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IMPLEMENTATION AND DESIGN OF TEMPERATURE CONTROLLER UTILIZING PC BASED DATA ACQUISITION SYSTEM

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ABSTRACT

Closed loop or Feedback control is a popular way to regulate and improve results and responses in variety of industrial processes and systems. An effort in the same direction is attempted with this paper in which the design and development of a feedback control system for the purpose of maintaining the temperature of a process at a desired set point is described. This system is designed with a PC-based data acquisition unit used as an input and output interface between the PC and the sensor circuit and Hardware. The implementation of a proportional, integral, and derivative controller is undertaken in the LabVIEW software environment. Results and the performance of the system is discussed for the purpose of temperature control.

Keywords— LabVIEW, DAQ, Temperature Sensor, PID, Control System.

INTRODUCTION

Control systems is the basis of all the instrumentation found almost everywhere. They form an integral part of various industries, automobiles, workshops, households, businesses and any equipment used in any thinkable industry on the globe. Control system is fundamentally employed for the fixed point retention of something which has a tendency to vary and change from the recommended state(Olsson, 2006). Control systems are found everywhere and the human body is no exception to it; the functions like regulation of heartbeat, maintaining body temperature, balancing the body, etc. are efficiently undertaken by various control mechanisms innate to the human body (Mombaur, Truong, & Laumond, 2010). Similarly, another example of control system can be found in the households in the form of temperature control system. It is a feedback control system which carries out functions in a closed loop manner to constantly keep the temperature of the house at a fixed value. The functions undertaken by this system are sensing of the ambient temperature of the house, then comparing it with the desired temperature which is set by the user and finally initiating corrective action or the error signal which would help bring

the temperature of the ambient air at or near the fixed desired value. This researcher paper has been undertaken to demonstrate the design and implementation of a regulatory control system which would maintain the temperature of a process at a pre-set desired point. The system which is described above is also intended to incorporate a data acquisition system which is PC based with the help of LabVIEW software package(Basher & Isa, 2005) (LabVIEW is a graphics-based programming language developed by National Instruments, popularly used for control system application simulations).

The development of the above system would be undertaken by the following method. A heating element would be employed which would give out a constant amount of heat. The surface temperature of the heating element is a function of the internal heat produced and the cooling that it receives. The cooling of the heating element which is regulating variable here and is implemented by employing a small electric fan which is positioned in such a way that the direction of cooling is in the line of the heating element and the cool air is directly forced over it. Thus, the rate of air flow directly impacts the amount of heat transferred from the heating element. Hence, the control system so designed varies the speed of the cooling fan thereby varying the rate of airflow on the heating element and hence monitoring the surface temperature of the element.

DATA ACQUISITION SYSTEM

The technique of controlling the temperature in the said system utilizes a PC based data acquisition system (DAQ). This the input from the system is processed in the lab having the PC and the output is given to the control system which controls the process by generating appropriate control signals. The processing of the input signals in the PC is done with the help of an algorithm which is implemented in the LabVIEW software and is connected to the DAQ system. The LabVIEW software package is developed by National Instruments and is a specialized software for the development and implementation of system specific customised data acquisition and control program (Carter et al., 2005).The flow of the program is initiated with the measurement of the temperature from the process, undertaking the comparison with the desired set point and finally generation of appropriate control signals for the final control element thereby adjusting the rotational speed of the electric fan. The above system is illustrated with the help of a block diagram as shown in **(Refer Figure 1 below).**

NATIONAL INSTRUMENTS SCXI

The control system in this study, employs the National Instruments the Signal Conditioning extensions for Instrumentation (SCXI) system for the purpose of input output interface. This National Instruments SCXI data acquisition system comes in a modular form which has an input module, output module and housed chassis

consisting of terminal blocks; along with the ability to connect to a PC. Signal conditioning is the supplementary job done by the SCXI system apart from the basic I/O. The design of this is such that it connects to the DAQ card located in the PC. The primary functions of the DAQ card involves the Analog/Digital and Digital/Analog conversion, along with signal timing and multiplexing ("SCXI Chassis User Manual and Specifications," n.d.).

