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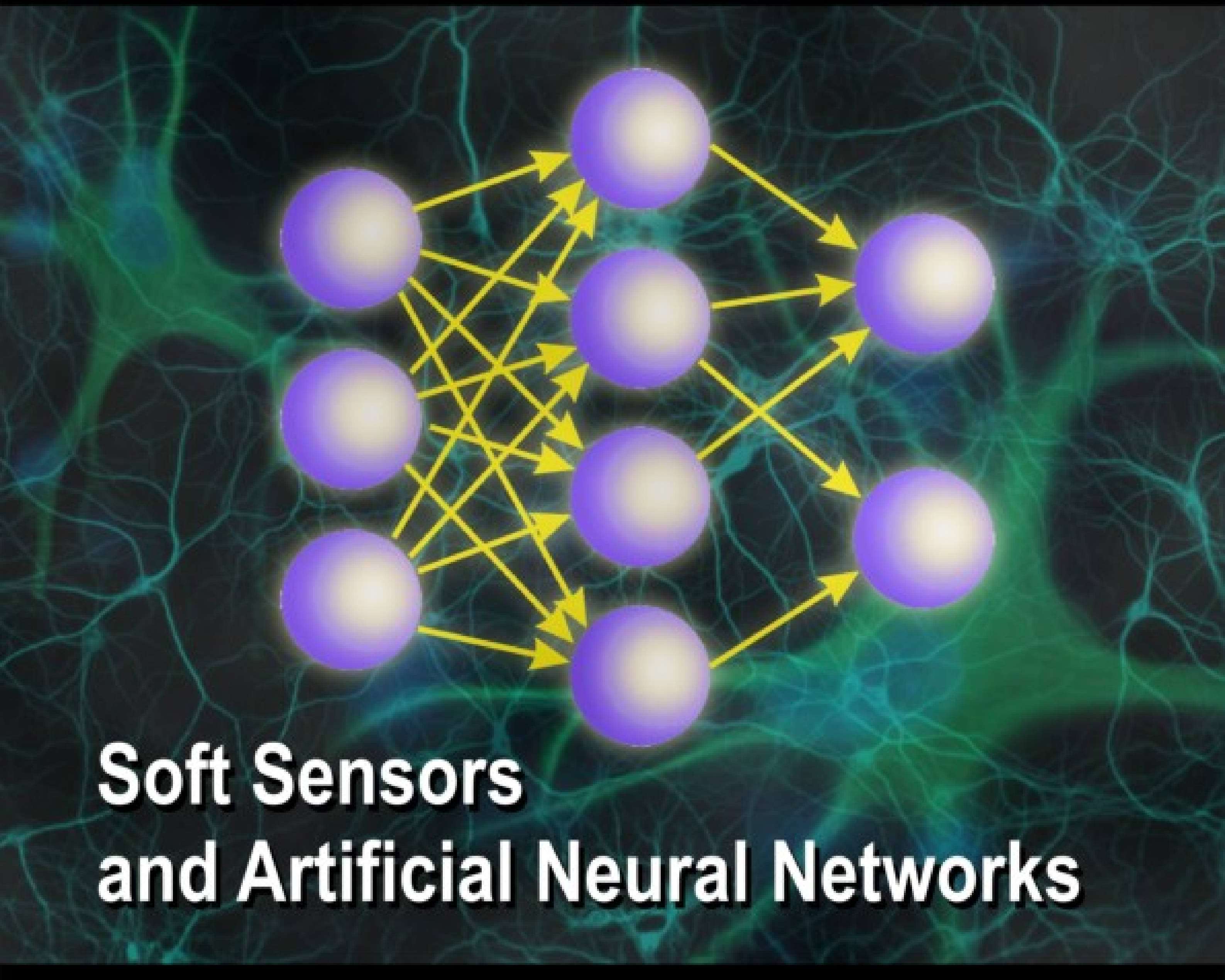

