Smart Box Development for Food Storage with PCI-Based Temperature PID Control

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Abstract. Temperature measurement with a control system aims to improve the quality of automation processes in the field of instrumentation, automatic systems and especially food production. The primary function of the control system is to maintain predetermined or changeable variables under specified conditions. The control system is determined by three factors, namely, process variables, controller variables and manipulated variables. In this study, the temperature response was measured in an acrylic box with a size of 30×30×20 cm³ using a PT100 sensor. The temperature response was verified with a PID control system integrated with LabVIEW software and acquired by a PCI 6221 card. The PT100 sensor calibration with the Voltcraft digital temperature shown a linear relationship. The results of the temperature response test with the PI system produced P and I parameters of 9.03 and 2.7 min, respectively, while in the PID system the P, I and D parameters were 13.2, 6.2 min and 0.2 min, respectively. The response of the control system with the PI type is more stable and consistent than the PID type. Based on the results obtained, the temperature control process using a PI or PID control system with a TD value of 0 is more recommended.

1. Introduction
Temperature control systems are commonly found in bread or food warmer equipment. This system is useful for preserving food. The core function of the control system is to maintain predetermined or changeable variables under predetermined conditions, which is determined by three main factors, namely, manipulated variables, disturbances, and controller variables [1]. The temperature in the box was set by comparing predetermined values and giving proper control action, which will keep the ambient temperature according to the predetermined value.

One of the tools that use a temperature control system is an oven or microwave. However, this tool can only control ON-OFF, which will shorten the storage life and spoil the food because within a specified time the moisture content will fall to its lowest point due to repeated heating ([2,3]). Research on temperature control has also been carried out by [4] using Arduino Uno, which has limited resolution and control such as ON-OFF mode. Another research on temperature control with LabVIEW based PLC interface system and programming made the system more complicated [5].

Based on those constraints, this research has succeeded in designing a smart box with a regulatory control system using the 37 pin PCI 6221 Module and graphical-based Labview software from National Instrument (NI). One of the advantages of the PCI 6221 module is that it can perform many measurements in real-time with a high resolution, namely 16 bits and can be integrated with the LabVIEW programming system using a PID control system [6].

This control system maintains the temperature simultaneously in the food warmer box at the desired set point to produce the optimum value. The heating element surface temperature is adjusted...
by varying the pre-programmable set point temperature. The PID system intelligently regulates temperature by correcting the measured value from the temperature sensor based on the set point. The smart function is demonstrated by making regular heating by increasing the set temperature around 30 °C to 50 °C for 2 to 5 minutes and lowering the set temperature set point back to its initial setting.

2. Research Methods

2.1. Temperature sensor PT100
The PT100 (Fig. 1) is a high accuracy temperature sensor made of platinum metal and classified as the Resistive Temperature Detector (RTD). It has a positive temperature coefficient, which means that the resistance value rises with increasing temperature. The PT100 sensor is calibrated at 0 °C, which has 100 Ω resistance. Based on its accuracy, there are two types of PT100, namely Class A and Class-B. The PT100 Class-A has an accuracy of ± 0.06 Ω and the PT100 Class-B has an accuracy of ± 0.12 Ω. This accuracy decreases with increasing temperature. The accuracy of the PT100 Class-A can decrease to ± 0.43 Ω (± 1.45 °C) at 600 °C, and the PT100 Class-B can lower to ± 1.06 Ω (± 3.3 °C) at temperature 600 °C [7].

![Figure 1. The physical form of the PT100 sensor](image)

RTD systems are based on the principle that metal resistance increases compare with temperature. The temperature coefficient resistance (TCR) for a resistance temperature detector (α₀), is usually defined as the mean change in resistance per °C based on (i) the temperature range of -200°C ≤ t ≤ 0°C as in equation (1).

$$R_t = R_0(1 + At + Bt^2 + C(t - 100)t^3)$$

and for a temperature range of 0°C ≤ t ≤ 650°C the equation becomes:

$$R_t = R_0(1 + At + Bt^2)$$

The constant A is 3.90 ×10-3, B is -5.75×10-7 and C is -4.19×10-12.

2.2. Temperature Control System
The control system is based on sensor readings, comparing it with the desired set of points, then calculating the desired control output and providing error signal feedback to control variable input [8]. A typical control system mainly consists of process variables which are system parameters that need to be controlled, such as temperature (°C), pressure (bar), or mass flow rate (L/s). Sensors are commonly used to measure process variables and provide feedback to the control system. The setpoint is the command or desired operating value for the system process variable, such as 70°C, in this case, will be a temperature control system.

