm{s}} \cdot S_i \cdot \alpha' \qquad (3)$$

Where A_{s} is the area of the material that covers the greenhouse surface, S_i is the intensity of the sun and α' is the total permeability of the roofing material.

(3) Energy provided by heating equipment:

$$Q_{heat} = \eta \cdot N_{heater} \cdot \frac{Q_{heater}}{A_g} \qquad (4)$$

The above formula η is expressed as the heater efficiency. and N_{heater} is the number of heaters activated, A_g is the greenhouse surface temperature and Q_{heater} is the heater output.

(4) The formula for energy loss outside the greenhouse:

$$Q_{conv} = UA \cdot \frac{A_s}{A_g} \cdot (T_{in} - T_{out}) \qquad (5)$$

UA in the formula for energy loss at the periphery of the greenhouse is the heat transfer coefficient of the covered area of the greenhouse. A_g is the surface temperature of the greenhouse. T_{in} and T_{out} are the temperatures inside the greenhouse and outside.

(5) Ventilation loss energy formula:

$$Q_{ven} = V_R \cdot C_P \cdot \rho \cdot (T_{in} - T_{out}) \qquad (6)$$

In the above formula, V_R represents the ventilation rate, C_P is the specific heat of the air and ρ is the density of the air, both of which are constant.

(6) Potential heat consumed by evapotranspiration:

Transpiration is the process of water losing from the surface of living plants (mainly leaves) to the atmosphere in the state of water vapor. Latent heat consumption formula:

$$Q_{tran} = \lambda \cdot (Q_{fog} + E_T) \qquad (7)$$

The above formula λ is the latent heat of water evaporation; Q_{fog} is the evaporation rate of spray cooling; E_T is the welding speed, which is more unstable.

Through analysis, we get the dynamic balance equation, which is established according to Takakura's greenhouse energy equation [24, 25]:

$$\rho \cdot C_{\mathrm{p}} \cdot V \cdot \frac{\mathrm{dT}_{\mathrm{in}}(t)}{dt} = Q_{\mathrm{heat}} + Q_{\mathrm{rad}} - Q_{\mathrm{con}} - Q_{\mathrm{ven}} - Q_{\mathrm{tran}} \qquad (8)$$

By substituting the above equations (2-7) into equation (8) and arranging them, and performing a series of calculations and analyses on the arranged equations, we get the greenhouse temperature model:

$$\frac{\mathrm{dT}_{\mathrm{in}}(t)}{dt} = \frac{1}{\rho C_P V}[Q_{heater}(t) + S_i(t) - \lambda Q_{fog}(t)] - (\frac{V_R(t)}{V} + \frac{UA}{\rho C_P V})[T_{in}(t) - T_{out}(t)] \qquad (9)$$

B. Greenhouse Humidity Models

If there is no condensation in the greenhouse, evaporation on the surface of the greenhouse can be ignored. It can be concluded that the total evaporation of water vapor is cooling evaporation and crop transpiration respectively. The dynamic equation of humidity is as follows:

$$(\mathrm{W}_{in} - W_{out}) \cdot \mathrm{V}_{\mathrm{R}} \cdot \rho = E \qquad (10)$$

In the formula, V_R represents the ventilation; ρ is the air density, which is the same as the previous formula; E is the total water vapor evaporation rate per unit area of the greenhouse. The mass energy balance equation [24,25], a mathematical model of dynamic greenhouse humidity of first order differential equations:

$$\rho \mathrm{V} \frac{dw_{in}(t)}{dt} = E - [w_{in}(t) - w_{out}(t)] \cdot V_R(t) \cdot \rho \qquad (11)$$

The ρ and V in the above formula are the air density and the volume of the greenhouse respectively.

C. Greenhouse Energy Consumption Models

The premise of cost reduction is crop quality and yield, which is the optimal control strategy. In the energy consumption model, the control input is heating, spraying and ventilation, the control output is energy consumption, andA formula can be used to express greenhouse energy consumption as:

$$P = P_{Q_{heater}} + P_{Q_{fog}} + P_{V_R} \qquad (12)$$

Where $P_{Q_{heater}}$ is the heating power; $P_{Q_{fog}}$ is the spray power; and P_{V_R} is the ventilation power.

