Advances in Technology Innovation, vol. 4, no. 2, 2019, pp. 94-104

Implementation of Adaptive Embedded Controller for a Temperature Process

J. Satheesh Kumar[1,*], Deepu Sankar [2]

[1]Department of Electronics and Instrumentation, Dayananda Sagar College of Engineering, Bangalore, India

[2]Department of Electronics and Instrumentation, Karunya University, India

Received 08 December 2017; received in revised from 11 April 2018; accepted 18 August 2018

Abstract

The paper proposed and carried out an adaptive embedded control strategy with the help of Arduino open hardware platform. The proposed control strategy is to carry out a cost-effective interface between the simulation software and a real-time process. The data acquisition and control is done with the help of Arduino Uno which has been interfaced with MATLAB Simulink The control algorithms developed in Simulink model can be downloaded into the Arduino Uno, working as a standalone controller. In this paper, various control algorithms are used to control the temperature process, including embedded Modified Model Reference Adaptive Control (MMRAC). Its performance is compared to other control algorithms. The result shows that the MMRAC scheme improves the transient performance of the temperature control system.

Keywords: embedded, control, MATLAB, Simulink, MRAC

1. Introduction

Nowadays, the automation and control of most of the real-time systems are achieved by using a computer connected through the expensive Data Acquisition System (DAS). The specification and requirement of DAS depend on the software being used. The proposed methodology uses a low-cost DAS and an embedded system to develop a controller that can give better performance. The development of DAS and the controller in the same hardware improves the compactness of the proposed system. In this paper, the Arduino Uno micro controller is used for the development of DAS and controller. The control algorithm is developed using MATLAB Simulink tool. Tawanda [1] presented similar algorithm developments using Simulink. The MATLAB Simulink provides a platform to interface Simulink with Arduino Uno through Arduino IO library and support package. The development of the control algorithm in the embedded system has become simpler by this approach. The early versions of the embedded target devices for Simulink tool are expensive. The Real-Time Interface (RTI) developed by Arduino Uno, is cost effective.

Five different control algorithms, namely Proportional Control (P), Proportional-Integral Control (PI), Proportional Integral Derivative Control (PID), Model Reference Adaptive Control (MRAC) and MMRAC were developed to control a temperature process using Simulink. There are two ways to test the developed algorithm in real-time. One method is to use the Arduino Union, along with the MATLAB Simulink running on the PC. Another way is to use Arduino Uno as a standalone controller in real time. In the second case, after downloading the control algorithms in Arduino UNO microcontroller, the computer can be disconnected from it. The second method provides the flexibility of using the Arduino Uno as a standalone embedded controller. This embedded controller is used to control the temperature process in real-time environment.

* Corresponding author. E-mail address: jsatheeshngl@gmail.com
Tel: +91-9003368217

The PID controller is used in process industries to control various processes. Based on the necessity and nature of the process, the adaptive controller is considered as a suitable controller for many processes. MRAC is one such adaptive controller. Several adaptive control structures are discussed by [2] and [3]. The robustness of the control system are improved by combining both PID and adaptive control action. The result presented by [4] shows the improved performance by the addition of PID in adaptive control.

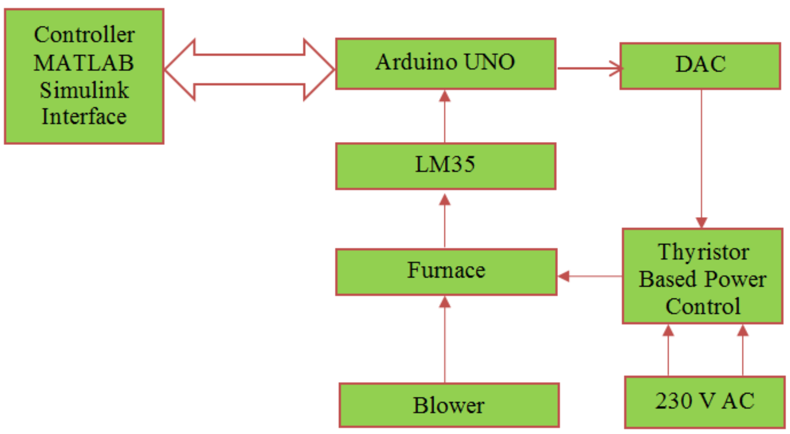
A modified control scheme of MRAC is discussed in this paper. In the Modified MRAC, PID controller action is included. The error given to the PID controller is derived from the model output and the process output. The combined action of the PID controller and MRAC drives the final control element in the process. This adaptive controller will give better settling time and efficiency compared to MRAC. Therefore an Arduino aided MMRAC is another main aspect of the paper. The most significant property of a real-time interface in MATLAB Simulink and Arduino UNO helps in the development of standalone controller. Hence this work is identified as an Adaptive Embedded controller for a temperature process.

2. Simulink-Arduino Real Time Interface

MATLAB and Simulink have been associated with engineering and academic world as a design and development tool. The method of linking, design, and development into the real-time process in an optimized way is a challenging task. Standard data acquisition cards are available to facilitate the real-time interface. Data acquisition systems for MATLAB are discussed in [5]. Software specific data acquisition systems are used in many cases; however, these DAS can only be used in a specific software application and may not be compatible with other applications, and such systems are presented in the article [6]. MATLAB provides the platform to interface the Simulink with the real-time process through the Arduino IO package or Arduino Support package. The Simulink model can be developed using the Arduino IO Library blocks. The required control algorithms are developed using Simulink and Arduino support package. The Arduino support package converts the Simulink model to code, which runs directly on Arduino Uno. Therefore the Arduino Uno can be disconnected from the host computer, and it controls the real-time process independently.

