PSO based Energy Efficient IR Heating System

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Abstract

Objectives: Maintaining uniform temperature with low power consumption is an important factor in various household and industrial applications. This paper presents the development of energy efficient IR heating system using particle swarm optimization. Methods/Statistical Analysis: The IR heating system model is developed by process identification method using step input, controllers are designed, simulated using MATLAB/Simulink and implemented using Arduino. Findings: Experimentally, the PSO based PID controller is proven to be a method for saving of power for temperature control of IR heating system and also shows superiority over the conventional PID controller in terms of performance indices. PSO based energy efficient IR heating system has overcome the drawbacks associated with temperature control of IR heating system like repeated two position switching and inferior time domain specifications which leads to more power consumption. Application/Improvements: PSO based energy efficient IR heating system can be used in various commercial and industrial applications to maintain the temperature with low power consumption.

Keywords: Arduino, IR Heater, MATLAB, Modeling, PID, PSO

1. Introduction

IR heaters are widely used in plastic, printing and packaging, pharmaceutical, textile, automobile, food industries etc. and are becoming more and more popular as heating systems for offices, pubs, cafes and restaurants, public halls, shops, schools and others. They provide highly efficient and cost effective heating and can be controlled remotely.

In most of the industries, PID controller with optimum tuning parameters is used for temperature control over the last five decades. The two methods derived by Ziegler-Nichols in 1940’s are still used for tuning of controller parameters in industries. Even though many other tuning methods are derived in recent years, this method is proven to be the efficient. Routh-array allows us to calculate the optimum parameters for the IR heating system. Controller optimum parameters for IR heater are evaluated by using PSO. Wireless communication using HC-05 Bluetooth module allows us to communicate the desired temperature to the heater control system, which is an added advantage of the proposed system. Android mobile and IR heater control system are the main parts of the proposed system.

2. Proposed IR Heating Control System

The desired temperature to the heater control system is set by the android smart phone. Figure 1 and Figure 2 shows the communication device and heater control system of the proposed model.

![Figure 1. Communication device.](image-url)
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The PWM signal used to control the IR heater temperature is generated by arduino based on the set point. As shown in Figure 2, heater control system consists of arduino uno, IR heater (1KW), HC-05 Bluetooth module, dimmer circuit sensor and other accessories. Arduino based PID controller with optimum tuning parameters set by PSO algorithm is used to maintain the desired temperature of IR heater with low power consumption. A dimmer circuit is introduced to control the input supply of the heater to maintain the required temperature at the heater node.

HC-05 Bluetooth module establishes the wireless mode of communication between remote node and the heater node. LM-35 is used to sense the temperature and send the data to Arduino Uno. Arduino is an ATmega328 microcontroller board with accessories. The Arduino compiles the LM-35 analog data and compares that value with set point and perform the PID action on the heater.

LCD is used to display the set point temperature. Power saving and enhanced user comfort are the advantages of the proposed system.

3. IR Heater Model

For a change in voltage due to set point or load changes, IR heater takes a certain time to reach the steady state condition and exhibit first order response. Here, the empirical model of IR heater is developed based on the experimental data. A step change of 75V using dimmer stat is applied at the input of the IR heater as shown in Figure 3. The temperature of the IR heater is measured with LM-35. The temperature readings from the LM-35 are noted down for every 60 seconds until it reaches to steady state. The step response of IR heater i.e., time in seconds vs temperature in degrees C is plotted and shown in Figure 4 from which the time constant, steady state gain and delay time are calculated. Sample readings obtained from the experimentation are shown in Table 1.

![Figure 3. Heater modeling experimental setup.](image)

![Figure 4. IR heater response.](image)

| Time (sec) | Temperature (°C) |
|-----------|------------------|
| 0         | 31.1             |
| 60        | 32.5             |
| 120       | 33.4             |
| 300       | 38.2             |
| 360       | 40.9             |
| 420       | 42.9             |
| 1680      | 61.2             |
| 1740      | 61.2             |
| 1770      | 61.3             |
| 1800      | 61.4             |

The transfer function of IR heating system is approximated as first order with dead time system.

\[
G_C(S) = \frac{k_p e^{-\frac{t_d}{\tau}}}{\tau s + 1}
\]  

(1)

From the above graph, Time constant ($\tau$) = 684 sec
Gain = \frac{\text{change in output}}{\text{change in input}} = \frac{61.4 - 31.1}{75 - 0} = 0.404

Delay (\theta) = 6 \text{ seconds}

\text{Transfer Function} = \frac{0.404 e^{-6s}}{68s + 1} \quad (2)

\text{By using 1st order pade approximation,}

e^{-6s} = \frac{35 + 1}{35 + 1} \quad (3)

\text{Therefore, the overall transfer function is}

G(S) = \frac{-1.212s + 0.404}{205.2s^2 + 687s + 1} \quad (4)

4. PID Controller Design

Figure 5 shows the schematic of PID controller with the process. Transfer function of controller is

\[ G_c(s) = \frac{1}{T_i s + 1} + \frac{1}{T_d s} + K_c = \frac{1 + 1/T_i s + T_d s}{T_i s + 1} \quad (5) \]

Figure 5. Schematic of PID controller.

