Synthesis of a digital PID controller to control the temperature in the agricultural products drying chamber

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Abstract. This article provides information and results of measurement and automatic temperature control with a proportional-integral-derivative controller. A microcontroller including special software is used for automatic control the temperature at a given value. For fixation continuity of changes, an algorithm for controlling the temperature in the drying chamber has been developed. The researched process on a computer model and an algorithm for temperature control in chamber was developed. Based on the analysis, transient characteristics of the drying process were obtained.

1 Introduction

It is a well-known fact that the process of drying agricultural products is characterized by such main parameters as temperature in the drying chamber, the initial moisture content of the raw material, the mass of raw materials per unit area, and the thickness of the dried raw material. The main task is to create a control system for the above given parameters.

Characteristic features of the drying process of fruit crops (for example, tomato product) under the influence of temperature, is a change in the inner properties of the product. To control this parameter, the principle of operation of P, PI and PID controllers [1].

2 Materials and methods

Management of a technical object usually consists of development of commands, implementation of which provides a purposeful change in the state of this object, subject to predetermined requirements and restrictions.

There are two ways to manage technological processes:

- with feedback, that is, closed control systems;
- without feedback, that is, open-loop control systems.

The systems without feedback, a special actuator is used to directly control the object, and there is no feedback.

For example, let's suppose there is an electric motor that, at a given voltage, rotates at a certain speed. But reality shows, under load in the power supply circuit, the voltage can change. As a result, the speed of the electric motor changes accordingly [2].

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The above given issue can be solved with the help of the feedback. Between the electric motor and the regulator, the speed sensor connected. The system, having received the current value from the sensor, independently controls the signal to the motor so that the speed of revolutions corresponds to this task. This function in the system is handled by the regulator.

According to the law of regulation, regulators are divided into the following types, P - proportional, PI - proportional-integral, PID - proportional-integral-derivative [3].

PID controller is the most common automatic controller. It is a universal device that is used in almost all technological processes where automatic control is needed. (For example, when controlling the temperature in special ovens, refrigeration units, incubators, drying chambers, etc. Or maintaining the speed of electric motors for machine tools, robotic devices, and many others).

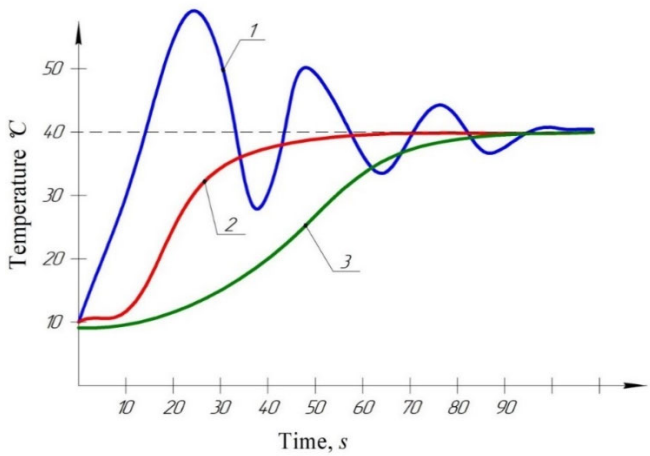

Fig. 1. Temperature controller transient curve in the drying chamber 1.3 - not satisfactory, 2 - optimal curve.

There are other controllers, for example, a linear-quadratic controller.

Many automatic control systems consist of the following elements:

- The regulator, which is the "center" of the control system. The regulator, in this sense, is a mathematical algorithm or program code that is entered into the controller (or microcontroller).
- The control object is the device that needs to be controlled.
- The control device (actuator) is a device that acts on the control object according to the control signal from the regulator. The control signal, in the form of a number, can be pulse or analog.
- The sensor is a device that receives the current value of the parameter from the control object and gives it to the controller.

The below elements together form a closed loop system with feedback.

For the correct operation of the system, a setting is supplied to the regulator. That is, this is the number to which the regulator must bring the current value from the sensor. The setting can be entered into the program code of the controller or set by external influence. The installation is set by a person, according to the requirements of the technological process [4].

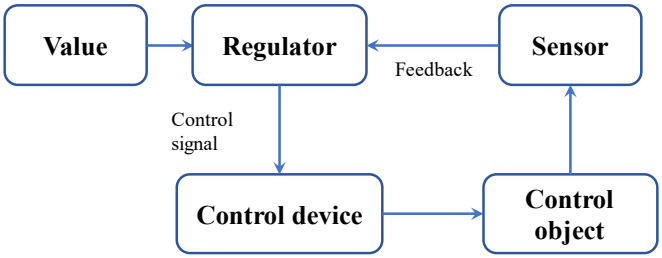

Fig. 2. Closed-loop control system diagram.

The task of the ACS is to compare the current value with the setting and issue a control signal to the control device. Programmatically (Figure 3), these actions can be designated as follows:

- entering a new installation;
- the regulator receives a signal from the sensor;
- performing calculations;
- control signal output.

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adjustable setting = new installation;
regulated input = signal from the sensor;
regulation.calculation();
apply(regulated input);
wait(dt);
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Fig. 3. Program code.

