PI Controller for The Heating Process in The Real Time System Based on LAB VIEW 8.2 Packages

Ahmed Sabah Abdul Ameer Al-Araji

Abstract

This paper experimentally investigates the control of the heating process in a water tank. A trial and error method is used to find the best system response depend on the tuning parameters of the PI controller based on a Matlab simulation package in order to replace these parameters in the real time digital PI controller system based LabVIEW package. The PI control action in the real time system technique shows more oscillation in comparison to that the PI simulation control action. Simulation and real time results for heating process experiment has successful for maintaining water tank temperature.

1- Introduction

Many industrial applications used PID control to maintain constant process variable. The output of PID controllers (proportional-integrative- derivative controllers) is linear combination of the input, the derivative of the input and the integral of the input therefore it is widely used and enjoy significant popularity, because it is simple, effective and robust [1]. The first Ziegler-Nichols tuning rule for (usual, integer) PIDs for the plant to control is needed only an S-shaped step response [2]. Also the PID control has been implemented for a heat exchanger in a closed flow air circuit [3]. A new adaptive internal model control scheme based on adaptive finite impulse response filters for the heating process provides the same design procedure for both minimum and non-minimum phase plants [4]. Also method for auto-calibration of PI & PID controllers, using a frequency domain model of the air heater process to be controlled (obtained by relay excitation) is compared with the Ziegler – Nichols method to cover a large domain of current real application [5].

Actually, the trail and error tuned PIDs often perform in a non-optimal way. But even through further fine – tuning be possible and sometimes necessary and provide a good starting point. Their usefulness is

* Information and Technology Engineering Department, University of Technology/Baghdad

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2412-0758/University of Technology-Iraq, Baghdad, Iraq
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obvious when no model of the plant is available, and thus no analytic
means of tuning a controller exists, but this method may also be used when a model is known. In the
work, we present here, experimentally investigates the
parameters of the PI controller of the heating process by
using trial and error method to find the best system response based on a
Matlab simulation package in order to replace these parameters in the
real time digital PI controller system based LabVIEW (lab Vision
Instrumentation Engineering Workbench) package approach is
proposed.

The organization of this paper is as follows: Section two represents the
proposal scheme describes design and implementation in real time
temperature control of a heating process and analysis of the mathematic
model of the system and describes hardware design. Section three
describes control methodology use PI controller and simulation results
(Matlab package) and real time results by using LabVIEW package.
Section four contains the conclusions of the entire work.

2- Experimental Arrangement in Real Time Implementation:
The proposed scheme describes design and implementation in the real time
temperature control of a heating process. In these
experiments, a stand d IBM PC-type Pentium IV is used for the
computation in real time. Data
acquisition is accomplished by standard parallel port protocol and the controller is implemented in
LabVIEW 8.2 a graphical programming language.
The picture of the experimental facility for the real-time control of
temperature of a heating process and
the schematic of the experimental arrangement used in this work is
shown in figures (1 and 2) respectively. The process is
composed of a heating actuator, water tank, and temperature sensor
thermocouple type J. AC power
supply provides power to the heater actuator. Initiating an appropriate
controlling signal from the digital
phase controller by using AT89C51
micro-controller and the computer
program algorithm can control this
power magnitude. The proposal
process can be considered as a first-order time delay system as the
mathematical model described it and
used heating actuator with heat energy (0 to 1500) watt (input to
heating process) and the output is
the temperature of water tank.

2-1 Mathematical Model:
The mathematical model of
the heating process can be driven as
follows by using heat balance equation [6]:
Heat input – Heat output = Heat accumulation
\[ Q_1(t) - Q_{\text{loss}}(t) = Q_{\text{Act}}(t) \]
(1)
Unsteady equation is:
\[ Q(t) - hAT(t) - T_{\text{air}}(t) = MCp \frac{dT(t)}{dt} \]
(2)
Steady equation at t=0 is
\[ Q_i(0) - hA(T(0) - T_{\text{air}}(0)) = 0 \]
(3)
The difference between the equations
\[ Q_i(t) - hAT(t) = MCp \frac{dT(t)}{dt} \]
(4)
By take Laplace Transformation
\[ Q_i(s) - hAT(s) = MCpST(s) \]
(5)
\[
T(s) = \frac{1}{hA} \quad \text{---(6)}
\]
\[
Q(s) = \frac{MCP}{hAS + 1}
\]
\[
T(s) = \frac{K}{\tau S + 1} \quad \text{-----(7)}
\]
Where \( K = 1/hA \) and \( \tau = MCP/hA \).

The real parameters of the heating process can be taken from table (1). After apply the parameters of the system in equation (7), the final equation that describes the model is:

\[
T(s) = \frac{1.21}{10.6S + 1} \quad \text{---(8)}
\]

Where the time constant \( \tau \) is equal to 10.6 hour or 38181.8 second.

