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LOW-COST TEMPERATURE CONTROL SYSTEM FOR CLASSROOM

Julián Guillermo Ortiz-Trujillo, Christian Mateo Guevara-Puentes and Diego F. Sendoya-Losada
Department of Electronic Engineering, Faculty of Engineering, Surcolombiana University, Neiva, Huila, Colombia
E-Mail: diego.sendoya@usco.edu.co

ABSTRACT

This document presents the design and implementation of a low-cost and easy-to-handle temperature control system. The system allows to manipulate the power and luminosity of an incandescent lamp and in this way control the temperature, by varying the firing angle of a TRIAC. Both the user interface and PI control are implemented with the Arduino UNO board. This document is intended to serve as a guide for the application of power systems, without having extensive knowledge in the control area.

Keywords: disturbance rejection, PI control, setpoint tracking, temperature control, TRIAC.

1. INTRODUCTION

In recent years, some proposals have been made to design a control with which the luminosity, temperature, and power consumption of different types of lamps can be manipulated, in order to solve problems of everyday life.

Currently, different types of lamp drivers are being implemented either LED or incandescent lamps, in order to efficiently manipulate the required power consumption, altering their luminosity and other factors, such as temperature, in the case of incandescent lamps.

For this purpose, different control methods applied to this type of systems are used, with the PID being the most common of them [1-5]. In the part of the digital control that the plant requires, different controllers are used such as PLC, Arduino, among others. In the case of academic applications, Arduino is the best option in terms of cost and simplicity [6].

This article aims to expand the information on the design and implementation of a temperature, light, and power control system for an incandescent lamp, in which MATLAB software is used to calculate PI control. This facilitates the design without having greater knowledge in the control area.

The project is based on the implementation of two Arduino UNO boards, one as a user interface, and the other as a power control stage that provides the digital signals to control the TRIAC firing angle. This makes the project economical compared to those on the market, as well as being easy to apply for teaching in the academic field.

2. MATERIALS AND METHODS

2.1 Materials

The implemented circuit is divided into two main stages: the user interface and control stage.

2.1.1 User interface

This stage is composed of the keyboard, the display with I2C communication, an Arduino UNO board, which is used to receive the data entered by the user and later send them to the control stage through the DAC TLC5615 (See Figure-1).

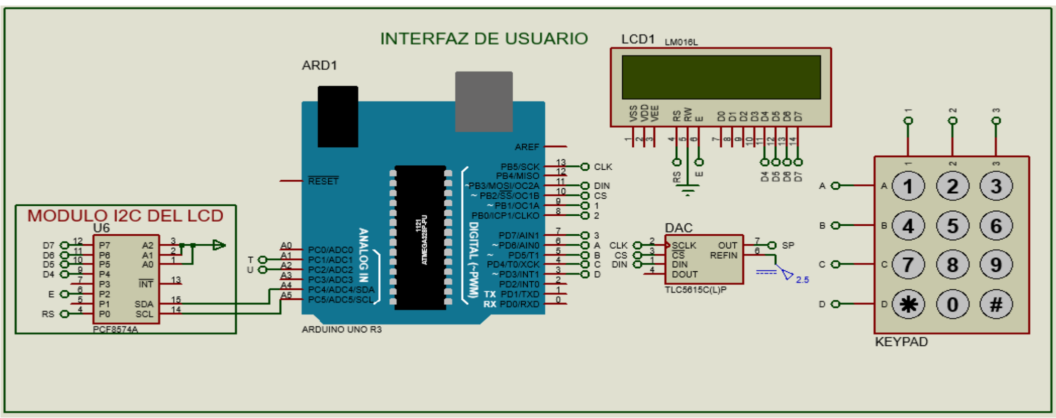

Figure-1. Circuit used for the user interface.

