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Closed-loop temperature control using MATLAB@Simulink, Real-Time Toolbox and PIC18F452 microcontroller

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Abstract. Today's way of life is closely linked with technology and it would be impossible without a microcontrollers. They are represented in all spheres of life: in the automotive industry, robotics, computer systems, home appliances, etc. Also, today's life is unthinkable without computers. The combination of computer and microcontroller provides a very great possibilities, which uses the good features of both. This paper describes the use of a computer in combination with MATLAB@Simulink, Real-Time Toolbox and PIC18F452 microcontroller for closed-loop temperature control. Control and settings for temperature are in MATLAB@Simulink and they can be very easily adjusted. Also, all the information: the refrence temperature, information from controller and the measured temperature are available at any time in MATLAB@Simulink and can be processed and stored. For real-time operation is used Real-Time Toolbox. The information is sent from computer over serial port to PIC18F452 microcontroller. The PIC18F452 microcontroller receives information and processes them. Information from PIC18F452 microcontroller is amplified using a transistor that works as the switch and the thyristor which is used to turn on the heater. Turning off thyristor is automatically passing supply voltage through zero. Temperature measurement is performed using the temperature sensor LM335. Output signal from the sensor is amplified by using operational amplifier LM324 and after that sent in PIC18F452 microcontroller. The microcontroller processes information and after that send it over serial port to computer. In this way the loop of temperature control is closed using a computer and PIC18F452 microcontroller.

Keywords: MATLAB@SIMULINK, Real-Time Toolbox, PIC18F452 microcontroller, Temperature sensor, Heater.

1 Introduction

Temperature is a fundamental and quantitative physical science size of heat. As such, it had to first of all get independent, objective measure for accurate quantitative comparisons of the degree heat of object, system or process. Temperature is a measure of the internal energy of the system, while heat is measure of how energy transferred from one system to another.

MATLAB is a very developed language of technology that combines low cost, visualization and programming in simple development environment MATLAB [1], [2]. It contains a collection of predefined functions that are grouped in tool groups (Toolboxes) intended to solve various problems from scientific field. MATLAB contains different Toolboxes: Optimization Toolbox, Neural Network Toolbox, Fuzzy Logic Toolbox, Control System Toolbox, Signal Processing Toolbox, Statistics Toolbox, Real-Time Toolbox, etc. There are many applications of these tools, but we are focused on the RealTime Toolbox [3], [4].

Real-Time simulation represent the simulation speed of execution as in the real time, there is no faster or slower than reality. It is based on the integration of fixed step time, which is specified in microseconds or milliseconds. Simulation time represents simulation real-time display and measured simulation time in real time which performs simulation.

The use of real-time simulation include [5]:

- Setting up and development of prototype
 - ❖ Validation algorithm
 - ❖ Easy and fast implementation
- The failures (defects) on equipment
 - ❖ Security system test
 - ❖ Test reproduction
- Testing of industrial equipment
 - ❖ Integration generate disorders
 - ❖ Analysis of equipment from different manufactures

Here is described one practically implemented system for closed-loop temperature control. The described system is realized using the PIC18F452 microcontroller from family 18F Microchip manufacturers.

The PIC18F452 microcontroller has many number of components. PIC microcontroller owns 40 or 44 I/O pins, which makes it a good choice for the realization of these simple devices. Main features are: collection of 35 instructions, 1024x14 bits of program memory flash type, 68x8 bit memory RAM type of data, 64x8 bit memory EEPROM type of information, 13 I/O lines, 8-bit timer, 4 interrupt sources, possibility of programming protective bits, using energy saving sleep mode. Practical realization use standard quartz crystal operating frequency of 4 MHz [6]-[9].

In this paper is described use of PIC18F452 microcontroller in combination with software package MATLAB@Simulink and Real-Time Toolbox for closed-loop temperature control.

2 Closed-loop temperature control

Temperature is one of the most important and the most common measurement size in the technique. We are constantly related with temperature. Air temperature is something we face every day, daily temperature changes, seasonal temperature changes, temperature of human body, temperature coolant in the car, etc.

Temperature is a physical value which is used for expressing the thermal state of a substance and is one of the basic measurement size in thermodynamics. It depends on how much of internal energy has a certain object with certain weight and pressure. Temperature can not be passed from object to object. For precise temperature control is used closed-loop system. It is shown in Figure 1. Temperature reference value or desired temperature is compared with measured temperature value. Deviation between reference and measured temperature value is sent in controller. Based on error, controller affects on executive element in order to reduce this error to zero. In this case executive element effects on heater, which heats the space or some object. Temperature is measured with temperature sensor. Sensor usually measured temperature convert in electrical value. This size is very small and need additional amplifier, which is then compared to reference value.