III. IMPROVED MULTI-OBJECTIVE OPTIMIZATION BASED ON NSGA-II

The multi-objective optimization problem can be described as the following model:

$$\min f(x) = (f_1(x), f_2(x), \dots f_m(x))$$

$$\text{s.t.} \quad \begin{cases} \mathrm{g}_i(x) \le 0, i = 1, 2 \dots\dots p \\ \mathrm{h}_j(x) = 0, j = 1, 2 \dots\dots p \\ x \in R^n \end{cases} \tag{13}$$

$x = (x_1, x_2 \dots x_n)$ in the above model is an N-dimensional decision variable; $(f_1(x), f_2(x), \dots f_m(x))$ ($\mathrm{m} \ge 2$) is the objective function; $g_i(x)$ is the i inequality constraint; $h_i(x)$ is the j inequality constraint; $x \in R^n$ is the decision space.

The operation process is to hybridize the genes of the parent population with SBX, which will transfer the excellent genes of the parent population to the next generation. Its operation is defined as follows:

$$\begin{aligned} X_A^{t+1} &= \alpha X_A^t + (1-\alpha) X_B^t \\ X_B^{t+1} &= (1-\alpha) X_A^t + \alpha X_B^t \end{aligned} \tag{14}$$

The α in the above formula is a parameter generated arbitrarily, in the SBX cross. Thus, it can be seen that Its large-scale search performance is relatively weak, so its Compared to others, the effect of global search is weaker. In the arithmetic crossover operator, α is defined as follows:

$$\alpha = \frac{X.rank}{X.rank + Y.rank} \tag{15}$$

The non-dominant grade value of individual X can be expressed as $X.rank$, and $Y.rank$ can be used to represent the non-dominant grade value of individual Y, and the coefficient α of the crossover operator is related to the non-dominant grade information of the individual in the parent. In the early stages of the algorithm, α will fluctuate greatly due to the definition and uncertainty of $Y.rank$ and $X.rank$ .The modified mutation operator is used to define the mutation probability of the algorithm, as shown below:

$$\begin{aligned} & e(X_i) = \frac{E(X_i)}{\sum_{j=1}^{M} E(X_j)} \overline{P}_m \cdot M \\ & P_m(X_i) = 2 \cdot P_m - e(X_i) \qquad i = 1, 2, \cdots, M \end{aligned} \tag{16}$$

From the above formula, we can get:

$$\begin{aligned} \frac{1}{M} \sum_{j=1}^{M} P_m(X_j) &= \overline{P_m} \\ \frac{1}{M} \sum_{j=1}^{M} e(X_j) &= \overline{P_m} \end{aligned} \tag{17}$$

According to the above formula, the conclusion after analysis is that individual adaptability is inversely proportional to the rate of change.

Improved variational method advantage is to ensure that the overall probability of change and diversity algorithm, and can speed up the optimization process in the rate.

In this paper, a cumulative ranking fitness allocation strategy is proposed, which considers not only the single Pareto ranking value, but also the density information. $y_1, y_2, \dots, y_n$ is the set of individuals in the population of Generation T who dominate individual Y, and the cumulative ranking value of individual Y is defined as the sum of the Pareto values that dominate individual Y:

$$rank(y,t) = 1 + \sum_{i=1}^{n} r(y_i, t) \tag{18}$$

Multi-objective benchmark functions zdt1 and zdt2 simulation, the number of iterations and the number of iterations is 200 times. When the population size and evolutionary generation are small, the search results are generally poor. However, when the population number and generation number are greater than 500, better results will be obtained, but the efficiency will be reduced due to excessive running time consumption