2.1.2 Control stage

This stage is composed of: i) Zero crossing detector circuit, which is responsible for indicating to the Arduino when the 120V AC power signal crosses zero. This in order for the Arduino to wait long enough to generate the trigger pulse for the power stage. ii) Power stage, which is responsible for conditioning the digital signal from the Arduino to perform phase control of the 120V alternating voltage signal (DC-AC Converter). iii) Microcontroller, in this stage there is an Arduino UNO

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board that is in charge of acquiring, manipulating the data, and creating the trigger signal that is delivered to the power stage. It is also in charge of calculating the voltage applied to the lamp, and of sending this data through the DAC MCP4725 to the Arduino of the user interface so that it can be processed and then displayed on the LCD (See Figure-2).

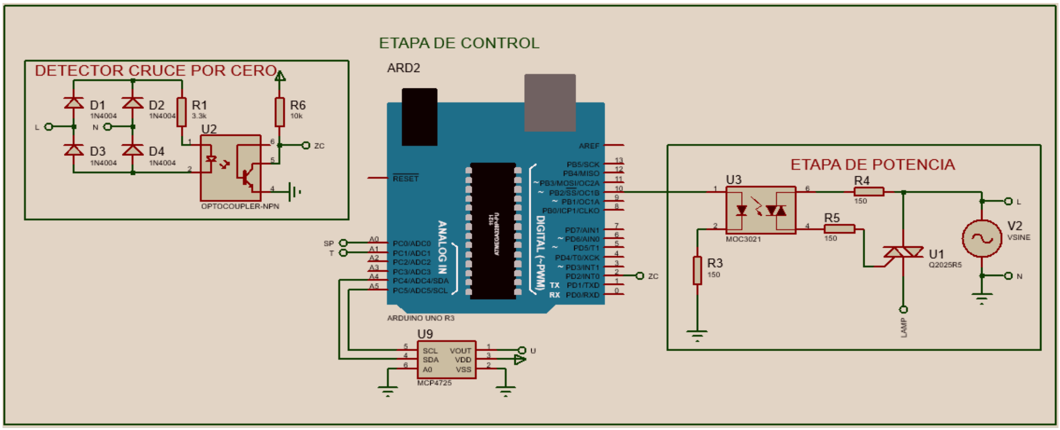

Figure-2. Circuit used for the control stage.

2.2 Methods

In order to obtain a good operation of the final plant, the following process must be carried out.

a) Initially, a relationship between the desired temperature, which is entered through the user interface, and the voltage applied to the lamp, to obtain said temperature, must be found. For this, the circuit of Figure-3 must be implemented.

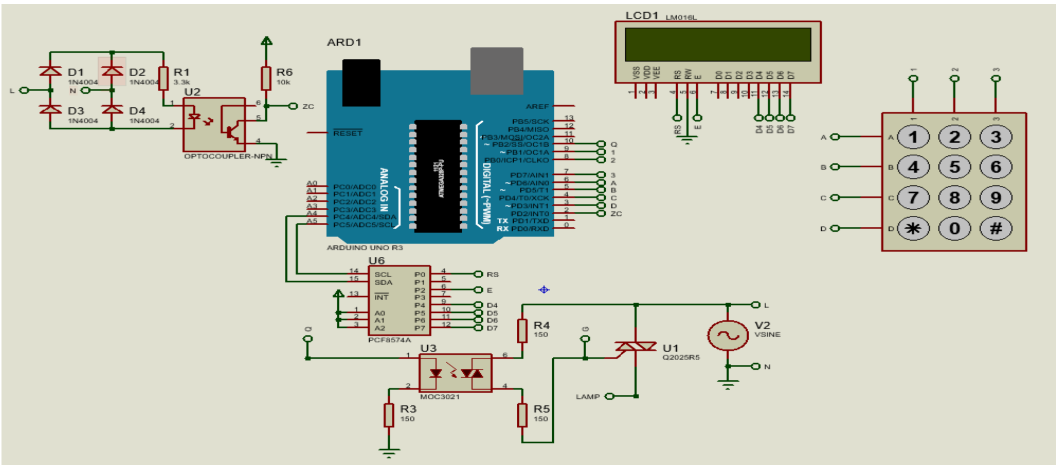

Figure-3. Circuit to find the relationship between α, V_{RMS}, and temperature.