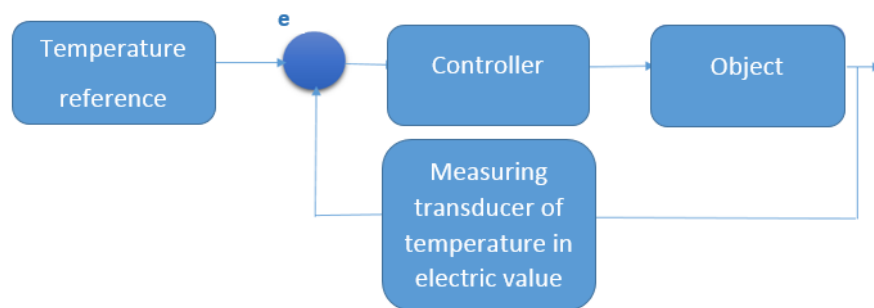


Fig. 1. Closed-loop temperature control

Two most used types of temperature controllers are:

- The controller with direct ON/OFF temperature control
- Proportional controller with widthmodulated temperature control

2.1 The controller with direct ON/OFF temperature control

An *ON/OFF* controller is the simplest form of temperature control device. Output from the device is either „on“ or „off“, with no middle state. *ON/OFF* temperature controller switch output only when temperature crosses the setpoint. For heating control, output is „on“ when temperature is below the setpoint, and „off“ above setpoint. On-off control is usually used where precise control is not necessary, in systems which cannot handle energy's being turned „on“ and „off“ frequently, where mass of system is so great that temperatures change extremely slowly, or for a temperature alarm [10].

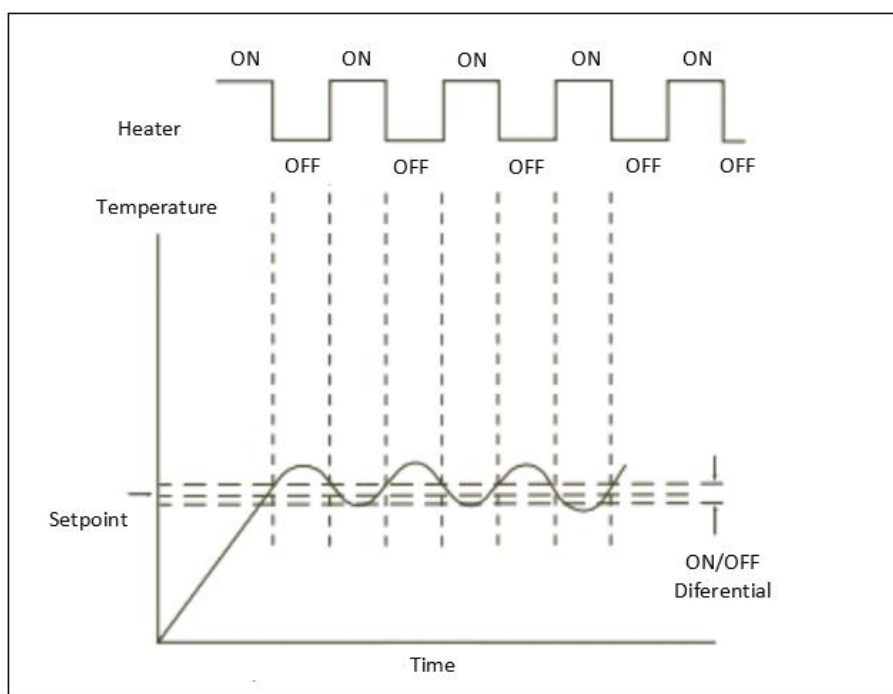


Fig. 2. ON/OFF temperature control

2.2 TheProportional controllers with width-modulated ON/OFF temperature control

Proportional controls are designed to eliminate cycling associated with on-off control. Proportional controller decreases average power being supplied to heater as temperature approaches setpoint. This has effect of slowing down heater, so that it will not overshoot setpoint but will approach setpoint and maintain stable temperature. This

proportioning action can be accomplished by turning output “on” and “off” for short intervals [10]. Proportioning action occurs within a “proportional band” around the setpoint temperature. Outside this band, the controller functions as an on-off unit, with the output either fully on (below the band) or fully off (above the band).

