Real Time Implementation of Gain Scheduled Controller Design for Higher Order Nonlinear System Using LabVIEW

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Abstract— One of the main problem in process industries is to control process parameters due to their nonlinear behaviour. Control in the level of liquid in a nonlinear spherical tank is challenging due to variation in the cross section area with height. This paper is about the controlling of liquid level in a nonlinear Dual Spherical Tank Liquid Level System (DSTLLS) using Gain Scheduled PI controller (GPIC).The performance indices like ISE, IAE and time domain calculations similar to rise time, peak time and settling time are also calculated in this paper, for different servo and regulatory tracking cases. This research paper gives details about implementation and performance analysis of real time GPIC for DSTLLS by using LabVIEW.

Keywords— Dual Spherical Tank Liquid Level System (DSTLLS), PI controller,Gain Scheduled Proportional Integral Controller (GPIC), LabVIEW.

I. INTRODUCTION

Most of the process industries are having lot of control issue because of the dynamic nonlinear behavior of the plant. Many industries such as concrete mixing industry and waste water treatment industry are in need of efficient control techniques because of the inherent nonlinearity. Process industries are need in of the efficient controller for controlling the parameters such as settling time and rise time. The nonlinearity of the system will increase according to the area in the spherical tank [1]. Spherical tanks are widely used in process industries such as gas plants, food process industries, and waste water treatment industries [2]. The two important operational factors in the DSTLLS is the flow change from primary tank to the secondary tank and the fluid level [3]. . In heavy industries always the liquid is pumped through chemical mixtures. The mixing liquid will be send from one tank to the other tank in the dual spherical tank. This process need efficient controller for controlling output flow to the tank2 with respect to the inflow of tank1.An attempt was made for the implementation of real time controller using LabVIEW environment for the purpose of regulating the level of the liquid in the output tank, if the level of the tank is too low, for the sequential operations it may have bad consequences, if the level of the tank is very high it may disturb the response of the system [2, 4].Skogested Proportional Integral Derivative (PID) controller is the name that is widely heard as a part of process control industry [5].Designing of model based controller in real time in [5,6] was done for a spherical tank to compare the performance between different classical controllers . Intelligent techniques are used in [7] for modeling both interacting and non interacting systems.

Generally comparing the linear problems nonlinear problems are much less understandable and complicated to solve. Spherical tanks have greater advantages compare to conical tank system while washing and it is intensified production and the cost is also less compare to the conical tanks[7][8].Chidambaram.M et al[9] discussed the limitations of PI controller for a nonlinear process. Bhuvaneswari N.S et al [10] studied on time-optimal control of tank level. Controller design via variable transformations in [11] have been experimented on a FOPTD system with a delay and the performance was documented. Ravi studied on multiple model control for the implementation of multi predictive controller [12] for a hybrid tank system. Implementation of decentralized PID controller was performed by Ravi [13] to control the level parameter of a non linear interacting system in simulation. Model reduction by classical rules [14], and fractional PID controller for controlling level of tank [15] are also studied in the earlier days. Naresh N.Nadola et al [16] have studied and mathematically designed a predictive controller for nonlinear hybrid system. A model based controller has been designed by K.Hari Krishna et al [17] for a spherical tank. State feedback controller for a nonlinear interacting system was designed and implemented by S.Latha et al [18].This paper describes modeling and designing of gain scheduled PI controller for DSTLLS. Design of gain scheduled controller for the nonlinear system has greater advantages such as higher levels of accuracy in controlling the process variables. In this paper an attempt has been made for implementation of real time controllers on hardware model and verifying their efficiency.

II. PROCESS DESCRIPTION

The hardware needed for implementing the above said process consists of DSTLLS. These tanks are connected with a manually operable valve as shown in Fig.1. Two tanks have both inflow and outflow of water which is being pumped by the motor. Through the pneumatic control valves flow is regulated into the tanks. The position of pneumatic control valves can be controlled by applying air to them. Having inherited dynamic nonlinear behavior in the DSTLLS, designing of controller for this type of systems is a challenging task.

