

A Novel Approach for Building Low Cost Wireless Distributed Control System

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Abstract: Distributed Control System (DCS) is considered as one the most advanced strategies in plantwide control. The implementation of such systems is not common as they involve high costs. In this paper we have implemented an efficient low cost wireless DCS with nRF24L01 wireless module and microcontroller on four process stations (Level, Temperature, Pressure, Flow), integrating and controlling them in distributed manner. Apart from these four station control unit (slave), there is a master control unit which will continuously monitor and control these four stations wirelessly. All the stations can be controlled by PI, PD or PID. In order to minimize the cost, Data Acquisition (DAQ) Cards with wireless communication feature is made with an Atmel Microcontroller and a User Interface with LabVIEW and wireless module. Thus bringing up all the features together, we were able build and implement in realtime a Wireless DCS which is efficient and less in cost.

Keywords: Distributed control system; LabVIEW; Data Acquisition; Process Control; Realtime.

1. INTRODUCTION

Distributed control system (DCS) is considered as a control methodology applied for a manufacturing system, plant or any kind of other dynamic system, where the control elements are distributed throughout the entire system, not centrally located. In DCS, a hierarchy of controllers is connected by communications networks for command and monitoring. A DCS typically uses custom designed processors as controllers along with proprietary interconnections and standard communications protocol for communication. A typical DCS consists of functionally and/or geographically distributed digital controllers capable of executing from 1 to 256 or more regulatory control loops in one control box. Today's controllers have extensive computational capabilities and, in addition to proportional, integral, and derivative (PID) control, can generally perform logic and sequential control. Modern DCSs also support artificial intelligence such as neural networks and fuzzy application [1]. In order to enhance the reliability of the plantwide control system, DCSs are usually designed with redundant processors. Most manufactures come up with DCS having displays and configuration software that enable the end-user to configure the control system without the need for performing low-level programming, allowing the user also to better focus on the application rather than the equipment. DCSs may employ one or more workstations and can be configured at the workstation or by an off-line personal computer. Local communication is handled by a control network with transmission over twisted -pair, coaxial, or fiber-optic cable. A server and/or applications processor may be included in the system for extra computational, data management and reporting capability [2]. The PCU's and MCU's are interconnected by two redundant data high way loops. If a loop fails, the communication hardware in the PCU and MCS will transfer automatically from the failed slave loop to the operating loop without loss of transmitted data on the loop. The latest developments in DCS include the following new technologies [3]:

1. Wireless systems and protocols
2. Remote transmission, logging and data historian
3. Mobile interfaces and controls
4. Embedded web-servers

Many DCS's are available today from different manufactures such as Yokogawa, Honeywell, and ABB etc are of high costs. The cost of a conventional DCS system generally ranges from \$100,000 to \$500,000. Also we could see that in DCS's largely used communication methods are Ethernet I/P, Foundation Fieldbus or Profibus. These all methods require wiring leading to wiring cost in the budget. If hazardous situation such as internal fire occurs, the entire communication link with the control station is lost. Hence a wireless communication system is applicable provided that the transceiver is placed in a safe location.

Keeping these two factors i.e. cost and communication in mind our research work leads to a low cost wireless DCS with a minimal implementation cost with reasonable performance. For wireless communication we use a low cost GFSK (Gaussian frequency-shift keying) [4] having 2Mbps data rate (on air). The advantage of this system over conventional DCS is that it is of low cost and an effective means of wireless communication.

2. PROCESS STATION DESCRIPTION

2.1 Flow Station

The station has a centrifugal pump that pumps water from the reservoir tank to the process tank. The direct measurement of the flow can be obtained from the rotameter, which is placed on the path after the control valve of equal percentage characteristics. An orifice plate with a differential pressure transmitter with an current output of 4-20 mA is used to communicate the process variable to the controller. The current signal is given to the controller through an I/V converter and ADC. The controller can perform various control actions. The controller compares this value with the set point and gives out a control signal to the I/P converter through DAC and a V/I converter. The output of the I/P converter is given to the control valve to manipulate the inlet flow to tank.