Modern regulators are made on the basis of microprocessor technology, and are discrete devices [4]. In this connection, the control signal, determined on the basis of calculations, must be generated at regular intervals, that is, with an equal period or frequency. This frequency is called the sampling period and is denoted by dt.

The main condition of the controller is that the control signal must affect the value from the sensor. In addition, the regulator must compensate for external influences on the system.

PID controller is adjusted accordingly. The PID controller is configured using three coefficients, k p - proportional, k i - integral and k d - differential.

The output from the PID controller, that is, the direct control signal consists of three components, proportional, integral and differential. This signal is formed as the sum of three values, each multiplied by its coefficient.

$$out = P \cdot k_p + I \cdot k_i + D \cdot k_d$$

here:

out - control signal;

P , I , D - respectively, proportional, integral differential component of the regulator;

k p , k i , k d – PID controller coefficients .

Each coefficient of the PID controller, individually, can be equal to zero.

In this case, the regulator component is equal to zero, that is, the regulator can have the form P , PI, PD or PID .

Different systems require different approaches, which is why The PID controller is universal.

The classic form of a PID controller can be described as follows:

$$K_p \cdot e(t) + K_i \int_0^t e(\tau)\, d\tau + K_d \frac{de}{dt}$$

3 Research results

Consider the program code that implements the role of the PID controller.

The proportional component of the controller is the difference between the current value from the sensor and the installation.

$$out = P \cdot k_p$$
$$P = setpoint\tau - input$$

here:

out – controller output (control signal);
setpoint - setting (set value);
input – input signal (transmitter value);
dt is the period of calculation and regulation.

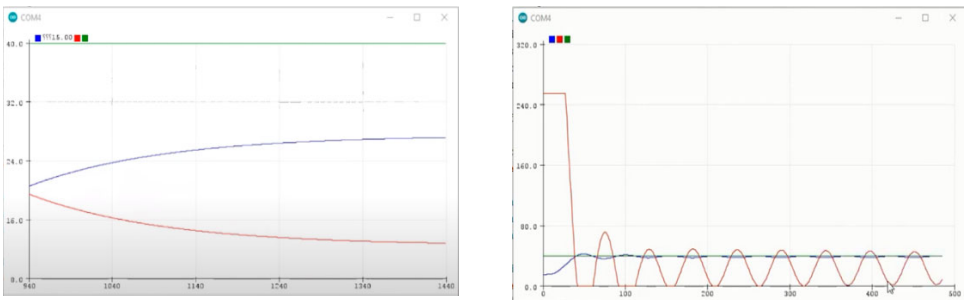
This difference is called the control error, that is, how far the system is from the setpoint. The larger the error, the larger the control signal and the faster the system will bring the controlled value to the set value. In the formula, the coefficient kp affects the amplification of the error [5-7].

If the system has reached the set value, then the error will become zero, and the control signal too:

$$setpoint\tau = input, P = 0, out = 0$$

In other words, the P controller will never be able to bring the system to a given value. There will always be some error in the system.

The P component is the main one in the regulator. The coefficient k p reduces the static error, that is, the error at each control step. The more k p, the smaller the control error, but it will not be possible to reduce it to zero. At the same time, an excessively large value of k p will lead to large jumps in the system (Figure 4).



a) b)

Fig. 4. P Regulator Transient Plots. a) at P = 1; b) at P > 10.

To reduce the control error to zero, the I component of the controller is applied. The integral component consists of the sum of the integral coefficient and the system error (the difference between the current and the set value) multiplied by the sampling period. That is, the integral of the error over time is actually calculated [8].

In the integral component of the controller, the error of the system accumulates, which allows the controller to completely eliminate it over time. That is, bring the system to a given value with high accuracy.

$$out = I \cdot k_i$$
$$I = I + (setpoint\tau - input) \cdot dt$$

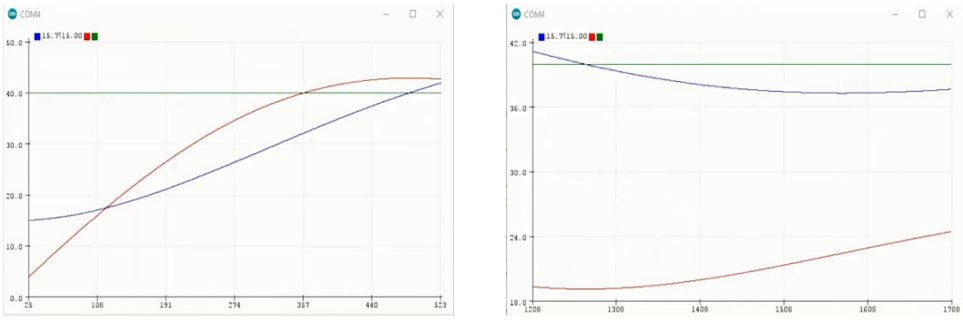
here:

out – controller output (control signal);
setpoint - setting (set value);
input – input signal (transmitter value);

dt is the period of calculation and regulation.

The integral component of the regulator produces such a control signal at which the error is equal to zero.