3. Experimental Analysis

The experiment is conducted in a thermal process analyzer, it includes a thyristor controlled electric furnace and an air blower. The air blower acts as a load variable in the process. The blower speed can be varied manually to introduce the disturbance. The controlled variable is the furnace temperature and the manipulated variable is the control voltage, to the thyristor-based power control system.


Controller MATLAB Simulink Interface
Arduino UNO
DAC
LM35
Thyristor Based Power Control
Furnace
Blower
230 V AC
Fig. 1 Block diagram of thermal process control systems

The above mentioned experimental setup is the prototype of a thermal process. The control system block diagram for the thermal system is shown in Fig. 1. According to the desired temperature, the control voltage is determined from the control algorithm, which is present in the microcontroller. The temperature measurement is made with the help of LM35 precision integrated-circuit temperature sensor. The output voltage of this sensor is linearly proportional to the Centigrade temperature and the scale factor is 10mV per degree centigrade. The temperature range of this sensor is -55℃ to 150℃. The measured temperature is acquired with Arduino Uno which is a microcontroller based on the ATmega328.

A thyristor-based power control circuit is used to regulate the temperature of the furnace. The control voltage for the thyristor-based power control circuit determines the temperature of the furnace by regulating the AC supply voltage using a pulse width modulation method. The control voltage is obtained from the Arduino Uno. Typically the control voltage is an analog signal. Since Arduino Uno supports only digital outputs an external Digital to Analog Convertor (DAC) is used. DAC circuit is designed using DAC0808 which is an 8-bit monolithic digital-to-analog converter. The control voltage from DAC is given to a thyristor-based power control for proper temperature regulation.

4. Embedded Adaptive Controller

The possibilities of embedded controller implementation using Simulink are summarized in this section. The real-time implementation of an adaptive controller using Simulink requires a target device. The various kinds of target devices compatible with Simulink are micro controllers, Digital Signal Processors (DSP) and xPC Target. Most of the target devices are costly and unbearable for a smaller level projects. The real-time control by xPC Target using Simulink is developed as mentioned in [7] and [8]. The xPC Target devices are compatible with high-performance industrial computers. The DSP based embedded platform provides the facility of model conversion from Simulink to real-time environment. It gives the flexibility of an interfacing more number of peripheral devices. Among these target devices, microcontrollers are the cheapest device used in an embedded system. In microcontroller category also various processors are available, some of the processors are ATmega, ARM processors, etc. The ARM processor-based embedded adaptive controller is developed as presented in [9]. Arduino is one of the microcontrollers used for the development of embedded controllers. Control algorithm development by Arduino Integrated Development Environment (IDE) is discussed in [10]. Through IDE, Arduino can be programmed using embedded programming. The IDE based control algorithm development is a bit complex and time-consuming. The Simulink model-based program is not possible with IDE. The Arduino support package facilitates the Simulink model-based programming in Arduino.

In this paper, a control algorithm is implemented in Arduino Uno using the Arduino support package. The process temperature is read by IC-based temperature sensor LM35. Arduino reads the temperature of the thermal system through its pin number 1. Since the Arduino is having 10-bit Analog to Digital Convertor (ADC), the maximum ADC value is 1024 and the reference is given 5V. The scaling has to be done properly to get the process temperature. As per the data sheet, the output of LM35 is 10mV/℃. The actual temperature is found by Eq. (1).

$$T = \frac{V_{out} \times 5}{1024 \times 0.01} (°\mathrm{C}) = 0.483 V_{out} \tag{1}$$

where V_{out} is the output of LM35 in decimal equivalent.

The equivalent temperature value is given to the control algorithm to compute the required control signal. The control signal is sent to its digital output pins as shown in Fig. 2. The control signal generated is converted into 8-bit data and is given to 8 digits write blocks. Integer to bit converter block demands only integer values, hence a rounding function is used before it. The 8-bit conversion requires the multiplication of the control signal with constant so that the 0-5V will be converted to 0-255. The multiplication constant 51 is chosen to convert 0-5 range to 0-255 range. The 8-bit digital outputs are sent to digital pins 4, 5, 6, 7, 10, 11, 12 and 13 of Arduino. The thyristor-based control circuit requires an analog voltage. Hence these digital signals are converted into analog signal by a Digital to Analog Convertor (DAC). An external DAC is used for this conversion.