SYSTEM CHASSIS

The SCXI-1000 is a 4-slot chassis which is designed to have the capability to power and control up to four modules. The incorporation of more than one chassis is allowed and can be done by daisy-chain method for it to act as one system. The chassis facilitates the modules with power as well as a communication bus which is a connection to the PC.

DATA ACQUISITION CARD

The DAQ device is required for the PC connection of the SCXI chassis and modules. The analog-to-digital and digital-to-analog conversion indispensable for interfacing the I/O signals to the PC is done by it. The card is used here is manufactured by National Instruments called the 6040E PCI card. The specifications of the same are 16 analogy inputs, 2 analogy outputs, 8 digital I/O lines, and two 24-bit counter/timers.

ANALOG INPUT

The SCXI-1102C is the analogy input module used and it comes with 32-Channels. This is an ideal choice when the system implementation requires the measurement of small voltage and current inputs. It also includes a Cold Junction Compensation circuit which can be use with thermocouple sensors. The terminal block which provides the wiring terminals for the external signals connection is connected at the front of the SCXI-1102C.

ANALOG OUTPUT

To facilitate analog output, a SCXI-1124 6-Channel Isolated Analog Output Module is provided. It has the capability to provide six channels of slowly varying DC voltage or current signals. The output voltage range can be set via software having the maximum permissible swing between ±10 volts.

SOFTWARES USED IN THE IMPLEMENTATION OF THE SYSTEM

The software is considered as the heart of the system thus one can deduce that it is the most important part of the system. Here, the controller is in the form of the software. A control algorithm at the centre of all the analysis of the input from the process and the decisions on the corrective output actions. The instrumentation is also dependent on the software for it displays data on the PC screen which is the solitary indication to the human operator on the status of the system functioning and behaviour. The

software also facilitates in the control process by giving the option to enter a set point which may be done manually also.

NATIONAL INSTRUMENTS LABVIEW 7 EXPRESS

LabVIEW is a software package having programming features with graphical language facilitating functions like data acquisition, measurement, examination, demonstration, and regulation. LabVIEW program comprises of a front panel and diagram. Programs are graphical in form and functions are defined in such a form are called Virtual Instruments, also known as "VI's" executable independently or "sub- VI's" facilitating the similar functions in larger programs. The programming in LavVIEW follows a style which is in the lines of C programming language, however, instead of using a text editor like in the case of C, input is given graphically making it simplified for the use of non-programmers also quickly create and debug applications.

This software is a seamless link between data acquisition and measurement products manufacture by National Instruments. Thus, the application with SCXI system, results in speedy development of powerful measurement and control applications. Another important and significant feature of the LabVIEW system that hundreds of VI's are readily available to be used in custom program (LabVIEW 7 user manual, n.d.).

LABVIEW SOFTWARE VI'S

The software is considered as the heart of the system thus one can deduce that it is the most important part of the system. Here, the controller as well as the instrumentation is in the form of the software. The main function, or main VI, is interfaced at the front panel allowing the operator of the complete control and monitoring of the system. This main VI is programmed with various sub VI's which are called by the main VI to perform functions like gathering analog input, sending analog output, and devise a PID control algorithm (*LabVIEW 7 user manual*, n.d.).

