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Real Time Implementation of Fractional Order Controller For Three Tank Process

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ABSTRACT

In this paper deals with the designing of a multiloop controller for a three tank system using Fractional OrderPI^{λ} controller. Integer Order Proportional Integral (IO-PI) controller and Fractional Order Proportional Integral (FO-PI) controller has been designed for Integer Order System (IOS) by approximated Z-N tuning rule and fractional Ms constrained integral gain optimization(F-MIGO) rule respectively. The performance and evaluation of integer order system and fractional order PI controller has been analyzed based on t_s, ISE, IAE criterion. Fractional OrderPI^{λ} controller is stable and robust giving the desired values of command signal (setpoint) . The hardware result of these two control schemes is done using VDPID data acquisition module for the three tank process

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INTRODUCTION

The PID controller is most widely used in all process industry like aircrafts, refinery process, power plants, and chemical industries because of simple design, robustness, simplicity and stability. The designing of fractional order controller is a mathematical technique is allows obtain the process model in real time more accurate than the conventional PI controller. Many methods are available to design a multiloop controller for recent technology; the fractional order system is more accurate and suitable for higher order system. This higher system used to approximate an first order model. In present technology, fractional order (Chen, Y.Q., 2006) systems and controllers based on order of fractional value has more gain and increasing the controller performance .The many physical systems are approximated by differential equations and order of fractional system .In this paper, the fractional order controller is used to design a controller for MIMO process. The basic concept of fractional controller is given by

$$C(s) = k_p + \frac{k_i}{s^{\lambda}} + k_d s^{\mu} \quad (1)$$

Where
k_p - proportional constant,
K_i - integration constant and
K_d - differentiation constant.

The fractional order control algorithm is represented by a differential - fractional integer equation of type as follows

$$C(t) = K_p e(t) + K_i D^{-\lambda} e(t) + K_d D^{\mu} e(t) \quad (2)$$

Where, D is the integer-differential operator (VarshaBhambhani and Yang Quan Chen, 2008), the input of controller is e(t) and u(t) is the controller output. The values of the orders μ and λ, will be choose depending on the order of the system. Fractional order controller, for some particular intervals, taking integrator of real order μ=1 and differentiator of real order λ=1 is used for the conventional PID controller. The selection of λ=1 and μ=0 leads to the PI controller, λ=0 and μ=1 gives the PD controller, and also λ=0 and μ=0 results in P controller. This paper described with designing of fractional order (TriptiBhaskaran, YangQuan Chen and Dingy 2007) controller with fractional Ms constrained integral gain optimization (F-MIGO) method to control the level of three tank system. The proposed work is explained as follows: Part II gives a three tank Process description. In Part III, integer and fractional order PI controller is designed for IOS using F-MIGO and Z-N tuning rule technique. The comparison of simulation results for the control performance for fractional and integer order PI controller based on ISE criterion are presented in Part IV. Finally, results and conclusion were discussed in Part V.

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1. Three Tank Process:

The aim is to control the level in tank1 and tank3 with two pumps. The process inputs are fin1and fin3 (input voltages to the pumps) and the outputs are $y_1$and y_2 (current from level measurement differential pressure transmitter). The schematic diagram of three tank process is shown in Figure