At certain times, the differential term between the process variable (PV) and the setpoint (SP) is used by the control system programmed (compensator), to determine the optimum control output to stabilize the system (plant). If the measured process temperature variable is 40 °C, and the desired set point temperature is 70 °C, then the control output will determine by the control logic programmed to drive the heater as the actuator. Actuator control will turn on the heater to warm up, and resulting
increment in the temperature as a process variable and called the closed-loop control system [9]. This increment is because of the reading process from the sensor will provide continuous feedback and calculating the amount of actuator output opening; this process repeated continuously and at a fixed loop level as described in Fig. 2.

![Figure 2. Typical closed-loop system block diagram [10]](image)

The system can be affected not only come from a manipulated variable, for example, in room temperature, but there is also maybe a source of cold air which sometimes blows into the room and giving any disturbances to the temperature reading. Such terms are known as distractions. The control system was designed to minimize the effect of variation on process variables due to any external disturbances [11].

2.3. Control PID

The process control basic design begins by determining the minimum requirements to meet the system performance. Control system performance is usually measured by applying the step function as a set point command variable, and then measuring the response of the process variable changed. In general, the response is quantified by measuring the process variable characteristics of the specified waveform. Rise Time is the amount of time required for the system to go from 10% of the process value to 90% of the steady-state or final value [12].

Percentage of Overshoot is the number of process variables that exceed the final grade, expressed as a percentage of the final value. Completion time is the time it takes for a variable process to complete a certain percentage (usually 5%) of the final value. Steady-State Error is the differential value between process variables and point setpoints [13].

The control system is known to have several control parameters, such as P (Proportional), PI (Proportional - Integral), PD (Proportional Derivative) and PID (Proportional Integral and Derivative). This PID type control system can be described mathematically [13].

\[
V = K_e e + K_i \int_0^t e dt + K_d \frac{de}{dt}
\]

(3)

The system response given control output can be changed from time to time or is related to several variables. Nonlinear systems are those in which will control parameters that produce the desired response at one operating point may not provide a satisfactory response at another operating point. The system exhibits an unwanted behaviour called deadtime. Deadtime (DT) is the delay between a process variable start changes after manipulated variable start alterations, and when that change can be observed. Deadtime value can also cause the system or output actuator being slow to respond to control commands changing, for example, a valve opening response too slow to open or to close. A common source of plant downtime in chemical plants is delays caused by fluid flow pass through pipes [15].
2.4. Tuning in the PID Control System

Tuning is some activities carried out to improve or enhance the performance or performance of a system; in this case, the control system. This tuning has several objectives, namely (i) minimizing the inaccuracy of the integral, namely by keeping the PV and SP distances to a minimum, (ii) reducing the error area of the integral, namely keeping the PV and SP areas as small as possible, (iii) making the control system faster, being a basic requirement in operations, (iv) minimizing the wear and tear of controlled equipment, (v) no over-shoots at startup and (vi) minimizing the effects of known process interruptions. The Ziegler and Nichols method perform this tuning, which is divided into two modes, namely the open-loop and closed-loop methods. Before tuning, it is important to know the Ziegler - Nichols reaction curve method by using the correlation between the magnitude of the change in control output and the response rate of the process variable [16].

The calculation of control system components P, I, and D depends on (a) the point in time when the SP (SetPoint) changes, (b) the time in minutes remaining before being seen in the change in PV (process variable) measured as L (The effective Lag time), (c) POI (The point of inflection) on the PV curve (d) is dotted where the PV changes at 63.2% to calculate the LTC (Loop Time Constant).

(i) Ziegler - Nichols Open Loop Tuning Method (first)

The effective lag value (L) and the time needed in minutes until the real rate of change is observed, as well as the N value (the PV slope at the point of the maximum rate of change). From these two values, the value of the tuning constant for the P, PI and PID controllers according to the Ziegler - Nichols formula are follows like PID control algorithm using the formula:

\[ K_c = 1.2 \times \frac{OP \% \text{ min} \times L \text{ min}}{N \%} \]  

(4)

\[ T_{\text{INT}} = 2 \times L \text{ (min)} \]  

(5)

\[ T_{\text{DER}} = 0.5 \times L \text{ (min)} \]  

(6)

(ii) Ziegler – Nichols Open Loop Tuning Method (second)

In this method, the time derivative of the gain, integral, derivative uses the same reaction curve as method 1, and the output of the control uses a control valve. The tuning value is calculated by following the PGu and Tu constants:

\[ PGu = \frac{2 \times \Delta V}{\Delta C} \text{ and } Tu = 4L \]  

(7)

(iii) Ziegler - Nichols Closed Loop Tuning Method

This method requires determining the critical value of the controller gain (\(K_c\)), which will make continuous oscillations in the controlled loop. This oscillation can happen if the number of loop gain (\(K_{\text{Loops}}\)) is equal to 1. The value of gain (\(K_c\)) then becomes the ultimate gain (\(K_u\)).