2.2 Temperature Station

In this station temperature of the furnace is controlled which is the process variable. A thyristor control unit is used for controlling the current through heater coil which is the manipulated variable. This unit is controlled by 4-20mA current generated by a data acquisition card, designed and fabricated by us. Temperature within the furnace is sensed by a thermocouple. The output from thermocouple is given to a temperature transmitter where corresponding output in the range 4-20mA signal is generated. This signal is converted to voltage by means of I/V converter, which is given to ADC. Thus the designed graphical program using LabVIEW software in local PC will access the card for getting the values from ADC and also after processing it will write value to DAC for controlling the thyristor unit. Many control algorithms such as PI, PD and PID can be implemented in the software.

2.3 Pressure Station

The system mainframe has a control panel. Process tank consists of air muffler, the relief valve etc., the upper rack houses the pressure transmitter, I/P convertor and control valve. The control panel houses the multi-output DC power supply, the input/outputs of the transmitters/control valves. The front panel of the cabinet holds the process schematic, pressure gauges and the electrical and pneumatic, terminations.

The right end side of the cabinet holds the pressure regulators and the signal conditioning electronic circuitry comes with the data acquisition board which is in the computer. The Pressure transmitter has supply and output connections terminated on the main control panel. A I/P convertor mounted on the channel has all signals and supply lines terminated on the main control panel. The diaphragm actuated control valve also has the signal connection terminated at the main control panel. A rectangular cabinet (control panel) at right end of the top rack contains the power supply, 2 pressure gauges, air regulator, two digital ammeters, and a computer interface provision. A 230 V AC power cord and 1/4" flexible air line with proper fittings supply electrical and pneumatic power to the station. Pressure taps are provided to permit measurement of pressure drops around the system, across valves and fittings, etc. to evaluate system performance. One Pressure process tank is mounted on base plate. The process tanks are cylindrical structures of length 15" and diameter 5.5". The tank has 3 tappings for air inlet, Relief valve, Dial type pressure gauge & vent.

2.4 Level Station

In the level process, the level of the tank is taken as the control variable and the inlet flow as the manipulated variable. A capacitive type level transmitter is used to sense the level of the tank which gives an output in the range 4-20mA, which is given to the controller through DAQ card designed. The controller can perform various control actions. The controller compares this value with the set point and gives out a control signal to the I/P converter through DAQ card. The I/P converter converts control signal in mA current to corresponding pressure signals. These pneumatic signals are given to the control valve to manipulate the inlet flow rate.

3. SYSTEM DESIGN

3.1 Data Acquisition Card with I/V – V/I converter

Data acquisition (DAQ) cards generally consists of analog to digital converters (ADC), digital to analog converters (DAC), communication interfaces etc. Voltage to current (V/I) and current to voltage (I/V) converter forms the integral part of distributed control system. Since all the devices connected to the system works with industrial standard 4-20mA. We need to convert 4-20mA to voltage and also vice versa, for communicating with a PC. For generating 0-5V we use PWM technique in a microcontroller. This pulse width modulated signal is fed to operational amplifier for converting to current. At the same time another

