# Wireless Networked - Monitoring and Control of Pressure Process Analyser

**Swapna. P and Sharmila. B**

*Abstract—*

Wireless Network Control System (WNCS) has received considerable attention with advances in control and communication technologies. This paper presents the stability analysis of real time PI controller design and Smith Predictor control strategy for the compensation of assumed delay in the plant. Mathematical modelling of the plant is obtained and the parameter estimation of the traditional controller design is obtained by IMC tuning relationship which is a comprehensive model-based design method. Real time laboratory test demonstrates the mobile based wireless control of the plant with the help of the application Data Dashboard for LabVIEW that enables the creation of custom user interface that can monitor and control LabVIEW applications remotely. Comparative chart for the performance of the plant with and without wireless network for the various control designs is also made.

*Keywords: Dashboard, LabVIEW, PI, Pressure Process Analyser, Smith Predictor, Wireless Network Control System*

## 1. Introduction

For several decades, the traditional direct communication structure for control system has been implemented in industries by the physical wire connections [10][2]. In order to reduce the cost, system wiring, diagnosis, maintenance and to increase system agility a new wireless shared network scheme has aroused in recent years known as Wireless Network Control System (WNCS)[5][11]. However because of the limited bandwidth channel, the time-varying transmission channel is extremely easy to crash or conflict [9]. The Wireless Network Control System (WNCS) has its own significant advantages and has been widely applied. Sensors, controllers, and actuators are connected through the wireless network like Wi-Fi, Zigbee etc., hence WNCS provide a convenient way for information exchange among the system components. However the involvement of wireless network induce some imperfections during the transmission of data which becomes the potential source of instability and poor performance of WNCS. In the analysis and synthesis of WNCS the impact of network induced delay receives wide attention[1][3][4][12]. This paper focus on the analysis of stability and performance of designed controllers induced by network delay. This also focus on the implementation of the hierarchical structure of NCS[10]. It contains main controller and remote closed loop system. This paper utilize the gadget like mobile to act as a main controller and remote system as PC. Main controller computes and sends the reference signal in a frame or a packet via a wireless network to the remote system periodically. The remote controller process the reference signal to perform control action and returns the sensor measurement to the main controller. Moreover several hardware units can be controlled by a single main controller.

## 2. Plant Dynamics

Pressure process control is the wide sought of control in process control industries. Pressure like liquid pressure, gas pressure and vapour pressure are generally controlled in process industries. For analysis and design of controller, there is a requirement of knowing the mathematical model of Pressure process analyser. The basic principle is that the mass of gas stored in cylindrical vessel of fixed volume at constant temperature varies directly with its pressure. The model of the plant is shown in the (Fig. 2.1).

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Swapna . P (M.E)
Sri Ramakrishna Engineering College, Coimbatore
Tamilnadu, India
email : swapnashakthi12@gmail.com


Dr. B. Sharmila M.E., Ph.d.,
Sri Ramakrishna Engineering College, Coimbatore
Tamilnadu, India
email : sharmila.rajesh@srec.ac.in

**Fig. 2.1** Model of the Pressure Process
Analyser Tank
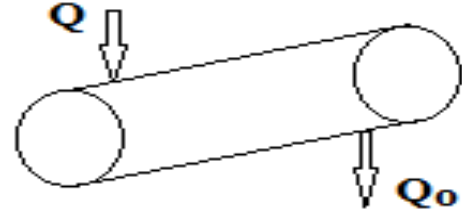


For constant air density ρ, a mass balance yields,

$$\frac{dm}{dt} = \rho Q - \rho Q_o \tag{2.1}$$

where the Q and $Q_o$ are the input and output pressure of the cylindrical vessel. The mass accumulation term in (Eq. 2.1) can be written as (Eq.2.2),

$$\frac{dv}{dt} = Q - Q_o \tag{2.2}$$

The plot of the process to a step change in input is referred as process reaction curve method. Using the process reaction curve method, the open loop transfer function of the process is found as (Eq. 2.3),

$$\frac{Y(s)}{U(s)} = \frac{K}{\tau s + 1} \tag{2.3}$$

where Y(s) and U(s) are the Laplace transform of output and input variable; K the process gain is found by,

$$K = \frac{\text{Pressure at initial time } - \text{Pressure at final time}}{\text{Final valve setting} - \text{Initial valve setting}} \tag{2.4}$$