FRONT PANEL

The front panel is the interface with the operator and it allows various functions like control and monitoring of the process. It comprises of software controls and indicators which are in fact the representative forms of physical controls like buttons, sliders, LEDs, and charts. A screenshot of the Front panel is depicted in **(Refer Figure 2).**

The system here monitors and controls the temperature of the process. Thus, a thermometer-style indicator is implemented here for the display of the temperature of the process also, this temperature is recorded on a strip chart which also has the set point value. This depiction on the strip chart makes it easy for the observer to see how the system responds with changing set points. Also, the front panel

is facilitated with a sliders one of which is to manually control the fan speed and another to adjust the temperature set point specifically for the automatic control. Also given is a toggle switch which helps the operator to select between either of the two modes of operation i.e. Manual and automatic control. The sampling rate controlling the speed of the software loop is controlled by the dial control which is also given on the panel. To set the PID values a numerical control box is provided. There are two push button switches below the PID control box. Out of them, the switch which is marked as Autotune triggers an an automatic tuning routine which helps determine the best values forthe P, I, and D constants and is assisted by using Zeigler-Nichols ultimate gain method which are updated in the PID box after successful calculation from the routine (*LabVIEW 7 user manual*, n.d.).

BLOCK DIAGRAM

The block diagram typically represents the underlying software program in a graphical way incorporating constants, variables, subroutines, and loops from the program in a graphical manner. A screenshot of the block diagram for this system is shown below in (**Refer Figure 3**).

DESIGN OF HARDWARE AND CIRCUITS

POWER SUPPLY TO THE SYSTEM

The adequate power to run the said system comprising of electronics and the fan is supplied by a 12-volt regulated power supply. The fan and the circuits of op-amp are powered by using a simple voltage regulator IC which provides positive 12-volt rails. All this is based on the 15 volt regulated power supply of the laboratory.

HEATING CIRCUIT

The heating element in this system is simple resistance heater circuit. This circuit which comprises of two 270Ù resistors which are connected in parallel and the combination is directly powered from the 12-volt power supply is an easy method to reach up to 160F temperature. A total of approximately 1.2 watts of power is given up as a result of the heating of resistors.

SENSING THE TEMPERATURE

The Temperature feedback to the control system is given by sensing the temperature of the heating element with the help of a temperature sensor which is attached to the surface of the heating element. A J type thermocouple having a capability of sensing temperatures from 32-900 degrees Fahrenheit is used for this purpose and is also aptly suited to be used with SCXI system.

INTERFACE CIRCUIT FOR THE FAN

The control of the DC fan is a necessary function which would be done using a custom interface circuit Although, the direct connection of the fan to the SCXI-1124 output module would be easiest, but is not possible owing to the following reasons. The output module sources the current at 5mA whereas the fan requires

about 60mA of current for proper functioning. Also, it must be noted that the voltage requirement of the fan is different output module. Hence, the fan is interfaced with the output module using PWM circuit as shown in Figure 4. The method of speed control of fan is of utmost important when interfacing it by using PWM technique. **(Refer Figure 4)**

VARIABLE VOLTAGE METHOD

The speed control of the fan can be easily done by varying the supplied voltage of the fan between the minimum and the maximum value of voltage i.e. 0 V to 12 V. This is a simple method and also the regulator provides 1 A of current which is adequate to run the fan. However, the power loss in the form of heat in the regulator is a significantly high value which is a major issue. Also, running the fan continuously at a voltage which is much lower than the rated value of 12 V shortens the life of the DC motor in the fan and is thus discouraged to be used.

PULSE WIDTH MODULATION METHOD

This technique of modulating the pulse width to regulate the amouny of power flowing in the fan is a better way to regulate the fan speed. Here, a square wave is generated to switch the power MOSFET On/Off. MOSFET is a transistor which is capable of handling currents as large as 4 Amps. Here, the duty cycle of the said square wave is changed according to output signal obtained from analog output module. The duty cycle shows the effective ON time of the MOSFET from 0% to 100% and thus changing the amount of power supplied to the fan by a proportionate value.

SYSTEM IMPLEMENTATION

The system of the interface hardware was first implemented using breadboard and jumper wires thereby allowing any changes to be made to the circuit unlike Printed circuit boards.

BREADBOARD CIRCUIT

The hardware circuits described above i.e. PWM circuit, heat circuit and the power circuits have been implemented on the breadboard as shown in the photograph **(Refer Figure 5)**.