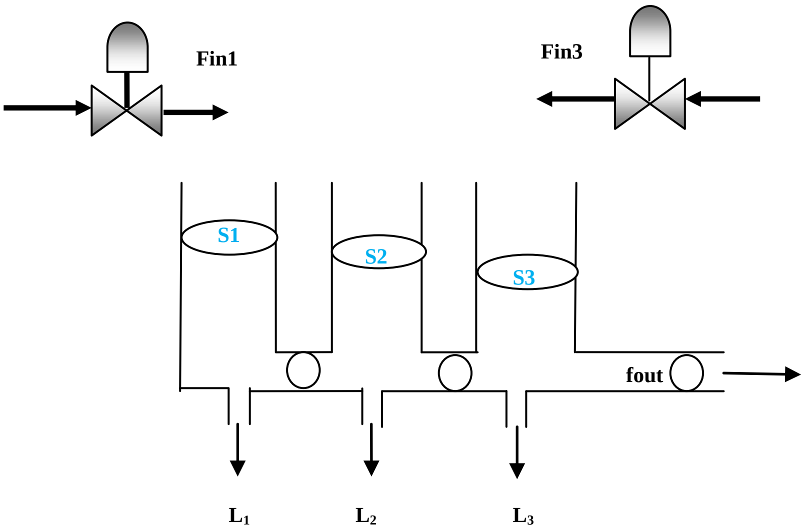

Fig. 1: Schematic diagram of three tank process

Applying the mass balance equation for the three-tank system is given by

$$\frac{dh1}{dt}=\frac{fin1}{s1}-\frac{Az1}{s1}\sqrt{2g(h1-h2)} \quad (3.1)$$

$$\frac{dh2}{dt}=\frac{AZ1}{s2}\sqrt{2g(h1-h2)}-\frac{Az3}{s2}\sqrt{2g(h2-h3)} \quad (3.2)$$

$$\frac{dh3}{dt}=\frac{fin3}{s3}+\frac{Az3}{s3}\sqrt{2g(h2-h3)}+\frac{Az2}{s3}\sqrt{2gh3} \quad (3.3)$$

Where

Fin1 and fin3- inflow of tank1 and tank3 in ml/sec.

S1, S2 and S3- Area of tank1, tank2 and tank3 in m^2

L1, L2, L3 -Are the fault variables or load disturbance.

Fout- The outflow tank3 in ml/sec.

Az1, Az2, Az3 -Outflow coefficient h1, h2, h3- Water level of tank1, tank2 and tank3.

g - The Acceleration due to gravity in m/sec^2

The steady state operating data of the three-tank system is given in Table1.

Table 1: Steady State Operating Parameters of Three Tank Process

Parameters	Values
h1, h2, h3 in cm	11,10,9
fin1 and fin3 in ml/sec	100
Outflow coefficient (Az1, Az2, Az3)	2.251e-5,3.057e-5 ,2.307e-5
Area of tank (S1-S3)in m^2	0.0154
Acceleration due to gravity in m/sec^2	9.81

Three tank system consists of three cylindrical tanks with equal cross sectional area and they are connected by cylindrical pipes of uniform cross sectional area, these three tanks are interconnected through manual valves. From the storage tank the process liquid is pumped into the first tank through a control valve, the input flows to tank 1and tank3 are fin1 and fin3 respectively.. The main objective is to control the level of liquid in tank1 and tank 3 by varying the inflow rate (fin1) in the tank 1 and (fin3) in the tank3. The controlled variables are the level of the tank1 (h1) and level of the tank3 (h3) and manipulated variables are in flow of tank1 (fin1) and in flow of tank3 (fin3). From the open loop response to obtain the parameters of the transfer function of the FOPDT model by letting the response of the actual system and that of the model to meet at two points, which describe the two parameters τ and θ. The proposed times, t_1 and t_2, are estimated from a step response curve on the 28.3% and 63.2% response times respectively. Based on the values of t_1 and t_2, the time constant τ is calculated as given in equation (17), and time delay td is calculated as given in equation (18). Another important parameter of the process model, the process gain K_p is calculated as given in equation (19).

$$\tau = 1.5(t2 - t1) \quad (17)$$

$$\theta = t2 - \tau \quad (18)$$

$$K_p = \frac{\text{Change in process output}}{\text{Change in process input}} \quad (19)$$

The real time transfer function of the process is determined by

$$G_p(s) = \begin{bmatrix} \frac{5.558e^{-69s}}{72s+1} & \frac{4.3218e^{-7s}}{63s+1} \\ \frac{6.773e^{-71s}}{106.5s+1} & \frac{6.9263e^{-10s}}{105s+1} \end{bmatrix}$$

3.3Experimental Three Tank Process Setup:

The experimental setup has a three tank, pump, water reservoir, Differential Pressure Transmitter (DPT), rotameter and Current to Pressure (I/P) converter, interfacing module, and a Personal Computer (PC). The VDPID module supports two analog input channel and two analog output channel, and two pulse width modulation inputs with sampling time 0.01 sec and baud rate 38,400 bytes per sec with 8-bit resolution. It is operating in the input voltage range from 0 volts to 5 volts and output ranges from 4mAto20mA of digital to analog converter. The front panel diagram of the three tank process setup is shown in **Figure3.2**. The three tank is made up of stainless steel and is mounted vertically on the stand. The water comes into the tank from the top and flows out to the reservoir, which is placed at the bottom of the tank. The level of the water in the three tank is measured by means of the Differential Pressure Transmitter (DPT). The measured level of water in the form of current in the range of (4-20) mA is fed to the Current to Voltage (I/V) converter. The process variable in the form of analog voltage is transmitted to ADC module of the VDPID interfacing card, which converts the analog data to digital data and sent it to the PC. The PC acts as the controller and stores the data.