The process contains identical dual spherical tanks named as tank1 and tank2 whose heights are H (45cm) and radius R (22.5cm).For the interconnection of these two tanks a manually controlled valve (MV_{12}) is fixed at the bottom of the tank. The input flow to the tank1 is represented as F_{in1}.The output flow of the tank2 is represented as F_{out2} [4].Differential Pressure Transmitters are used for measuring liquid heights in the spherical tanks. These values are transmitted in the output current range of 4-20mA to the interfacing unit of the PC through the NI-DAQmx 6211 data acquisition module card which can support 2 analog output channels and 16 analog inputs within the range of voltage between ±10 volts. This data acquisition module is having the sampling rate of 250Ks/S with 16 bit resolution. Through the data acquisition module LabVIEW program is linked to the system. Main aim is the control of the height in tank2 with respect to the input flow F_{in1}.

This paper talks about the two interacting spherical systems so throughout the experiment two spherical tanks are used. Transmission of height of the water in the tanks is done to the personal computer (PC) in the form of 4-20mA through NI-DAQmx 6211 data acquisition module card. Control signal is transmitted to the I/P converter after executing the programmed logic in the PC. Then I/P converter pass the pressure to the pneumatic valve proportional to the current provided to it.

Fig.1. Real time Hardware Setup of DSTLLS

TABLE I
Technical Specifications of hardware Setup

Hardware parts	Description
Dual Spherical Tanks	Material: Stainless Steel Diameter:45cm
Differential Pressure Transmitter	Type :Capacitance Range :2.5 to 250)Mbar Output :4 to 20 mA Make :ABB
Control valve	Size :1/4”,Pnematic Actuated Type :Air to close Input(3-15)PSI 0.2-1 Kg/cm2
Air Regulator	Size ¼” BSP Range:(0-2.2) BAR
Pump	Centrifugal 0.5 HP
I/P Converter	Input:4-20 mA Output :(3-15)PSI
Pressure Gauge	Range:(0-30) PSI Range :(0-100) PSI

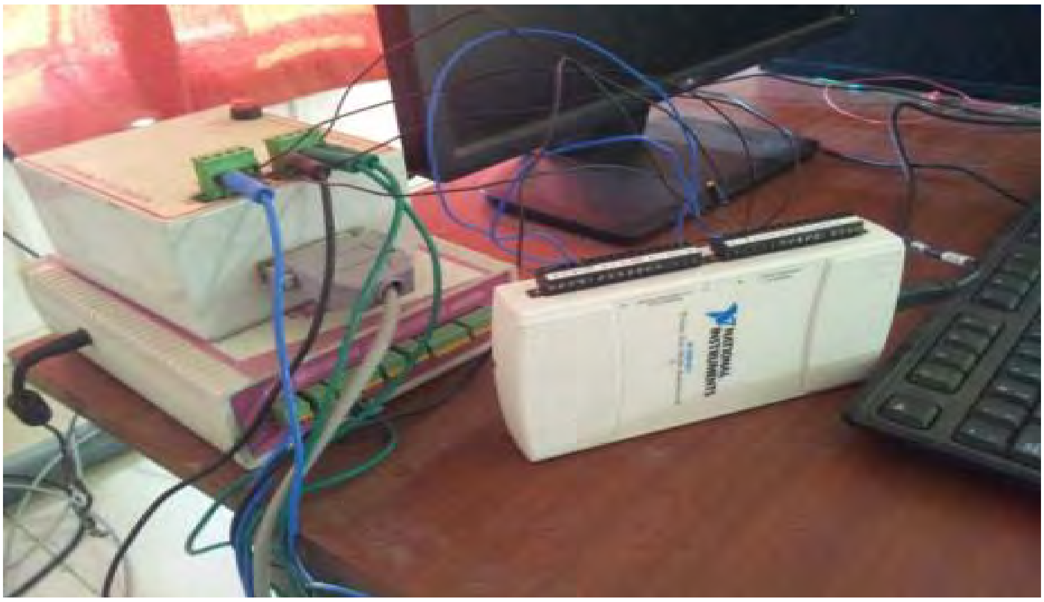

Fig.2. Interfaced NI-DAQmx 6211 data acquisition module card to the PC

III. SYSTEM IDENTIFICATION

3.1 Mathematical Modeling of DSTLLS

Gain scheduling problem is one of the interest for many researchers and it concerns with both practical and theoretical aspects in controlling the various process parameters. For the system controlling it is the one of the popular engineering method. This section derives nonlinear transfer function for the DSTLLS [9][14]. In this work DSTLLS is considered as a SISO process in which level h_2 in tank 2 is considered as measured variable and F_{in1} as manipulated variable. Mathematical modeling of liquid level system is derived using conservation principle on total mass balance [20] .

$$\frac{Accumulation\ of\ total\ mass}{Time} = \frac{Input\ of\ total\ mass}{Time} - \frac{Output\ of\ total\ mass}{Time}$$

For DSTLLS the mathematical model is derived by using the equation 1 and equation 2, which give the relation between flows and heights of DSTLLS respectively.