IV. IMPROVED NSGA-II AND ITS APPLICATION IN GREENHOUSE MICROENVIRONMENT CONTROL

In this work, the objective function f (1) is a function of temperature and is affected by heat, and f (2) is a humidity function whose main influence is spray and f (3) is a function of energy consumption. In the greenhouse, the decision variable is ventilation. In order to achieve cost reduction, the overall objective F(X) needs to be as small as possible. When its value is as small as possible and the temperature and humidity are within the proper growth and development range, the power will be reduced and the cost will also be reduced. Create a dynamic model of the temperature and humidity of the greenhouse environment:

$$\begin{aligned} \frac{\mathrm{dT_{in}}(t)}{dt} = {} & \frac{1}{\rho C_P V}[Q_{heater}(t) + S_i(t) - \lambda Q_{fog}(t)] - \\ & (\frac{V_R(t)}{V} + \frac{UA}{\rho C_P V})[T_{in}(t) - T_{out}(t)] \end{aligned} \tag{19}$$

$$\begin{aligned} \frac{dw_{in}(t)}{dt} = {} & \frac{Q_{fog}(t)}{V} + \frac{1}{V}[E(S_i(t), w_{in}(t)] - \\ & [w_{in}(t) - w_{out}(t)] \cdot \frac{V_R(t)}{V} \end{aligned} \tag{20}$$

Control input heating, spray and ventilation are standardized:

$V_{R\%} = V_R / V_R^{\max}$, $Q_{fog\%} = Q_{fog} / Q_{fog}^{\max}$, $Q_{heater\%} = Q_{heater} / Q_{heater}^{\max}$, and $C_0 = \rho C_P V_T$, $\alpha' = \alpha(\lambda V)^{-1}$, $\lambda' = \lambda Q_{fog}^{\max}$, $V' = V_H / Q_{fog}^{\max}$.

Therefore, the equation can be simplified as follows:

$$\frac{dw_{in}(t)}{dt}=\frac{Q_{fog\%}(t)}{V'}+\alpha' S_i(t)-[w_{in}(t)-w_{out}(t)]\cdot\frac{V_{R\%}(t)}{t_v} \tag{21}$$

$$\frac{\mathrm{dT_{in}}(t)}{dt}=\frac{1}{C_0}[Q_{heater\%}(t)\cdot Q_{heater}^{\max}+S_i(t)-\lambda' Q_{fog\%}(t)]-(\frac{V_{R\%}(t)}{t_v}+\frac{UA}{C_0})[T_{in}(t)-T_{out}(t)] \tag{22}$$

The important parameter that needs to be collected during sampling is that time is required for air exchange.From the previous equation, the output is the differential of temperature and humidity. For convenient calculation, it can be converted into integral form:

$$T_{in}(t)=e^{-\int(\frac{V_{\mathrm{R}\%}}{t_v}+\frac{UA}{C_0})dt}(\int e^{\int(\frac{V_{\mathrm{R}\%}}{t_v}+\frac{UA}{C_0})dt}[\frac{V_{R\%}(t)\mathrm{T}_{out}(t)}{t_v}+\frac{Q_{heater}^{\max}Q_{heater\%}(t)+S_i(t)}{C_0}-\frac{-\lambda' Q_{fog\%}(t)}{C_0}+\frac{UAT_{out}(\mathrm{t})}{C_0}]dt+C_{T_0}) \tag{23}$$

$$w_{in}(t)=e^{-\int\frac{V_{R\%}}{t_v}dt}(\int e^{\int\frac{V_{R\%}}{t_v}dt}[\frac{V_{R\%}(t)w_{out}(t)}{t_v}+\alpha' S_i(t)-\frac{Q_{fog\%}(t)}{V'}]dt+C_{w_0}) \tag{24}$$

C_{T_0} and C_{w_0} in the formula represent the initial state of temperature and humidity respectively

In summer, the temperature in the shed is usually higher than the outdoor temperature because of the high outdoor temperature and high light intensity. Thus, cooling measures are usually adopted in summer. Heating control input is not required in the model. The temperature equation of greenhouse is changed to:

$$\frac{\mathrm{dT_{in}}(t)}{dt}=\frac{1}{C_0}[S_i(t)-\lambda' Q_{fog\%}(t)]-(\frac{V_{R\%}(t)}{t_v}+\frac{UA}{C_0})[T_{in}(t)-T_{out}(t)] \tag{25}$$

$$T_{in}(t)=e^{-\int(\frac{V_{\mathrm{R}\%}}{t_v}+\frac{UA}{C_0})dt}(\int e^{\int(\frac{V_{\mathrm{R}\%}}{t_v}+\frac{UA}{C_0})dt}[\frac{V_{R\%}(t)\mathrm{T}_{out}(t)}{t_v}+\frac{S_i(t)-\lambda' Q_{fog\%}(t)+UAT_{out}(\mathrm{t})}{C_0}]dt+C_{T_0}) \tag{26}$$