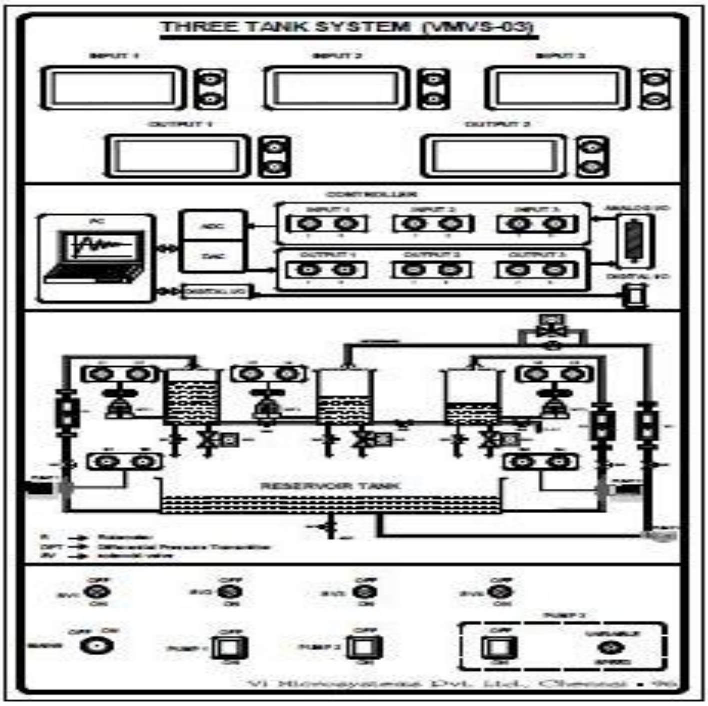

Fig. 3.2: ThreeTank Process Front Panel Diagram

The tank level considers the process variable and manipulated variables are in flow of tank1 (fin1) and in flow of tank3 (fin3). The DAC module of the VDPID converts this manipulated variable to analog form and transmit to the Voltage to Current (V/I) converter, which converts the analog voltage signal in the range of 0-5 volts to 4-20 mA current signal. The technical specifications of three tank process are given in **Table 3.**

Table 3: Technical specifications of experimental setup

Part Name	Details
Level Transmitter	Piezo - electric with µC based built in sensor
Rotameter	(50-500) Litre / Hour.
Pump	6500 Rpm and 230 VAC , 50Hz.

Process tank	Capacity 15 liter and Dimension 140 x 1000mm
Solenoid Valve	Magnet Type and ½’’BSP(F) Thread
Orifice plate	Diameter 3.5mm(4mm) ,Upstream distance 25 x D Downstream distance 5xD.
Thyristor Power Driver	Input signal (4-20)mA, Input Supply 230 V AC/50Hz and Output 0-230VAC 50Hz.

2 .Controller design:

2.1 Fractional order controller:

A Fractional [14] order PI^{λ} Controller let P(s) and C(s) be the plant and controller transfer function respectively. The fractional order PI^{λ} controller transfer function is given by

$$C_f(s) = k_p + \frac{k_i}{s^{\lambda}} \quad (8)$$

The fractional PI controller in time domain is denoted by

$$c(t) = K_p e(t) + K_i D^{-\alpha} \quad (9)$$

Where D is the fractional integer-differential operator. The general calculation of fractional order is defined as:

Where a and t are respectively the lower and upper bounds, and α is the order of derivative or integrals, which can be non-integers, or complex numbers. The tuning rules for FO-PI controller based on Fractional Ms[6] constrained integral gain optimization method (FMIGO) for generic FOPDT model is given by

$$K_P = \frac{1}{k_p}\left(\frac{0.2978}{\tau + 0.000307}\right) \quad (10)$$

$$T_i = T\left(\frac{0.8578}{\tau^2 - 3.402 + 2.405}\right) \quad (11)$$

$$\alpha = \begin{cases} 1.1 & if\ \tau \ge 0.6 \\ 1\ if\ 0.4 \le \tau < 0.6 \\ 0.9\ if\ 0.1 \le \tau < 0.4 \\ 0.7 & if\ \tau < 0.1 \end{cases} \quad (12)$$

$$\tau = \frac{L}{L + T} \quad (13)$$

Where T and $k\ p$ are the time constant and steady state gain and L is the time delay.