K is found to be 1.7. τ is the time constant which can be calculated by finding the time corresponding to 63.2% of final steady state value of the open loop response which is found to be 8.6 seconds. By substituting the values of K and τ in (Eq. 2.3) the transfer function of Pressure Process analyser is obtained as (Eq. 2.5),

$$\frac{Y(s)}{U(s)} = \frac{1.7}{8.6s + 1} \tag{2.5}$$

### 3. PI Controller

A successful operations of automatic control system requires anti-jamming capability, stability and ability to meet the given performance index. Since the physical structure and the working process of the controlled object are constant, the output value of the given signal could not meet the needs of system. Therefore, a controller needs to be included. PI (Proportional Integral) control is a widely used control method for fast process. It has huge advantage in the fields of control engineering [8]. PI controller has simple structure, excellent stability, reliability performance and convenient adjustability. When the structure and the parameters of the controlled object cannot be completely acquired or cannot manifest a clear mathematic model, PI control technology becomes more useful. Because it was designed for the situation where users cannot thoroughly learn about a system with a controlled object, or cannot obtain the system parameters by using the effective measuring methods. PI controller structure is shown in the (Fig. 3.1).

**Fig. 3.1** PI Controller Structure of a Process
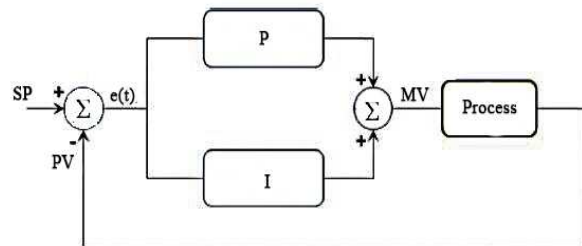
Where, MV - Manipulated Variable; PV – Process Variable; SP – Set Point; P – Proportional controller; I – Integral controller. The PI controller is mathematically denoted as (Eq. 3.1),

$$G_c = K_p + \frac{K_i}{s}$$
(3.1)

Where, $G_c$ - Controller Transfer function, $K_p$ - Proportional gain, $K_i$ - Integral gain.

Integral control action added to the proportional controller converts the original system into high order. Hence the control system may become unstable for a large value of $K_p$ since roots of the characteristic equation may have positive real part. In this control, proportional control action tends to stabilize the system, while the integral control action tends to eliminate or reduce steady-state error in response to various inputs. As the value of $T_i$ (Integral time) is increased, the overshoot get decreases and the speed of response is reduced.

## 4. Parameter Estimation

A more comprehensive model-based design method, Internal Model Control (IMC) was developed by Morari. The IMC method is based on assumed process model and leads to analytical expressions for controller settings. The IMC approach has the advantage that it allows model uncertainty and tradeoffs between performance and robustness to be considered in a more systematic fashion. The IMC tuning relationship for first order system is given by (Eq. 4.1 and 4.2)

$$K_p = \frac{\tau}{K \times \tau_c}$$
(4.1)

$$K_i = \frac{1}{\tau}$$
(4.2)

The PI controller tuning parameter is obtained using the above IMC tuning relationship. The parameters are found to be $K_p= 0.6022$ and $K_I = 0.1162$.

## 5. Smith Predictor Control Strategy

Smith's [1957] principle provides a criterion for selecting a control strategy for time delay processes and dead-time compensation techniques. The technique is an approach to control of systems with long dead times[6]. The block diagram of Smith predictor is shown in the (Fig. 5.1). The closed loop transfer function is given by (Eq.5.1).

$$\frac{Y(s)}{Y_{sp}(s)} = \frac{G_c(s)G_p(s)e^{-\theta s}}{\left(1 + G_c(s)G_m(s) + \left(G_c(s)G_p(s)e^{-\theta s} - G_c(s)G_m(s)e^{-\widetilde{\theta s}}\right)\right)}$$
(5.1)

**Fig. 5.1** Block Diagram of Smith Predictor Controller
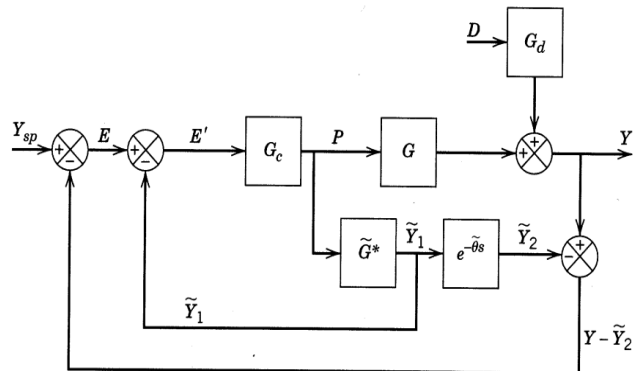


As the process and the model are equal the Equation (9) becomes

$$\frac{Y(s)}{Y_{sp}(s)} = \frac{G_c(s)G_p(s)e^{-\theta s}}{1 + G_c(s)G_m(s)}$$
(5.2)

