DESIGN, FABRICATION AND TESTING OF A HUMAN MACHINE INTERFACE SCADA SYSTEM FOR PROCESS CONTROL

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Abstract
The rapid adoption of the personal computer in the last 20 years catalyzed a revolution in instrumentation for test, measurement and automation. One major development resulting from the ubiquity of the computer is the concept of virtual instrumentation mainly referred to as Supervisory Control and Data Acquisition (SCADA). The major attraction of such systems is the ability to significantly reduce operating labor costs, while at the same time improve plant system performance and reliability. However the use of obsolete technology and skills has crippled global competition among developing countries. In seeking solution, a prototype of a SCADA system has been developed, the goal is to come up with an affordable, reliable and accurate Human Machine Interface (HMI) SCADA system. A lab view based HMI SCADA was developed and used on a fabricated heat exchanger prototype, in which the level and temperature of the system were the test parameters. The system was tested by issuing different set points for level/ temperature and measuring the response there after, the response was quantized by analyzing the characteristic waveform(s) obtained to determine the system response parameters (Rise time, steady state error, percentage overshoot and settling time), robustness and dead time. The system was found to have a better dynamic and static response characteristic compared to the commonly used embedded ON/OFF controllers, while the control algorithm simple to adopt.

Key words: HMI Lab view SCADA System, process control

1 Introduction

Automatic control systems have been evolving since the past 150 years (Wagoner and Macia, 2004). These systems began as simple mechanical feedback devices and have evolved into complex electronic and computer controlled systems (Ogata, 2010) which in turn gave birth to virtual instrumentation commonly known as Supervisory Control and Data Acquisition (SCADA). These systems tightly coupled to the manufacturing control systems, are in the best position to not only acquire massive amounts of data, but to sort it out and deliver the appropriate information to the right people (Kumar, 2001). In as much, the main objective of these systems is to give the means to the human operator to control and command a highly automated process (Lakhoua, 2010). Even though these systems have a high performance and are robust, their cost is prohibitive ruling out most entities that would have benefited from their use (Aung *et al.*, 2008).

This paper implements the use of human machine interface (HMI) SCADA system in process control. It consists of apparatus that demonstrates the use of HMI SCADA to control the temperature of an open heat exchange chamber. The open chamber represents a real life unpredictable disturbance to the system. Supervisory control and data acquisition is accomplished by the use of a personal computer (PC) running LabView software. Automatic control was accomplished by sensing the temperature and controlling the heater and a mixing pump in the chamber.

1.1 System Overview

The overall system consists of three main parts, the main controller which is a PC running Labview software, electronic circuitry for communication and signal manipulation, and the process to be controlled (temperature in the heat exchange chamber). Figure 1 shows the interaction between the three building blocks of the system.

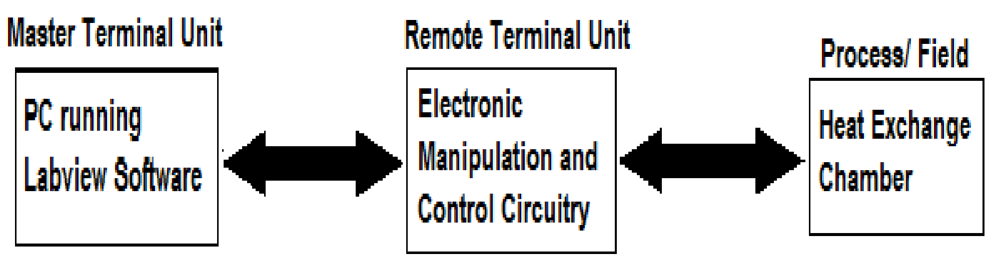

Figure 1: Block Diagram of the System

1.2 Mechanical Design

The heat exchange chamber consisted of 6 main components; tank reservoir, solenoid valve, heater, pump, fan and a negative temperature coefficient thermistor. The chamber was constructed of a 19 cm width inside Perspex glass square that is approximately 30cm in height. See Figure 2. The operating capacity of the tank was approximately 1000 cm^3 of water.