2.2 Conventional PI controller:

The transfer function of conventional PI controller is represented by

$$C_f(s) = k_p + \frac{k_i}{s} \quad (14)$$

Tuning rules for conventional PI controller based on Z-N tuning technique for FOPDT model is given by

$$kc = \frac{0.9\tau}{k_p * t_d} \quad (15)$$

$$T_i = 3.33T_d \quad (16)$$

The controller parameters of fractional (Chen, Y.Q., 2006) and conventional PI controller are shown in Table 2.

Table 2: Controller Parameters

Controller Scheme	Loops	
	Loop-1	Loop-2
Conventional PI controller	$2.3240 + \frac{0.035753}{s}$	$2.1140 + \frac{0.02443}{s}$
Fractional order PI controller $C_f(s)$	$0.1095 + \frac{0.01227}{s^1}$	$0.49274 + \frac{0.0198}{s^{0.7}}$

RESULTS AND DISCUSSION

In this work, the fractional order based control is considered for the three tank System under nominal operating conditions. The closed loop response of the fractional order PI controller for a set point change in tank1 from its operating value of 11cm to 16cm is shown in **Fig 7** and its corresponding effect of interaction in tank3. Fig.8 shows the closed loop response of tank3 for a set point change of 9cm to14.0cm from its operating value and its corresponding effect of interaction in tank1 and their values are tabulated in **Table 3**. With same operating conditions, a simulation runs are carried out for conventional PI controller using Z-N based three tank processes for comparative study. The simulated servo and regulatory responses tank1 and tank3 are in **Fig 4 and Fig 5**. The performance indices are calculated in terms of settling time, Integral Square Error (ISE) and Integral Absolute Error (IAE) and values are charted in Table3.the servo track and regulatory response of fractional order PI controller are shown in **Fig 6 to Fig 9** for tank1 and tank3 respectively. Similarly integer PI controller for a set point change in tank1 from its operating value of 11cm to 16cm is shown in **Fig 10** and its corresponding effect of interaction in tank3. **Fig 11** shows the closed loop response of tank3 for a set point change of 9cm to14.0cm from its operating value and its corresponding effect of interaction in tank1 and their values are tabulated in Table 3.servo and regulatory responses are plotted in **Fig 12 to13**.The servo tracking and regulatory responses are plotted in **Fig 14to 17**.for tank1 and tank3 respectively. The performances of these controllers are evaluated and tabulated in **Table 3**. From the table, it is clearly indicates that the control augmented the control system is considerably reduced the effect of load disturbance in the process variable compared to integer PI controller.