Table 1. Ziegler - Nichols closed-loop PID control tuning parameter settings

| Controller   | Proportional Only | Proportional Integral | Proportional Integral Derivative |
|--------------|-------------------|-----------------------|---------------------------------|
| Gain \(K_c\) | \(K_c = 0.5 \times K_u\) | \(K_c = 0.45 \times K_u\) | \(K_c = 0.6 \times K_u\) |
| Integral Time \(T_{\text{INT}}\) | - | \(Pu / 1.2\) | \(Pu / 2\) |
| Derivative Time \(T_{\text{DER}}\) | - | - | \(Pu / 8\) |

Based on Table 1, the calculation of ISA (Instrument Society of America) can be compared with applications in PLC (Programmable Logic Control) / DCS (Distributed Control System). Based on the ISA equation, which has a dependence if the KC control gain changes, the integral and derivative will also change.
\[ CV = K_c \left[ E + \frac{1}{T_{INT}} \int_0^t Edt + \frac{T_{DER}}{dt} \frac{E - E(n-1)}{E/df} \right] + \text{bias (manual)} \]  

or,

\[ CV = K_c \left[ E + \frac{1}{T_{INT}} \int_0^t Edt + \frac{T_{DER}}{dt} \frac{PV - PV(n-1)}{PV/df} \right] + \text{bias (manual)} \]  

K_p = K_c  

K_C = \frac{K_p}{T_{INT} \times 60 \text{ s/min}}  

K_D = K_C(T_D) \times 60 \text{ s}  

TC = 0.9(T75 - T25)  

DT = (T75 - T0) - (1.4 \times TC) + \text{Controller update time}  

In this study, tuning was carried out based on the ISA equation consisting of parameters P, I and D. These parameters are expressed in equations (15), (16) and (17).  

P = \frac{A}{PG} \left( \frac{DT}{TC} \right)^B  

D = TC \cdot A \left( \frac{DT}{TC} \right)^B  

I = \frac{TC}{A} \left( \frac{DT}{TC} \right)^B  

2.5. Temperature Response Test Block Diagram

This research begins with the calibration of the PT100 temperature sensor compared to the Volcraft Digital Thermometer Detir. Furthermore, the temperature response test was carried out in an acrylic box measuring 30\times30\times20 \text{ cm}^3. Figure 3 shows a system consisting of a transducer.

![Figure 3. Block diagram of a temperature control system using PID using LabVIEW and PCI](image)

This box aim is to maintain the temperature provided by the 220V 50W heater. The temperature in the box is measured using a PT100 sensor. The temperature response is tested using the PID control system integrated with the LabVIEW software.

The transducer is a module consisting of a sensor and a transducer that has an output of 0 to 10 VDC. The output of the transducer is selected based on the type of analog input from the 37 pin PCI.
NI Card acquisition system in the form of a voltage, namely AI.0. The transducer output is connected to the analog input AI.0 input, and the temperature transducer output is coupled to the heater with the AI analog input.

Analog input temperature transducer had a scale from 0 °C to 100 °C, while the temperature transducer scale from 0 °C to 100 °C to 0 to 10 Volts DC. The PID control program is made in LabVIEW Software by tuning parameters P, I, D, and compared with the setpoint given to the system. The PID control system loop will compare the setpoint value and the process value from the temperature and respond to the control output in the form of a heater to make the process value always equal to the setpoint value. The controller output response also uses a scale of 0 to 10 Volts DC to the actuator. This control process system is a closed-loop that will take place a continuous process. A good response, fast and stable system can be achieved by measuring the process value, comparing it with the setpoint and responding to the actuator by providing parameters in the PID control such as gain ($K_c$), integral ($T_i$) and derivative ($T_D$).

This tool is designed to observe how fast the system responds to changes in the set point of temperature and humidity in getting the ideal value for storing food in storage media with a PID-based control system. When the power to the system is turned on, PCI 6221 will read all hardware from input to output, the transducer reading, PID control and actuator control. This study consisted of two experiments, namely by varying the temperature set point in the range 30 °C to 70 °C.

3. Results and Discussion

3.1. Temperature Calibration

The temperature in the box room was calibrated using a Voltraf digital thermometer with a resolution of 0.1 °C as the calibrator. The results of the PT100 temperature calibration integrated with the PCI 6221 with a calibrator are shown in Figure 4.