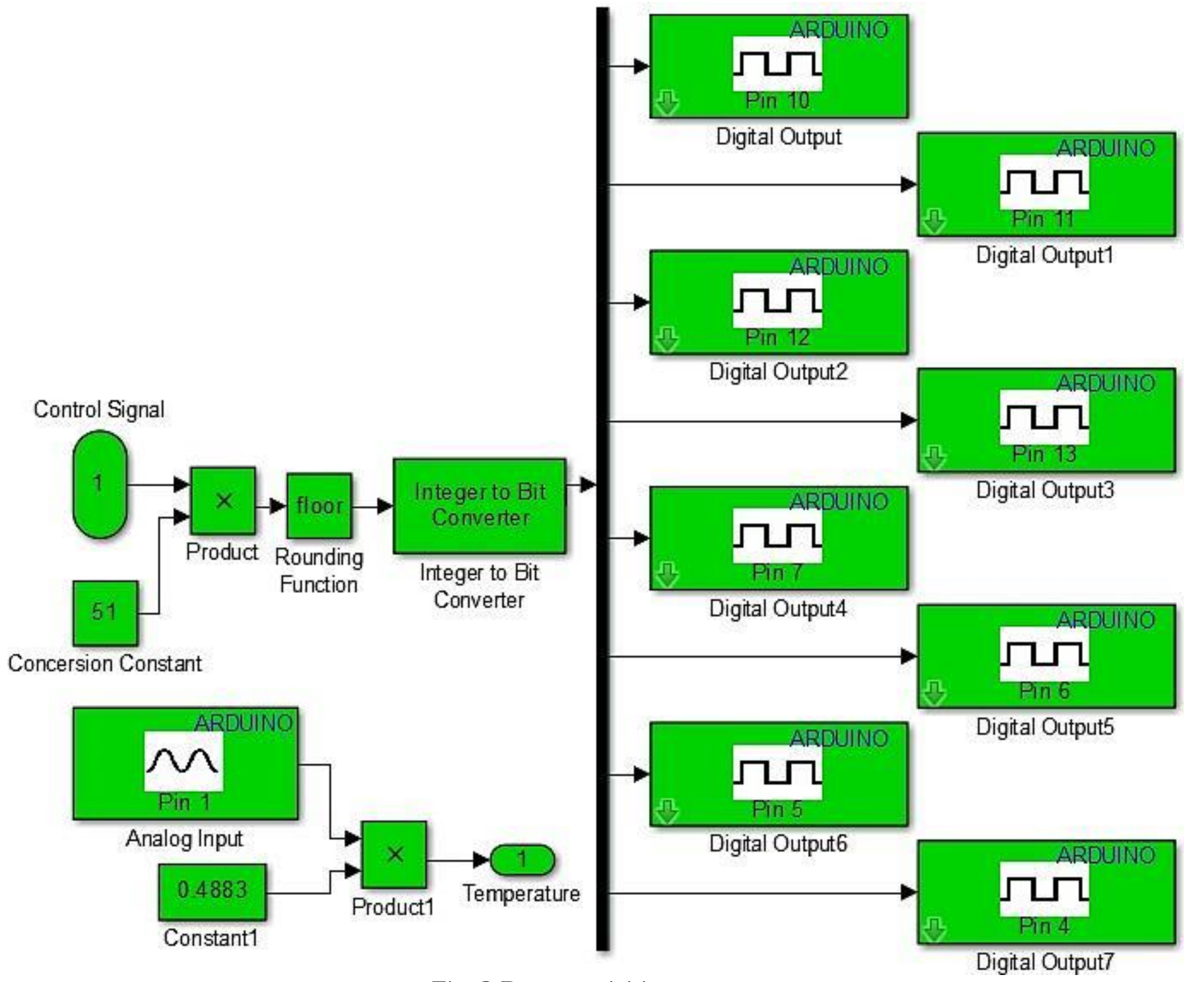

Control Signal
1
Product
51
Concersion Constant
floor
Rounding Function
Integer to Bit Converter
Integer to Bit Converter
ARDUINO
Pin 1
Analog Input
0.4883
Constant1
Product1
1
Temperature
ARDUINO Pin 10 Digital Output
ARDUINO Pin 11 Digital Output1
ARDUINO Pin 12 Digital Output2
ARDUINO Pin 13 Digital Output3
ARDUINO Pin 7 Digital Output4
ARDUINO Pin 6 Digital Output5
ARDUINO Pin 5 Digital Output6
ARDUINO Pin 4 Digital Output7

