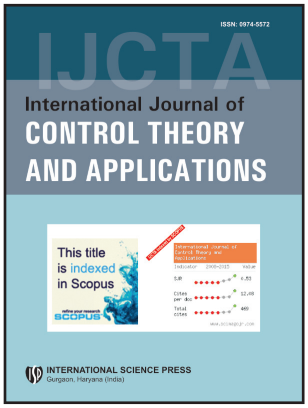

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Amigo Based PID Control Design for Non-Linear Process

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Abstract: The main aim is to develop AMIGO technique based controller design for a real time non-linear process. Process industries utilize conical tanks since they provide enhanced drainage of solid mixtures and viscous liquids. In process industries non-linear control system is of highly significant and it is highly challenging task for designing controller for non-linear process to maintain the process to be stable irrespective of the effect of disturbances. In non-linear process system identification is through black box modeling and the system needs to be modeled as FOPDT. The tuning of controller is applied utilizing AMIGO PID tuning approach. The objective is to design an appropriate controller for conical tank for controlling liquid level at given set point. The results were analyzed based on various performance indices like IAE, ITAE, ITSE and ISE. It is also verified that the controllers executed using AMIGO techniques performs well for lower values of Msd.

Keywords: PID, AMIGO tuning method, conical tank.

Nomenclature:

AMIGO	Approximate M constrained Integral Gain Optimization
FOPDT	First order plus dead time
K_p	Proportional gain
T_i	Integral time
T_d	Derivative time
T	Time constant
t_d	Dead time
M_{sd}	Sensitivity function
IAE	Integral Absolute Error
ISE	Integral Squared Error
ITAE	Integral Time Absolute Error
ITSE	Integral Time Square Error

1. INTRODUCTION

Control of industrial processes such as temperature, level, flow and pressure is a difficult task. Basic problem faced by most of the process industries is controlling liquid level in a tank and flow of liquid from one tank to another. In most of the process for example distillation columns, evaporators, and reboliers maintaining liquid level is highly significant in process action. If a level is too high may effect equipment or result in overflow of hazardous liquid. If the level is too low it might have awful outcomes. Controlling the level of liquid is a vital task in process industries. Most of the control theory involved in the design of linear controller with linear system. PID controller evidenced as an impeccable controller for linear processes. For a non-linear controller, the parameters of controller have to be adjusted continuously for a dynamic process.

Shape of process tank has a dynamic role in controller design. For a level control process the shape of a tank may be cylindrical or cubical which is a linear process. This category of tanks does not have a complete drainage. To accomplish the system with complete drainage of liquids, process industries make use of conical shaped tanks in which nonlinearity is present throughout the tank. The effectiveness of drainage of plant is enhanced if the tank is completely made as conical shaped structure. Due to high non-linearity behavior of the plant, controlling liquid level becomes challenging. This plant is mainly utilized in process industries like food processing industry, paper making, petroleum industry, and hydrometallurgical industries and in water treatment industries. Controller tuning is done by adjusting the process parameters. Since conical tank is highly nonlinear we utilize AMIGO based PID controller to control the water level. Controlling level in conical tank is a difficult task and it demands for advance controller technique implementation in real time.

D. Marshiana and P. Thirusakthimuruga (2015) utilized conical tanks to evade settlement and slurry in Storage tanks [1]. Astrom and Hagglund, 1996; Vrancic et. al., 2004 explained that conventional controllers holds a key role in control applications due to the complication in an advanced algorithm and in its controller tuning [2] [3]. Several approaches are existing in the previous works about tuning PID controller for nonlinear process. PID controllers are considered by several researchers like Rivera et. al., [4], Chien [5], Chen and Seborg [6], Skogestad [7]. Shamsuzzoha and Lee [8] and Vijayan and Panda [9-10] considered PID controller having a set point filters that decreases peak overshoot. Astrom and Hagglund (2004) suggested the methodology based on AMIGO method for tuning PID controllers [11].