The differential equation describing the relation between $h_{1,}$ h_2 and $F_{in1}$for tank1is given in equation (1)

$$\frac{dh_1}{dt} = \frac{\frac{3}{4}\left\{\left(F_{in1} - \frac{4h_1}{3}\frac{dA_1}{dt} - \beta_1\sqrt{h_1 - h_2}\right)\right\}}{A_1} \quad (1)$$

The differential equation describing the relation between $h_1$and h_2 for tank 2 is given in equation (2)

$$\frac{dh_2}{dt} = \frac{\frac{3}{4}\left\{\left(\beta_1\sqrt{h_1 - h_2} - \frac{4h_1}{3}\frac{dA_2}{dt} - \beta_2\sqrt{h_2}\right)\right\}}{A_2} \quad (2)$$

$$\frac{\partial h_2}{\partial F_{in1}} = \frac{R_2}{\tau_1\tau_2 s^2 + [\tau_1 + \tau_2 + A(h_1)R_2]s + 1} \quad (3)$$

Where,

R_2 = Valve resistance of tank2

h_1 = Height of spherical tank1

h_2 = Height of spherical tank 2

A =Area of cross section of spherical tank

F_{in1} = Volumetric inflow rate of tank1

The above shown differential equation (3), represents the general transfer function which is a second order nonlinear system, which is further derived by solving equations (1) and (2) respectively. To find the valve resistance (R_2) in the transfer function, an experiment was performed by collecting volume of water from tank2 through the open valve in different time periods. Table II shows that values of valve resistances (R_2) in different time periods from 5sec to 15 sec.

TABLE II
Resistance of valve (R2) for different time periods

Time (sec)	Volume(ml)	Flow(q_1)lph	Resistance(R_2)ohms
5 sec	9x250	450	0.08
10 sec	17x250	425	0.09
15 sec	25x250	416	0.09

By substituting value of valve resistance in equation 3, we obtained the transfer function which is given by,

$$\frac{\partial h_2}{\partial F_{in1}} = \frac{0.09}{364167s^2 + 6934s + 1} \quad (4)$$

3.2. Designing of Gain Scheduled Proportional Integral Controller (GPIC)

The transfer function model for DSTLLS, which is derived in equation (4), due to its inherent non linearity, is an unstable process. The derivation of transfer function model will now pave the way to the controller design which shall be used to maintain the system to the optimal set point. This can be only obtained by properly selecting the tuning parameters K_p and τ_i for a PI controller. Ravi et al (2011) have discussed on the relationship between Interacting Spherical Two Tank System and PI controller for interacting conical two tank system [21][22]. The relation has been used by changing the area of two spherical tanks in interaction and the same is deployed to find the gain values.

$$K_p = \frac{A(h_2)(\tau_1 + \tau_2)}{\tau_1\tau_2} \quad (5)$$

$$\tau_i = \tau_1 + \tau_2 \quad (6)$$

To calculate the proportional gain and internal gain of PI controller above equations (5) and (6) are used. The calculated K_p and τ_i are observed as below:

Proportional Gain (K_p) = 6.42992234314861

Integral Time (τ_i) = 0.002928870823407

The various parameters needed in order to identify the system for the process shown in the above Table III. The gain values for the design of PI controller are derived from equations (3), (4) and these are performed for the three different operating points 5,15,25 centimeters of the tank's height. For the three operating points both the set point tracking and regulatory tracking are obtained for +50% and +75% of the tracking cases.