Here, the trigger angle for the TRIAC (α) is entered via a user interface. Equation (1) relates this angle to the voltage that is applied to the lamp. With the LM35 temperature sensor, the temperature obtained with each angle is recorded, resulting in Table-1. This also allows knowing the working range of the plant to be used.

$$V_{RMS} = 120\sqrt{1 - \frac{\alpha}{\pi} + \frac{\sin(2\alpha)}{2\pi}} \qquad (1)$$

With the obtained data, a linear regression is performed between the measured V_{RMS} and the temperature, in order to find a mathematical relationship that relates these two variables. Using Excel, an equation is found where "x" represents the measured V_{RMS} and "y" represents the temperature, as shown in Figure-4.

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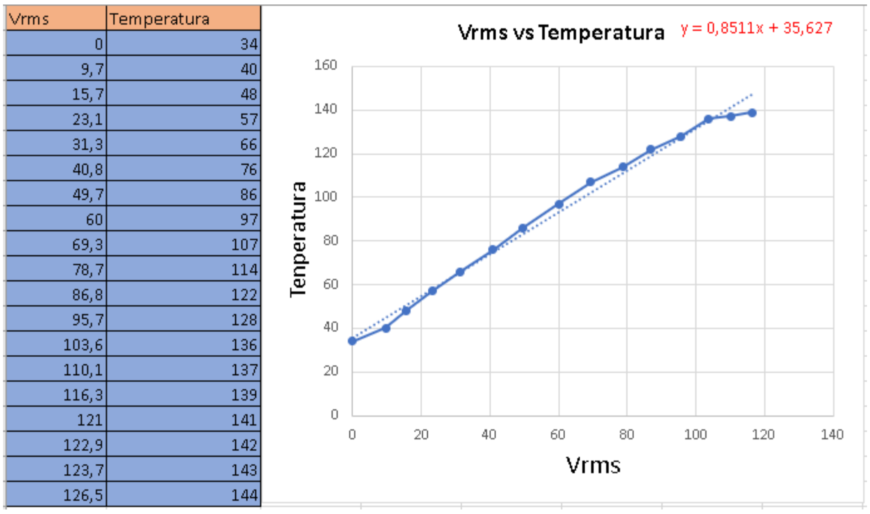
Table-1. Relationship between α, V_{RMS}, and temperature.

α (°)	Calculated V_{RMS} (V)	Measured V_{RMS} (V)	Temperature (° C)
180	0	0	34
170	4	9.7	40
160	11	15,7	48
150	20	23.1	57
140	30	31.3	66
130	41	40.8	76
120	53	49.7	86
110	64	60	97
100	74	69.3	107
90	84	78.7	114
80	93	86.8	122
70	101	95.7	128
60	107	103.6	136
50	112	110.1	137
40	116	116.3	139
30	118	121	141
20	119	122.9	142
10	119	123.7	143
0	120	126.5	144



Vrms	Temperatura
0	34
9,7	40
15,7	48
23,1	57
31,3	66
40,8	76
49,7	86
60	97
69,3	107
78,7	114
86,8	122
95,7	128
103,6	136
110,1	137
116,3	139
121	141
122,9	142
123,7	143
126,5	144

Figure-4. Linear regression.

Since the temperature is entered in the end user interface, then the expression is manipulated so that the V_{RMS} is calculated from the temperature. Equation (2) presents this relationship.

$$V_{RMS} = \frac{Temp - 35.627}{0.8511} \quad (2)$$

As mentioned above through the user interface a temperature is entered and using (2) the V_{RMS} is obtained. This voltage is used in (1) to find the firing angle necessary for the TRIAC to deliver adequate power to the lamp, thereby reaching the desired temperature. As in (1) the variable α cannot be found by algebraic methods, then an iterative method is used to find the value of the firing angle.

b) After this, it is necessary to obtain a mathematical model of the plant to subsequently carry out its control using a PI algorithm.

To carry out this process, the circuit of Figure-3 is used. To start, an angle α from Table-1 must be chosen. Using MyDAQ and LabVIEW® software, the monitoring and the data acquisition are performed.

The data recorded for $\alpha = 120°$, $V_{RMS} = 49.7$ V, and $Temp = 86°$ C, are presented in Figure-5.