Figure 1 depicts experimental setup of conical tank, area of tank varies constantly controlling the level of such a process is challenging. Conical tank measures 500mm in height, 300 mm top end diameter, tapering end is 20 mm. Pressure variation is measured by using differential pressure. Has a maximum flow rate of 800LPH. Pump is used as actuator which has a driving capacity of 800LPH and 6500rpm. Operational Structure of conical tank contain level transmitter, rotameter and thyristor power driver which is utilized to control the speed of pump that is proportional to the inflow to the tank.

Figure 1: Experimental setup of conical tank

Application of AMIGO method is simple because by using the set of equations, parameters of the controller can be calculated in AMIGO method. Besides, this approach is utilized in the systems whose performance is estimated by FOPTD model or integrator plus time delay, by this means huge applications in the process industry. In this method the model is experimentally analyzed utilizing system identification procedure. The tuning of controller is done by utilizing AMIGO based PID controller tuning and results are analyzed based on performance indices like IAE, ITAE, ITSE and ISE. It is verified that the controllers executed using AMIGO techniques performs well for lower values of Msd.

2. MODEL IDENTIFICATION

In this paper for conical tank modeling is supported by two point methodology. By allowing actual system and response of the model to intersect at two points defined by τ and t_d FOPDT model parameters are obtained. From step response curve times t_1 and t_2, are assessed which relates to 23.8% and 63.2% of response time respectively. Standard form of FOPDT model is given in equation (1) [12]. Figure 2 denotes various variables utilized for modeling plant transfer function by two point approach. The data attained are estimated to FOPDT model and parameters of model are obtained as in equation (5)

$$Q(s) = \frac{k}{\tau s + 1} e^{-t_d s} \tag{1}$$

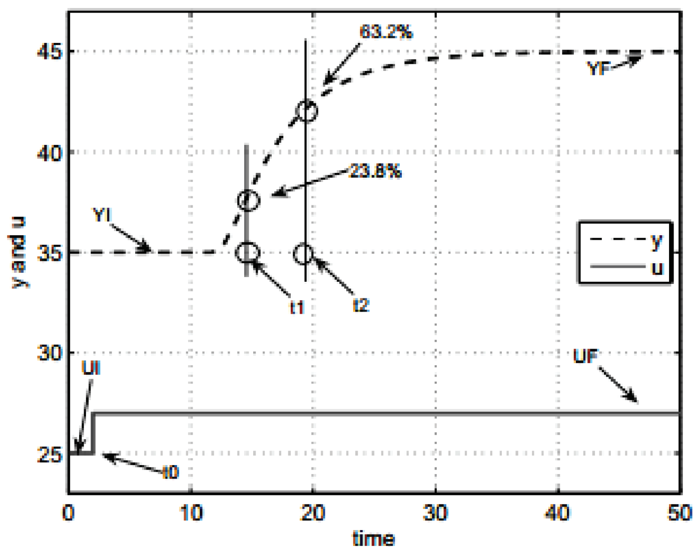

Figure 2: Two Point Method

$$k = \frac{Y_F - Y_I}{U_F - U_I} \tag{2}$$

$$\tau = 1.5(t_2 - t_1) \tag{3}$$

$$t_d = 1.5\left[(t_1 - t_0) - \frac{1}{3}(t_2 - t_0)\right] \tag{4}$$

From (2), (3) and (4) we obtain the mathematical model as in equation (5)

$$Q(s) = \frac{k}{\tau s + 1} e^{-t_d s} = \frac{0.925}{25.05 s + 1} e^{-1.09 s} \tag{5}$$

3. CONTROL DESIGN

In Astrom and Hagglund (2004) proposed AMIGO method to overcome the issue of adjusting PID controller that reduce the effect of disturbance in SISO systems [11]. In AMIGO method the parameter of the controller is calculated by the set of equation which is similar to that of a Ziegler- Nichols method. The sensitivity function M_{sd} is used to indicate the robustness of the controller design. The range of the sensitivity function is between the range 1.1 and 2. This method is utilized in the systems whose performance is estimated by FOPTD model or integrator plus time delay, by this means huge applications in the process industry. For a FOPDT model the AMIGO tuning rules for PID controllers are given by equation (6) (7) (8). The value of a_i where $i = 1, 2, ..., 7$ depends on the value of M_{sd} as shown in table (1) that is used for the design.