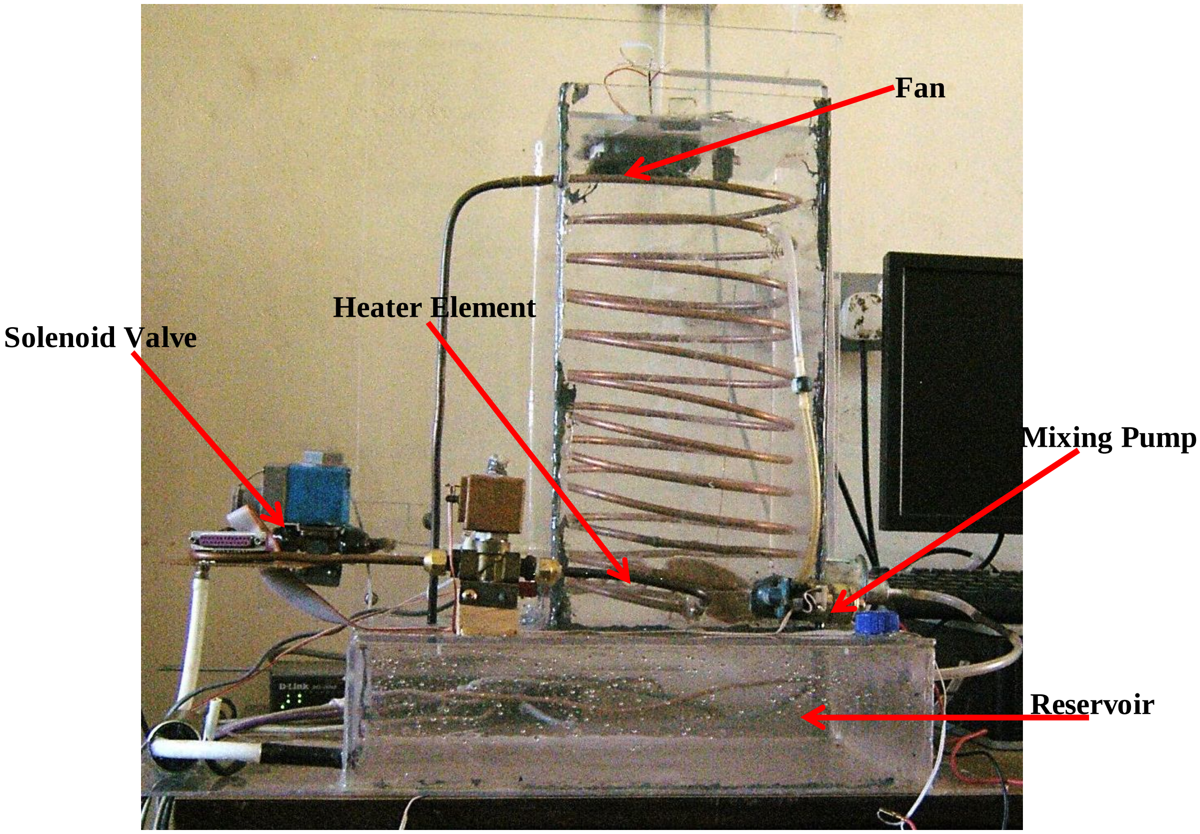

Figure 2: Heat exchanger chamber

A combination of ¼ inch diameter copper fittings and pipe served as an inlet, over flow and outlet for the liquid which allowed connection to the gate valves and pumps. The thermistor located an inch above the bottom of the chamber measured the temperature of the liquid while the pump was used to recirculate the water whenever the heater was turned on to ensure equal distribution of thermal heat from the heater. The solenoid valve was used to allow a constant flow of liquid to the chamber which provided a step disturbance causing the temperature in the chamber to change. The fan was also used to provide a constant flow of outside air into the system causing the temperature of the chamber to change.

1.3 Electrical circuit design

The circuit design consists of several different sections. The fundamental part of the circuit is a data acquisition circuit which receives analogue signals from the thermistor converts it into a digital signal with a resolution of 8 bits with a step size of 19.6 mV for a resolution of 5V. The digital output is then inputted into the PC via the DB -25 printer port status and control lines; the data lines are used by the PC running the Labview program to communicate to the pump,fan, solenoid valve and heater. See Figure 3.