TABLE III
Modelling Parameters

Parameter	Description	Value
D	Spherical Tank Diameter	45 cm
R	Spherical tank radius	22.5 cm
H	Spherical tank height	45 cm
A	Area of Spherical Tank	1590.4cm^2
F_{in1}	Input flow to the tank1	107.85 cm^3/sec
β_{12}	Valve coefficient of MV_{12}	78.28 cm^2/sec
β_2	Valve coefficient of MV_2	19.69 cm^2/sec

Gain Scheduled PI controller is implemented using LabVIEW environment. With 45cm height as reference point positive tracking cases are performed at the each set point 5cm,15cm,25cm with +50% and with +75% in the increasing direction. By implementing the PI controller for various step variations we have calculated the values of Integral Square Error (ISE) and Integral Absolute Error (IAE) for the different operating points.

IV RESULTS AND DISCUSSION

4.1 Performance Analysis

The performance of the controller is tested for this DSTLLS which is a nonlinear system. At various operating points response of the controller is obtained without changing the input flow rate. PI controller performance is shown in the following figures. Tracking cases are considered for the increment of +50% and +75% at the each operating point 5 cm, 15 cm and 25cm. Fig.3,Fig.4 and Fig.5 show us the +50% and +75% tracking cases for the set points of 5,15 and 25 cms of tanks height respectively. In all the cases it can be observed that the optimum set point tracking is achieved. Table IV gives the information of the performance measures in each tracking case for all the regions of operation. It can be observed that the rise time and peak time for all the 75% tracking cases is higher than that of the 50% tracking cases, for all the regions of operation. And contrarily, it can be observed that settling time follows a different increasing pattern for 50% case and decreasing pattern for the 75% cases of tracking respectively. It can be also seen that Integrated Absolute Error (IAE) and Integrated Squared Error (ISE) are on the higher note for the 75% tracking cases than that of 50% tracking cases in all the regions of operation.

The level pertaining within the tank for +75% case is greater than that of the +50% case. Thus it can be understood that the rise time and peak time for the later will be greater than that of the former. The optimized tuning parameters chosen for the designed system have made the settling time relatively lesser. The error introduced for the +75% case is greater than that of the +50% case. Thus it is evident that IAE and ISE values shall also follow the same pattern of increasing values for +75% tracking case when compared for +50% tracking case.

