Linearization Algorithms for a Level and PH Process

Subbulekshmi[1], Kanakaraj[2]

[1.] Corresponding Author, Dept of Instrumentation and control systems Engineering, PSG College of Technology, Coimbatore, Tamilnadu, India
[2.] Dept of Electrical and Electronics Engineering, PSG College of Technology, Coimbatore, Tamilnadu, India
dslsubbu03@yahoo.com

Abstract: The aim of this work is to keep the interacting liquid level and pH parameter at a desired value. This article presents Kravari's decoupling and linearization algorithm and Generic Model Control (GMC) and Hischorn's algorithms for an approximated model of interacting level and pH process. The comparison with the above algorithms is shown. Control laws obtained from the above algorithms are relatively simple and accurate. These algorithms make the closed loop system linear in an input-output sense. Simulations are carried out using PI, PI-SPW (Set point Weighting), Fuzzy Logic Controller (FLC) and Model Predictive Control (MPC). Control performance of a Hirschorn's with MPC is found to be better. The control laws obtained for Hirschorn's algorithm gives improved Settling Time (Ts) and Integral Square Error (ISE).
[Subbulekshmi, Kanakaraj. **Linearization Algorithms for a Level and PH Process.** *Life Sci J* 2012;9(4):2528-2533]. (ISSN: 1097-8135). http://www.lifesciencesite.com. 374

Keywords: Decoupling, Multivariable, Interacting, GMC, Hirchorn's Algorithm

1. Introduction

The nonlinear, strongly interacting nature of multivariable chemical processes necessitates the development of solid control methodologies that are capable of coping with both nonlinearities and interactions (Chung et al., 2007).

In this work for a process with significant nonlinearities, the linear analysis is valid only in an infinitesimally small neighborhood of the operating point. Here three decoupling and linearization state feedback laws are applied to an interacting nonlinear level and pH process. An external linear conventional decentralized PI controller is implemented in the above mentioned level and pH process (Ahsene et al., 2012).

Control of pH is important in the chemical industry especially in waste water treatment. However pH processes are difficult to control due to their nonlinear dynamics (Alexd *et al*., 2005). In a chemical process involving the mixing of reaching streams (acid, base, salts), the pH is a measure of the hydrogen ion concentration, that determines the acidity / alkaline of a solution (Yoon *et al*., 2005).

This work is concerned with the comparison of a three linearization algorithms for the synthesis of the nonlinear controller for multivariable interacting nonlinear level and pH process that makes the system linear (Crespo and Sun., 2004).

The Hirschorn's algorithm is found to be most accurate and efficient as in presented comparison. Decoupling and linearization algorithm and GMC needs some further model refinement but also give acceptable results. The aim of this article is to evaluate the comparison between performance of Hirschorn's algorithm, decoupling and linearization and GMC algorithms based on approximated model as a possible approach to control in real world installations.

In this paper is a brief description of the basics of decoupling and linearization algorithm. Further the available literature is also surveyed in this section. Then deals with the liquid level and pH process. Next describes the basis of Kravaris algorithm. Also describes the basis of GMC algorithm. Then describes the basis of Hirschor'n algorithm. Presents the simulation results with decoupling algorithms along with PI, PI-SPW, FLC, MPC controller such as Kravari's, GMC and Hirschorn's are presented after the application to the model.

2. Material and Methods

General Formulation of the MIMO System

Consider an open loop stable multivariable system with n-inputs and n-outputs as shown in Figure 1. In this process two of the controlled outputs and manipulated inputs are shown in Figure 2. It has the following two control loops. Liquid level and pH coupling with acid flow rate u_1 and base flow rate u_2. Where r_i, i=1…..n are the reference inputs; u_i , i=1….n are the manipulated variables ; y_i , i=1…..n are the system outputs G(s) and $G_c(s)$ are process transfer function matrix and full dimensional controller matrix with compatible dimensions, expressed by

$$G(s)=\begin{bmatrix} g_{11s} & g_{12s} & -- & g_{1ns} \\ g_{21s} & g_{22s} & -- & g_{2ns} \\ -- & -- & -- & -- \\ g_{n1s} & g_{n2s} & -- & g_{nns} \end{bmatrix} \text{ and}$$

$$Gc(s)=\begin{bmatrix} g_{c11s} & g_{c12s} & -- & g_{c1ns} \\ g_{c21s} & g_{c22s} & -- & g_{c2ns} \\ -- & -- & -- & -- \\ g_{cn1s} & g_{cn2s} & -- & g_{cnns} \end{bmatrix}$$