Integrated controllers are not used in control systems. The reason for this is that integral regulators are too slow and cause oscillations in the system (Figure 5).



a) b)

Fig. 5. Transient process graph of I regulator. a) at I = 1; b) for I > 10.

PI regulators are used in control systems (Figure 6).

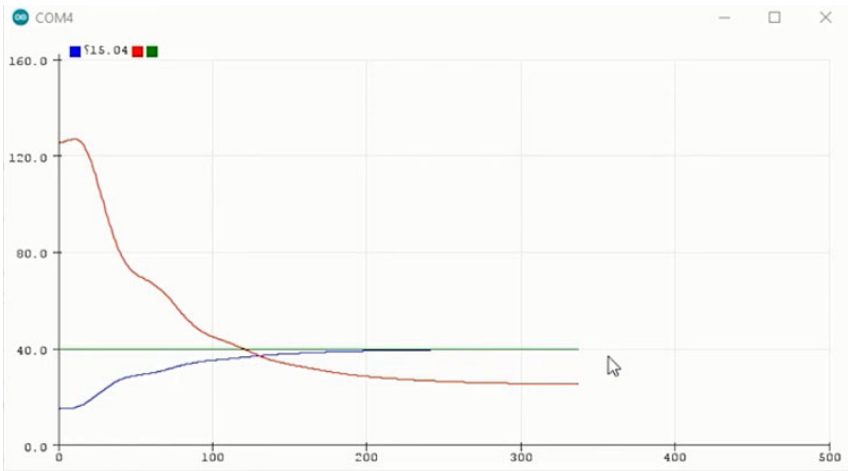


Fig. 6. PI Regulator Transient Plots. a) at P = 1, I = 1; b) at P > 10, I > 10.

The differential term corrects future system errors.

The D component of the controller is the difference between the current and previous errors divided by the time between measurements, that is, by the sampling period dt. In other words, it is the derivative of the error with respect to time.

$$out = D \cdot k_d$$

$$err = setpoint - input$$

$$D = \frac{err - prevErr}{dt}$$

$$prevErr = err$$

here:

out – controller output (control signal);

setpoint - setting (set value);

input – input signal (transmitter value);

err is the current system error;
prevErr - previous system error;
dt is the period of calculation and regulation.

The differential component reacts to a change in the signal from the sensor, and the stronger change occurs, the greater the value is added to the total amount. That is, the D component allows you to compensate for sudden changes in the system and, with the right settings, prevent strong overshoot and reduce fluctuations [9, 10].

Coefficient d allows you to adjust the weight, or the sharpness of changes in the system, as well as other coefficients regulate their components. The D component is primarily needed for fast systems, that is, for systems with abrupt changes.

With regard to slow processes, the differential component of the regulator is not used.

The D component corrects possible future errors by analyzing the speed.

Based on the above, we can conclude that the P component of the regulator sets the main signal, that is, it increases the output speed by the set value, increases the control signal. But it causes fluctuations and does not bring the system error to zero.

The coefficient I of the regulator allows you to completely eliminate the error and allows you to bring the system exactly to the setpoint, over time. At very large values of the I coefficient, undamped oscillations may also appear in the system. Therefore, the integral sum in the controller algorithm is often limited so that it cannot increase and decrease indefinitely.

The D factor of the regulator allows you to smooth out jerky movements and panting for a fast and ideal transient.

At the same time, with inaccurate signals from the sensor, the D component of the controller can cause inadequate system behavior and constant jumps in the control signal. For each sharp change in the signal from the sensor D, the regulator component will respond by changing the control signal, therefore, in order to obtain ideal regulation, it is necessary to filter the signal from the sensor.

Setting the PID controller coefficients for the system under study is carried out as follows. Set all controller coefficients to zero. Then we gradually increase the coefficient P until the appearance of undamped oscillations. The obtained value of the coefficient will be written into the variable P 1. We determine the oscillation period of the system, with the found value of the coefficient P, and denote it as T. The coefficients for the PID controller are determined by the following mathematical calculation:

$$kP = 0.6 \cdot kP_1$$

$$kI = \frac{2 \cdot kP}{T} dt$$

$$kI = \frac{2 \cdot kP}{8dt}$$

For the temperature control system under study in the drying chamber, undamped oscillations appeared at P 1 = 20, oscillation period, T = 3 seconds. The period dt in the system is 50 ms (0.05 s). Calculate the coefficients of the PID controller:

$$kP = 0.6 \cdot 20 = 12$$

$$kI = \frac{2 \cdot 12}{3} \cdot 0.05 = 0.4$$

$$kI = \frac{2 \cdot 12}{8 \cdot 0.05} = 60$$

4 Conclusions

Based on the analysis, it was determined that the control method using the PID controller allows to increase the reliability and accuracy of reproduction of the required mode parameters.

The PID controller is a microprocessor device designed to collect, convert, process, store information and generate control commands within real-time operation.

Thus, the registration and storage of process parameters, the formation of control actions on the drying process of fruit products using a digital PID controller contributes to a number of advantages:

- allows one to fully automate the process;
- there is a wide field for the use of modern intelligent technologies in the drying process of various products.

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