Fig. 2 Data acquisition system

4.1. Implementation of P, PI, and PID controllers

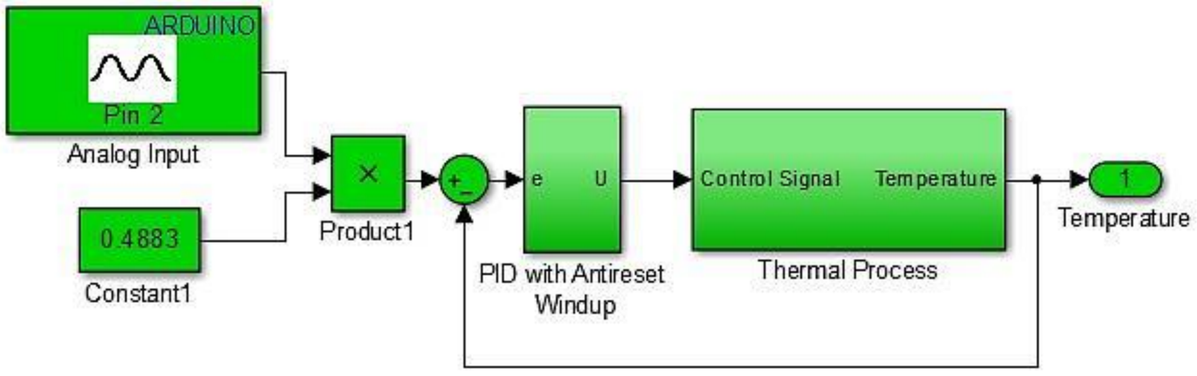


Fig. 3 P, PI & PID controllers using Simulink Arduino support package

The real-time implementation of P, PI and PID controllers using Simulink Arduino support package is shown in Fig. 3. The developed control algorithm is downloaded into Arduino to work as a standalone controller. All the three control functions are achieved using the same MATLAB subfunction by properly enabling the proportional, integral and derivative gains. The setpoint is given to pin number 2 of the Arduino Uno using a potential divider circuit. This circuit provides the output in the range of 0-5V to pin number 2 of Arduino Uno. The provision for adjusting the setpoint is also properly scaled based on Eq (1). The integral controller may experience the integral windup in real-time process control. The PID control algorithm includes the anti-reset windup algorithm to reduce integral windup. The data acquisition system for the thermal process shown in Fig. 3 is illustrated in Fig. 2.

4.2. Development of mathematical model for the temperature process

The laboratory-based temperature process analyzer consists of a smaller size furnace. The operating region is in between 25°c to 80°c. Process reaction curve method is used to find the mathematical model of the process. The feedback in Fig. 3 is removed. The initial steady state is noted. A step input of known magnitude is given to pin number 2 of the Arduino at time T1. The time at which the process variable begins to change is noted as T2. The process variable is allowed to reach the new steady state. The difference between T1 and T2 is the dead time of the process. The change in the process variable is computed by subtracting the new steady state of the initial steady state. Time taken by the response to reach 63.2% of process variable change is noted as T3. The time constant of the process is the difference between T3 and T2. The process gain is calculated by dividing the magnitude of the final steady state by the magnitude of the change in step input. The derived model is a first-order system with the dead time process. The model of the system is given in Eq. (2).

$$G(s)=\frac{1.2e^{-10s}}{55s+1} \tag{2}$$

4.3. Implementation of model reference adaptive control

Adaptive control is one of the widely used control strategies to design advanced control systems for better performance and accuracy [11]. Model Reference Adaptive Control (MRAC) is a direct adaption strategy with an adjustable mechanism to adjust controller parameters. The implementation of MRAC for the first order process is carried out as discussed in [12]. The MRAC works on the principle of adjusting the control parameters so that the output of the actual plant tracks the output of a reference model having the same reference input [13]. The implementation of MRAC and the design of adjustment mechanisms are referred to from [14].

The reference model is used to give an ideal response of the adaptive control system to the reference input. The controller is usually described by a set of adjustable parameters. In this paper two adjustable parameters, θ_1 and θ_2 are used to describe the control law. Adaptive mechanism is used to alter the parameters of the controller so that the actual plant could track the reference model. Mathematical approaches like MIT rule, Lyapunov theory, and theory of augmented error can be used to develop the adjusting mechanism. Since the experimental thermal process is a first order system, MIT based MRAC for a first order system is followed for the development of controllers.

The model of the temperature process and the reference model are given in Eqs. (3) and (4).

$$\mathrm{G}(s)=\frac{y(s)}{u(s)}=\frac{b}{s+a} \tag{3}$$

where y is the output from the process and u is the control input to the process.

$$G_m(s)=\frac{y_m(s)}{u_c(s)}=\frac{b_m}{s+a_m} \tag{4}$$

where y_m is the reference model output and the u_c is the command signal to the reference model.

The controller equation is given in Eq. (5).

$$u=\theta_1 u_c - \theta_2 y \tag{5}$$

where θ_1 and θ_2 are the controller parameters, y is the measured temperature and u is the controller output.