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Contents

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Adaptive PI Controller for a Nonlinear System

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Abstract: Most of the industrial processes are inherently nonlinear in their behaviour. Designs of controllers for these nonlinear processes are difficult, as they do not follow superposition theorem. Adaptive controller can change its behaviour in response to changes in the dynamics of the process and disturbances. Hence adaptive controller can be used to control nonlinear processes. Direct Model Reference Adaptive Control is a technique, in which a reference model involving the desired performances is specified. In the present work, a DMRAC is designed and implemented to achieve satisfactory control of a nonlinear system in all its local linear operating regions. The closed loop system is made BIBO stable by proper control techniques. The controller is designed through simulation in Matlab platform and is validated in real time by conducting experiments on the laboratory Air Flow Control System using the dSPACE interface. *Copyright © 2009 IFSA.*

Keywords: Nonlinear system, Direct model reference adaptive control (DMRAC), Adaptive MIT control, Adaptive PI control, Fixed gain controller

1. Introduction

Control of nonlinear dynamic system is a challenging task because nonlinear processes do not share many properties with linear system [1]. The knowledge about a system and its environment is required apriori to design a control strategy [2]. The most commonly used control techniques for nonlinear systems are the PID control [3], optimal control, adaptive control [4] and robust control. Adaptive control schemes [4, 5] are useful for systems with unknown or slowly time-varying or nonlinear processes and represent a class of advanced control algorithms. On the other hand, PID [6–8] control algorithms still continue to be widely used for solving industrial control systems, particularly in the chemical process industries. This is mainly because PID controllers have simple control structures and are easy to maintain and tune. Hence it is still attractive to design an advanced control systems with PID control structures. One may not be able to get good control performance in the case of nonlinear processes. In order to improve the closed loop response of the nonlinear process, Model Reference Adaptive Control [9-10], auto tuning [11–13] and self-tuning PID control [14–21] can be designed.

In this paper a procedure to design and implement DMRACs after modelling a nonlinear system is proposed. The basic idea of modelling is to represent the nonlinear system into a family of local linear models. Each linear model represents the dynamics of the complex system in that particular local region. These models are used to design local controllers specific to that region.

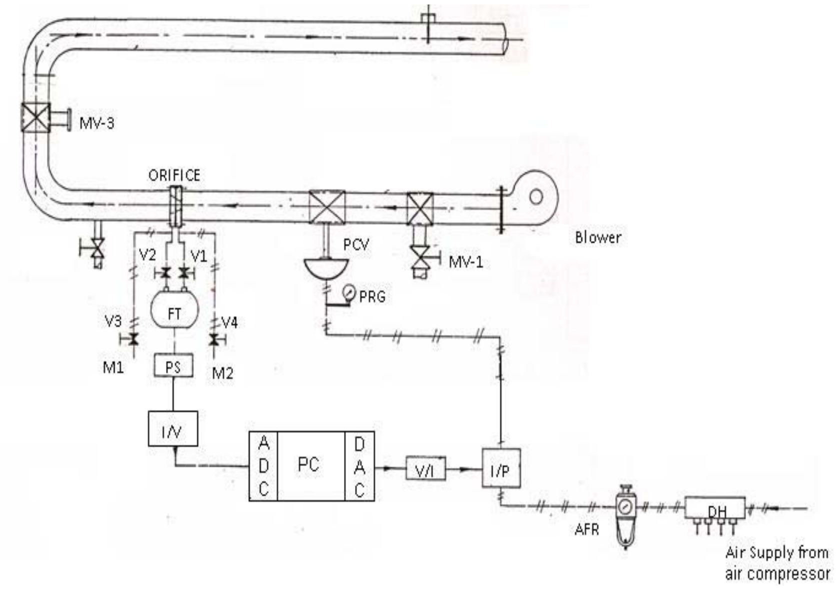
Adaptive MIT and Adaptive PI controllers are designed and implemented for a nonlinear air flow control system. The designed controller has a conventional inner loop followed by a separate adaptive outer loop to adjust the controller's gains (theta1, θ_1, theta2, θ_2, Proportional gain, K_P , Integral gain, K_I) based on the modelling error to equalize the coefficients of closed loop plant to the coefficients of the plant model [2, 18, 22]. The advantage is that the proposed technique can deal with the nonlinear nature of the process and also retain the designer's intuition and insight through the relatively simple design scheme that is proposed. Hence, the plant output converges to model's output. The control law is implemented using DS1104 board of dSPACE interface with the process to perform experimentation and the results are analyzed.

