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# Study on Optimum Model of Temperature and Humidity Control in Grain Bulk Based on Particle Swarm Optimization Algorithm

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***Abstract***

Temperature and moisture are the most important factors affecting the safe storage of grain. Too high or too low temperature and humidity will cause the decomposition of organic matter in grain and food security problems such as pests, diseases and mildew. The regulation of temperature and humidity in grain storage is a multi-variable coupling and multi-objective optimization problem. In this paper, by analyzing the characteristics of grain humidity and temperature regulation process, the parameters of model are optimized by using GPSO particle swarm optimization algorithm, then the model predictive control is realized, and the proposed algorithm is simulated and experimentally studied. Experiments show that the algorithm has a high degree of fitting for predicting the humidity and heat control process of large grain stacks, and has a good prediction effect for temperature and humidity trend change.

***Keywords:*** *Grain Bulk, Particle Swarm Optimization, Temperature and Humidity Control, Multi-objective Optimization*

## 1. Introduction

Grain storage needs to achieve safety, quality and energy saving. To achieve these three objectives, it needs to control the temperature and humidity of stored grain, and further optimize the quality of grain and reduce energy consumption of the system[1]. There are two traditional ways for grain humidity and temperature transmission control system, temperature-drying and mechanical ventilation. Because there are many difficulties in controlling the timing, volume and duration of ventilation according to grain temperature and humidity, it is necessary to make a breakthrough in the optimization model of temperature and humidity control.

During the ventilation process, there are three main characteristics: super-large time lag, coupling and non-linearity. in the process of ventilation, cooling of grain is slow because of high wind resistance which leads to slow temperature transfer, and therefore temperature and humidity has great hysteresis. Feature of coupling and non-linearity: in the process of ventilation, serious non-linearity can be found between input and output quantity because of highly coupling of temperature and humidity.

It is a non-linear process with large time lag from the beginning of humidity and heat regulation to the effect on grain humidity and heat parameters farther away from the vent. Therefore, compensation lag, multivariable coupling and multi-objective

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optimization should be considered when choosing controlling method[2-3].

By analyzing the features of ventilation and controlling problems of ventilation, particle swarm optimization is adopted to optimize parameters of humidity and heat regulation model, further to realize model predictive control[4-7]. The proposed control method is simulated and experimentally studied, at last analyze the application of controlling method[8].

## 2. Design of of temperature and humidity prediction control system of grain bulk

The predictive control system is a multi-input and multi-output model mechanism, as shown in Figure 1. Grain temperature ($T_g$) and humidity ($H_g$) are controlled objects while temperature ( $T_{a\text{-}in}$ )and relative humidity( $T_{a\text{-}in}$ )of air in vent is control objects.

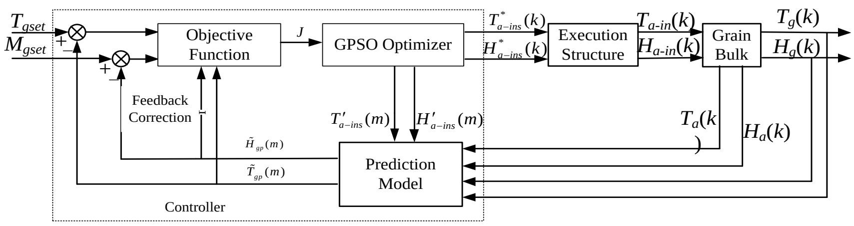


Fig. 1. Prediction control system of temperature and humidity in grain bulk

It can be seen from figure 1 that controller is key to evaluate the control structure. Controller is made up of optimizer and prediction model. Optimizer first compute the value of $T^{*}_{a-ins}$ and $H^{*}_{a-ins}$ in the next moment according to the value of Tgset and Hgset in present condition by applying the rule choosen by optimizing calculation. Then temperature $T_a$ and humidity $M_a$ as prediction model input be adjusted based on feedback again by the prediction model. Next optimization is carried out by the optimizer for several cycles, at last optimizer will calculate optimal output $T^{*}_{a-ins}$ and $H^{*}_{a-ins}$ which will be sent to actuator and adjustment of grain temperature and humidity will be done there.

Prediction model is the base of prediction control. For nonlinear prediction model, model function is critical and its basic function is based on input of historical information and predictive output of a certain period in a certain future.

Prediction model adopts heat and mass mechanism model and is made up of grain humidity equilibrium equation, air humidity equilibrium equation, grain heat equilibrium equation and air heat equilibrium equation.