$$K_p = \frac{a_1 t_d + a_2 \tau}{k t_d} \tag{6}$$

$$T_i = \frac{a_3 t_d + a_4 \tau}{T + a_5 \tau} \tag{7}$$

$$T_d = \frac{a_6 t_d \tau}{T + a_7 t_d} \tag{8}$$

Table 1
Parameter α_1 for various values of M_{sd} [11]

M_{sd}	α_1	α_2	α_3	α_4	α_5	α_6	α_7
1.1	0.057	0.139	0.400	0.923	0.012	1.59	4.59
1.2	0.103	0.261	0.389	0.930	0.040	1.62	4.44
1.3	0.139	0.367	0.376	0.900	0.074	1.66	4.39
1.4	0.168	0.460	0.363	0.871	0.111	1.70	4.37
1.5	0.191	0.543	0.352	0.844	0.146	1.74	4.35
1.6	0.211	0.616	0.342	0.820	0.179	1.78	4.34
1.7	0.227	0.681	0.334	0.799	0.209	1.81	4.33
1.8	0.241	0.740	0.326	0.781	0.238	1.84	4.32
1.9	0.254	0.793	0.320	0.764	0.264	1.87	4.31
2.0	0.264	0.841	0.314	0.751	0.288	1.89	4.30

The controller has the transfer function is given by equation 9.

$$C = K_p \left(1 + \frac{T_d s}{1 + T_d s} + \frac{1}{T_i s} \right) \tag{9}$$

4. RESULT ANALYSIS

The proportional gain, time delay and time constant are obtained from the equation (5). For appropriate value of M_{sd} the value of controller parameter K_p, T_i, T_d is calculated by using equation (6) (7) (8). The value of controller parameters K_p, K_i, K_d for the different values of parameter α_i and sensitivity function M_{sd} is as shown in table (2). By using equation (9) the transfer function of the controller is obtained. Figure 3 demonstrates the overall block diagram for nonlinear process.

Figure (4) (5) (6) (7) (8) depicts simulation and real time analysis of results for different values of process variable at different M_{sd} respectively. It has been shown that the robustness specification given by the maximum magnitude of the sensitivity function (M_{sd}) has an important effect on the design results. As M_{sd} increased and consequently the design specifications are not fulfilled for large values of M_{sd}. On the other hand, for small values of M_{sd} the FOPTD models properly fit. The results are analyzed based on performance indices like IAE, ITAE, ITSE and ISE as shown in table (3). From the Figure (4) (5) (6) (7) (8) it is verified that the controllers executed using AMIGO techniques performs well for lower values of M_{sd}.

Table 2
Controller parameters for various values of α_i and M_{sd}

M_{sd}	K_p	T_i	T_d
1.1	3.5151	17.0627	0.3740
1.2	6.5959	11.5600	0.3938
1.3	9.268	8.0686	0.4081
1.4	11.6103	6.0327	0.4198
1.5	13.6973	4.8372	0.4317
1.6	15.5326	4.0580	0.4426
1.7	17.1649	3.5283	0.4511
1.8	18.6459	3.1296	0.4596
1.9	19.9767	2.8332	0.4682
2.0	21.1801	2.6076	0.4743