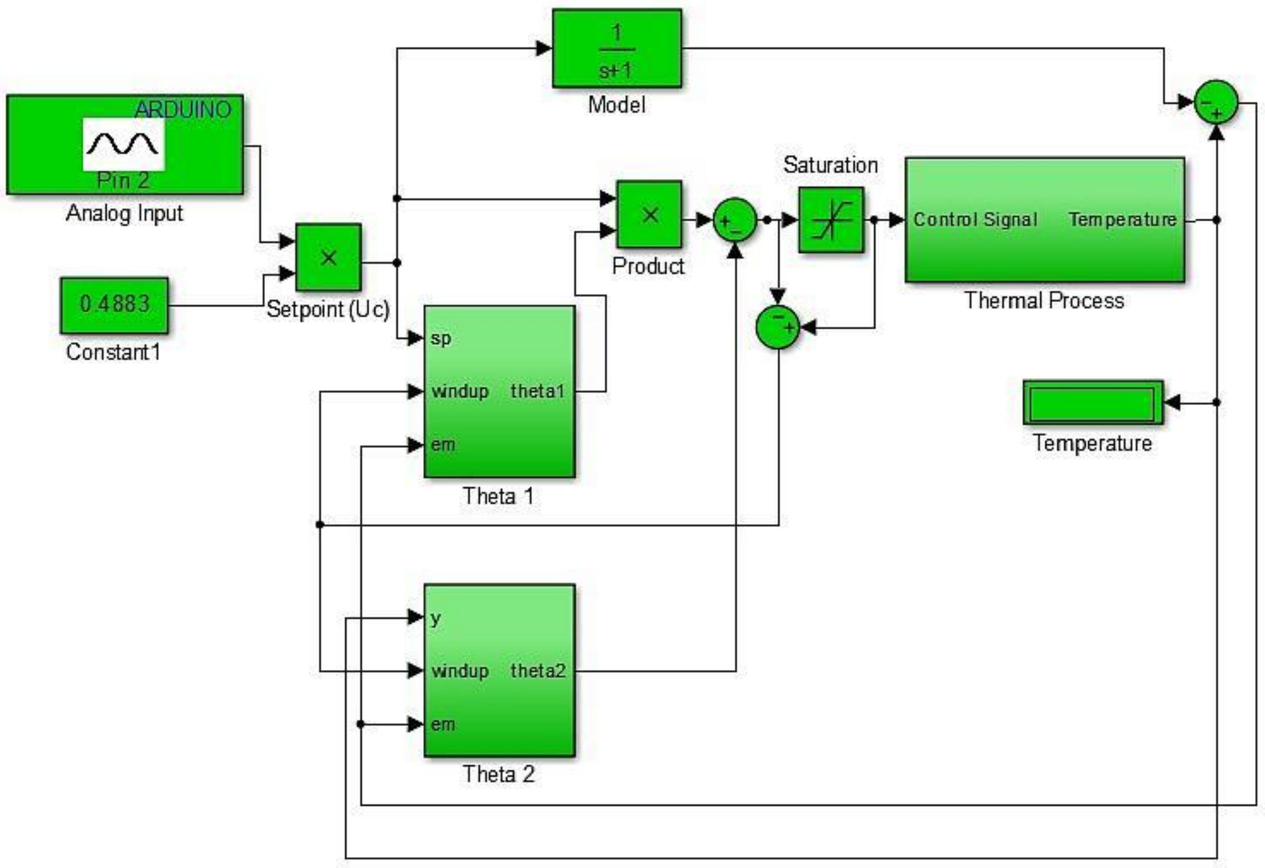


Fig. 4 MRAC using Simulink Arduino support package

As per the MIT rule, the controller parameter has to be changed in the direction of the negative gradient of cost function J. The cost function is chosen in this application is given in Eq. (6) and the rate of change of controller parameter is described in Eq. (7) $\frac{\partial e}{\partial \theta}$ is known as sensitivity derivative.

$$J = \frac{1}{2}e^2 \tag{6}$$

$$\frac{d\theta}{dt} = -\gamma'\frac{\partial J}{\partial \theta} = -\gamma' e\frac{\partial e}{\partial \theta} \tag{7}$$

where e is the error given in Eq. (8).

$$e = y - y_m \tag{8}$$

where y is the process output and it is described by Eq. (9). From Eqs. (3) and (5), y is derived.

$$y = \frac{b\theta_1}{s+a+b\theta_2}u_c \tag{9}$$

The controller parameters are obtained from Eqs. (8) and (9). The denominators of sensitivity derivatives are approximated as per Eq. (12).

$$\frac{\partial e}{\partial \theta_1} = \frac{b}{s+a+b\theta_2}u_c \tag{10}$$

$$\frac{\partial e}{\partial \theta_2} = -\frac{b}{s+a+b\theta_2}y \tag{11}$$

$$s+a+b\theta_2 = s+a_m \tag{12}$$

The MIT rule is applied to determine the controller parameters. The sensitivity parameters given in Eqs. (10) and (11) are substituted in Eq. (7) to find out the controller parameters. The parameters b and a_m are combined with adaptation gain γ'. The equations for updating the controller parameter θ_1 are given in Eqs. (13) and (14). Similarly, the other controller parameter θ_2 is updated using Eqs. (15) and (16).

$$\frac{d\theta_1}{dt} = -\gamma'\left(\frac{b}{s+a_m}u_c\right)e = -\gamma\left(\frac{a_m}{s+a_m}u_c\right)e \tag{13}$$

$$\theta_1 = -\gamma\left(\frac{a_m}{s+a_m}\right)u_c\int edt \tag{14}$$

$$\frac{d\theta_2}{dt} = \gamma'\left(\frac{b}{s+a_m}y\right)e = \gamma\left(\frac{a_m}{s+a_m}y\right)e \tag{15}$$

$$\theta_2 = \gamma\left(\frac{a_m}{s+a_m}\right)y\int edt \tag{16}$$

where γ is the adaptation gain, u_c is command signal, e is an error and y is the measured process variable.

Practical implementation leads to integral windup due to the integrator present in the equations. Hence anti-reset windup is also included in the control algorithm. The reason for reset windup is the accumulation of the input to the integrator. The accumulated value leads to the saturation of the controller output. The anti-reset algorithm helps to remove the integral windup. The anti-reset windup procedure includes a saturation block, which limits the controller output. The controller output before the saturation block is subtracted from the controller output after the saturation block. The subtracted output is added to the input of the integrator. This procedure will not allow the integrator to accumulate its output. This procedure doesn't have any effect till the controller output is below the saturation value because the subtracted value before and after the saturation block is zero. Once the controller output begins to increase from the maximum value, the anti-reset windup procedure will start functioning. The same anti reset procedure is used in all the controller implementations described in this paper.

The controller implementation is shown in Fig. 4. The control signal from the algorithm is limited to 5V using the saturation block in the Simulink. As shown in Fig. 2, this output from the saturation block is converted into corresponding digital output. Using a DAC the digital output is converted to analog and given to the thyristor-based power control circuit to control the furnace temperature.