1) Grain humidity equilibrium equation

$$\frac{\partial M_g}{\partial t} = -R_w \tag{1}$$

2) Air humidity equilibrium equation in grain bulk

$$\rho_a \psi \frac{\partial M_a}{\partial t} = \frac{f_a}{\Delta x}\left(M_{a-m} - M_a\right) + R_w \rho_g \tag{2}$$

3)Grain heat equilibrium equation in grain bulk

$$\rho_g c_{pg} \frac{\partial T_g}{\partial t} = h_{g-a}\xi(T_a - T_g) - R_w \rho_g [(L_{vap} + c_{pv}(T_a - T_g)] \tag{3}$$

4)Air heat equilibrium equation in grain bulk

$$\rho_a c_{pa} \frac{\partial T_a}{\partial t} = \frac{f_a}{\Delta x} c_{pa}(T_{a-in} - T_a) - h_{g-a}\xi(T_a - T_g) + c_{pv} T_a R_w \rho_g \tag{4}$$

The meaning of parameters of equilibrium equation is as follows: t stands for time; $\rho_g$ stands for grain density; $h_g$ stands for grain humidity; $R_W$ stands for rate-of-loss of water; $\psi$ stands for porosity; $f_a$

stands for vertical air velocity; $M_{a-in}$ stands for air absolute humidity in the vent; $T_g$ stands for grain temperature; $c_{pg}$ stands for specific heat capacity; $h_{g-a}$ stands for coefficient of convection and heat transfer between grain surface and air; $\xi$ stands for specific surface area of which grain contact with the air; $L_{vap}$ stands for vaporization heat of grain humidity content; $c_{pv}$ stands for specific heat capacity of vapor; $T_{a-in}$ stands for temperature in vent.

Control variable of system is $\boldsymbol{U}=[H_{a-in}\ T_{a-in}]^{\mathrm{T}}$ and it is an input in the model. The formula (5) is adopted for transformation from relative humidity to absolute humidity of air in the vent.

$$M_{a-in} = 0.622 \frac{P_{vs} H_{a-in}}{P_{atm} - P_{vs} H_{a-in}} \tag{5}$$

The present grain temperature and humidity and relative humidity as original input, combining two control variables of air temperature and humidity in the vent by using prediction model, it comes out the formula $\boldsymbol{X}=[Hg\ M_a\ T_g\ T_a]^{\mathrm{T}}$, in which $\boldsymbol{Y}=[Hg\ T_g]^{\mathrm{T}}$ is controlled variable by the system.

## 3. Design of objective function for optimizing temperature and humidity transfer

For optimum control of humidity and temperature transfer of large grain bulk, optimizing object function can be used for objective optimization, it is about how to reduce energy consumption on the premise of guaranteeing grain quality in the process of controlling grain temperature and humidity transfer. Therefore, object function focuses on humidity, temperature, quality and energy consumption of grain.

### 3.1 Design of optimizing object function of grain temperature

Temperature is another key factor in the process of safe grain reserve. Temperature has a great influence on growth and breeding of pests and microorganism. For most pests, the suitable temperature for them to live is between 22°C to 32°C， therefore, lower or higher temperature will help to restrain growth and breeding of pests, or even kill them. For most microorganism, the proper temperature for them to grow and breed is between 28°C to 30°C. When it is below 20°C， the growing speed of most microorganism will slow down and when it is below 15°C, the breeding of fungus will be restrained. Moreover, temperature is crucial to grain respiration because respiration get stronger in pace with the rising of temperature. Therefore, grain reservation under low temperature can reduce the loss caused by respiration and guarantee grain quality and it is a must to keep a suitable temperature in barn.

Hence it is necessary to set reasonable object valve of grain temperature control and set up optimizing object function of grain temperature, and the optimizing object of grain temperature is the minimum value of the function.

$$J_T = (T_g - T_{gd})^2 \tag{6}$$

In this function, $T_{gd}$ stands for the set value of grain temperature.