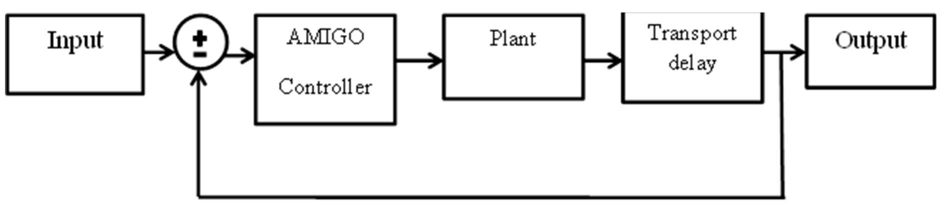

Figure 3: Overall block diagram for nonlinear process

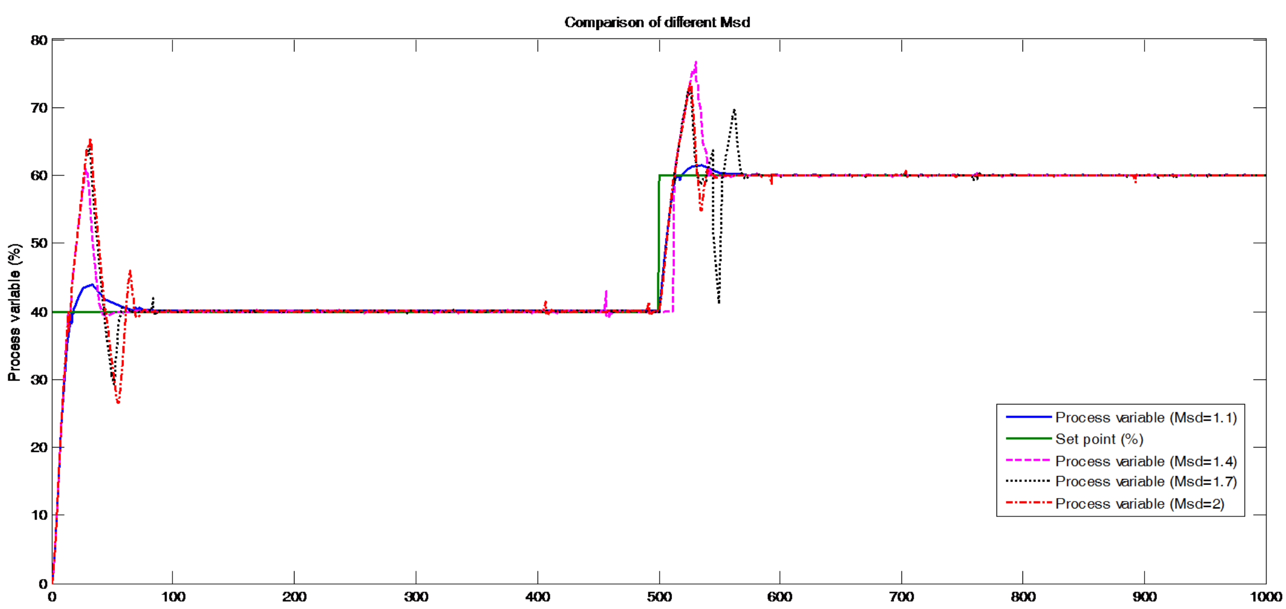

Figure 4: Simulation results for different values of process variable at different M_{sd}

Table 3
Performance analysis at different Msd values

M_{sd}	*IAE*	*ISE*	*ITAE*	*ITSE*
1.1	570.2	1.016e+04	9.438e+04	9.178e+05
1.4	1080	1.976e+04	2.711e+05	4.073e+06
1.7	1191	1.952e+04	2.607e+05	2.752e+06
2.0	1142	1.96e	1.827e+05	1.98e+06