Thus inclusion of smith predictor compensator removes the delay from the characteristic equation there by allowing increase value for controller gain as shown in (Eq. 5.2). A Smith predictor achieves some form of derivative action required for compensating dead time in first- order processes by a lag in its feedback path. By matching the lag in the smith predictor to the lag in the dead time process, the input manipulated variable follows the process lag exactly but delayed by the dead time. The delayed predictor output is compared to the measured process output and the resulting model error quantity is added to the current predictor output to correct for predictor deficiencies, provided that the model is a true representation of the process and there are no further disturbances to the process during the dead time period. It is observed that the optimal predictor part of the controller algorithm changes also with the time delay. The Smith predictor is an optimal dead time compensator for only those systems having disturbances for which the optimal prediction is a constant over the period of the dead time.

## 6. Data Dashboard Application

The technological development of the mobile and web devices has changed how the human beings interact with the environment. LabVIEW- based remote monitoring and control systems from a mobile application platform is an increasingly important aspect to a efficient, reliable and flexible system. Data Dashboard for LabVIEW is a mobile application that enables the creation of user interface that monitor and control the applications developed in LabVIEW platform remotely [14]. The I/O used in Dashboard for LabVIEW are shared variables which is used for both reading and writing the data to the host system. Shared variables interact with the host LabVIEW application via the LabVIEW Shared Variable Engine (SVE) and update in Data Dashboard when it receives the updated information from the main server. Shared Variables support standard data types (eg. Numeric Doubles, Booleans and Strings) as well as arrays of those standard data types.

Shared variables interact with the LabVIEW application through the LabVIEW Shared Variable Engine (SVE) and the updates are handled and maintained via the Publish Subscribe Protocol (NI-PSP). Deploying the shared variables to the SVE through a library project item enable the access of those variables. After deployment, the SVE will reserve a memory space for those variables which will remain in the allocated memory space for interaction.With larger data types and data types which vary in size (strings and arrays) it is important to keep in mind that mobile devices are very different from a full development system (i.e) limited resources available on these mobile devices. Therefore, with varying size data types , as it get larger, it over burdens the application causing problems and even crashes the application developed. With the continuous monitoring update mode of shared variables and the ability to send the updated data to the mobile application rapidly, it is important to be cognizant of this so that risks of crashes are lessened. Shared variables are a quick and easy way to integrate Data Dashboard into a host LabVIEW application. It is easy to create and add to an existing VI.TCP-based network communications are used by the shared variables to interact with dashboard. Network Firewalls should be turned off while using the shared variable concept.

## 7. Wireless Control Demonstration

With the aroused interest in WNCS, laboratory test demonstrate the real time wireless transfer of packets for the monitor and control of the plant which is shown in the (Fig. 7.1).

**Fig. 7.1** Hardware Setup of Wireless Control of Pressure Process Analyser
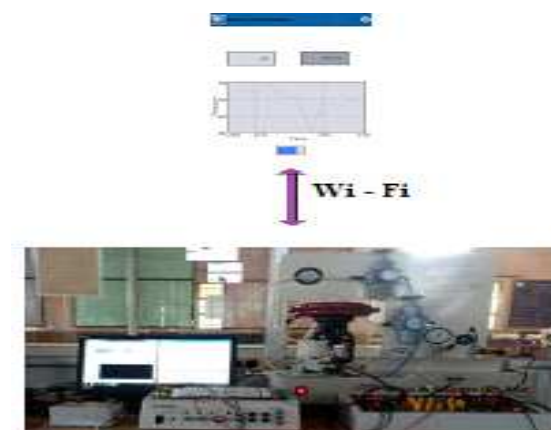


Let the plant be the Pressure Process analyser. As the air input 20 psi is given to the plant by the air regulator of 0-2.1 bar, the  pressure inside the tank will be sensed by the piezo electric transducer (0-6  bar) which is the conventional 4-20 mA , it