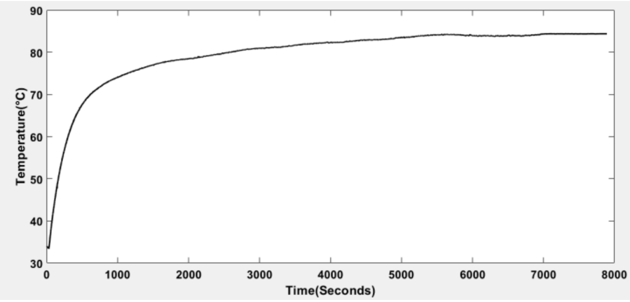


Figure-5. Test for modeling.

Subsequently, using the systems identification tool present in MATLAB®, a transfer function that represents the dynamics of the plant at that setpoint is obtained. This transfer function is fit to the measured data by 94.95%.

$$G(s) = \frac{0.5937s+0.0003352}{s^2+0.4435s+0.000196} \quad (3)$$

With the transfer function, the control to improve the response of the plant is designed.

c) For the design of the PI controller, the PID block present in SIMULINK® is used, in order to be able to tune the parameters automatically and not have complications by applying mathematical methods to calculate the controller. The proposed diagram is presented in Figure-6.

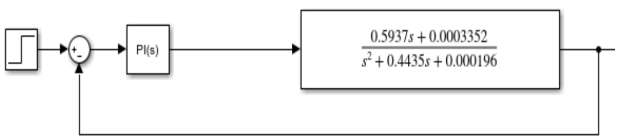


Figure-6. SIMULINK® block diagram.

The PI controller parameters are: $P = 0.9779$ and $I = 0.1015$.

A simulation is performed to check the improvement of the dynamic response of the plant. The results are presented in Figure-7.

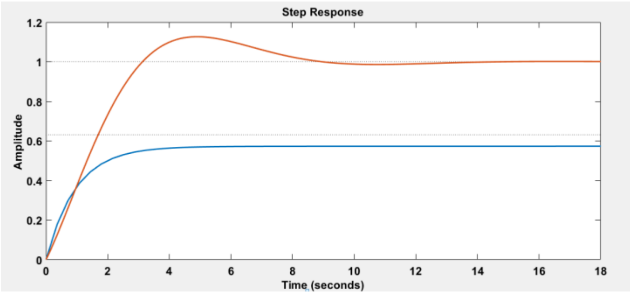


Figure-7. Closed-loop system response without controller (blue) and with controller (red).

As can be seen, the blue signal corresponds to the closed-loop response of the plant with unitary feedback but without controller; the red signal is the closed-loop response of the plant with PI control and unitary feedback. An improvement in the steady state error and the settling time is observed when PI control is applied.

Finally, there is the control law that will be implemented in the microcontroller. For this; the mathematical model of the PI controller is used.

$$\frac{U(s)}{E(s)} = P + \frac{I}{s} \quad (4)$$

A first-order backward Euler discretization scheme is used in this work, which leads to the following discretized PI dynamics:

$$u_t = u_{t-1} + (P + I)e_t - Pe_{t-1} \quad (5)$$

By replacing the values of P and I, the control law is found:

$$u_t = u_{t-1} + 1.079e_t - 0.9779e_{t-1} \quad (6)$$

3. RESULTS AND DISCUSSIONS

The closed loop system performance verification was conducted towards two scenarios to compare the behavior of the PI algorithm. The performance of the controller is evaluated for the tracking to a reference level, and the effective rejection of the disturbances.

3.1 Scenario 1: Setpoint Tracking

The setpoint temperature used to design the controller (86° C) is entered through the user interface, and the response parameters such as stability and error at steady state are observed.

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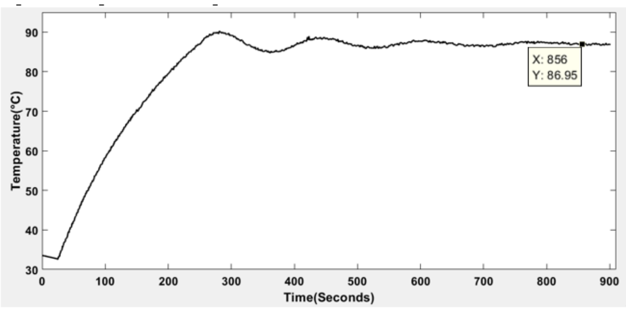

Figure-8. Tracking at setpoint 86° C.