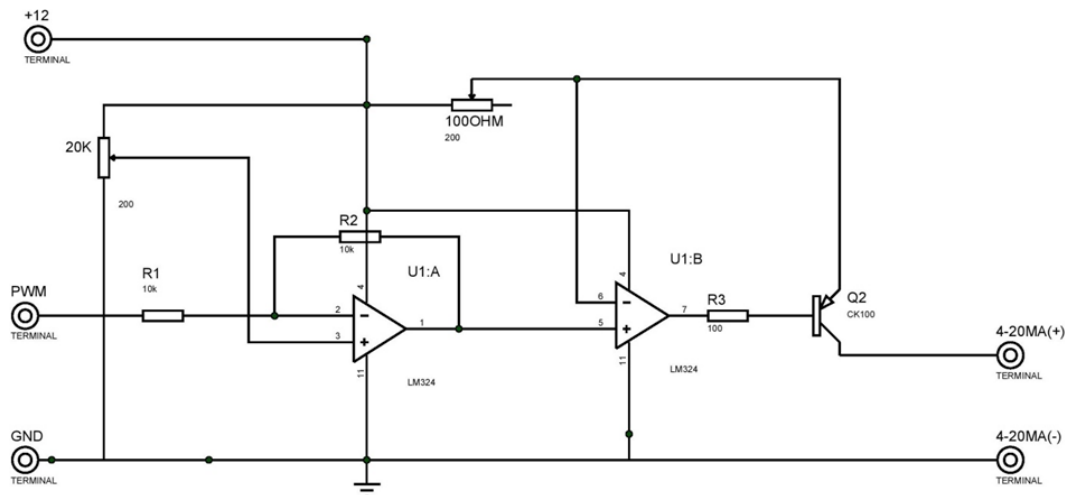


Figure 1: Voltage to current (V/I) converter

set of operational amplifier is used to convert 4-20 to 0-5V, thus it can be fed to ADC for measurement. Circuit used for V/I and I/V is shown below. The voltage to current converter shown in figure 1 makes use of two opamps. The first opamp act as a difference amplifier and the second one is to manipulate the current to base of the transistor which is to drive the I/P converter with input current in the range 0f 4-20 mA. In first stage, a PWM signal is given to inverting terminal and a reference voltage is given to non-inverting terminal.

Thus with the variation in the PWM signal, difference amplifier will generate a voltage. This voltage is fed to non-inverting terminal of other opamp, which will act as a current buffer with transistor Q2. Thus with the variation in the difference voltage there will be a proportional change in the current flowing through collector terminal of transistor. This will affect the current through the emitter and the load connected to it. Thus with the PWM we will be able to control the load current. Both the potentiometers are adjusted to get 4-20mA signal at load.

As seen in figure 2, in the case of I/V converter only a single opamp is used as a voltage follower. Here the drop across the resistor is fed to the non-inverting terminal. This method improves the voltage gain and avoid loading. Since the voltage limit of ADC in the microcontroller can handle maximum of 5V, a 4.7V Zener diode is connected across the load for over-voltage protection.

Apart from DAC and ADC operation chip programmed in the data acquisition card can also perform signal conditioning. A median-mode filter [5] is used to remove the noise occur while reading ADC values. Block diagram for filtering procedure is shown in figure 4. When there is a request to get samples from the measurement, a hundred samples of ADC readings are taken and then saved to an array, which is then sorted and averaged to avoid noise.

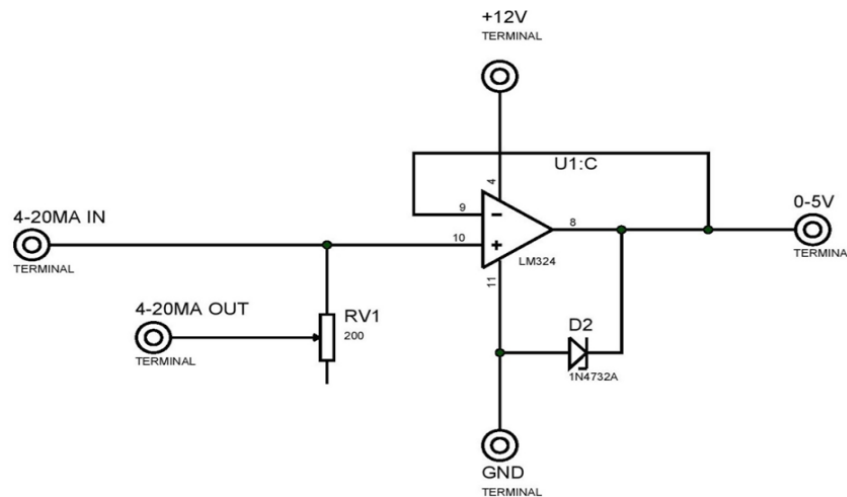


Figure 2: Current to voltage converter (I/V) converter

The averaged value is then again multiplied with the resolution of ADC, considering the input supply voltage at that instant.