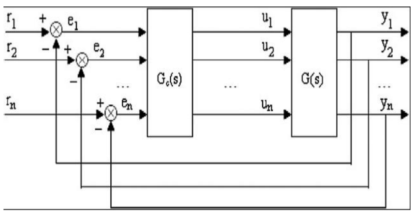

Figure 1 Closed loop multivariable control system

We consider the nonlinear systems with equal number of inputs and outputs of the form

$$\dot{x}=f(x)+\sum_{j=1}^{m} g_j(x)u_j \qquad (1)$$

$$y_i=h_i(x)\ ,i=1,2,......m \qquad (2)$$

Where

$$u=\begin{bmatrix} u_1 \\ . \\ . \\ u_m \end{bmatrix}\Xi R^m,\ y=\begin{bmatrix} y_1 \\ . \\ . \\ y_m \end{bmatrix}\Xi R^m,\ x=\begin{bmatrix} x_1 \\ . \\ . \\ x_n \end{bmatrix}\Xi R$$

$f(x)$ is a smooth vector field on IR^n , $g_1(x)......g_m(x)$ are smooth vector fields on IR^n, $h_1(x).....h_m(x)$ are smooth scalar fields on IR^n and $m<n$. This is a comparison of linearization algorithms like kravaris decoupling and linearization, GMC, Hirschorn's algorithm.

Level and pH process

A neutralization reaction process, which is schematically shown in Figure 2. A strong acid (HCL) at a concentration of CAO and a strong base (NaOH) at a concentration CBO is also studied (Kravaris and Chung, 1991). This process is nonlinear and an interaction also exists between the parameters. The aim of this control process is to keep the liquid level and the pH at desired values. It is an established fact that this control problem is challenging when the set point is near the point of neutrality, even if the control system is a SISO. The aim of the control is to keep the liquid level and the pH in the tank at the desired values. Y_1 is a level sensor output and Y_2 is a pH sensor output. As level and pH depends on u_1 (feed flow rate of acid) and u_2 (feed flow rate of base). It is clear, however that an interaction exists in this process.

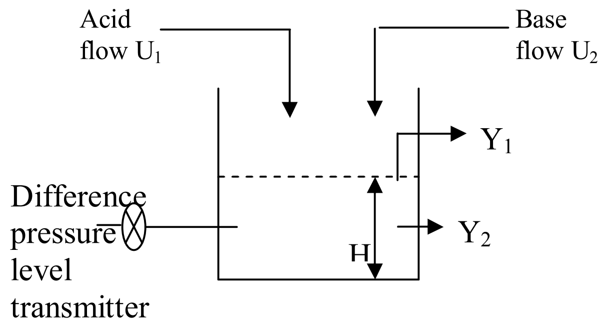

Figure 2 Schematic Diagram for the level and pH control process. (a) u_1 is the feed flow rate of acid (b) u_2 is the feed flow rate of base (c) Y_1 is the level sensor output (d) Y_2 is the pH sensor output. (e) H is the height of the liquid.

The process model under the appropriate assumptions is given by

$$\dot{x}_1=\left(\frac{-k}{s}\right)x_1^{1/2}+\frac{1}{s}(u_1+u_2) \qquad (3)$$

$$\dot{x}_2=\left[\frac{-1}{sx_1\log_{10}(a)}\right]\left[(b-CAO)U_1+(b+CBO)U_2\right] \qquad (4)$$

Where $b=-10^{x_2-14}+10^{-x_2}$,

$a=10^{x_2-14}+10^{-x_2}$

Output equation is given by

$y_1=x_1$

$y_2=x_2$

Here x_1 and x_2 are the liquid level and the values of pH respectively. u_1 and u_2 are feed flow rate of strong acid and strong base respectively. The tank is a stirred column of 75 cm height and 15.6 cm diameter. A strong acid (HCL) is at a concentration CAO and strong base (NaOH) is at concentration CBO. The aim of this control process is to keep the liquid level and the pH at the desired values. It is known that this control problem is very difficult when the setpoint is nearer to the point of neutrality. The values 's' and 'k' are cross sectional area of the tank 191cm^2 and constant coefficient 1.8cm$^{5/2}$s^{-1} respectively. The feed concentrations are CAO=CBO =0.03mol cm^3. The feed rates are constrained as $0\le u_1, u_2 \le 22$cm^3 s^{-1}.