The controller tuning parameters are estimated using Z-N method and tabulated in Table 2. The estimated values of ultimate parameters (Ku and Pu) using Z-N method for IR heating system are 534.6 and 19.03 respectively.

Table 2. Z-N tuning parameters

| Controller | K_c | T_i | T_d |
|------------|-----|-----|-----|
| PID        | K_c /1.7 | P_u /2 | P_u /8 |

5. PSO-PID Controller Design

Particle Swarm Optimization (PSO) is a swarm intelligence based optimization technique which gives global best solution. PID optimum parameters are evaluated by a fitness function. This function for IR heating system considered as a function of performance indices is

\begin{align*}
F &= (1 - \exp(-\beta)) (M_p + E_{ss}) + (\exp(-\beta)) (T_s - T_r) \quad (6)
\end{align*}

where F is fitness function, M_p is peak overshoot, T_s is settling time, T_r is rise time and \( \beta \) is scaling factor (0.5). Parameters which greatly effects the global optimization need to be defined and initialized are shown in Table 3. Figure 6 and Figure 7 represents the flow process and schematic of PSO based PID controller.

Figure 6. Flow chart of PSO- PID controller.

Figure 7. Schematic of PSO- PID controller.
Table 3. PSO parameters

| Parameter                | Value |
|--------------------------|-------|
| Swarm size               | 100   |
| No. of generations       | 100   |
| Velocity coefficient c1  | 0.12  |
| Velocity coefficient c2  | 2     |
| Inertia weight factor w   | 0.9   |
| Dimension of the problem | 3     |

6. Experimental Setup

The experimental setup of the system comprising of wireless communication device and heater control system is shown in Figures 8 and 9. The temperature sensor is connected to pin A0 of Arduino. The Arduino Uno pin 3 is connected to dimmer MIC IC 3rd pin. The PWM signal from the Arduino switches the heater ON/OFF and the dimmer output is fed to the heater.

7. Results and Discussion

7.1 Comparison of Performance Indices

PID and PSO-PID controllers for the IR heating system are simulated using Matlab/Simulink software. The output of IR heating system using PID and PSO-PID are shown in Figures 10 and 11. Tuning parameters of PID and PSO-PID are given in Table 4 and performance indices observed from the unit step responses are tabulated in Table 5. The tabulated results clearly show better performance indices with PSO-PID compared to conventional PID controller.

Table 4. Comparison of tuning parameters

| Parameter | PID  | PSO-PID |
|-----------|------|---------|
| $K_p$     | 340.09 | 250.02  |
| $K_i$     | 0.105 | 0.1     |
| $K_d$     | 2.38  | 2.05    |

Table 5. Comparison of performance criteria

| Performance indices | PID   | PSO-PID |
|---------------------|-------|---------|
| Rise time (sec)     | 3.79  | 5.7     |
| Peak time (sec)     | 15.1  | 17.69   |
| Settling time (sec) | 57.1  | 40.75   |
| Peak overshoot (%)  | 51.6  | 26.02   |
| Steady State error  | 0     | 0       |

7.2 Comparison of Power Consumption

The energy consumption of 1KW heater to maintain
40°C temperature is observed with PID and PSO-PID controller. The experimental results related to energy consumption are tabulated in Table 6. Tabulated results clearly show 23.02% energy saving with the PSO-PID controller compared to conventional PID controller.

**Table 6. Energy consumption (Set point = 40°C)**

| Algorithms | Time in hours | Energy in kWh |
|------------|---------------|---------------|
| PID        | 1             | 0.139         |
| PSO-PID    | 1             | 0.107         |

8. Conclusion

An energy efficient method for temperature control of IR heating system using PSO-PID algorithm is proposed in this paper. In the IR heater control system, the generated error signal is fed to the Arduino based PSO-PID controller to maintain the desired temperature. PSO based PID control algorithm is proved as intelligent and energy efficient technique for IR heating system from the experimental results. The simulated results show the superiority in performance indices with PSO-PID over conventional PID controller.

In future, the efficient energy saving technique can be identified by using other evolutionary algorithms like ACO, ABC, DE etc.

9. References

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