### 3.2 Design of optimizing object function of grain water content

Grain water content is one of the most important conditions in steady and safe grain reserve. Moisture is necessary medium for all kinds of biochemical reaction and all metabolism activities must be done with the existence of water. High temperature and high moisture leads to stronger respiration, faster metabolism and faster speed of material consumption, all of which will decrease the stability of grain. Higher humidity and moisture will also cut down the immunity of pests and microorganism. The appropriate humidity is in the range from 70% to 75% and moisture is from 13% to 13.5%. In the case of keeping relative air humidity below 65% and keep the corresponding moisture, it is possible to hold almost the activities of all microorganism. Control system is to make controlled variables reach target value designed, therefore, the less the deviation between controlled value and set target value, the better. Moisture target function is as follows:

$$J_M = (M_g - M_{gd})^2 \tag{7}$$

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### 3.3 General optimizing object function and constrained condition of system

As mentioned above, general object function of temperature and humidity transmission control is shown in formula (8):

$$J = \alpha J_M + \beta J_T + \gamma J_E \qquad (8)$$

$\alpha$ , $\beta$ , $\gamma$ each stands for weight of moisture, temperature and system energy consumption. Different ventilation process and system will be possible by setting different values and their value will affect influence on object function caused by changes of different parts of the object function. The minimum value of object function can be achieved by finding minimizing process of three different physical quantities and influence caused by process of temperature and humidity is considered in constrained conditions.

In accordance with different aims of temperature and humidity control, the restrained condition should be carried out based on relative data from grain condition (grain varieties, average temperature of grain pile, maximum temperature of grain pile, gradient value of temperature of grain pile), space condition in barn (temperature and humidity in the barn), environmental condition (air temperature and air humidity). The optimizing object functions and restrained conditions formulated are as follows:

(1)Cooling and ventilation

$$Hg<Hg_{div},\ T_g \le T_{gd}$$

$$\min_{T_{a-in},H_{a-in}} J = \alpha(M_g - M_{gd})^2 + \beta(T_g - T_{gd})^2 + \gamma[3600P_{fan} + m_a|T_{a-in} - T_{am}|(c_{pa} - c_{pv}M_{a-in})]t'_{v2} \qquad (9)$$

subject to:

$$Hg_d - \Delta M \le Hg_e \le Hg_d$$

$$T_{DPa} < T_g$$

$$T_{min} \le T_{a-in} \le T_{max}$$

$$H_{min} \le H_{a-in} \le H_{max}$$

Among the above, $T_{Dpa}$ stands for dew-point temperature. Since the most important thing in cooling ventilation is to prevent condensation of moisture, restrained conditions of the dew-point is a needed.

(2)Reducing humidity and ventilation

$$\min_{T_{a-in},H_{a-in}} J = \alpha(M_g - M_{gd})^2 + \beta(T_g - T_{gd})^2 + \gamma[3600P_{fan} + m_a|T_{a-in} - T_{am}|(c_{pa} - c_{pv}M_{a-in})]t'_{v2} \qquad (10)$$

Subject to :

$$Hg_d - \Delta M \le Hg_e \le Hg_d$$

$$T_{DPr} < T_{a-in}$$

$$T_{min} \le T_{a-in} \le T_{max}$$

$$H_{min} \le H_{a-in} \le H_{max}$$

Among the above, $T_{gd}$ stands for optimal object value according to different climatic conditions and grain conditions. This process can be regarded as that cooling ventilation and reducing humidity ventilation are carried out the same time. In order to prevent over loss of moisture, restrained conditions of equilibrium of moisture are added. It is $Hg_d - \Delta M \le Hg_e \le Hg_d$, in which $Hg_e$ stands for a function containing air temperature in the vent and relative humidity.

The basic point of grain temperature and humidity transmission process is a process with multiple targets optimization. Except an initial dividing between $J$ and its constraint conditions based on temperature and humidity of grain in the process, it needs to find another group of compromising solution sets to optimizing multiple objects simultaneously further to avoid more than one optimal solution that will make optimal object impossible to find. The key in the optimizing process is based on the value taking of $\alpha$, $\beta$, $\gamma$ in the function $j$ studied in this chapter.

## 4. Prediction model of grain bulk temperature and humidity transmission based on particle swarm optimization

### 4.1 Prediction process of generalized particle swarm optimization algorithm

The process of control prediction of grain temperature and humidity transmission based on particle swarm optimization is as follows:

(1)Initialization, set the position and speed of particle in particle swarm.

$$\begin{bmatrix} x_{11} & x_{12} & v_{11} & v_{12} \\ x_{21} & x_{22} & v_{21} & v_{22} \\ \cdots & \cdots & \cdots & \cdots \\ x_{N1} & x_{N2} & v_{N1} & v_{N2} \end{bmatrix} \quad (11)$$

Among the above, $x_{ij}$ ($i$=1,2,...,$N$, $j$=1,2) stands for particle position and $v_{ij}$ stands for the particle speed.

Computation of adaptation of each particle, that is choosing object function $J$.