3.2 Wireless Communication

Four process stations and master control unit communicate themselves by means of wireless communication. For wireless communication we make use of a GFSK RF module, NRF24L01 [6]. It has 2.4GHz ISM band operation with wide range of data rates (250kbps, 1Mbps and 2Mbps) with low power consumption. It can be programmed to communicate in six individual data pipes. It also works even with a

low voltage range (1.9 to 3.6V). Since frequency modulation is used, it has got better noise isolation over amplitude modulation. GFSK is achieved by passing frequency modulated signal through a Gaussian filter. By using this method pulses will get smoothed and also limit the modulated spectrum width. By this pulse shaping method spectral width will be limited.

The nRF24L01+ is a single chip transceiver with an embedded baseband protocol engine (Enhanced ShockBurst™), suitable for ultra-low power wireless applications. The nRF24L01+ is designed for operation in the world wide ISM frequency band at 2.4 - 2.48GHz. It can be easily connected and configured by use of SPI (Serial Peripheral Interface). The embedded baseband protocol engine (Enhanced ShockBurst™) is based on packet communication and supports various modes from manual operation to advanced autonomous protocol operation. Internal FIFOs ensure a smooth data flow between the radio front end and the system’s MCU. Enhanced Shock-Burst™ [7] reduces system cost by handling all the high speed link layer operations. It uses GFSK modulation and also user can configure parameters like frequency channel, output power and air data rate.

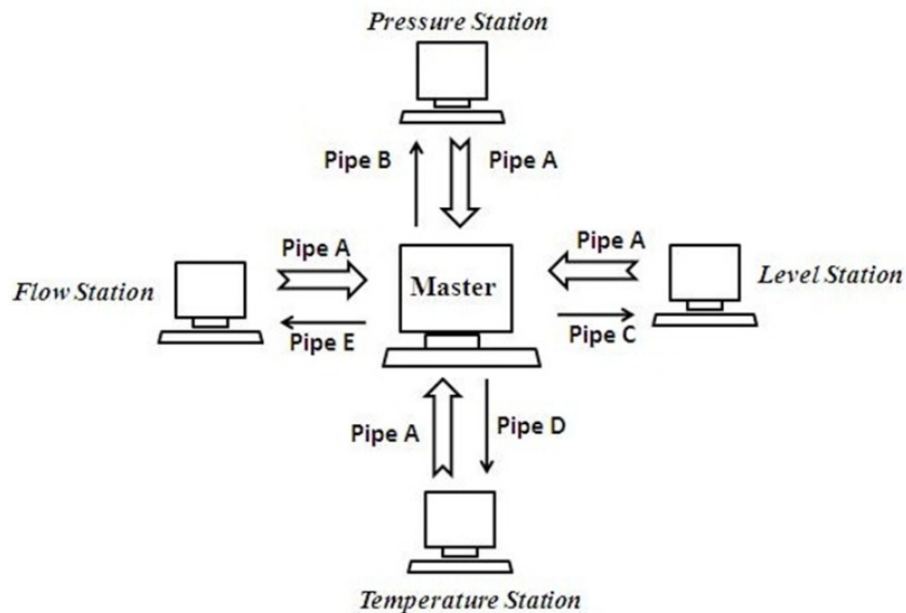


Figure 3: Wireless communication between process stations (slave) and master

Among six available transceiver data pipes we use five of them. Since there are four individual stations, four individual pipes are used for data transmission from master to these stations. But in the case of receiving data, master only uses one data pipe. MCU associated with the master will identify the data from different stations. This is done by means of formatting. Data from different stations are formatted to a particular string and transmitted. Here is the sample transmitted data packet.