WRITING AND DEBUGGING THE SOFTWARE

The program is developed on the LabVIEW environment which uses a graphical programming language facilitated by the drag and drop of code element and structure into the program also eliminating the need to memorise syntax and codes. Running and debugging is done in the same window making it much simpler.

TESTING THE SYSTEM

The said system was tested in various parts. In the circuit of PWM, each component was tested during the development phase. The sending and receiving signals using the SCXI system was assessed distinctly from the software. The step by step troubleshooting approach makes

problem finding and isolating much easier. The complete system when tested means the testing of breadboard circuit connected to the SCXI modules, and also running the LabVIEW VI along with them.

Testing the SCXI hardware is pretty straightforward because it is facilitated with software configuration tool from National Instruments called Measurement and Automation Explorer which easily configures input and output channels at the same helps in testing them.

SETUP REQUIREMENTS

The entire system consisting of the breadboard circuit, the fan, and the appropriate connections SCXI input and output modules, along with a PC running the LabVIEW VI has to be supplied with power. The physical connection of the hardware to the controlling PC is not mandatory as long as it is connected to a networked PC via the SCXI system.

OPERATION

The process circuit is powered using a 15-volt DC power supply capable of providing both a positive and negative 15-volts supply to the breadboard circuit. The operation of the system is a simplified one after the circuit is properly connected and powered up. In the manual mode, the operator reads the current temperature from the front panel and manually adjusts the fan speed for the controlling process. After the settling of the system, the automatic mode can

be toggled to from the manual mode thereby making the controller use the PID algorithm. Here, the auto tuning function is also present which can be activated by pushing the Auto tune push button. As a result, a 4-step "wizard" dialog is started which prompts the operator to input the necessary inputs. At the end of the sub routine, new PID constants are automatically given into the control box. At any moment in the process running time, the set point and chart scale can be adjusted. The termination of the program or the process can be done at any time by a click on the Stop button.

RESULTS

After the said system is allowed to run with a powered supply, the results are discussed in this section. IT is noticed that the said system worked appropriately given the time constraints on design and construction. It was also noted that the fan had the ability to bring the temperature of the heated element to 110° F considering the fan rotating at its maximum speed.

When using the manual control, a smooth speed control of the fan from zero to maximum position was achieved and in the operation in automatic control, the temperature is efficiently maintained near the set point by the system with an error of some degrees in Fahrenheit even without tuning the optimal control loop. Figure 6 is a screenshot which shows the graph corresponding to the measured and set point

values. **(Refer Figure 6)** In the figure 6, the set point has undergone a step change of 5 degrees which is tried to m=adjusted by the controller. It can be noted that as the proportional gain is increased, the error from the set point is reduced, however, this results in the injection of oscillation in the system. Figure 7 is an enlarged diagram demonstrating the same. The PID VI used here also has an auto tuning function with the help of which the process temperature within ±½ degree of the set point. Figure 8 demonstrates the response of the auto tune to a 3 degree F step change. **(Refer Figures 7 or 8)**

Here, it can also be noted that the values of P, I, and D gains are set by the auto-tuning function.

CONCLUSION

A feedback control system which is implemented using proportional, integral, and derivative controller using the LabVIEW is described in the study and is an excellent method to study and understand the implementation of PID control. The entire method and technique to undertake the control mechanism is described in a simple way and is easy to understand. Here, the PWM method is used to supply the fan with power and the LabVIEW environment is used for controlling scheme which is a very intuitive and highly efficient means for this process.