Development of Non-Interacting Control Law

A non-interacting feedback control law is given by (Kravaris and Chung, 1991)

$$\begin{bmatrix} u_1(x) \\ u_2(x) \end{bmatrix}=\alpha_i(x)+\beta_{ij}(x)\begin{bmatrix} \gamma_1 \\ \gamma_2 \end{bmatrix} \qquad (5)$$

(i = 1, 2; j = 1, 2)

where γ_1 (x) and γ_2 (x) are new inputs.

According to Kravari's decoupling and linearization control theory, control of control law u_1 and u_2 are taken as

$$u_1 = \frac{S(b+CBO)}{(Cao+CBO)}[(\frac{k}{S})x_1^{1/2} - \zeta_{10}x_1 + V_1] + \frac{Sx_1\log_{10}(a)}{(CAO+CBO)}[-\zeta_{20}x_2 + V_2] \quad (6)$$

$$u_2 = \frac{S(b-CAO)}{(CAO+CBO)}[-(\frac{k}{S})x_1^{1/2} + \zeta_{10}\_V_1] + \frac{Sx_1\log_{10}(a)}{(CAO+CBO)}[\zeta_{20}x_2 - V_2] \quad (7)$$

Substituting u_1 and u_2 in the state model, results in state equation being in decoupled form and linearized form. Before applying this algorithm, liquid level Y_1 depends on u_1 and liquid pH Y_2 depends on u_1 and u_2. But now it is decoupled and interaction is eliminated.

$$\dot{x}_1 = -\delta_{10}x_1 + v_1$$

$$\dot{x}_2 = -\delta_{20}x_2 + v_2$$

Where v_1 and v_2 are new control inputs. x_1 is liquid level x_2 is liquid pH value. δ_{10}=δ_{20} is constant coefficients.

Development of GMC Control Law

The main objective of GMC is to guide a system from its initial condition to a desired setpoint by manipulating its input so that the system follows the behavior of a predefined reference model.

A reference model is specified for y_1 and y_2, according to the GMC formulation. Find a control law, such that y is equal to Ysp.

$$\begin{bmatrix}\dot{y}_1\\ \dot{y}_2\end{bmatrix} = \begin{bmatrix}K_{11} & 0\\ 0 & K_{12}\end{bmatrix}\begin{bmatrix}y_{1sp}-y_1\\ y_{2sp}-y_2\end{bmatrix} + \int\begin{bmatrix}K_{21} & 0\\ 0 & K_{22}\end{bmatrix}\begin{bmatrix}y_{1sp}-y_1\\ y_{2sp}-y_2\end{bmatrix}dt \quad (8)$$

GMC is mainly used to compensate for model errors and update the model parameters at steady-state as it is very difficult to determine the steady state case. GMC is a multivariable controller with interactions between variables taken into account in the calculation of the values and of the manipulated variables. For a same model GMC algorithm is also included.

According to GMC algorithm control theory, control law U_1 and U_2 taken as

$$u_1 = SV_1 + kx_1^{1/2} - \frac{[Sx_1\log_{10}(a)V_2 - bSV_1 - bkx_1^{1/2} + CAOSV_1 + CAOkx_1^{1/2}]}{(CAO+CBO)} \quad (9)$$

$$u_2 = \frac{[Sx_1\log_{10}(a)V_2 - b(SV_1 + kx_1^{1/2}) + CAO(SV_1 + kx_1^{1/2})]}{(CAO+CBO)} \quad (10)$$

Substituting u_1 and u_2 in the state model, results in state equation being in decoupled form and linearized form. Before applying this algorithm, liquid level Y_1 depends on u_1 and liquid pH Y_2 depends on u_1 and u_2. But now $\dot{x}_2$ depends on u_1 and u_2.