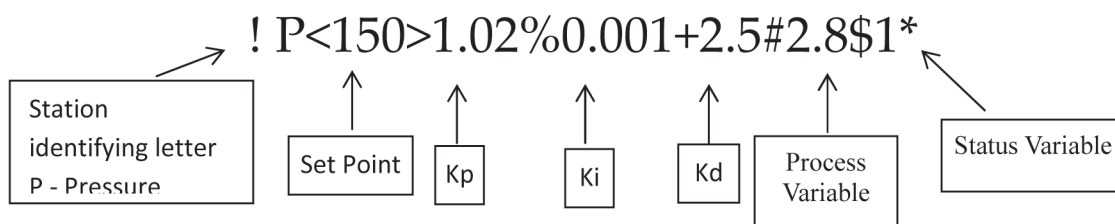


Figure 4: Sample Data packet for master/slave communication

Thus with this formatted string master station will get to know all various parameters related to local station. String will always starts with “!” and ends with “*”. With this same method master communicates with the local station.

But for communication with MCU, Serial Peripheral Interface (SPI) is used .In SPI, only one side generates the clock signal (usually called CLK or SCK for Serial Clock). The side that generates the clock is called the “master”, and the other side is called the “slave”. There is always only one master (which is almost always a microcontroller), but there can be multiple slaves (more on this in a bit).When data is sent from the master to a slave, it’s sent on a data line called MOSI, for “Master Out /Slave In”. If the slave needs to send a response back to the master, the master will continue to generate a prearranged number of clock cycles, and the slave will put the data onto a third data line called MISO, for “Master In/Slave Out”. Thus by SPI MCU get the values and will send to LabVIEW for processing. Master station runs with a time based polling technique. A specific time (5ms) is given for each station to communicate with master. After that period master will switch the station.

3.3 LabVIEW Communication and Processing

Every station is equipped with a computer capable of running LabVIEW. The MCU is connected in serial communication with Values to and from the MCU reach the LabVIEW by VISA module [8, 9]. VISA stands for Virtual Instrument Software Architecture. It is a standard for configuring, programming, and troubleshooting instrumentation systems comprising GPIB, VXI, PXI, Serial, Ethernet, and/or USB interfaces.NI-VISA includes software libraries, interactive utilities such as NI I/O Trace and the VISA Interactive Control, and configuration programs through Measurement & Automation.

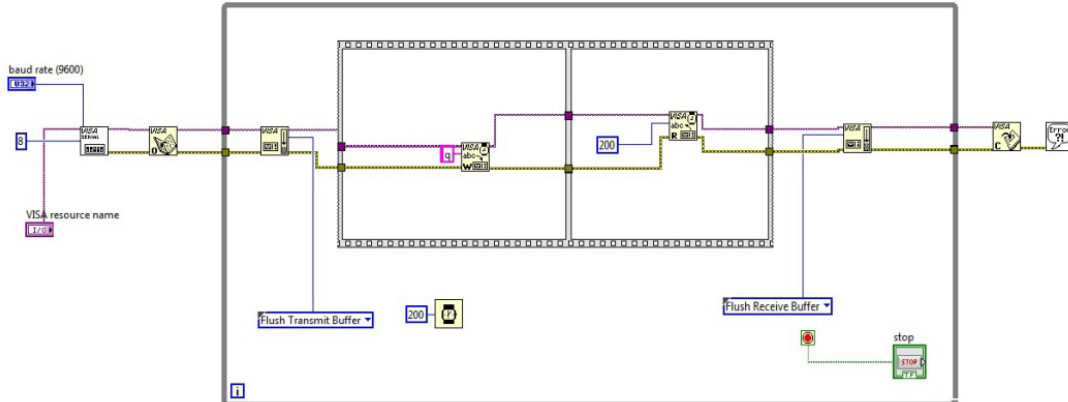


Figure 5: VISA communication with USB port

When the LabVIEW program starts, first it will open the communication port. Here all the communication with the MCU unit is done by USB port. By specifying the USB port VISA module will access the control over that port. Thus by VISA, LabVIEW could read and write to that port. Diagram shown below explains basic VISA communication with USB port.