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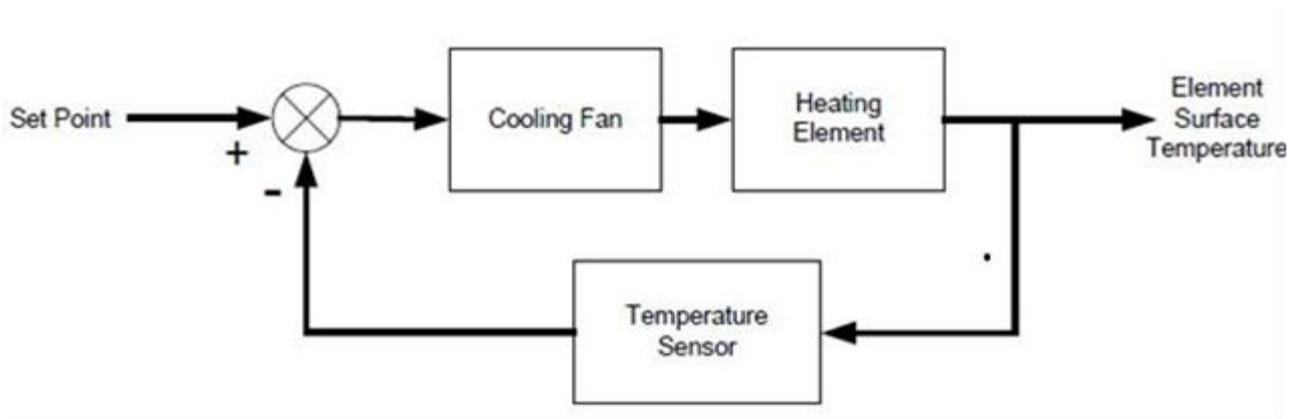
LIST OF FIGURES:
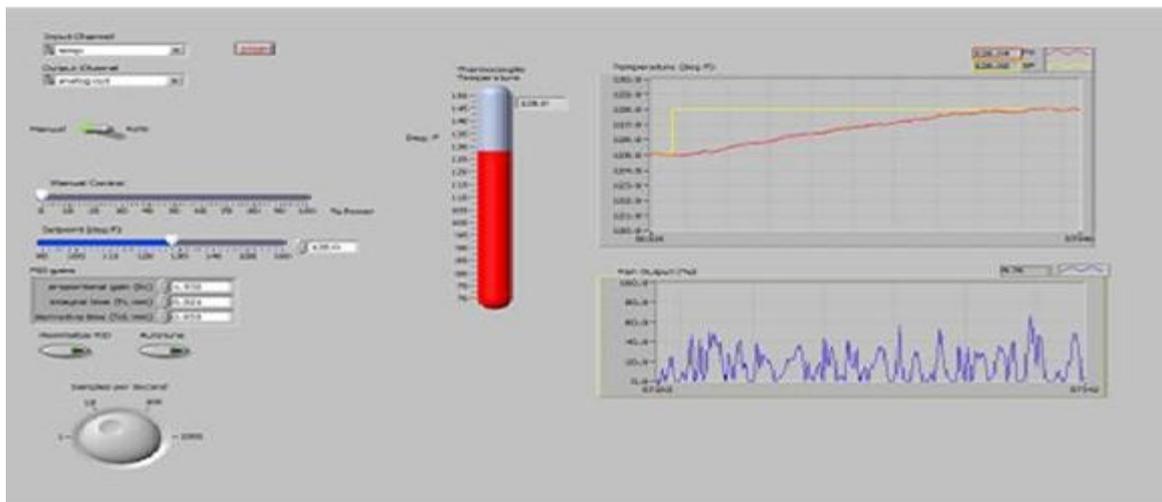