In the execution mechanism of greenhouse environment, the control inputs are temperature, water mist and fan, and the output results are temperature, humidity and water consumption. The objective function of energy consumption can be expressed as:

$$f(1)=\mathrm{a}\,Q_{heater\%}+bQ_{fog\%}+cV_{R\%} \tag{27}$$

In a certain range of temperature and humidity, the crops in the greenhouse environment can grow well. Therefore, a function of temperature and humidity is expressed as target:

$$f(2)=abs(T_{in}-T_{set}) \tag{28}$$

$$f(3)=abs(W_{in}-W_{set}) \tag{29}$$

In this formula, W_{set} represents humidity, and T_{set} is the median value of the greenhouse control range. Simulate the greenhouse environment in summer and winter, set the evolution algebra T of the optimization algorithm to 250 and set the initial population size N to 200. Through the comparison of the simulation results, the NSGA-II algorithm and the improved NSGA-II algorithm can be compared.

TABLE I
GREENHOUSE ENVIRONMENTAL MODEL PARAMETERS

Parameter	Unit	Value
C_0	$\min W^0C^{-1}$	-324.67
UA	W^0C^{-1}	29.81
t_v	min	3.41
λ'	W	465
α'	$gm^{-3}\min^{-1}W^{-1}$	0.0033
$1/V$	$gm^{-3}\min^{-1}$	13.3
	m^3	4000
$V_R^{\max}$	m^3/s	22.2
$Q_{fog}^{\max}$	$\min^{-1}m^3$	26
$Q_{heater}^{\max}$	Wm^{-2}	150

TABLE II
GREENHOUSE ENVIRONMENTAL INITIAL WINTER CONDITIONS

Parameter	Value
C_{T_0}	15
C_{w_0}	13
$T_{out}(t)$	-2
$w_{out}(t)$	5.2
$S_i(t)$	20
Temperature control range	24-30
Humidity control range	15.6-21.8

Table 1 shows the simulation parameters of the greenhouse environment model. Table 2 shows the initial winter conditions of the Greenhouse model. Table 3 shows the initial summer conditions of the greenhouse environment model. According to the above table data, it can be concluded that the improved NSGA-II algorithm is better than the original NSGA-II algorithm when considering the greenhouse temperature and energy consumption and taking the greenhouse humidity and energy consumption as multi-objective optimization. From the perspective of the distribution of the Pareto optimal boundary, compared to the original NSGA-II algorithm, the diversity and diversity of the set of the improved algorithm are better.

$$f(1) = a * Q_{fog\%} + b * V_{R\%} \tag{30}$$

V. ILLUSTRATIVE RESULTS AND DISCUSSION

This paper proposes an improved NSGA-II algorithm that can optimize the greenhouse micro-environment control system, and The laws of energy and material changes in the greenhouse environment are analyzed through heat balance and material balance equations.

TABLE III
GREENHOUSE ENVIRONMENTAL MODEL INITIAL SUMMER CONDITIONS

Parameter	Value
C_{T_0}	35
C_{w_0}	9
$T_{out}(t)$	30
$w_{out}(t)$	40
$S_i(t)$	200
Temperature control range	24-30
Humidity control range	15.6-21.8

Through the establishment of greenhouse temperature and humidity dynamic model and greenhouse equipment energy consumption model, this paper analyzes how to reduce the cost, which is conducive to the production of greenhouse crops. In order to optimize the greenhouse environment, The NSGA-II algorithm has been improved, and the most important of which is to propose arithmetic crossover operators and adaptive mutation operators. At the same time, In order to prove that the improved NSGA-II algorithm has more advantages, the prototype and the improved algorithm are applied to the greenhouse environment model, and the results show that the improved NSGA-II algorithm has better performance than the Pareto optimal frontier solution set and higher search speed of the classical algorithm. According to the simulation results, it is concluded that the improved NSGA-II algorithm has better performance in the optimization control of the greenhouse microenvironment.

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