is then converted to voltage by I to V converter ( 0 – 10 V). The converted voltage is given to the DAQ card ( NI PCI 6251) via the ELVIS kit for the conversion of A/D which in turn feed to the PC with LabVIEW, which constitute the remote system. The sensed pressure signal is given to both main controller i.e mobile with Dashboard application and the PC with LabVIEW, the main controller monitors the sensed data and sends the reference signal to the remote system, which will process the reference as well as the sensor measurement with help of the developed control algorithm to produce the control signal (0 – 100 %) for the control valve of equal characteristic type to get settle in order to maintain the pressure inside the cylindrical vessel. This can be achieved by sending the control signal to the DAQ card for the conversion of digital to analog data which is again given to V/I converter. The converted current is given to current to pressure converter (I/P - 3 to 15 psi ) for the successful operation of the control valve. The transfer of packets between the mobile and the PC is happened by utilizing the mobile data connection with the help of Wi-Fi hotspot technology.

## 8. Result Analysis

PI controller which is a feedback controller which drives the plant to be controlled by a weighted sum of the error which is the difference between the output (i.e) process variable and desired set-point and integral of that value. The response obtained for PI controller without network is shown in the (Fig. 8.1).

**Fig. 8.1** Response of PI Controller for Pressure Process Analyzer without Network
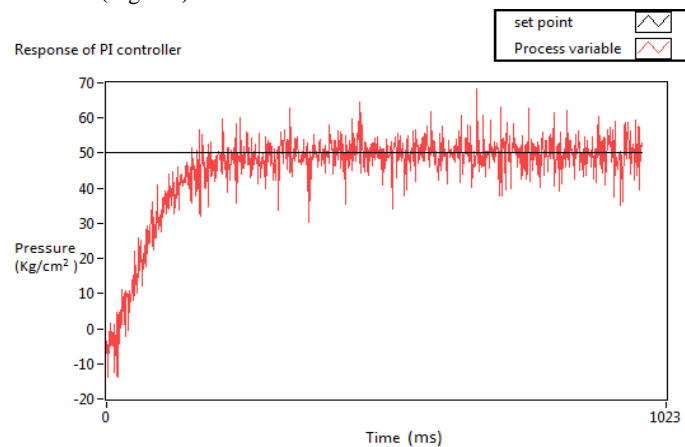


The response obtained shows the relationship between time in ms and pressure in $Kg/cm^2$. According to PI characteristics the response obtained has no overshoots, steady state error has been reduced. The response shows a settling time of 12 seconds.

According to the Hierarchical Structure of Network control system, the main controller (mobile) sends the set point and receives the sensor measurement (i.e) process variable and the remote controller (PC) acts a controller for the process. As the set point and process variable are assigned as shared variables which will be accessed from the mobile application. The (Fig. 8.2) shows the response of PI controller with wireless network obtained in the remote PC..

**Fig.8.2** Response of the PI Controller with Network
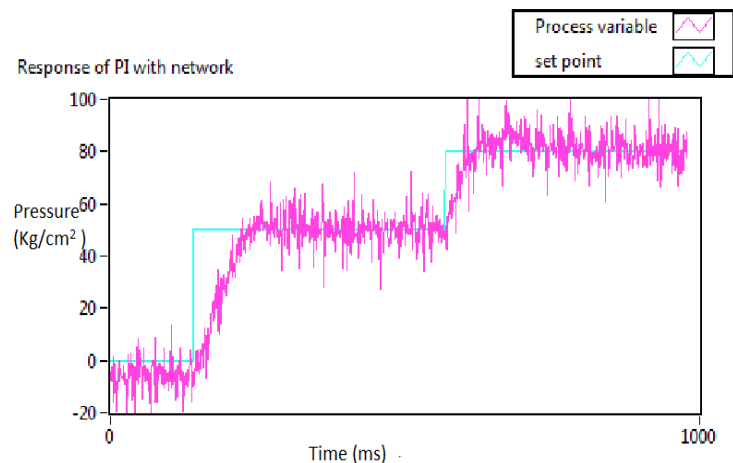


As the time take to start the program and set–point given from the data dashboard mobile application is showed as the dead time in the response (i.e) the response stay at zero pressure for certain time period. Once the set point as 50 $Kg/cm^2$ is given from the main controller (i.e) from mobile, the set point starts to increase from zero pressure to 50 $Kg/cm^2$. And according to

PI characteristics the response has no overshoot and gets settled at 26 seconds. This settling time includes the dead time due to network. The result obtained from main controller (i.e) mobile application –data dashboard is shown in the (Fig.8.3).