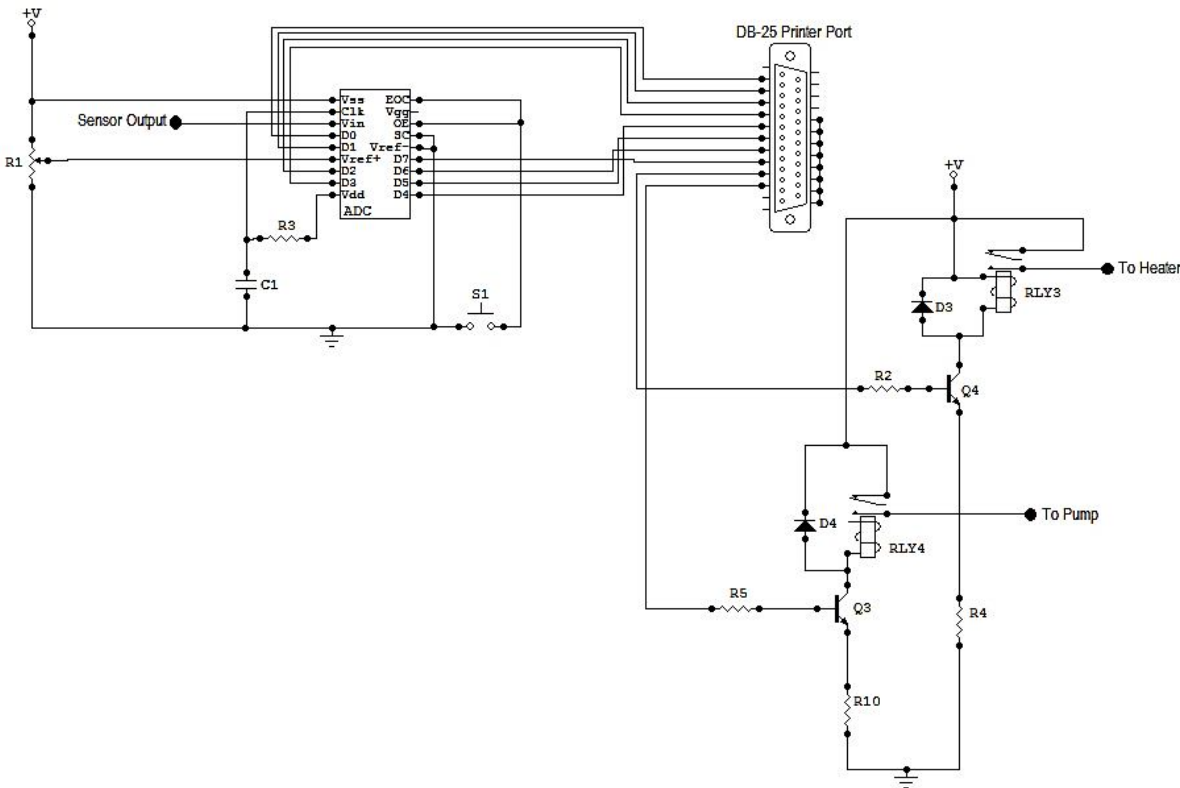

Figure 3: Circuit diagram of the manipulation and communication interface

The last component involved in the circuit design is the communication/ interface which in this case is the parallel port. Parallel ports use three I/O addresses. There is the data register, status register and control register with addresses 378 h, 379 h and 37A h (Cooley *et al.*, 2003). 5 data lines were used to switch on and/or off the heater, pump and solenoid valve via an interface constructed by the use of transistor and a relay; the status and control lines are combined in the Labview program to read 8 bits of data words and are connected to the output of the ADC0804. See Figure 4.

1.4 Labview Program

Labview 7.1 software from National Instruments was implemented as the HMI SCADA software to control the chamber system. Different virtual instruments (.vi) functions were used to develop the SCADA front panel and block diagram. The main .vi used included the out port and in port .vi used to read and write values to and from the printer port. Figure 4 shows a section of a Labview program that is to read the value on the control register (37A h) and status register (379 h) waits for 500 milliseconds, check the value. If the read value is greater than decimal 132 then it sends a binary value 110 to the data register (378 h) which toggles pins 3 and 4 of the DB -25 high else continues reading the registers until avalue greater than 132 is read.