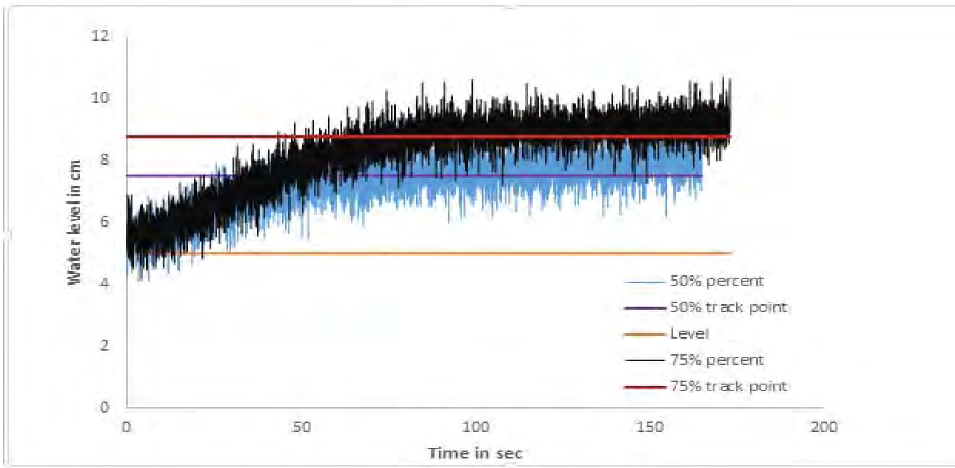

Fig.3. Set point tracking of +50% and 75% at operating point of 5cm

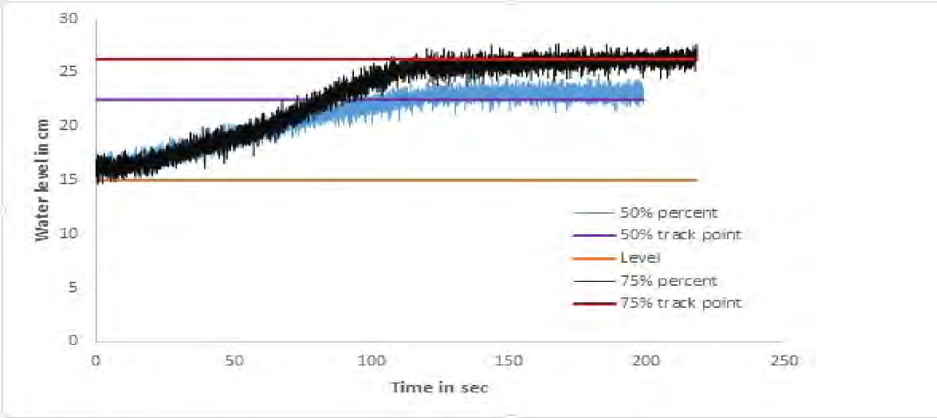

Fig.4. Set point tracking of +50% and 75% at operating point of 15 cm

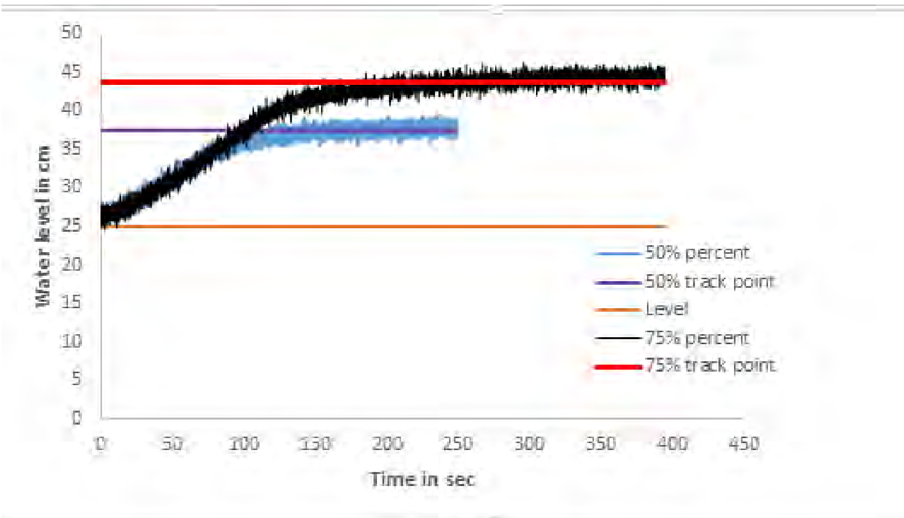

Fig.5. Set point tracking of 50% and 75% at operating point of 25cm

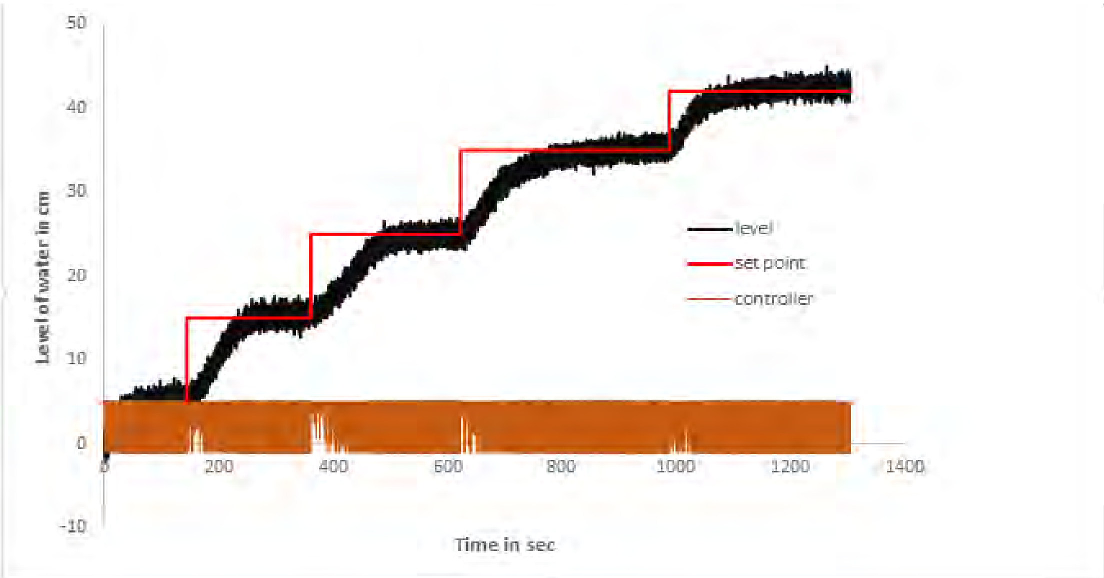

Fig.6. Servo Response obtained for changing Set Point profile

The servo response was also obtained for changing set point profile from 5cm to 42 cm without an influence of any external disturbance.Fig.6 shows the set point tracking for different changing set points of level in tank2. A sudden disturbance is given by pouring water into tank2 while the system becomes stable. The leakage of some amount of water from tank2 is considered as the error introduced to the system.Fig.7 shows the regulatory response obtained at different set points from 5cm to 42cm by introducing disturbance and the error in the tank2.

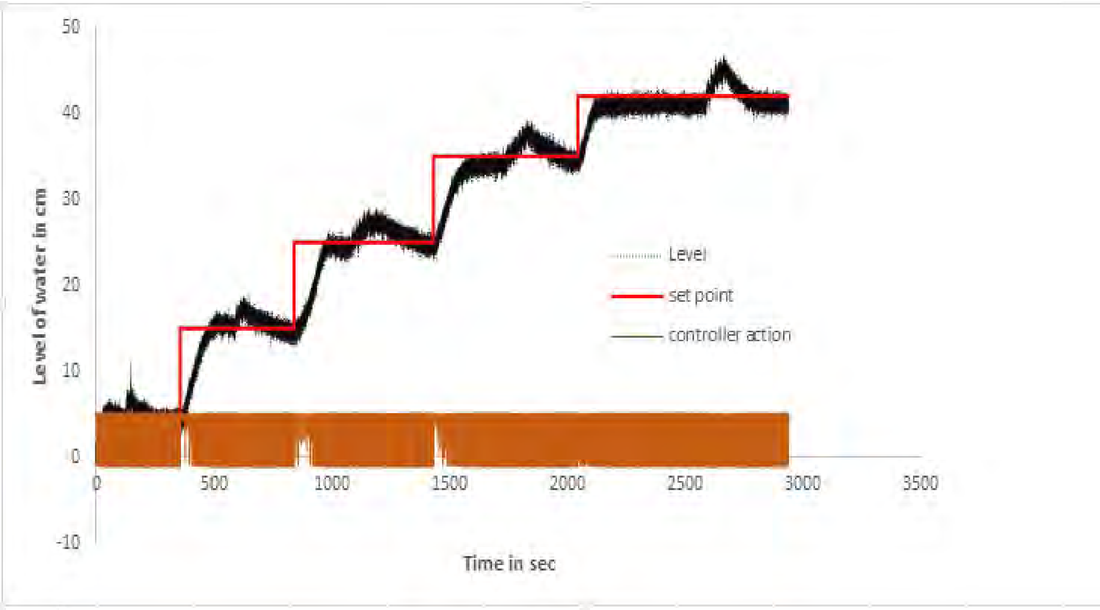

Fig.7. Regulatory response obtained for Changing Set Point Profile

TABLE IV
Calculations of performance measures in each tracking case

Region	ISE	IAE	Peak time (sec)	Settling time (sec)	Rise time (sec)
5+50%	1046.02	1633.1	163.32	9.68	146.9
5+75%	1308.11	1895.9	172.93	0.07	155.6
15+50%	1957.1	2234.8	182.56	35.62	164.3
15+75%	1208.6	1578.5	206.50	11.68	185.8
25+50%	1267.8	1873.5	248.4	146.13	223.56
25+75%	3359.0	3726	251.1	143.3	225.9

V.CONCLUSION

In this study, DSTLLS is considered as a nonlinear system for implementation of real time GPIC controller on hardware model through LabVIEW environment. The real time controller performance for this dual spherical tank system was tested in different operating regions at different tracking cases. The servo response and regulatory response for different set points was also tested and the performance was plotted. It was also observed that the GPIC controller gave an optimum tracking performance for all the tracking cases. Graphical programming was used throughout the experiment along with the additional hardware like NI-DAQmx-6211 for implementation of real time controller that efficiently adapts to the changing set point profiles of required output height in the tanks.

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