**Fig. 8.3** Response Obtained in Data Dashboard for PI Controller



The response obtained in data dashboard shown above where the numerical control showing the 50 kg/cm$^2$ is the given setpoint, the numerical indicator showing 50.62 kg/cm$^2$ is the process output which tracks the setpoint. The waveform shows the process output. The switch provided below the waveform is used to start and stop the program in block diagram.

Smith predictor technique is a model based controller used for time delay compensation in Process control industries. In this paper the process is assumed with a small delay of 0.006 sec as the pressure process will have negligible delay in practice because it is a fast process. The response obtained for Smith Predictor technique without network for pressure process analyser is shown in the (Fig 8.4).

**Fig. 8.4** Response of Smith Predictor without Network
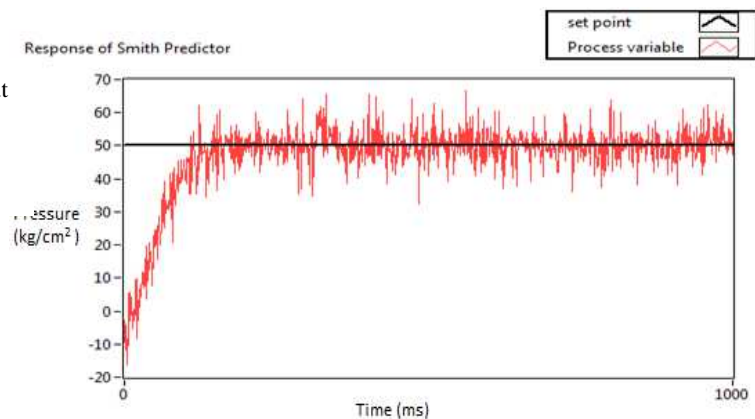


The response which is obtained as a result of implementing Smith Predictor technique for Pressure process analyzer which in turn provides a compensation of delay assumed in the process with the settling time of 10 seconds with no overshoot.

**Fig. 8.5** Response of Smith Predictor with Network Obtained in Remote System
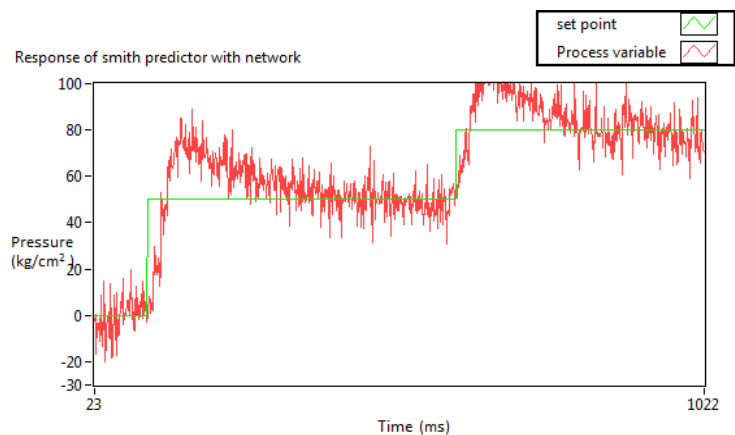
The Figure shows the response of Smith Predictor control strategy with wireless network obtained in the remote system. The response have peak over shoot and gets settled at 33 seconds. In this case a better performance has not been obtained when compared to PI controller due to the induced delay in network. This settling time includes the dead time due to network[7][13]. The result obtained from main controller (i.e) mobile application –data dashboard is shown in the Figure 10.

**Fig.8.6** Response Obtained in Data
Dashboard for Smith Predictor Technique



The response obtained in data dashboard shown above where the numerical control showing the 50 kg/cm$^2$ is the given setpoint, the numerical indicator showing 49.7 kg/cm$^2$ is the process output which tracks the setpoint. The performance index of the designed controllers for without and with wireless network environment is shown (Table 8.1)
.

**Table 8.1**
Performance Index
Table for Designed
Controllers

| Controller | Setting time Seconds | Overshoot | Stability |
|---|---|---|---|
| PI without network | 12 | No | Stable |
| Smith predictor without network | 10 | No | Stable |
| PI with wireless network | 23 | No | Stable |
| Smith predictor with wireless network | 33 | Yes | Stable |

**9. Conclusion**

This paper considers the network induced delay in the wireless network. With designing PI and Smith Predictor controllers the Pressure process analyzer have been implemented under both conditions of with and without wireless network. Analysis of stability shows a considerable results i.e remain stable at all the control designs. Whereas in the case of delay analysis there is performance degradation in the case of smith predictor control strategy. Further investigation and compensation should be done over the network induced delay.

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