Proportional controls are designed to eliminate the cycling associated with ON/OFF control. Proportional controller decreases the average power being supplied to heater as temperature approaches setpoint. This has effect of slowing down heater so that it will not overshoot the setpoint, but will approach setpoint and maintain a stable temperature. This proportioning action can be accomplished by turning the output “on” and “off” for short intervals. Time period between two successive turnons is known as the “cycle time” or “duty cycle”. Proportioning action occurs within a “proportional band” around the setpoint temperature. Within the band, the output is turned “on” and “off” in the ratio of the measurement difference from the setpoint. At the setpoint (the midpoint of the proportional band), the output on/off ratio is 1:1 [10]. If temperature is below setpoint, output will be “on” longer. If the temperature is too high, output will be “off” longer. One of the advantages of proportional control is simplicity of operation. It may require an operator to make a small adjustment (manual reset) to bring the temperature to setpoint on initial startup, or if process conditions change significantly. This proportional controller varies the ratio of “on” to “off” to control temperature in closed-loop.

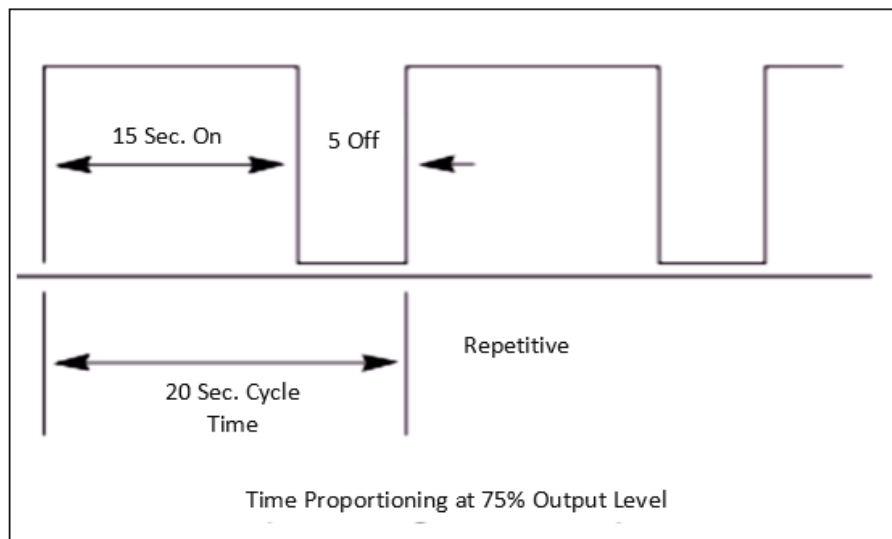


Fig. 3. Proportional controllers with width-modulated ON/OFF temperature control

3 Closed-loop temperature control using matlab@simulink, real-time toolbox and PIC18F452 microcontroller

In this paper is suggested use of programming language MATLAB@SIMULINK and PIC18F452 microcontroller for closed-loop temperature control. For real-time operation is used Real-time Toolbox.

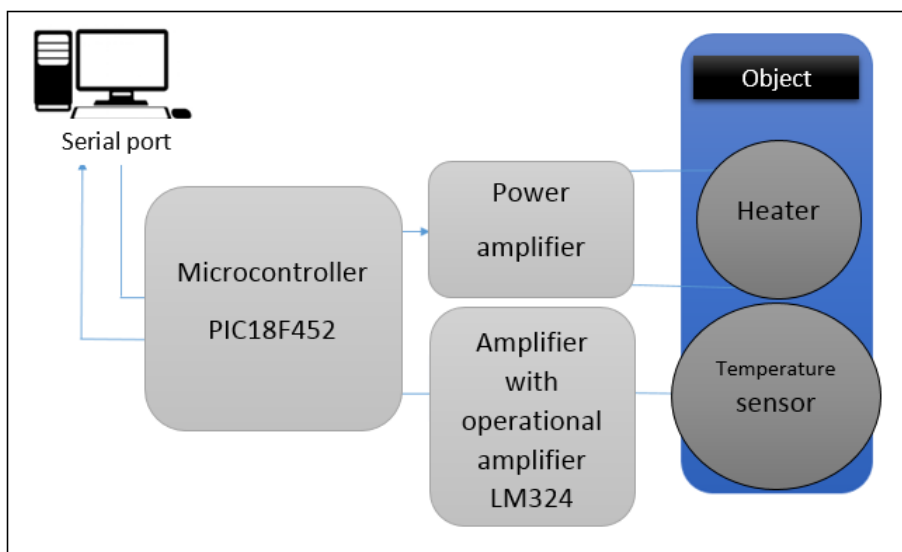


Fig. 4. Block diagram for temperature control using PIC18F452 microcontroller

In Figure 4 is shown functional block diagram for closed-loop temperature control. Data from computer over serial port and integrated circuit MAX232 are sent in PIC18F452 microcontroller. The PIC18F452 microcontroller processes received data and forward them to output port RB7. After amplification in power amplifier, which is realized by using transistor and thyristor, turns on heater that heats the object in which there is heater.