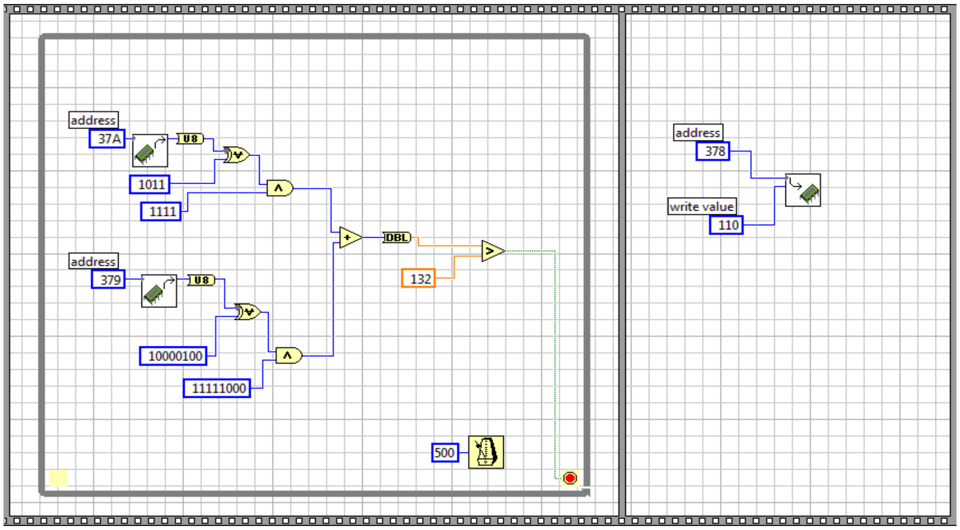

Figure 4: In port and out port .vi's

The Labview program developed helps the computer to monitor and control the chamber system through the connections to the electronic circuitry. The voltage from the thermistor was used to indicate the temperature on a front panel. During the operation of the system, the computer continuously regulates the heater, mixer pump and fan using the feedback from the thermistor. It continues to regulate the heater, mixing pump and fan to control the temperature of the chamber to a change in the set point or to a change in the temperature input to the system. Temperature input to the system is through a fan mounted on top of the chamber rotating at a maximum speed of 1260 rpm and a pump that delivers a constant supply of a liquid at a rate of 6.69 cm^3/s. Figure 5 is the front panel of the SCADA program.