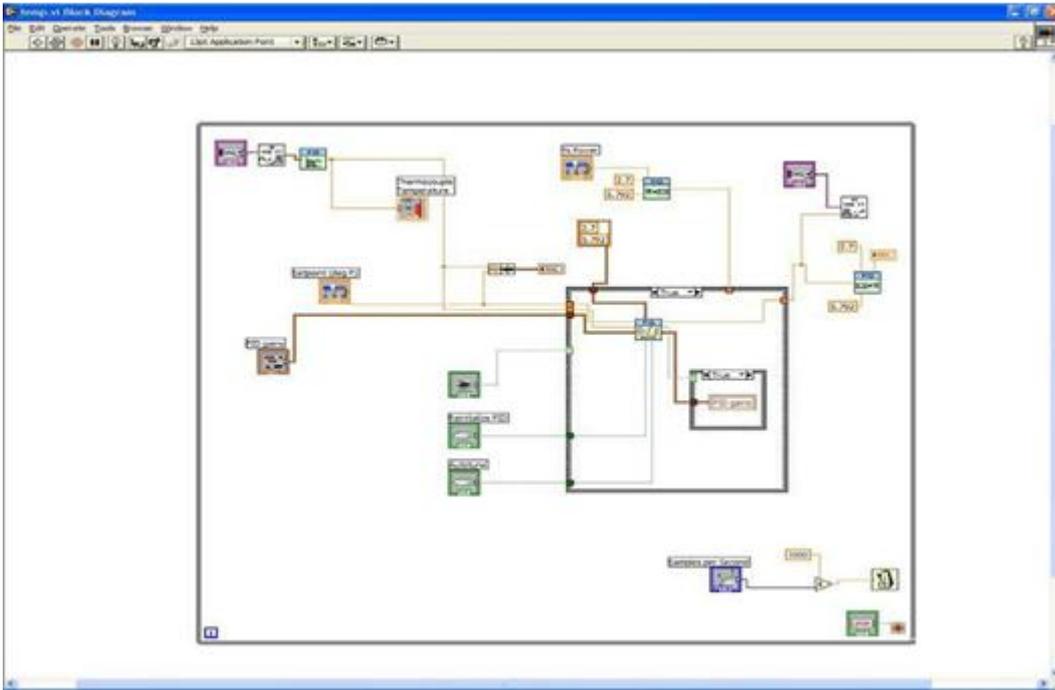Figure 1 Feedback System Block Diagram

Figure 2 Front Panel

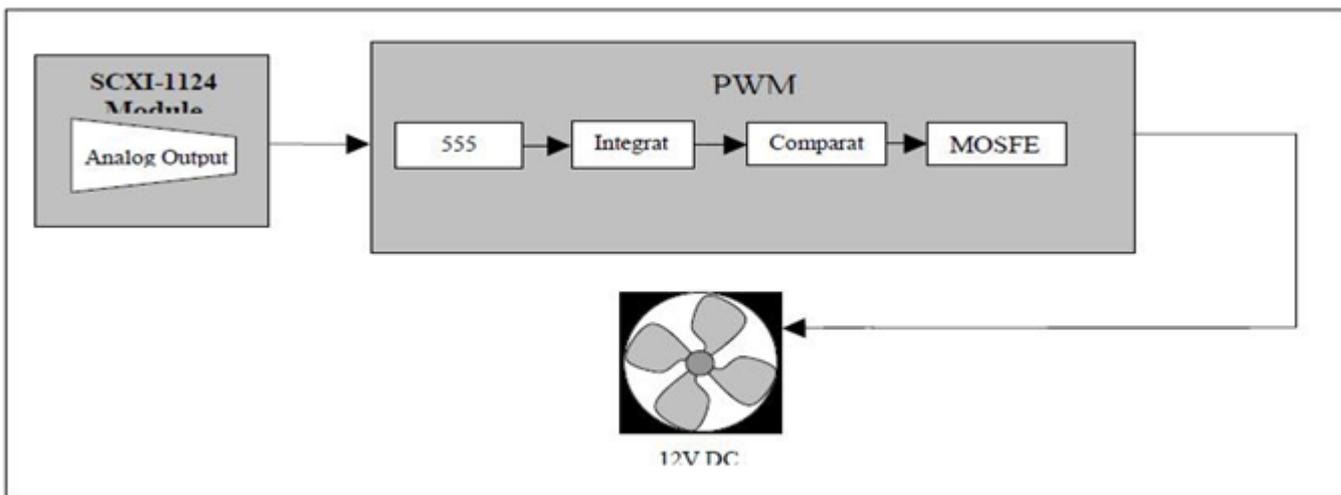Figure 3 Block Diagram of the software implementation