Turning off thyristor is automatically when passing the supply voltage heaters through zero. With temperature sensor LM335 is measured temperature inside object. Information of measured temperature is sent to amplifier implemented with operational amplifier LM324.

Sensor LM335 on its output provides change of 10 mV when temperature change for 1 K. It is small signal and for that reason it must be amplified using operational amplifier LM324. That amplified signal is sent in PIC18F452 microcontroller, ie pin RA1. From pin RA1 analog signal is forwarded in A/D convertor.

In A/D convertor analog voltage value is converted to digital. Digital information of measured temperature value, using serial port, is forwarded to computer. In Figure

5 is shown appearance of finished system for closed-loop temperature control using MATLAB@Simulink, Real-Time Toolbox and PIC18F452 microcontroller.



Fig. 5. Appearance of finished system for closed-loop temperature control

In the black box is located heater and temperature sensor, and it is environment in which temperature is controlled. As the box is made of metal, there are also a large heat loss, which requires more frequent involvement of the heater.

For communication (sending and receiving data) with PIC18F452 microcontroller are used simulink blocks "Packet Input" and "Packet Output" which are previously set for serial communication. That is shown in Figure 6. Of course, the same set is in PIC18F452 microcontroller.

In Figure 7 is shown simulink scheme that is used for temperature control using PIC18F452 microcontroller. Using Real-Time Toolbox is allowed to work in real time. For that is used Real Time Windows Target rtwin.tlc.

Measured temperature is processed in PIC18F452 microcontroller and then over serial port is forwarded to block „Packet Input“. After that, receiving, measured temperature is sent to block „Processing the measured temperature“. In this block information of temperature is processed and adjusted for the range in which there is reference temperature value.

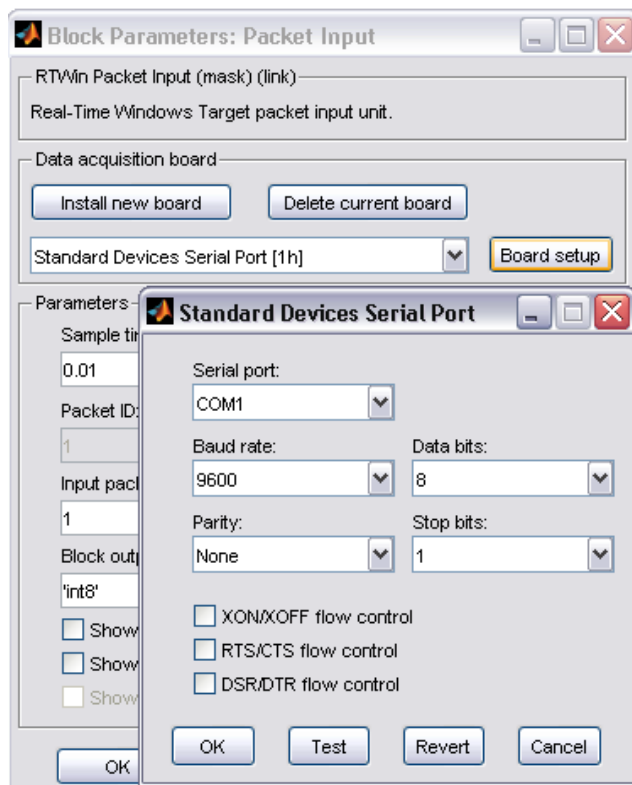


Fig. 6. Block “Packet Input” for receiving data using serial port

In Figure 7 is shown simulink scheme that is used for temperature control using PIC18F452 microcontroller. Using Real-Time Toolbox is allowed to work in real time. For that is used Real Time Windows Target rtwin.tlc.

Measured temperature is processed in PIC18F452 microcontroller and than over serial port is forwarded to block „Packet Input“. After that, receiving, measured temperature is sent to block „Processing the measured temperature“. In this block information of temperature is processed and adjusted for the range in which there is reference temperature value. However, for room temperature output value from this block is zero and with increasing temperature at the same time that value is also increasing. Than, processed value of measured temperature in adder is compared with the reference temperature value. Using, in this case, ON/OFF temperature controller, this value is processed and sent to block „Packet Output“, and than over serial port is forwarded to PIC18F452 microcontroller and power amplifiers on heater.