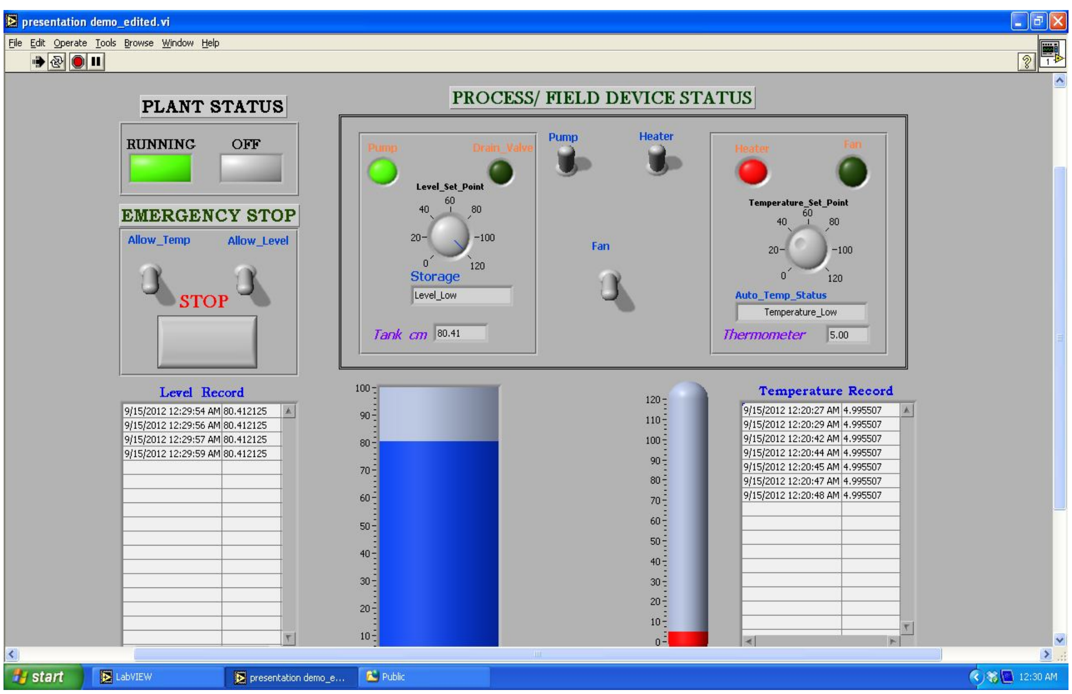

Figure 5: Labview program front panel

2 Results

2.1 System Calibration

To test the accuracy and reliability of the designed communication interface of the SCADA system, calibration was done using a standard digital thermometer, then the temperature of water being heated was taken at different intervals of time and a comparison between the designed system and that of a standard thermometer was made to ascertain the level of accuracy, Figure 6.

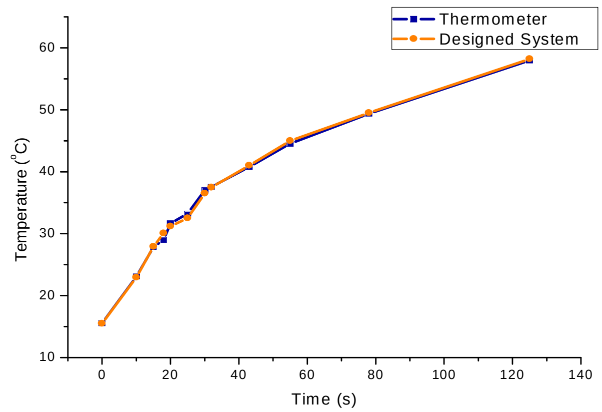

Figure 6: Comparative results of system calibration

The designed system measured temperature to an accuracy of ± 0.263^{0}C with a loop cycle of 0.5 seconds which is ideally suitable for a faster control loop (National Instruments, 2011).

2.2 Heat Exchange Chamber System

Any control design begins by defining the performance requirement. Control system performance is often measured by applying a step function as the set point and measuring the response of the process variable (Bschoff *et al.*, 1997). Several response parameters were considered. The first was steady error, the difference between the set point value and the actual temperature in the chamber (Gupta, 2002). This was approximately 1.97% with a loop cycle of 3 seconds over a neutral zone (dead band) of ± 0.25^{0}C in the initial test in which water at 28.2^{0}C was heated and maintained at a set point of 43.5^{0}C. Other response characteristics considered were the settling time and percent overshoot. These values were 110 seconds and 4.06%. See Figure 7.

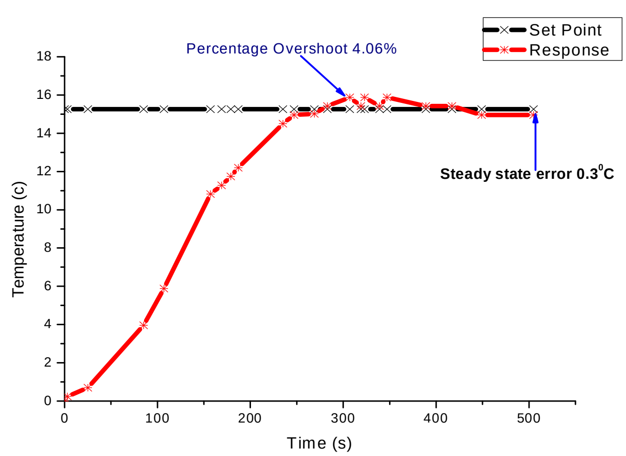

Figure 7: System set at a loop cycle of 3.0 seconds

Considering the actuators used in this system only operate in two positions; fully On or Off; adjustments had to be made on the control program so as to reduce the percentage overshoot and the steady state error. The loop cycle and dead band were reduced to 1.5s and ± 0.0625^{0}C respectively. The percentage overshoot and steady state error were 1.35% and 0.28% respectively under the new values. See figure 8. The loop cycle and dead band can be reduced further to reduce the error but the system will become unstable causing the actuating relays to oscillate.