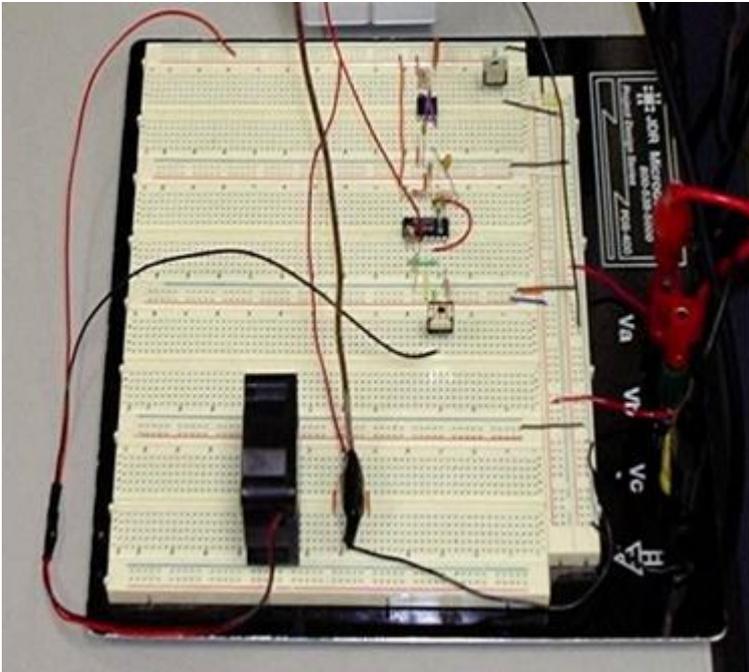Figure 4 Connection of the Fan using Interface Circuit
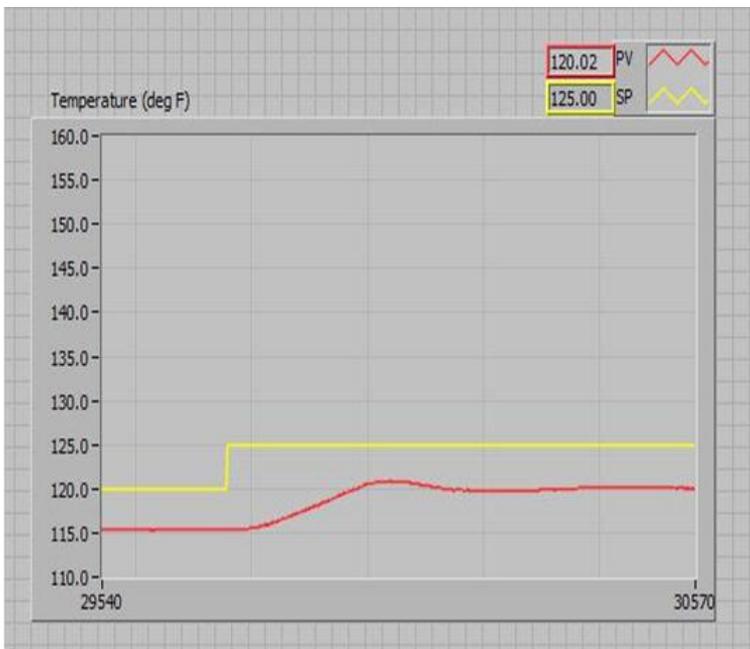
Figure 5 Breadboard implementation