2-2 Hardware Design:

The design and implementation of the control circuit is shown in figure (3). It consists of the thermocouple temperature sensor J type with analog device AD594 is used as a Celsius thermometer and linearization output voltage of the thermocouple with sensitivity is equal to \( 10mV/C \) with range of operation (0 to 100) \( C \) [7], applied signal condition circuit with gain (10) by using TLO64 CMOS operation amplifier, and 12 bit a high speed, low power analog to digital converter ADC574 successive approximation with one LSB is equal to 2.44mV/count [8,9]. Some TTL devices are used for interface with standard parallel port (Line Printer Port) LPT1 with SPP protocol mode [10].

Digital Phase Controller is designed and implemented by using microcontroller AT89C51 [11]. The digital phase controller receives digital data action from personal computer (parallel port) then analysis data by using the assembly program of 89C51 microcontroller which convert the digital data action (00 – FF) hex to the firing angle pulse (0 – 20) mSec (assume the AC frequency is 50Hz) on the gate of the Traic device BT136 through isolator pulse transformer in order to control the AC power of the heater actuator (0 – 1500) watt.

The isolator has been used as interface between the DAQ (Data Acquisition card) and the heater actuator to prevent the possibility of any back flow of AC current to the DAQ card from Triac device controller of heater actuator.

The phase detector control action program has been written in assembly language of AT89C51 microcontroller as shown below:

```
ORG 000h
SJMP START
ORG 003H
MOV IE,#00H
MOV R0,P2
CLR TF0
CLR TR0
Count: MOV TL0,#0DCH
MOV TH0,#0FFH
SETB TR0
Cheak1: JNB TF0,Cheak1
CLR TR0
CLR TF0
DJNZ R0,Count
SETB P1.0
MOV TL0,#18H
MOV TH0,#0FCH
SETB TR0
Cheak2: JNB TF0,Cheak2
CLR TR0
CLR TF0
DJNZ R0,Count
SETB P1.0
MOV TL0,#18H
MOV TH0,#0FCH
SETB TR0
```

START: CLR P1.0
CLR TF0
CLR TR0
MOV TMOD,#01H
The control algorithm has been written in the LabVIEW 8.2 as shown in figure (4).

3- Control Methodology

Varying the power of heater actuator can control the water temperature inside the tank. The PI control algorithm has been implemented and their details have been discussed in the following section.

3-1 PI control

The input to the actuator or the output \( u(t) \) of the PI controller is the summation of proportional gain, and integral action, which is expressed as:

\[
u(t) = K_p e(t) + K_i \int e(t) \, dt \quad ---(9)\]

Where \( e(t) \) is the error between the set-point \( T_{set} \) and the actual output \( T_w(t) \), \( K_P \) Proportional gain, and \( K_I \) Integral gain.

The PI parameters affect system dynamics are most interested in four major characteristics of the closed-loop step response. They are: Rise Time, Overshoot, Settling Time, and Error Steady-state.

The effects of increasing each of the controller parameters \( K_P \), and \( K_I \) can be summarized as in table (1) [2].

The proper tuning of the PI parameters are therefore essential for proper control and the parameters for the PI control have been determined using trial and error method depended on the simulation Matlab (6.5) package to find the best system response.

3-2 Simulation Result:

In this section, it is applied the mapping between the real process and the simulation Matlab (6.5) package as shown in figure (5). The proposal of the Traic device transfer function in conjunction with the heater unit is linear with saturation transfer function that slope is equal to 150 as a gain and limit to 1500 watt maximum depend on the heater description.

The open loop step response of the heating process is shown in figure (6), when apply step change in the heater actuator and it is equal \(21.45\) watt that will increase one-centigrade degree in the output temperature from \(25 C^o\) to \(26 C^o\).

And from this response the time constant of the heating process is equal to \(10.6\) hour or \(38181.8\) second as show in figure (6).

In the Matlab simulation package, apply the block diagram in figure (5) with the trial and error method for many times to find the best system response by tuning parameters of the PI controller, and then choose the best PI controller parameter in the simulation package as shown in table (2).

The closed loop time response of the water heater with only P-controller in Matlab simulation is illustrated in figures (7-a, b) for the initial temperature condition is \(25 C^o\) and have small error steady state.

The closed loop time response of the water heater with PI-controller in Matlab simulation is illustrated in figures (8-a, b) for the initial temperature condition is \(25 C^o\).

The response of the process in figure (7-a) reaches the steady state at (600 sec.) and has small error with smooth control action as shown in figure (7-a).
b). But the response of the process in figure (8-a) reaches steady state at (550 sec.) with oscillation control action at steady state to eliminate the error as shown in figure (8-b).