4.4. Implementation of modified model reference adaptive control

In order to improve the transient performance of the control system, the MRAC scheme is modified [15]. In the modified MMRAC, classical PID control action is also included. The modified controller output u is derived as per the Eq. (17). The controller parameters θ_1 and θ_2 have the same purpose similar to the MRAC. The MMRAC is developed by subtracting the effect of PID controller action from the MRAC [16].

$$u = \theta_1 u_c - \theta_2 y - \left(K_p e + K_i\int edt + K_d\frac{de}{dt}\right) \tag{17}$$

where K_p, K_i and K_d are the proportional, integral and derivative gains for the PID controller.

The optimal values of PID controller parameters are appropriately chosen to provide the best process regulations.

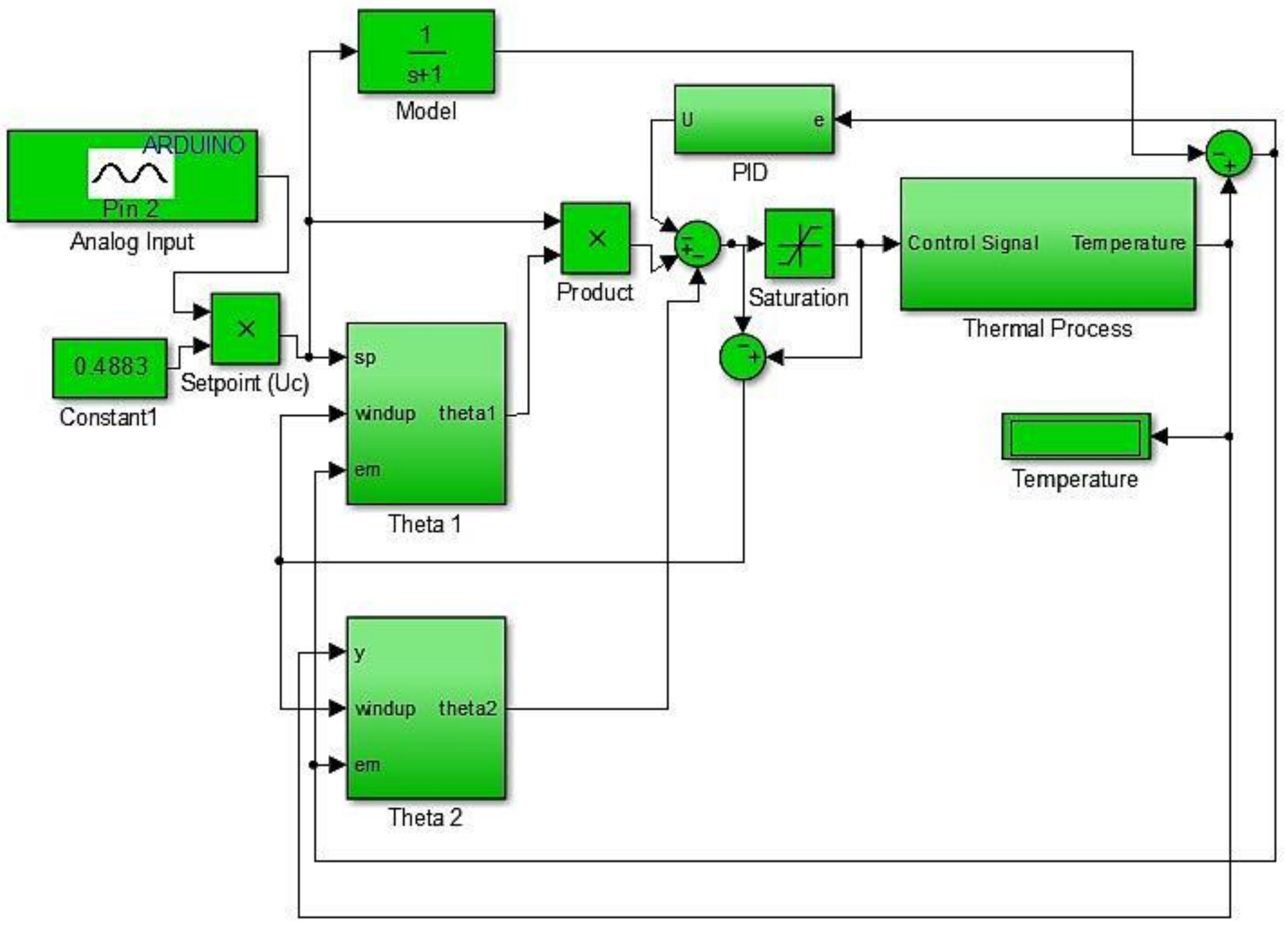


Fig. 5 MMRAC using Simulink Arduino support package

Even though many tuning procedures are available, choosing PID controller parameters is a challenging task for control engineers, hence for a real-time process, control engineers prefer trial and error method [17]. The derivative action of PID control improves the predictive nature of the control system and improves the speed of response. It predicts future controlled output by computing the rate of change of error and accordingly takes the control action to minimize the error. The integral action removes the offset in the controlled variable. The integral windup due to the integral action is removed by the anti-reset windup procedure mentioned in the previous section. Hence the modified control scheme includes all the advantages of PID control and MRAC. The integrator's used in the computation of θ_1 and θ_2 also produces reset windup; hence the same anti-reset windup procedure is followed to remove the integral windup.