Particle training, compute the value of position $\boldsymbol{P}_{bi}(m)$, in which the particle has best adaptation ever experienced till current optimizing moment m.

$$\boldsymbol{P}_{bi}(m) = \begin{cases} \boldsymbol{P}_{bi}(m-1) & J(\boldsymbol{x}_i(m)) > J(\boldsymbol{P}_{bi}(m)) \\ \boldsymbol{x}_i(m) & J(\boldsymbol{x}_i(m)) \le J(\boldsymbol{P}_{bi}(m)) \end{cases} \quad (12)$$

$$\boldsymbol{P}_{bi}(m-1) = [x_{i1}(m-1) \quad x_{i2}(m-1) \quad \cdots \quad x_{in}(m-1)] \quad (13)$$

$$\boldsymbol{x}_i(m) = [x_{i1}(m) \quad x_{i2}(m) \quad \cdots \quad x_{in}(m)] \quad (14)$$

(4)Optimization in overall situation, train optimal position that all particles in the swarm have experienced.

$$G_{bi}(m) = \min\left\{J(\boldsymbol{P}_{bi}(m))\right\} \quad (15)$$

(5)Update optimal particle speed and positon.

$$v_{ij}(m+1) = v_{ij}(m) + c_1 r_1 (P_{bij}(m) - x_{ij}(m)) + c_2 r_2 (G_{bi}(m) - x_{ij}(m)) \quad (16)$$

$$x_{ij}(m+1) = x_{ij}(m) + v_{ij}(m+1) \quad (17)$$

Among the above, $c_1$ and $c_2$ stand for learning rates, $r_1$ and $r_2$ are random number uniform distributed in the values range [0,1].

In order to improve the convergence function of the computation, the concept of inertia weight is introduced into Shi and others[107], the renewed formula of speed and positon is as follows:

$$v_{ij}(m+1) = wv_{ij}(m) + c_1 r_1 (P_{bij}(m) - x_{ij}(m)) + c_2 r_2 (G_{bi}(m) - x_{ij}(m)) \quad (18)$$

$$x_{ij}(m+1) = x_{ij}(m) + v_{ij}(m+1) \quad (19)$$

$w$ stands for inertia weight, and can decide to what extent it has of the current speed. Reasonable choise of w make particles have the ability of balanced exploration and development. The expression of nertia weight adopts linear gradually decreasing weithting strategy perposed by Shi[107] that can be seen as follows:

$$w = w_{\max} - (w_{\max} - w_{\min}) \times \frac{t}{T_{\max}} \quad (20)$$

Among the above, $T_{max}$ stands for maximum evolution algebra; $w_{max}$ stands for initial inertia weight; $w_{min}$ stands for inertia weight in the case of maximum evolution algebra. Usually $w_{min}$ takes the value of 0.4, and $w_{max}$ 0.9.

(6)Make judgement and comparison of adaptability of object function to see if it meets the requirement or advanced to iterations set before, if not, back to step (2).

### 4.2 Object description and parameters determination

#### 4.2.1. Experiment environment

The experiment environment adopts experiment platform of national grain engineering control laboratory. The experimental subject is wheat and overall size of grain crop in experiment barn is 12 meters long, 8 meters wide and 5 meters high. The sensors of grain temperature and humidity inside the grain bulk are arranged according that space between the thermometric cable is no more than 5 meters, and vertical dot pitch is no more than 2 meters, and thermometric locations up and down and all around should be set under the grain, against the wall, 30cm to 50cm above the floor. Arrangement of sensors is detailed as follows:

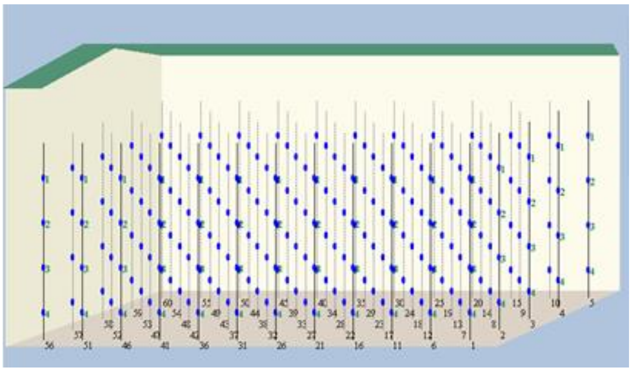
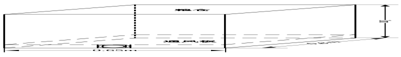


Fig.2. Diagrammatic sketch of arrangement of sensors

### 4.2.2. Parameters setting

About parameters setting of control prediction of grain temperature and humidity transmission, based on the amount of calculation, accuracy and optimization combination of model parameters, particles with group size 20, maximum iterative times 50 and particle dimension is set as 2 (reducing humidity) and 1 (cooling)according to different amount of variables. Inertial weight w adopts linearly decreasing weight strategy and learning factor both c1 and c2 take the value of 2, r1 and r2 0.65.