3-3 Real Time Results:

In this section, apply the same best tuning parameters of the PI controller in the discrete time "Real Time Computer Controller" after converting the continuous PI parameters controller of the table (2) to discrete PI controller by using Euler's method [6]:

\[ U(z) = (K_p + K_i \frac{T_s}{Z-1})E(z) \]
\[ \text{(10)} \]
\[ U(k) = K_pE(k) + (K_iT_s - K_p)E(k-1) + U(k-1) \]
\[ \text{(11)} \]

The sampling interval for the temperature of the heating system selected is one minute by using Shannon theory \( T_s = 1 \text{ Min}. \) The closed loop time response of the water temperature with only P-controller in real time is illustrated in figures (9-a, b, c, d) for the initial temperature condition is 25°C.

The response of the process in figure (9-a) reaches the steady state at 600 sec approximately and from figure (9-c) the steady state error of the process temperature is oscillation to ±2.2°C.

The closed loop time response of the water temperature with PI-controller in real time is illustrated in figures (10-a, b, c, d) for the initial temperature condition is 25°C.

The response of the process in figure (10-a) reaches the steady state at 550 sec approximately and from figure (10-c) the steady state error of the process temperature is oscillation to ±1°C.

The real time control action for P and PI controller have more oscillation than P or PI simulation controller because in the real time there are accumulation errors such as undesirable characteristics of temperature sensor "non-linearity, drift, and offset", offset of the operation amplifier, and the quantization error of the analog digital converter.

4-Conclusion:

The real time control system consist of a water tank, phase control based AT89C51 micro controller, temperature sensor such as thermocouple type J and data acquisition card in IBM PC AT.

The water tank temperature "heating process" has been controlled by variation of the heat energy from 0 to 1500 watt inside the water tank by digital control action from computer and digital phase gate control of the Triac device for the heater actuator.

Both the real time PI controller has been implemented in labVIEW platform through a DAQ card and the simulation PI controller using Matlab package are successful for maintaining water tank temperature.

In the simulation package, the trial and error method used for many times to find the best system response by tuning parameters of the PI controller, and then choose the best PI controller parameters. Then apply the same best tuning parameters of the PI controller in the discrete time "Real Time Computer Controller" after converting the continuous PI parameters controller to discrete PI controller.

The result of the real time control action has more oscillation than the simulation control action and the steady-state error in real time.
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is equal to (±1°C) for PI controller
but in the simulation is equal to zero
because in the real time there are
accumulation errors such as
undesirable characteristics of
temperature sensor “non-linearity,
drift, and offset”, offset of the
operation amplifier, and the
quantization error of the analog
digital converter.

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Table (1) The real parameters of the heating process

<table>
<thead>
<tr>
<th>Real parameter</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>A: surface area of the tank</td>
<td>0.075 $m^2$</td>
</tr>
<tr>
<td>h: over heat transfer coefficient</td>
<td>11 watt / $m^2 \cdot C^\circ$</td>
</tr>
<tr>
<td>M: mass of water in tank</td>
<td>7.5 Kg</td>
</tr>
<tr>
<td>Cp: specific heat of water</td>
<td>4.2 $kJ / Kg \cdot C^\circ$</td>
</tr>
</tbody>
</table>

Table (1): Effects of the controller parameters KP, and KI

<table>
<thead>
<tr>
<th>Response</th>
<th>Rise Time</th>
<th>Overshoot</th>
<th>Settling Time</th>
<th>Error S-S</th>
</tr>
</thead>
<tbody>
<tr>
<td>KP</td>
<td>Decrease</td>
<td>Increase</td>
<td>-</td>
<td>Decrease</td>
</tr>
<tr>
<td>Ki</td>
<td>Decrease</td>
<td>Decrease</td>
<td>Increase</td>
<td>Eliminate</td>
</tr>
</tbody>
</table>

Table (2): The best PI controller parameters in the Matlab simulation package

<table>
<thead>
<tr>
<th>Controller</th>
<th>KP</th>
<th>KI</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>50</td>
<td>0</td>
</tr>
<tr>
<td>PI</td>
<td>100</td>
<td>0.1</td>
</tr>
</tbody>
</table>
Figure (1): The picture of the experimental for the real-time control of temperature of a heating process.

Figure (2): The schematic of the experimental of temperature of a heating process.
Figure (3): The schematic diagram of the control circuit
Figure (4): The computer code in LabVIEW program
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Figure (5): The mapping block diagram between the real process
and simulation Matlab

Figure (6): Open loop step response
Figure (7-a): The Simulation output temperature of the heater process

Figure (7-b): The Simulation control Action
Figure (8-a): The Simulation output temperature of the heater process

Figure (8-b): The Simulation control Action C°.
Figure (9-a): The Real Time closed loop time response of the water temperature with only P controller

Figure (9-b): The Real Time heater control action
Figure (9-c): The Error between the desired temperature and the water temperature

Figure (9-d): Firing angle degree of Traic device
Figure (10-a): The Real time closed loop time response of the water temperature with PI-controller

Figure (10-b): The Real Time heater control action
Figure (10-c): The Error between the desired temperature and the water temperature

Figure (10-d): Firing angle degree of Traic device