$$\dot{x}_1 = \left(\frac{-k}{S}\right)x_1^{1/2} + \frac{1}{S}\left[\frac{(Sv_1 + kx_1^{1/2})(2CAO + bCAO + CBO)}{CAO+CBO}\right]$$

$$\dot{x}_2 = \frac{1}{CAO+CBO}\left[\begin{array}{l} b(Sv_1 + kx_1^{1/2})(2CAO + CBO + bCAO - b) - \\ CAO(Sx_1 + kx_1^{1/2})[CAO + CBO + b + bCAO] \\ (CBO - b)Sx_1\log_{10}(a)v_2 + (Sv_1 + kx_1^{1/2})(CAO - b)\end{array}\right]$$

So interaction exists even after implementing GMC algorithm in the process.

Development of Hirschorn's Control Law

A derivative function h along a vector field f is called a lie derive, denoted by $L_f h(x) = \frac{\partial}{\partial x}h(x)f(x)$. Note that $\frac{\partial h_j}{\partial x}$ is a (1,n) row vector and f (n,1) column vector.

If h and f are smooth mapping, the differentiate along the same or another vector field can be repeated, for example the twice repeated lie derivative along f is written as the function $L_f(L_f h(x)) = L_f^2 h(x)$, for k≥1, repeated lie derivative notation is

$$L_f^k h(x) = L_f(L_f^{k-1}h)(x) \quad (11)$$

$$L_f^0 h(x) = h(x) \quad (12)$$

Consider the non-linear system (3 &4), taking the time derivative of the each output component, Y_i=h_i (x), the smallest order of each output derivative that explicitly depends on the input u, as the relative degree ς_i.

$$\dot{y}_i = \frac{dh_i}{dt} = \frac{dh_i}{dx}\frac{dx}{dt} = L_f h_i(x) \quad (13)$$

$$\ddot{y}_i = L_f^2 h_i(x) \quad (14)$$

$$\vdots$$

$$y_i^{(\varsigma_i)} = L_f^{\varsigma_i}h_i(x) + L_g L_f^{\varsigma_i - 1}h_i(x)u$$

where $L_g L_f^{\varsigma_i-1}h_i(x)u$ denotes the (1,m) row vector with the j^{th} component $L_{gj}L_f^{\varsigma_i-1}h_i(x)$. The purpose of the differentiation is to obtain an explicit expression for the control input u.

In hirschorn's algorithm, $\varsigma^{(k^*)} = m$,

$F_l(k) = \text{constant}$, l=0,……..k^*-1. Further more, given by m x 1 matrices β_{ik} , i= 0,…..m, k=0,…….r_i -1 and an m x m invertible matrix Γ. The state feedback (Kravaris and Soroush, 1990)

$$u = \left[\Gamma L_g H^{(k^*)}(x)\right]^{-1}\left\{V - \sum_{i=1}^{m}\sum_{k=0}^{r_i-1}\beta_{ik} L_f{}^{k} h_i(x) - \sum_{l=0}^{k^*-1}\gamma_l [F_l \vdots I_m - \varsigma^{(l)}] E_l L_f H^{(l)}(x) - \Gamma L_f H^{(k^*)}(x)\right\} \quad (15)$$

where $H^0(x) = \begin{bmatrix} L_f{}^{r_1-1} h_1(x) \\ \bullet \\ \bullet \\ L_f{}^{r_m-1} h_m(x) \end{bmatrix}$

$$\varsigma^{(0)} = \text{Rank}\,[L_g H^{(0)}(x)] \quad (16)$$

k=0,1,2,…….