For particle group, there is a need to decide based on the range of air temperature and humidity for ventilation. Assume the j control of particle i is $x_{ij}$:

 (21)

In the formula, $x_{j\max}$ and $x_{j\min}$ stand for maximum and minimum value of control variable $j$ respectively, rand stands for random number uniformly distributed in the range of [0, 1]. Normal temperature for reservation inside grain bulk is no higher than 45 °C, thus variation range of air temperature in the vent are $x_{1\min}$=10℃, $x_{1\max}$=40℃.

Initialization of speed of component j of particle i can be achieved as follows:

$$v_{ij} = V_{j\min} + \text{rand} \times (V_{j\max} - V_{j\min}) \qquad (22)$$

In the formula, $V_{j\min}$ and $V_{j\max}$ each stands for maximum and minimum speed of component $j$ of particle. Also in the regulation of grain reservation, to avoid big effect on grain, moisture of grain is required not to vary greatly and humidity is usually set to be of plus or minus of 20%.

For the determination of weight coefficient, $\alpha$ should take the value as much as possible and assume $\alpha=4\times10^4$ to keep $J_M$ in the order rang of 0~$10^2$ with setting $\beta=1$, $\gamma=0.01$, $\Delta M=1\%$. Simulation has proved that the values of these parameters are properly chosen and able to achieve the goal of temperature and humidity control and optimal energy consumption.

In natural reservation condition, changes of grain pile temperature and humidity happen slowly. Therefore, termination conditions can be set within allowance error to prevent the problems of unstable system and overshoot. Control termination condition is as follows: $Hg_d-0.5\% \le Hg \le Hg_d+0.5\%$, $T_g \le T_{gd}$.

### 4.3 Experimental results and discussion and analysis

(1)Experimental results and analysis

Simulation and experiment data is from grain pile data, 45 thermometric cable with 3 testing dots on each cable which began at one o'clock of 6th, 9, 2017 and time interval of temperature and humidity acquisition is 15 minutes.

The height of grain bulk is 6 meters. The temperature sensor divides the height of grain bulk into four layers, each with a distance of 1.5 meters, that is, the first layer, the second layer, the third layer and the fourth layer. In the prediction study of temperature, the corresponding prediction study is made on the four layers of grain temperature. The predictions for the four layers are shown in Fig. 3 to Fig.6, respectively.

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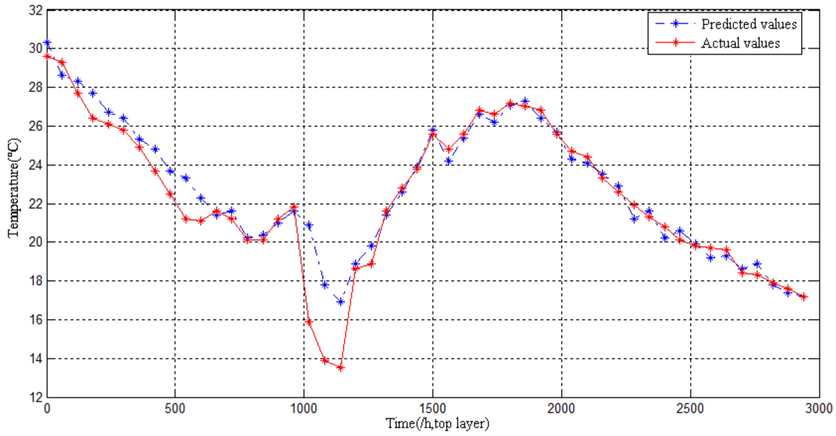