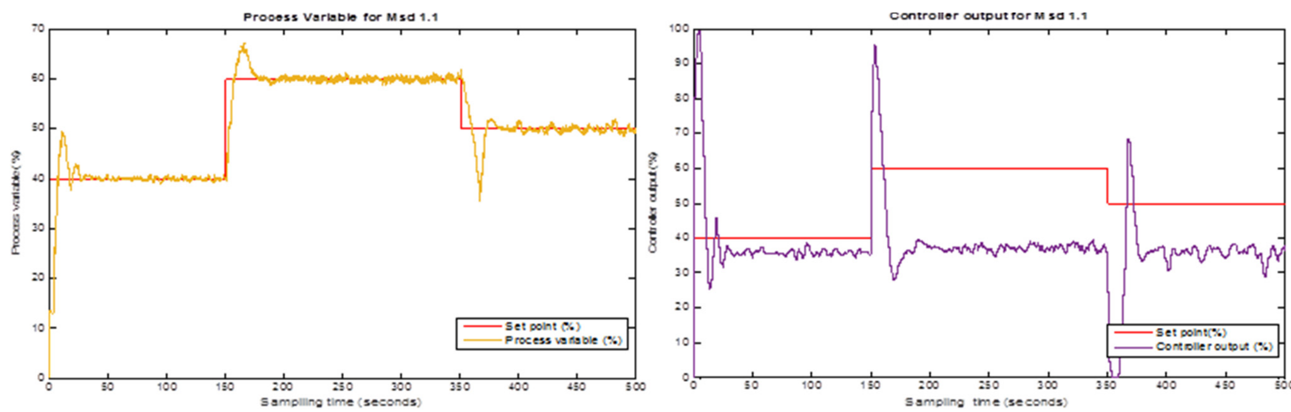

Figure 5: Real time results for process variable at M_{sd} 1.1

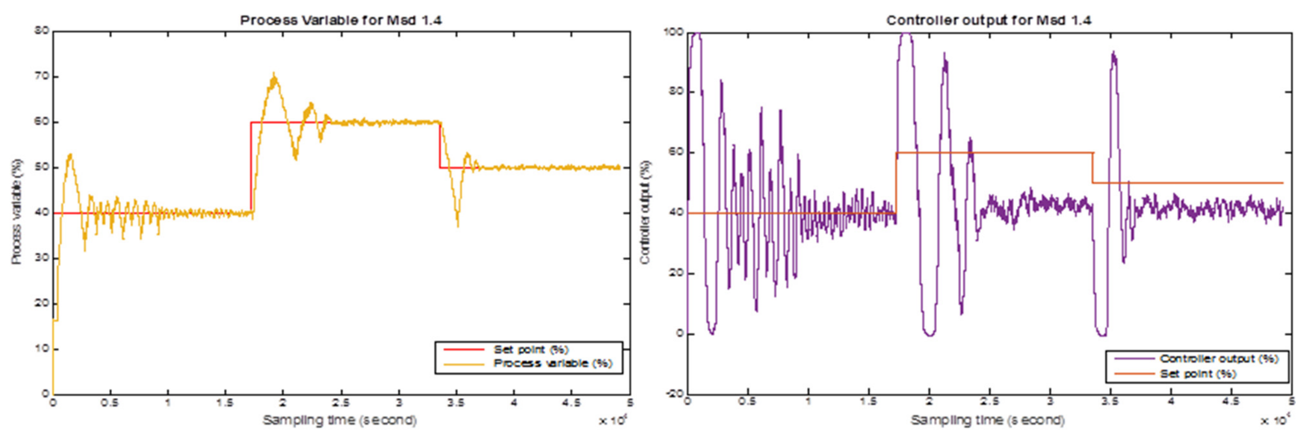

Figure 6: Real time results for process variable at M_{sd} 1.4

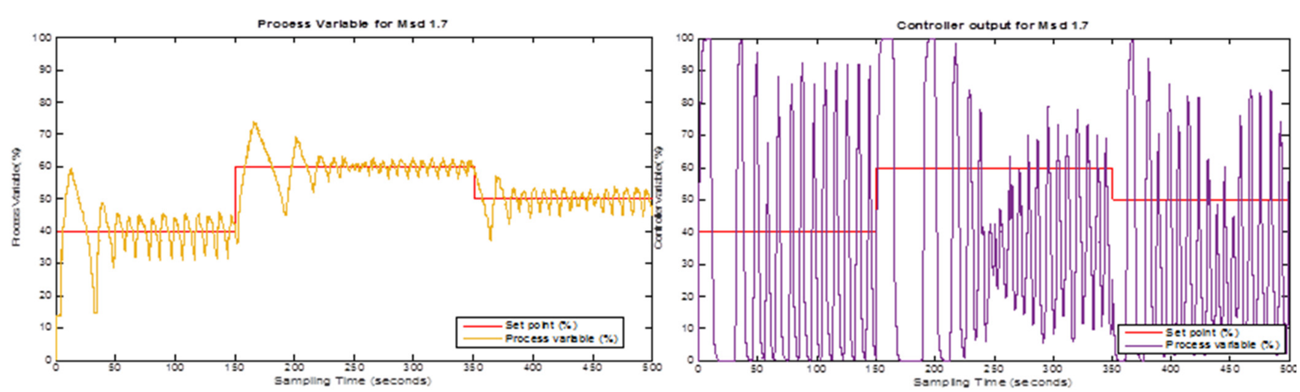

Figure 7: Real time results for process variable at M_{sd} 1.7

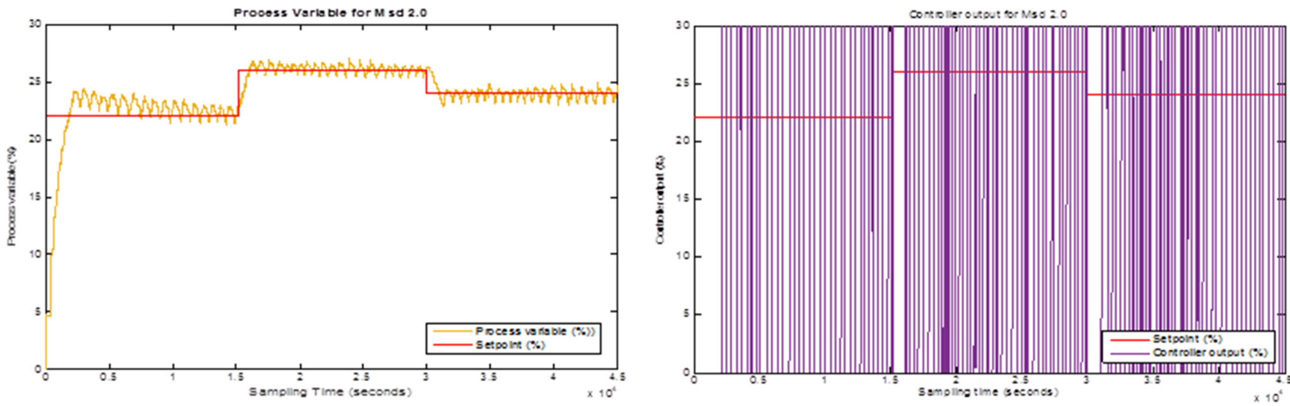

Figure 8: Real time results for process variable at M_{sd} 2.0

5. CONCLUSION

In this paper a methodology for tuning PID controllers for conical tank has been presented, which is built on AMIGO method. The proposed approach consists of an iterative identification and design method, where the estimation of FOPTD models by two point methods and the PID tuning by AMIGO method are combined. The feasibility of the methodology has been proved by simulation as well as in real time study. It has been shown that the robustness specification given by the maximum magnitude of the sensitivity function (M_{sd}) has an important effect on the design results. As M_{sd} increased and consequently the design specifications are not fulfilled for large values of M_{sd} . For smaller value of M_{sd} 1.1 with corresponding tuning parameters $K_p = 3.5151$, $K_i = 17.0627$, $K_d = 0.3740$ the FOPTD models properly fit. The results are analyzed based on performance indices like IAE, ITAE, ITSE and ISE. It is verified that the controllers executed using AMIGO techniques performs well for lower values of Msd.

Furure Work

The AMIGO PID tuning method can be extended for the multivariable PID controllers for a pilot plant binary distillation column setup which is present in our lab.

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