As can be seen, the settling time is reduced from 7894 seconds (Figure-5) to 856 seconds (Figure-8). A steady state error of 1.1% is also obtained. An overshoot is observed which is not very important considering that the main objective of the system is to increase or decrease the temperature in the shortest possible time.

Once the system has stabilized at 86° C, a new setpoint of 120° C is introduced to observe the robustness of the applied control and analyze whether it increases the settling time and the error in steady state.

As can be seen, the system settling time increases from 856 seconds to 1168 seconds, but it is still a fast response compared to the open loop response. A small decrease in steady-state error and overshoot can also be observed. (See Figure-9).

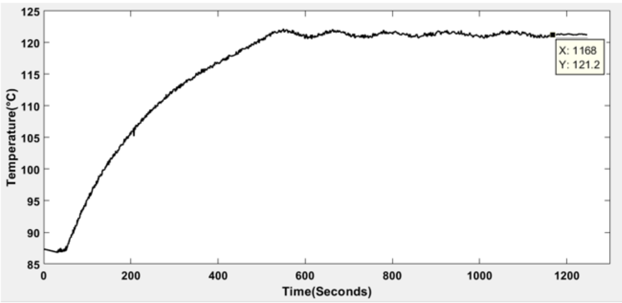

Figure-9. Tracking at setpoint 120° C.

It is observed that the control has enough robustness to support the changes to the new setpoints, an overall improvement in the settling time can also be observed. Regarding the errors of the steady state, it can be experienced that their influence on the plant can be negligible.

3.2 Scenario 2: Disturbance Rejection

To evaluate the disturbance rejection, the temperature of 86° C is entered again, and it is waited for it to establish. Then, a series of disturbances are introduced, altering certain conditions in the plant environment. The first disturbance is done by extracting heat from the plant by opening the container (at 500 seconds). Consequently, the control is responsible for increasing the power delivered to the lamp, raising the temperature again until reaching the setpoint. (See Figure-10).

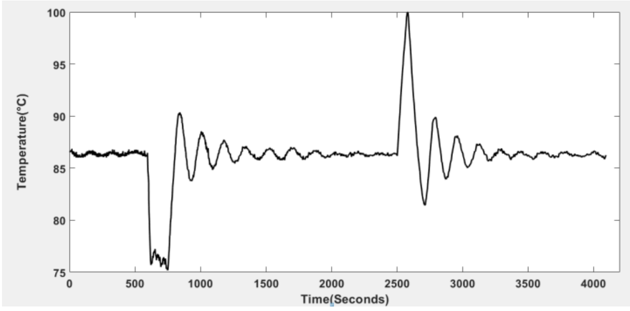

Figure-10. Disturbance rejection.

The second disturbance occurs when the container is closed (at 2500 seconds), trapping the heat again, and due to the power that the bulb has, the temperature increases by approximately 14° C above 86° C. Therefore, the control makes the lamp receive less power so that it reduces its temperature and reaches again at the setpoint.

4. CONCLUSIONS

Using the MATLAB® identification tool allows modeling of the plant without having much knowledge about signals and systems, which allows this process to be carried out without major difficulty.

Using the SIMULINK® PID block to find a suitable PI controller was an excellent choice, as the design is done intuitively, improving the important parameters of the plant. It also showed good robustness to setpoint changes and disturbance rejection.

The implementation of the system had a very low cost since Arduino UNO boards are used as main controllers, and low-cost devices such as the TLC5615 and the MCP4725 for communication between the two boards.

This type of system can be easily developed in a classroom, since it has low cost, easy implementation, and a simple user interface. This allows to focus the attention on power issues and not on control and programming.

All the parameters of the plant can be improved more than the response obtained if instead of applying a PI control, a PID control is used.

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