In the first section baud rate and source name is specified inside VISA configure serial port. In second block visa module will open the port for communication. After opening it will flush out the transmit buffer. Process of clearing buffer will happen at the starting of each loop. Then with the help of VISA Write we can write data to serial port and also we can read the data from port with the help of VISA Read. After reading the data receive buffer will be flushed out. When the control comes out of the loop visa port will get closed. All the data comes through the serial port will be in form of strings. From this string required

data is extracted. Sample formatted data is shown above. After the first character ie, “!” next character will be determining the station. String comparison, string extraction and converting string to integer forms three integral procedures for data acquisition in LabVIEW in this application. Once the required data has obtained and converted to integer form then it is fed to PID controller written in formula node. Advantage of writing PID in formula node is less computational load and better understanding of controller.

PID in time domain is of the form

$$U(t) = K_p \left(e(t) + K_i \int_0^t e(t)dt + K_d \frac{d}{dt} e(t) \right) \quad (1)$$

After Z transformation

$$U(z) = \left[K_p + \frac{K_i}{1-z^{-1}} + K_d(1-z^{-1}) \right] E(z) \quad (2)$$

When converting back to difference equation

$$U(k) = U[k-1] + K_1 e[k] + K_2 e[k-1] + K_3 e[k-2] \quad (3)$$

$$K_1 = K_i + K_p + K_d \quad (4)$$

$$K_2 = -K_p - 2K_d \quad (5)$$

$$K_3 = K_d \quad (6)$$

Value reaches at LabVIEW as voltage. This voltage is then again converted to current to current then corresponding conversion is done to obtain the process variable. Thus with the 4-20mA current signal can be converted to usable format. All the station except flow station has linear characteristics. Thus the current can be converted to required parameter by following this equation.

$$\text{Present Reading} = \text{Lowest Reading} + \left(\frac{\text{mA} - 4}{16} \right) * (\text{Highest Reading} - \text{Lowest Reading})$$

4. EXPERIMENTAL RESULT AND IMPLIMENTATION

Experimentation includes four stations with a LabVIEW running computer and a master station. Stations are interfaced with the computer by newly created data acquisition card. For all the stations four individual data cards are used. These data cards are capable of generating 4-20mA current signals and it can sense the same. All the data cards are equipped with 10-bit ADC. It is capable of communicating with the local station and the master station at the same time.

For all the four stations different LabVIEW panels are made. At the master station all the parameters related to local stations are able to observe. In case if there is an emergency occurs then the user will get acknowledged by use of visual method and by rising alarm. Figure 4 is an example of VI build for Pressure controls station. It is capable of communicating with the DAQ card, displaying information and also runs a PID controller. First gauge shows current value. Other two gauges shows voltage and pressure (PSI). In this panel we can adjust K_p , K_i , K_d and set point. Likewise all the stations are equipped with individual VI's.

Again in Figure 6 shows LabVIEW panel in master control station. It is capable of showing all the station status, rising an alarm and even generates control signal for remote station if an emergency occurs. It is connected to an MCU through VISA module. Through VISA module it will receive and transmit data. In this VI panel status each stations can be seen with an indicating color bar. Here Temperature Station and

flow stations are live and are self-running. But in the case of level and pressure station, there is no local control but it is controlled by master station. At the center there is a toggle switch which allows the user to work the entire system as distributed or centrally.