Rearrange the rows of $L_g H^{(k)}(x)$ so that the first $\varsigma^{(k)}$ rows are linearly independent and denote by E_k, the corresponding elementary matrix that performs this row rearrangement. Find a $(m - \varsigma^{(k)}) \, x \, \varsigma^{(k)}$ matrix $F_k(x)$ such that $[F_{k(x)} \vdots I_m - \varsigma^{(k)}] E_k L_g H^{(k)}(x) = 0$. Where $I_m - \varsigma^{(k)}$ denotes the $(m - \varsigma^{(k)}) \, x \, (m - \varsigma^{(k)})$ identity matrix, define

$$H^{(k+1)}(x) = \begin{bmatrix} \text{first } \varsigma^{(k)} \text{rows of } E_k H^{(k)}(x) \\ [F_k \vdots I_m - \varsigma^{(k)}] E_k H^{(k)}(x) \end{bmatrix} \quad (17)$$

$$\varsigma^{(k+1)} = \text{Rank}\,[L_g H^{(k+1)}(x)] \quad (18)$$

following the steps of the algorithm, a sequence of non negative integers $0 \le \varsigma^{(0)} \le \varsigma^{(1)} \le \varsigma^{(2)} \le \ldots \ldots \le \varsigma^{(k)} \le \ldots \ldots \le m$. Thus there is a least positive integer k^* such that $\varsigma^{(k^*)}$ is maximal. In other words, the algorithm will always terminate after a finite number of steps equal to k^*, and at the last step, one will either have $\varsigma^{(k^*)} = m$.

The Hirschorn's control algorithm based on non-linear feedback transformation is applied to a non-linear interactive level and pH process.

$$u_1 = \frac{S}{(CAO + CBO)}[bV_1 - b\zeta_{10} x_1 + b\frac{k}{s} x_1{}^{1/2} - \frac{bk^2}{2S^2} + CBOV_1 - CBO\zeta_{10} x_1 + CBO\frac{k}{s} x_1{}^{1/2} - CBO\frac{k^2}{2S^2} + x_1 \log_{10}(a) V_2 - x_1 \log_{10}(a)\zeta_{20} x_2] \quad (19)$$

$$u_2 = \frac{S}{(CBO + CBO)}[-bV_1 + b\zeta_{10} x_1 - b\frac{k}{s} x_1{}^{1/2} + \frac{bk^2}{2S^2} + CBOV_1 - CAO\zeta_{10} x_1 + CAO\frac{k}{s} x_1{}^{1/2} - CAO\frac{k^2}{2S^2} - x_1 \log_{10}(a) V_2 + x_1 \log_{10}(a)\zeta_{20} x_2] \quad (20)$$

Substituting u_1 and u_2 in the state model, results in state equation being in decoupled form and linearized form. Before applying this algorithm, liquid level Y_1 depends on u_1 and liquid pH Y_2 depends on u_1 and u_2. But now it is decoupled and interaction is eliminated.

$$\dot{x}_1 = v_1 - \delta_{10} x_1 - \frac{k^2}{2s^2}$$

$$\dot{x}_2 = v_2 - \delta_{20} x_2$$

Where v_1 and v_2 are new control inputs. x_1 is liquid level x_2 is liquid pH. $\delta_{10}=\delta_{20}$ is constant coefficients.

3. Results

At first, PI controller is added for level and pH process along with the decoupling kravaris algorithm. It is reproduced in Figure 3. It shows that the output response of the level and pH when the set point of the level is changed from 1 to 30cm and pH from 1 to 4. The sudden disturbance introduced at time of 200 sec in level is not affecting the pH process.

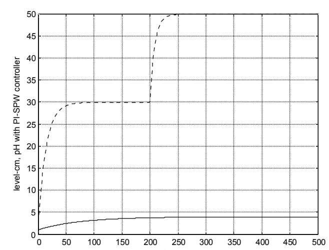

Figure 3 Process with decoupling (kravaris) with PI controller for level and pH process

Next PI-SPW controller is added along with the decoupling kravaris algorithm. It is reproduced in Figure 4. The sudden disturbance introduced at time of 200 sec in level is not affecting the pH process. It can be seen from the figure that the influence of the control performance is improved compared to Figure 3.

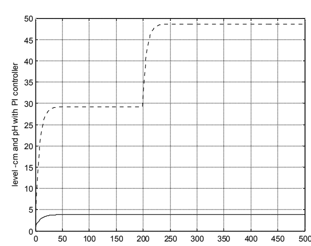

Figure 4. Process with decoupling (kravaris) with PI-SPW controller for level and pH process

Then FLC controller is added along with the decoupling kravaris algorithm. It is reproduced in Figure 5. The sudden disturbance introduced at time of 200 sec in level is not affecting the pH process. It can be seen from the figure that the influence of the control performance improved when compared to Figure 4.