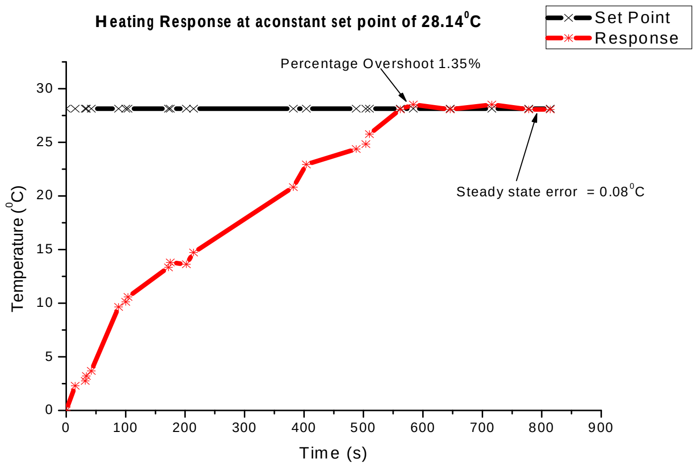

Figure 8: Response of the system at a loop cycle of 1.5 seconds

Figure 9 is a plot of the system response under different disturbances. The start of the plot was done with the system stabilized at a temperature of 28.2^{0}C. The set point was then increased to 35.5^{0}C and cool air blown into the system by a fan running at 1260rpm. Overshoot was approximately 1.56% with a settling time of 10 seconds and an average steady state error of 0.625%. Water at 32^{0}C was run into the system at a rate of 6.69cm^3/s. Overshoot was approximately 2.13% and an average steady state error of 0.97%. The variation in the steady state temperature is thought to be caused by the heating element which only allows two states of operation.

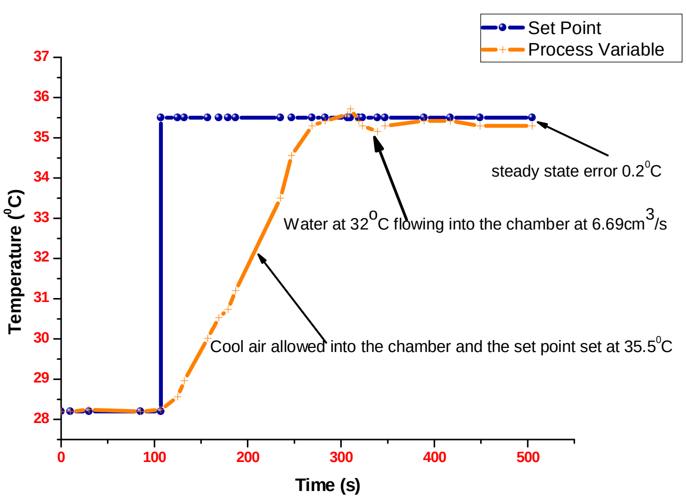

Figure 9: System under disturbance

3 Conclusion

The designed system was able to monitor and control the temperature in the chamber to within an average steady state error of 0.263^0C against disturbances that would occur in real time control. The average percentage overshoots of the system was 1.35%. The system emulates most of small scale businesses within the country relying on electromechanical control systems. The designed data manipulation circuitry and communication channel can easily be implemented into this systems without extraneous modification to the process, the advantages of computer control are achieved via the Labview based HMI SCADA system which makes the overall system modification achievable, reliable, accurate and affordable. The heat exchanger chamber system constructed can be used as a classroom model to demonstrate practical's in process control and virtual instrumentation courses.

Future work on this project will include; implementing proportional, derivative and integral control designs to the system and utilizing actuators that can accommodate this type of actions, applying the Ziegler & Nichols tuning rules to improve the performance of the control system and modeling the system in MATLAB/SIMULINK, simulating and applying the results to the physical system.

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