![Temperature calibration curve](image)

**Figure 4.** Temperature calibration curve

The temperature calibration curve produces a linear curve with $R^2 = 0.999$ indicates that the room temperature measured on the PT100 is precise and accurate with the calibrator.
Table 2. The results of the voltage to temperature calibration

| Voltage (V) | Temperature PT100 (°C) | Temperature calibrator (°C) | Error (%) |
|------------|------------------------|-----------------------------|-----------|
| 2.45       | 31.2                   | 31.5                        | 0.952     |
| 2.74       | 34.5                   | 34.4                        | 0.320     |
| 3.10       | 38.2                   | 38.0                        | 0.526     |
| 3.40       | 40.9                   | 41.0                        | 0.244     |
| 3.75       | 44.3                   | 44.5                        | 0.449     |
| 3.96       | 46.5                   | 46.6                        | 0.215     |
| 4.19       | 48.8                   | 48.9                        | 0.204     |
| 4.43       | 51.9                   | 51.4                        | 0.973     |

Based on table 2, the average measurement error is 0.5%. This measurement is the initial stage for temperature control, where the temperature is converted into a voltage by PCI 6221. This voltage value becomes a guideline for set points in the PID temperature control process.

3.2. PID Temperature Control System Test Results

The temperature PID control test is carried out with a control system in a box measuring $30 \times 30 \times 20 \text{ cm}^3$ with a heater as a heat generator. This system is given a temperature reference value (set point) of 50 °C.

Figure 5. Measurement data with open-loop test manipulated variable opening 50 %

Based on Figure 5, the time $T_0 = 60$ seconds, $T_{25} = 200$ seconds, $T_{75} = 630$ seconds, $\Delta PV = 20.7$ °C and $\Delta MV = 25\%$. The TC and DT values obtained from equations (11) and (12) are 387 seconds and 28.2 seconds, respectively. Process Gain is obtained by measuring the difference in the process value and then dividing it by the difference in the Measurement Value (MV) reading. The time constant (TC) parameter is the time requirement of the process variable (PV) value to reach a scale of 63.2% of the maximum value according to the Set Point (SP). The dead time (DT) parameter is the time for MV changed until the PV starts to change its value. Based on the results of this process, the tuning constants are obtained in Table 3.
Table 3. Data for calculating constants A and B for tuning PI and PID

| Parameter type | Load change | Setpoint change |
|----------------|-------------|-----------------|
|                | A           | B            | A       | B       |
| P only         | 0.902       | -0.985       | -       | -       |
| P              | 0.984       | -0.986       | 0.758   | -0.861  |
| I              | 0.608       | -0.707       | 1.020   | -0.312  |
| P              | 1.435       | -0.921       | 1.086   | -0.869  |
| I              | 0.878       | -0.749       | 0.740   | -0.130  |
| D              | 0.482       | 1.137        | 0.348   | 0.914   |

Based on Table 3, the obtained Process Gain (PG), dead time (DT), and time constant (TC) are 0.8 seconds, 28.2 seconds and 387 seconds, respectively. The PI and PID parameters generated in this test are shown in Table 4, which is calculated using equations (15), (16) and (17).

Table 4. Results of PID parameters

| Parameter | P | I (min) | D (min) |
|-----------|---|---------|---------|
| PI        | 9.03 | 2.7 | 0 |
| PID       | 13.2 | 6.2 | 0.2 |

Based on the results obtained, it is necessary to do parameter tuning to get a stable value. This value is obtained by changing the initial values P, I and D to the latest values acquired from the results of calculating. After getting the parameter values of P, I and D, these values are fed in Kc, Ti and Td in the PID control system and good results are obtained with a fast response, and the process value tends to be stable.

![Figure 6](image-url)
Figure 6 shows that the response of the control system with the PI type has a more stable and consistent result compared to PID. The relatively stable temperature reading of the PI control is due to the fast-moving parameter P due to the Kc ratio. The parameter I is needed to prevent offset caused by fast response time to retrieve the setpoint value. The addition of the D parameter causes the output control action to move quickly and become irregular, causing oscillations. This oscillation will make the loop unstable. Based on the results obtained, the temperature control process using a PI or PID control system with Td = 0 is more recommended.

4. Conclusion
Testing the temperature response with the PI system produces P and I parameters of 9.03 and 2.7 min, respectively, while in the PID system the P, I and D settings are 13.2, 6.2 min and 0.2 min, respectively. PI and PID parameters are generated in the test. This temperature response. The control system response corresponding with the PI type is more stable and consistent than the PID type. Based on the results obtained, the temperature control process using a PI or PID control system with a TD value of 0 is more recommended.

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