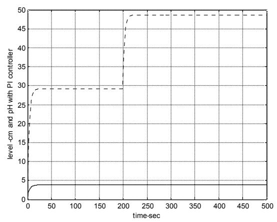

Figure 5 Process with decoupling (kravaris) with FLC controller for level and pH process

Next applying GMC algorithm with external PI controller is shown in Figure 6. It shows the output response of the level and pH when the set point of the level is raised from 1 to 30cm and pH from 1 to 4. The sudden disturbance introduced at time of 200sec in level is not affecting the pH process. It can be seen from the figure that under the influence of the controller performance, ISE is improved.

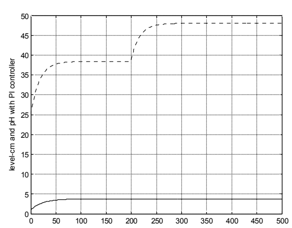

Figure 6 Process with decoupling (GMC) with PI controller for level and pH process

Next GMC algorithm with external PI set point weighting controller is shown in Figure 7. The sudden disturbance introduced at time of 200sec in level does not affect the pH process. It can be seen from the figure that the ISE is improved than Figure 6.

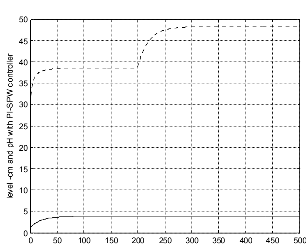

Figure 7 Process with decoupling (GMC) with PI-SPW controller for level and pH process

Then decoupling and linearization with external Fuzzy logic controller is added as shown in Figure 8. The sudden disturbance introduced at time of 200sec in level was not affecting the pH process. It can be seen from the figure that the influence of the control performance improved where compared to Figure 7.

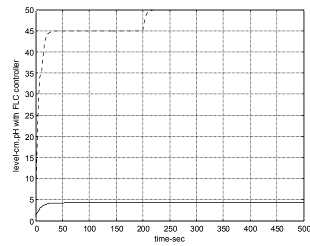

Figure 8 Process with decoupling (GMC) with FLC controller for level and pH process

Level pH control experiment with PI controller is carried out with the Hirchorn's algorithm. The result is shown in Figure 9 (Weijie et al 2009). It shows the output response of the level and temperature when the set point of the level is changed from 1 to 30cm and pH from 1 to 4. The sudden disturbance introduced at time of 200sec in level is not affecting the temperature process. It can be seen from the figure that under the influence of the controller performance, ISE is also improved

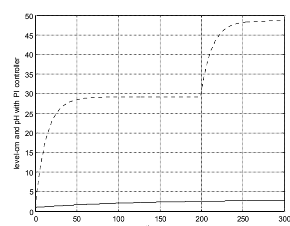

Figure 9 Process with decoupling (Hirchorn's) with PI controller for level and pH process

Next level and pH control experiment with PI-SPW controller is carried out with the Hirchorn's algorithm. The output response is shown in Figure 10. It can be seen from the figure that the control performance is improved when compared to Figure 9.

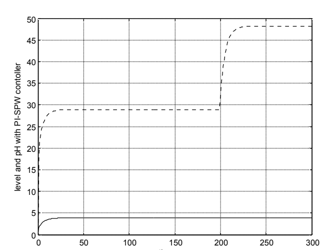

Figure 10 Process with decoupling (Hirchorn's) with PI-SPW controller for level and pH process

Then the level and pH control experiment with MPC controller is carried out with the Hirchorn's algorithm. The corresponding output is shown in Figure 11. It can be seen from the figure that the control performance is improved when compared to Figure 10.