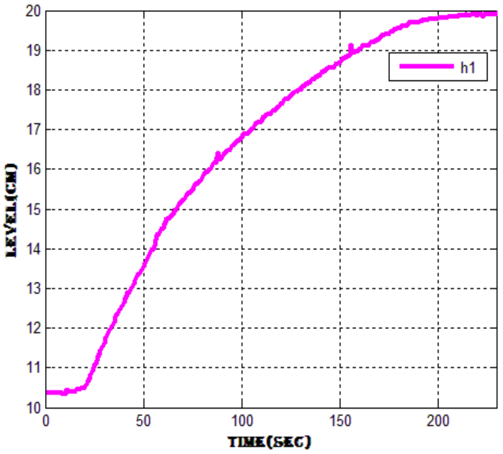

Fig. 3: Open loop response of three tank process in Tank1

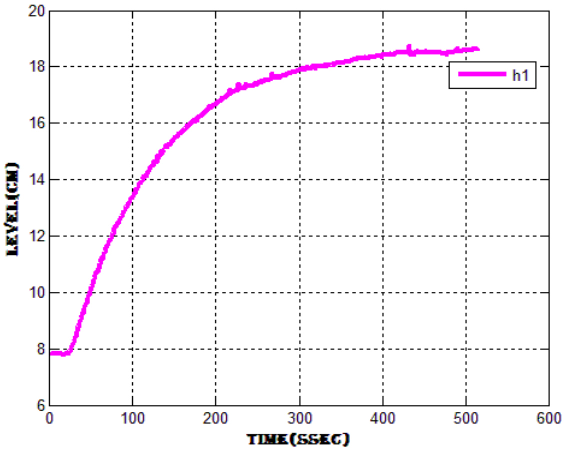

Fig. 4: Open loop response of three tank process in Tank3

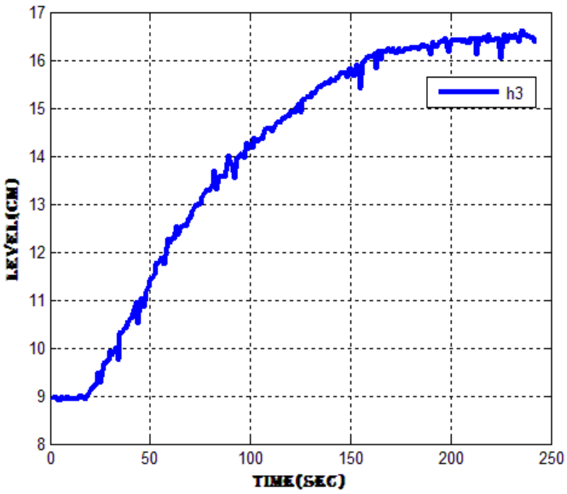

Fig. 5: Open loop response of three tank process in Tank3

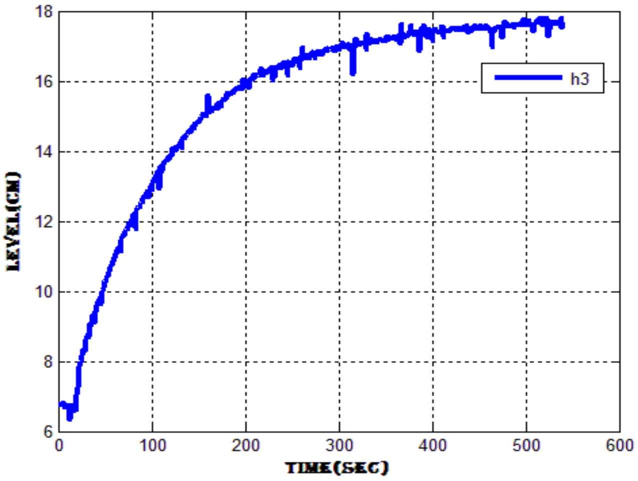

Fig. 6: Open loop response of three tank process in Tank3

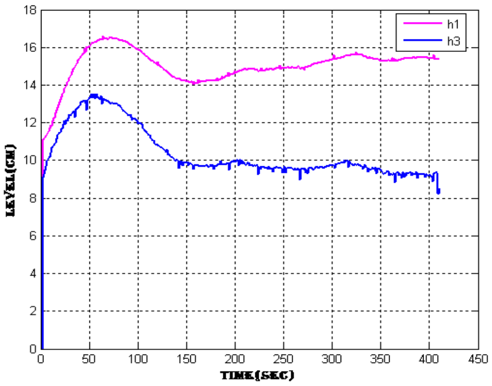

Fig. 7: Closed loop response of three tank process with Set point change in tank-3 (Integer PI Controller)

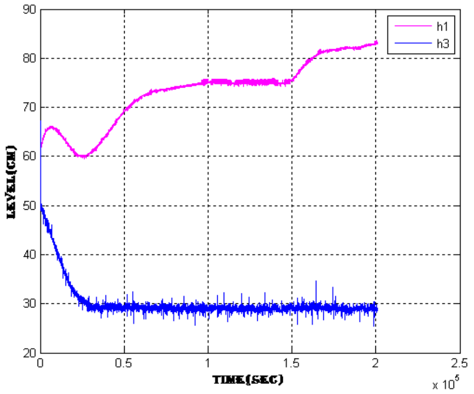

Fig. 8: Controller output for Tank-1 and Tank-3 (Integer PI Controller)

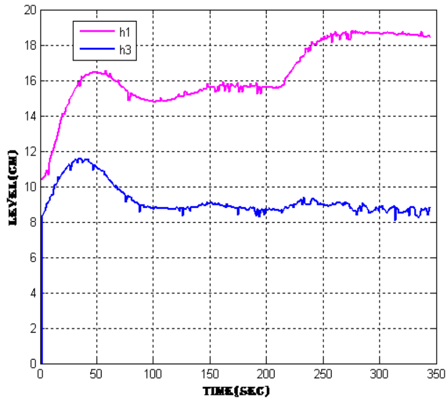

Fig. 9: Closed loop response of three tank process with Set point change in tank-1 (Integer PI Controller)