The real-time implementation of the modified model reference adaptive controller is shown in Fig. 5. The control algorithm is developed using Simulink Arduino support package. The real-time interface is developed by the help of Analog input block and the digital output block. The data acquisition system for the thermal process analyzer is developed in the subsystem as shown in Fig. 2. The setpoint of the standalone MMRAC is set with the help of the knob present in the hardware. The value set by the user is read by the controller and it is properly converted into engineering units. The control algorithm compares both the reference model output and the actual process output. The computed controller parameters force the process to follow the reference model. The computation is based on Eq. (17) so that the change in the controller parameter minimizes the error. According to the control algorithm, the desired control signal is sent to the thyristor-based power control circuit to control the temperature.

5. Results and Discussion

The classical PID controller algorithm and model-based algorithm was developed in this research. Real-time implementation using the microcontroller is simplified by this approach. The experimental setup shows the actual electric furnace with a blower. The thyristor-based power control circuit, controller implementation using Simulink and the Arduino Uno with the peripheral circuits are also depicted in Fig. 6. The control algorithms developed in this work are P controller, PI Controller, PID Controller, MRAC and MMRAC. The required control algorithm was downloaded into the Arduino Uno hardware. The electric furnace was allowed to settle at two different temperatures 40°c and 60°c. The controller performance was observed by plotting the response of the temperature control system with respect to time. The transient performance of the system is analyzed for all the controllers.

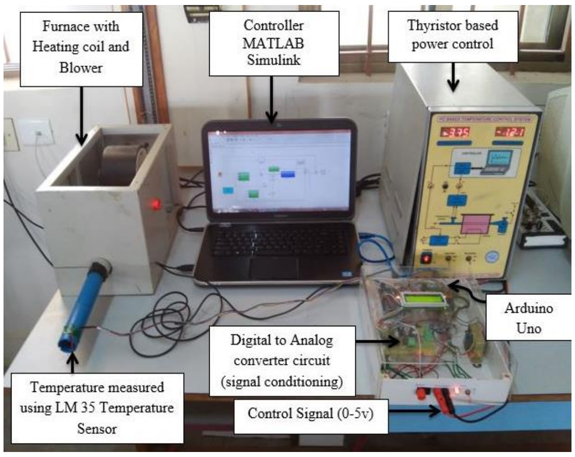

Furnace with Heating coil and Blower
Controller MATLAB Simulink
Thyristor based power control
Arduino Uno
Digital to Analog converter circuit (signal conditioning)
Temperature measured using LM 35 Temperature Sensor
Control Signal (0-5v)

Fig. 6 Experimental setup

5.1. *Controller observation and response*

The following control algorithms P, PI, PID, MRAC, and MMRAC were implemented in real time. A comparative analysis has been made using the available data. The temperature of the furnace is plotted in graphs with respect to time. The response of the furnace for the setpoint of 40°c is shown in Fig. 7. Since the setpoint is 40°c and it is closer to the room temperature, the process takes around 20 seconds to reach the setpoint. The rise time of the process varies with respect to the controllers used. The response of the furnace for the setpoint of 60°c is shown in Fig. 8. Since the process lag for the electric furnace is considerably high, it takes around 200 seconds to reach the setpoint. The time from 200 seconds to 380 seconds is used for the comparative analysis.

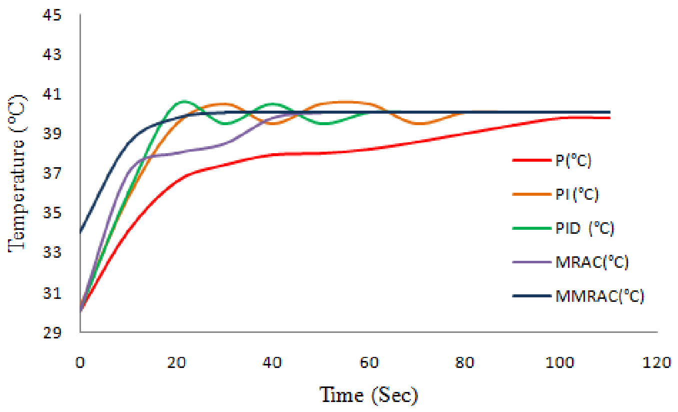


Fig. 7 Comparative response of furnace for 40°c setpoint

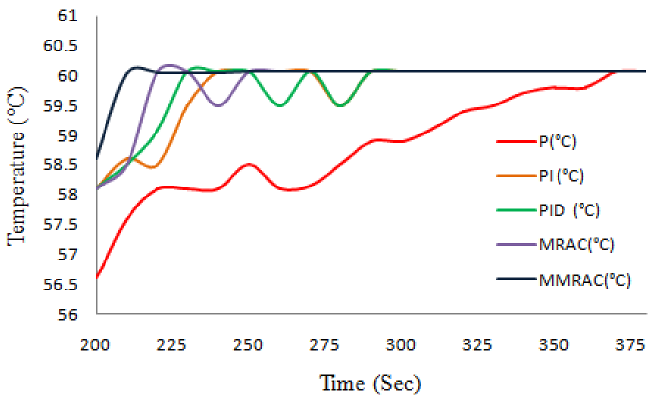


Fig. 8 Comparative response of furnace for 60°c setpoint

5.2. *Performance analysis*

The performance of the controller is analyzed using the settling time. The tolerance limit for the settling time is 1%. The comparative analysis is listed in Table 1. The MMRAC in real time shows better performance when compared with other controllers. The other performance metrics are not considered, because except for PI and PID controllers, other controllers have very negligible oscillations or zero oscillations around the setpoint. So there is no overshoot or negligible overshoot for Proportional Control, MRAC and MMRAC. The settling time of the process using MRAC and MMRAC, for the setpoint of 40°c is less than the rise time. The settling time and rise time are the same for the process using MRAC and MMRAC, for the setpoint of 60°c. In all operating regions, MRAC and MMRAC respond quickly to the process parameter changes and take the corrective action.