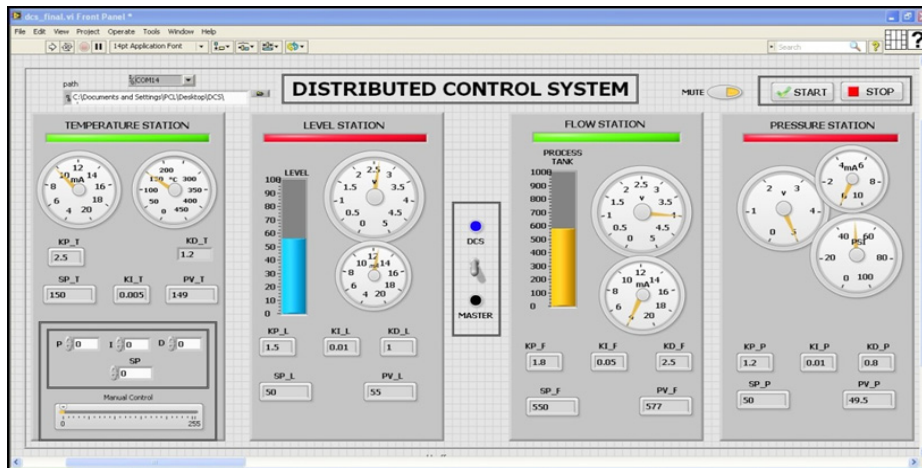


Figure 6: LabVIEW front panel in master control station

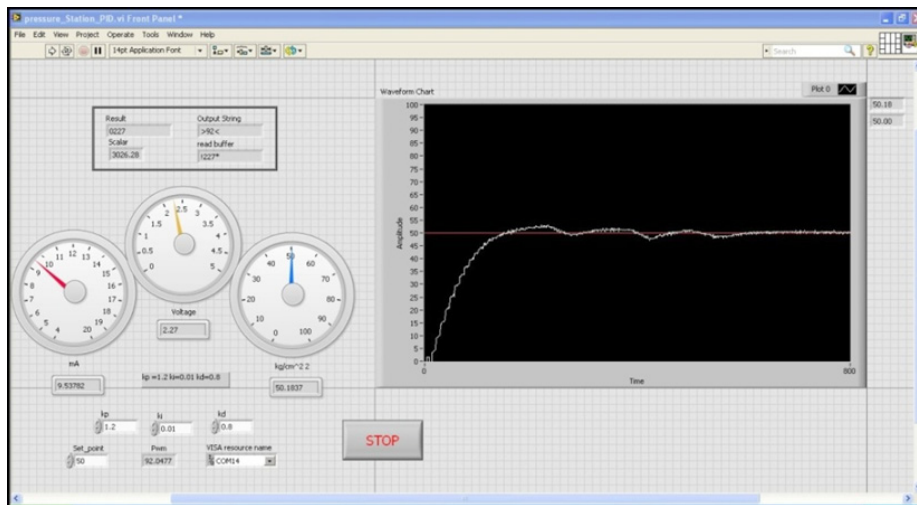


Figure 7: LabVIEW front panel of slave process station

5. CONCLUSION

With this approach we have implemented a low cost wireless DCS and tested in realtime. Whenever a slave system fails suddenly master take control over it hence safe running of the process is ensured. High amount of noise level has been attenuated with the mean mode filter designed. During the testing every system found to be working properly with good response over time. While considering the CPU load it is only of 2%, which is nominal value.

6. ACKNOWLEDGEMENT

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7. ABBREVIATION

DAQ	–	Data acquisition
PCU	–	Process Control Unit
MCS	–	Management Control Station
V/I	–	Voltage to Current converter
I/V	–	Current to Voltage converter
DCS	–	Distributed Control System
ADC	–	Analog to Digital Converter
DAC	–	Digital to Analog Converter
I/P	–	Current to Pressure converter
PID	–	Proportional Integral Derivative
LabVIEW	–	Laboratory Virtual Instrumentation Engineering Workbench

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