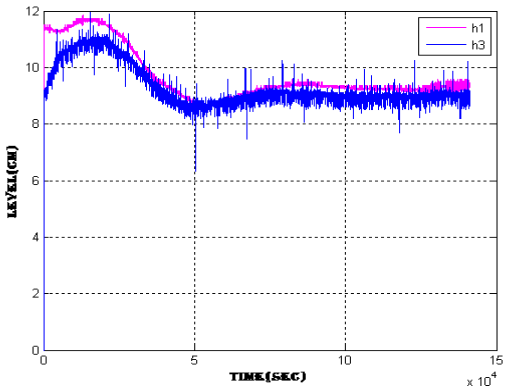

Fig. 10: Closed loop response of three tank process with Set point change in tank-1(Integer PI Controller)

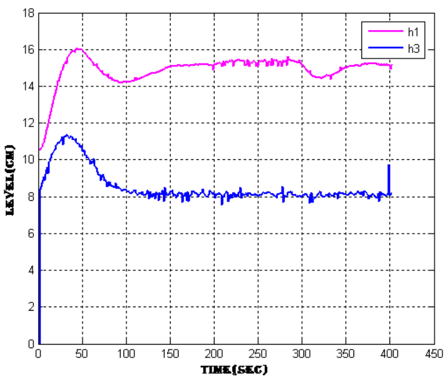

Fig.11: Servo and Regulatory response of three tank Process in tank-1(Conventional PI Controller)

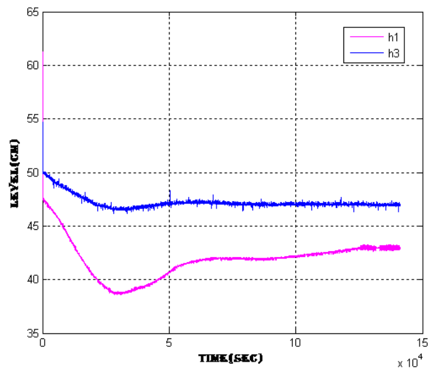

Fig. 12: Controller output for Tank-1 and Tank-3 (Conventional PI Controller)

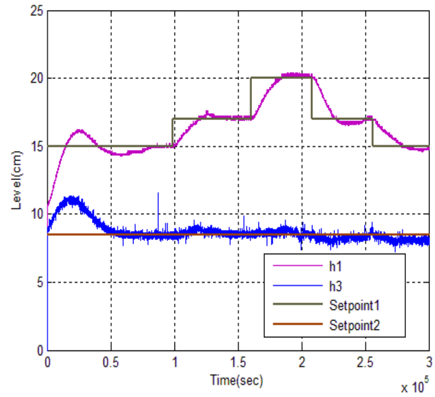

Fig. 13: Servo tracking and regulatory response of Tank1 (Conventional PI Controller)

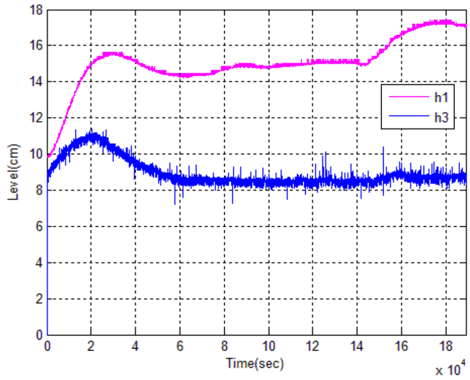

Fig. 14: Closed loop response of Tank1step change From (11cm to 16cm) (Fractional order controller)

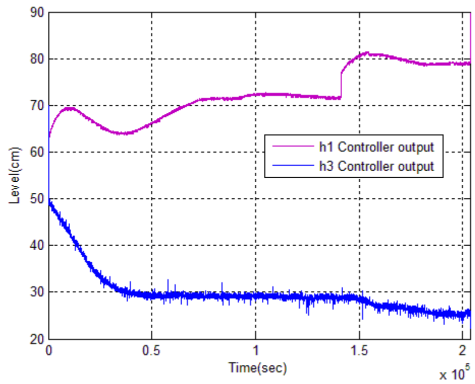

Fig.15: Controller output for Tank-1 and Tank3 ((Fractional order controller)