Fig.3. First layer Prediction and Prediction Curve

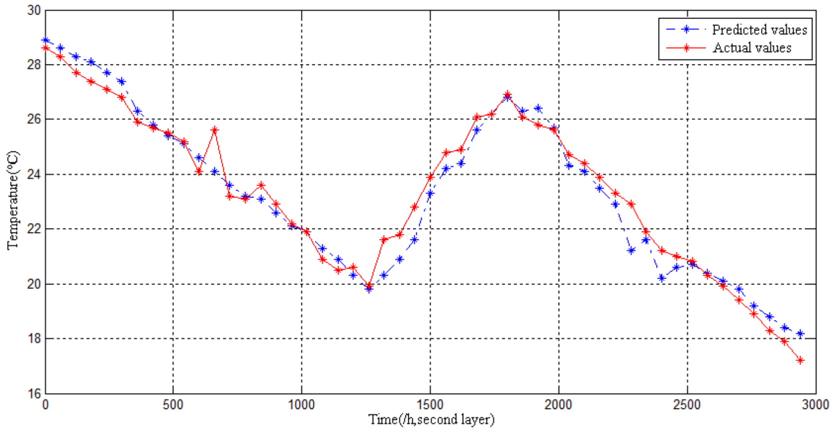


Fig.4. Second layer prediction and prediction curve

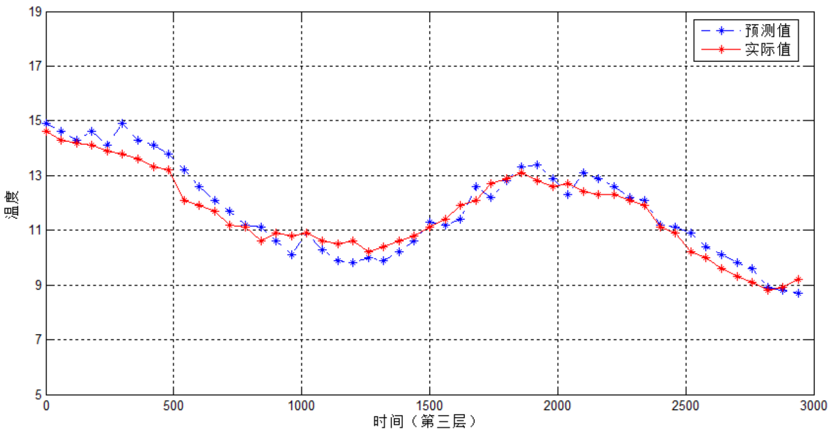


Fig.5. Third layer prediction and prediction curve

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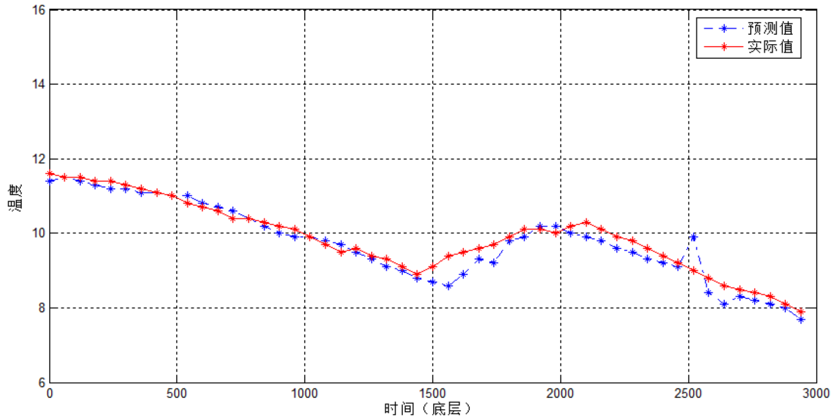


Fig.6. Forth layer prediction and prediction curve

From Fig. 2.5 to Fig. 2.8, it can be seen that although there is a sudden change point about 1200 hours in Fig. 2.5, about 700 hours in Fig. 2.6, and Fig. about 2500 hours in Fig.2.8, the sensor drift has been verified on site, and the predicted value has been proved correct after maintenance. Therefore, using the improved GPSO algorithm, the temperature and humidity prediction of large grain bulk has good results, and the fitting degree of prediction is very high.

## 5. Conclusion

It can be seen from the testing result, predictive control algorithm studied in this paper can carry out effective control over grain bulk, not only to control grain humidity and temperature effectively but also to optimize energy consumption at the same time. Compared with traditional control method, predictive control algorithm proposed by this paper is characterised by the following:

(1) In predictive control algorithm, by adjusting crop cooler and using air temperature and humidity in the vent, automatically adjust controlled variables to control grain temperature and humidity.

(2) In predictive control algorithm, it takes the process of temperature and humidity control as an optimization process to make grain temperature and humidity change according to curvilinear path formed after optimization.

(3) Simultaneous control over grain temperature and humidity to guarantee grain quality and realize optimization of energy consumption.

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