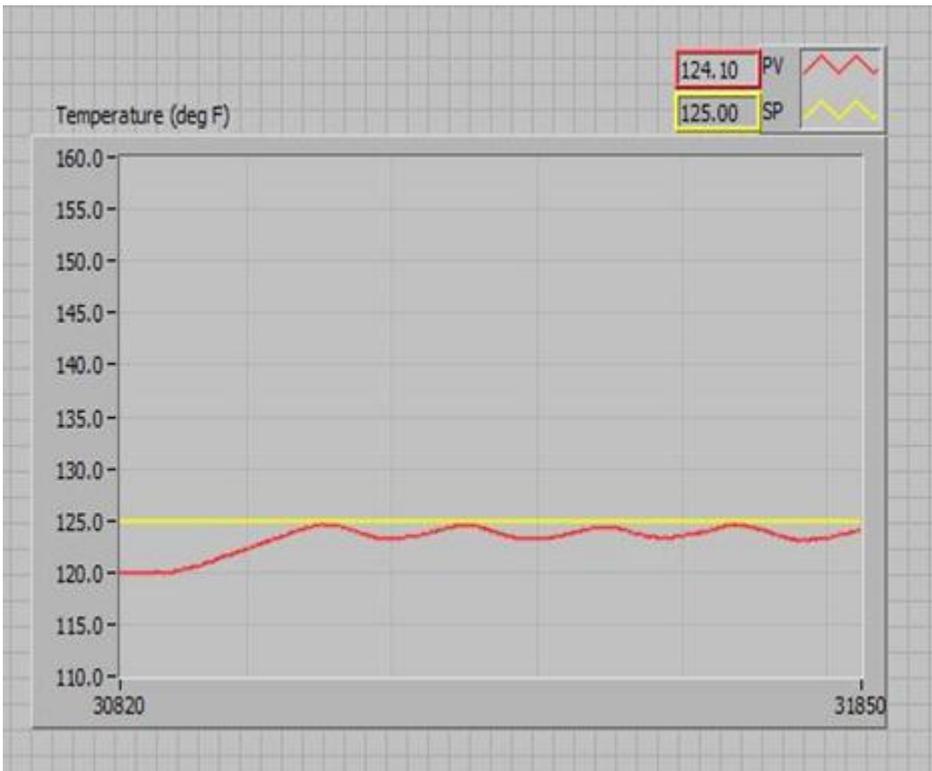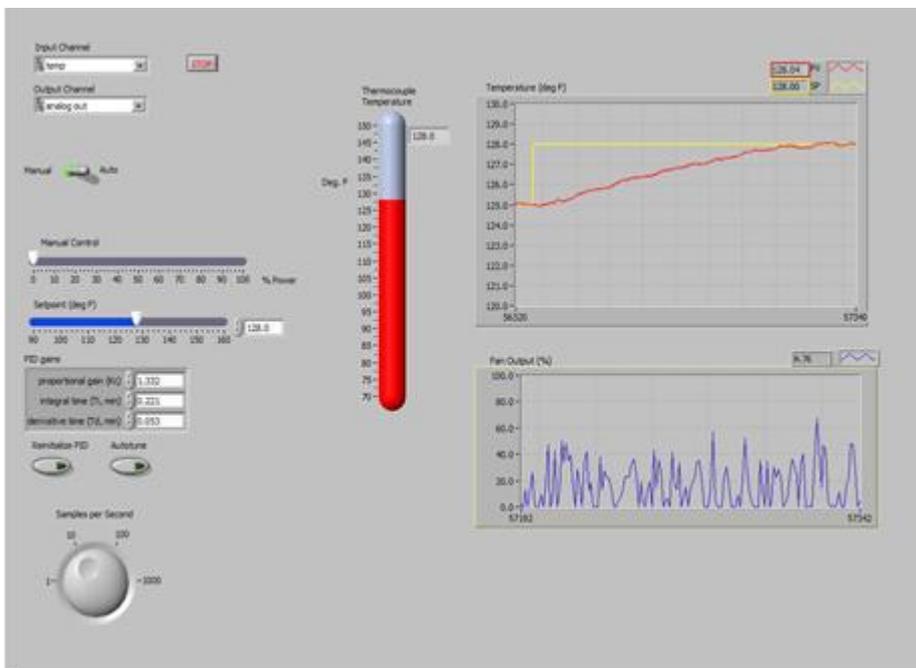Figure 6 Measured values and Setpoint values

Figure 7 Oscillations in the system

Figure 8 Three degree change in set point