Table 1 Performance Analysis

Controller	Set point = 40°c		Set point = 60°c	
	Settling time (sec)	Rise Time (Sec)	Settling time (sec)	Rise Time (Sec)
P	100	100	320	370
PI	80	30	230	240
PID	60	20	220	230
MRAC	40	50	220	220
MMRAC	20	30	210	210

6. Conclusions

The Arduino open hardware platform is used as a low-cost data acquisition system and controller. P, PI, PID, MRAC, and MMRAC are implemented in the Arduino microcontroller using MATLAB Simulink. The performance analysis is made in terms of settling time. The developed embedded controller provides the platform to implement any type of complex control algorithms. This will help in the field of process control to implement complex algorithms with low-cost devices. The embedded based MMRAC controller shows better performance over the other controllers mentioned in this paper. Hence, the system under study is best suited for MMRAC. This work may be extended by developing intelligent controller using the Arduino microcontroller. Implementing complicated algorithms can be simplified by using the real-time interface developed in this paper. Hence the proposed methodology will be beneficial to academic institutions and research organizations in testing and implementing various sophisticated algorithms.

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] T. Mushiri, A. Mahachi, and C. Mbohwa, “A model reference adaptive control system for the pneumatic valve of the bottle washer in beverages using Simulink,” Proc. International Conference on Sustainable Materials Processing and Manufacturing (SMPM 17), Elsevier, January 2017, pp. 364-373.

[2] B. M. Mirkin and Per-Olof Gutman, “Output feedback model reference adaptive control for multi-input-multi-output plants with state delay,” Systems & Control Letters, vol. 54, pp. 961-972, February 2005.

[3] R. A. Fahmy, R. I. Badr, and Farouk A. Rahman, “Adaptive PID controller Using RLS for SISO stable and unstable systems,” Advances in Power Electronics, vol. 2014, pp. 1-5, October 2014.

[4] R. A. Fahmy, R. I. Badr, and Farouk A. Rahman, “Adaptive PID controller Using RLS for SISO stable and unstable systems,” Advances in Power Electronics, vol. 2014, pp. 1-5, October 2014.

[5] K. K. McKee, Gareth L. Forbes, Ilyas Mazhar, Rodney Entwistle, and Ian Howard, “Low cost remote data acquisition system, ”Curtin University, Department of Mechanical Engineering, Technical Note, December 2013.

[6] S. Humayun, Maria Mehmood, and Faran Mahmood, “Developing a LabVIEW and MATLAB-based test bed for data acquisition, analysis and calibration of frequency generators over GPIB,” International Journal of Computer Applications, vol. 40, pp. 11-15, February 2012.

[7] Handbook of Networked and Embedded Control Systems. Birkhauser Boston, University of Maryland, 2008.

[8] D. Hercog, A. Rojko, M. Curkovic, B. Gergic, and K. Jezernik, “Embedded platform for rapid implementation of local and remote motion control experiments,” Przeglad Elektrotechniczny, vol. 87, pp. 73-76, March 2011.

[9] M. Engin, “Design and control applications of mechatronic systems in engineering,” 1st Ed. London: Intec, 2017.

[10] A. M. El-Nagar, "Embedded intelligent adaptive PI controller for an electromechanical system," ISA Transactions, vol. 64, pp. 314-327, September 2016.

[11] Ioana Nascu, Ioan Nascu, and G.Vlad, "Predictive adaptive control of an activated sludge wastewater treatment process," Advances in Technology Innovation, vol. 1, pp. 38-40, March 2016.

[12] M. P. R. V. Rao, "New design of model reference adaptive control systems," Journal of Applied Mechanical Engineering, vol. 3, pp. 1-3, January 2014.

[13] S.H. Rajani, B. M. Krishna, and U. Nair, "Adaptive and modified adaptive control for pressure regulation in a hypersonic wind tunnel," International Journal of Modelling Identification and Control, vol. 29, pp. 78-87, March 2018.

[14] K. J. Astrom and B. Wittenmark, "Adaptive control," 2nd Ed. New York: Dover Publications Inc., 2013.

[15] S. Zhang and S. Dian, "Controller design for compound pendulum with PID and MRAC switch control," Proc. International Conference on Automation Control and Robotics Engineering (CACRE 2018), IOP Publishing, July 2018, pp. 1-5.

[16] R.J. Pawar and B.J. Parvat, "MRAC and modified MRAC controller design for level process control," Proc. Indian Control Conference (ICC 18), IEEE Explore, January 2018, pp. 217-222.

[17] L. Guessas and K. Benmahammed, "Adaptive backstepping and PID optimized by genetic algorithm in control of chaotic," International Journal of Innovative Computing Information and Control, vol. 7, pp. 5299-5312, September 2011.