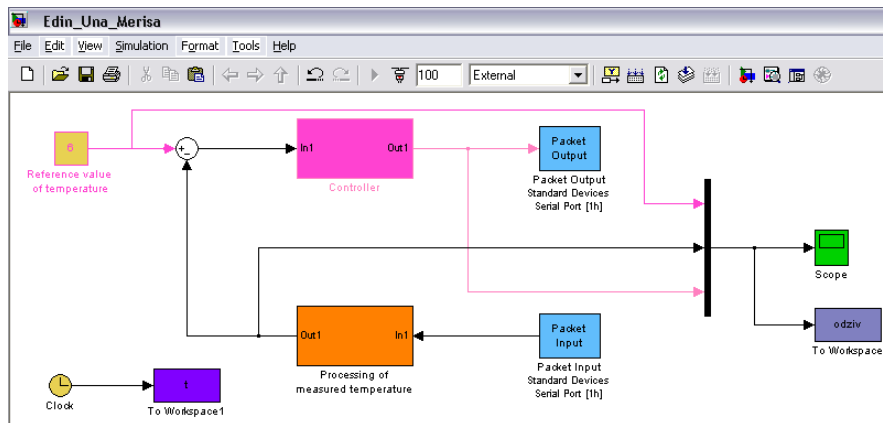


Fig. 7. Block “Packet Input” for receiving data using serial portSimulink scheme for closed-loop temperature control using MATLAB@Simulink and Real-Time Toolbox

4 Experimental results

In this section of paper are presented experimental results for closed-loop temperature control using MATLAB@Simulink, Real-Time Toolbox and PIC18F452 microcontroller. It is used ON/OFF temperature controller. Because of great features of simulink, we can quickly and easily replace ON/OFF temperature controller with another temperature controller, e.g. PID controller. Values of reference temperature is in relative units for easy and precise results presentation. After experiment analysis we got experimental results as shown in Figure 8.

Based on figure 8, we can conclude that closed-loop temperature control is working properly. When temperature exceeds set limit heater is turning off, and inversely. Maximum and min mum temperature value is adjusted within ON/OFF temperature controller. Error that occur when reading measured temperature occur because of to 8-bit resolution A/D converter. Taking average temperature value is obtained nearly ideal value of measured temperature. Temperature reference value can be optionally seted during work by simply entering another value in block „Reference value of temperature“. To show temperature value we can use different temperature scales.

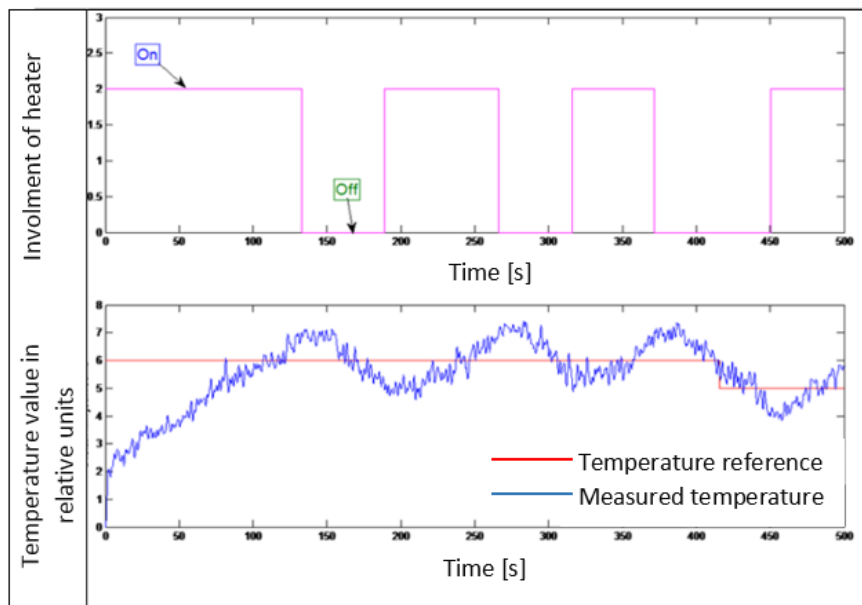


Fig. 8. Experimental results obtained using closed-loop temperature control for designed system

5 Conclusion

Based on experimental result, we can conclude that designed system is working properly and that can be used to measure temperature in closed loop. If generalize, we can conclude that combination of MATLAB@Simulink, Real-Time Toolbox and microcontroller can be used on different systems. In this way are used good features of MATLAB@Simulink for easy adjustment parameters of system as well as good features of PIC18F microcontroller series. All-important information's can be stored and displayed using wide spectrum of tools for graphical processing information.

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