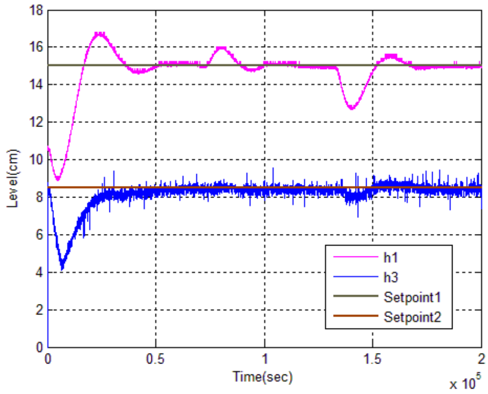

Fig. 16: Servo and Regulatory response of Tank1(Fractional order controller)

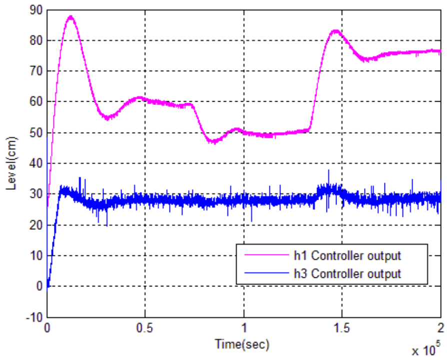

Fig. 17: Controller output for Tank-1 and Tank3 (Fractional order controller)

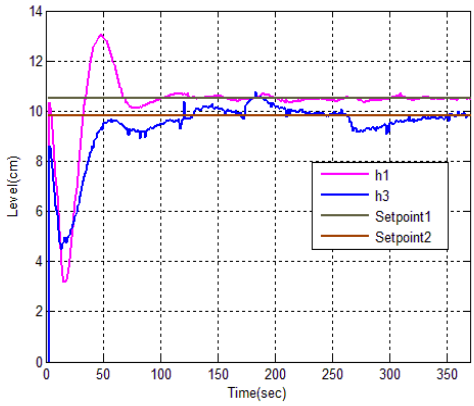

Fig. 18: Servo and Regulatory response of Tank3 (Fractional order controller)

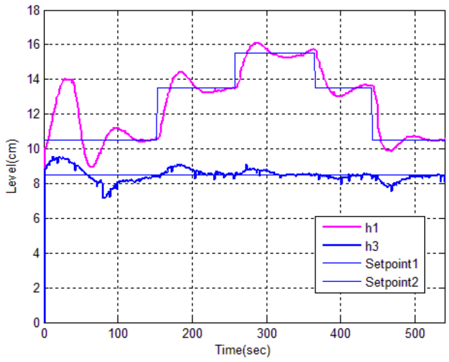

Fig. 19: Servo tracking and regulatory response of Tank1(Fractional order controller)

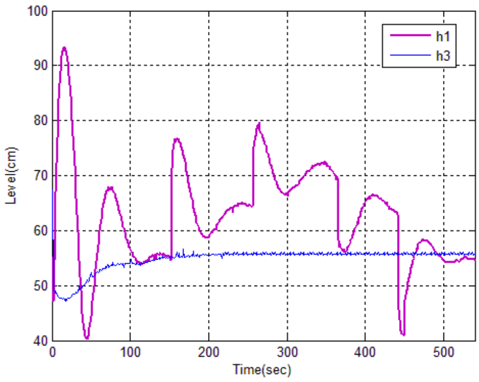

Fig. 20: Controller output for Tank-1 and Tank3 (Fractional order controller)

Table 3: Performance and Evaluation Of The Controller

Controller scheme	Performance Indices					
	Loop-1			Loop-2		
	T_s	ISE	IAE	T_S	ISE	IAE
Integer orderPI controller	350	1.4628e+005	2.6503e+004	398	6.1098e+005	4.7570e+004
Fractional orderPI controller	290	1.2054e+004	1.1356e+005	265	2.8120e+004	2.4818e+004

Conclusion:

In this proposed work, the fractional order PI controller is designed for MIMO process (three tank) FOPDT model and. compared with integer PI through Realtime. The Ts, ISE and IAE are taken as performance indices.Fractional order PI controller are very effective to handle the critical situations where the parameter variations and environmental changes occur and it is demonstrated clearly in results. The simulation results reveal that proposed controller have good set point tracking and load rejection at different operating point without any offset with reasonable settling time. The comparison of the present two controllers reveals that fractional order PI control is very well resulting in smoother controller output without oscillations compared to integer order PI controller.

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