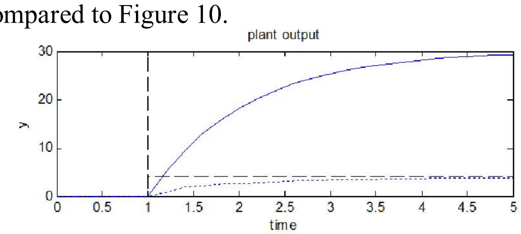

Figure 11 Process with decoupling (Hirchorn's) with MPC controller for level and pH process

4. Discussions

Table 1. Comparison of controller performance (Kravaris algorithm)

	Process	Ts(sec)	ISE
PI	Level	80	1.096e+004
	pH	80	165.58
PI-SPW	Level	50	5.935e+004
	pH	50	142.197
FLC	Level	30	3.338e+003
	pH	40	49.5

Table 1 shows the performance of Level pH process with controllers. It is inferred that FLC controller gives less Settling time (Ts) and Integral Square Error (ISE) for both the process to reach the desired set point.

Table 2. Comparison of controller performance (GMC algorithm)

	Process	Ts(sec)	ISE
PI	Level	80	Interaction exists
	pH	80	Interaction exists
PI-SPW	Level	50	Interaction exists
	pH	50	Interaction exists
FLC	Level	30	Interaction exists
	pH	30	Interaction exists

GMC is not suitable for the Level pH process. Interaction exists even after implementing GMC algorithm in the process.

Table 3. Comparison of controller performance (Hirchorn's algorithm)

Hirchorn's		Ts (sec)	ISE
PI	level	50	6.419e+003
	pH	50	585.07
PI-SPW	level	25	1.352e+003
	pH	25	30.79
MPC	level	3	25
	pH	4	25

Table 3 shows the performance of Level pH process with controllers. It is inferred that MPC controller gives less Settling time (Ts) and Integral Square Error (ISE) for both the process to reach the desired set point.

This work concerns the comparison of control laws of a linearization algorithms for the synthesis of controllers for multivariable nonlinear processes that makes the level and pH system linear. Hirchorn's linearization feedback algorithm is most accurate and efficient in the comparison. Decoupling and linearization feedback control law and GMC needs further model simulation. They too give acceptable results. This paper reports the simulation application of the Hirchorn's control law, Decoupling and linearization feedback control law and GMC control law to the chemical process, (level and pH control process). Results of these simulations are presented in Table 1. This includes that Hirschorns algorithm with PI controller gives less Settling time and Integral Square Error for both level and pH parameter.

Acknowledgements:
The authors would like to thank all colleagues and students who contributed to this study.

Corresponding Author:
D. Subbulekshmi
Department of I&CE,
PSG College of Technology,
Coimbatore, Tamilnadu, India.
E-mail: dsl@ice.psgtech.ac.in

References

1. Ahsene Boubakir, Salim Labiod, Fares Boudjema. A stable self-tuning proportional-integral-derivative controller for a class of multi-input multi-output nonlinear systems. Journal of Vibration and Control 2012; 18 (2):228-39.
2. Alexd.Kalafatis, Liuping Wang, William R. Cluett. Linearizing feedforward– feedback control of pH processes based on the Wiener model. Journal of Process Control 2005; 15:103–12.
3. Chung-Cheng Chen, Yen-Feng Lin, Ming-Huang Chen, Nonlinear Tracking with Almost Disturbance Decoupling and Its Application to Ball and Beam System. Journal of the Chinese Institute of Engineers 2007; 30 (3), 545-51.
4. Crespo L.G and Sun J.Q. On the Feedback Linearization of the Lorenz System. Journal of Vibration and Control 2004; 10 (1), 85-100.
5. Jenn-Yih Chen, Wen-Jieh Wang. A new Sliding Mode Position Controller for the Induction Motor Using Feedback Linearization. Journal of the Chinese Institute of Engineers 1998; 1 21 (2), 211-19.
6. Kravaris, C, Chung, C.B. Multivariable control experiments of non-linear chemical process using non-linear feedback transformation. AIChE J 1991; 33, 592-98.
7. Kravaris, C, Soroush, M. Synthesis and multivariable non-linear controllers by input / output linearization. AIChE J 1990; 36, 249-64.
8. Weijie Wang, Donghai Li, Yali Xeu. Decentralised two degree of freedom PID tuning method for MIMO processes. IEEE conference on Industrial Electronics 2009; 143-148.
9. Yoon S.S, Yoon T.W, Yang, D.R, Kang, T.S. Indirect adaptive non linear control of a pH process. Computers and Chemical Engineering 2005; 26, 1223–30.

31/10/2012