There is no guarantee that the Adaptive MIT and Adaptive PI controllers can provide a stable closed loop performance. Hence the closed loop system is made bounded input, bounded output stable (BIBO) by maintaining the gain of the closed loop system within limits always.

The rest of the paper is organized as follows. Section 2 describes the nonlinear air flow control system available in our lab, section 3 deals with the system modelling, section 4 and 5 discusses adaptive controller design and analysis with the stabilizing set of controller. A sample case from simulation and also from real time implementation along with the results are presented in section 6 which is followed by concluding remarks in section 7.

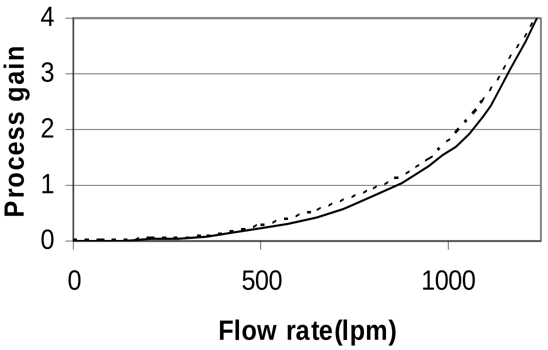
2. Laboratory Air Flow Control System

The process considered in this paper is a simple model of air flow process. The important aspect of the process is its simplicity. This is mildly nonlinear and can show acceptable range of linearization. This process can be modeled as First Order Plus Time Delay Process and the model dynamics depend on operating conditions. The piping and instrumentation diagram (Fig. 1) depicts the entire process and its associated control system. The controlled variable (air flow rate) is sensed by an appropriate sensor (differential pressure flow transmitter). This flow transmitter produces current output in the range of 4 to 20 mA. A current to voltage (I/V) converter is used to convert 4 to 20 mA into 1 to 5 Volts. This measured voltage (controlled variable) is compared with the reference signal. The difference between the two is given as input to the DMRAC. The controller produces manipulating variable based on the identified Process Parameters and the difference between the set point and controlled variable. The manipulating variable in voltage form is converted into current by a Voltage/Current (V/I) converter. A Current/Pneumatic (I/P) converter is used to convert this current to pressure (3 to 15 psi) accepted by the control valve. The air failure to open (AFO) pneumatic control valve restricts the path of the air flow in the process pipe line, thus controlling the air flow rate. The process gain for various flow rates in the process pipe line are shown in Fig. 2. The process shows the hysteresis nonlinearity in its character. The dynamic characteristic of the Final Control Element with Differential Pressure Flow Transmitter is shown in Fig. 3.The modeling and identification of the process is continued in the next section.



V1 to V4 - Manifold valves; FT - Flow Transmitter; MV-1 to MV-3 - Manual control valves; PS - Power Supply; M1 and M2 - Manometer connections; mA - Milliammeter; DH - De humidifier; I/P - Current to Pressure converter; AFR - Air Filter Regulator; PCV - Pneumatic Control Valve; PRG - Pressure Gauge ; G-2 - Galvanized pipe for cold air flow.

Fig. 1. Piping and Instrumentation Diagram of Air Flow Control System



--------- Increasing Flow Rate

- - - - - - Decreasing Flow Rate

Fig. 2. Characteristics of Air Flow Process.

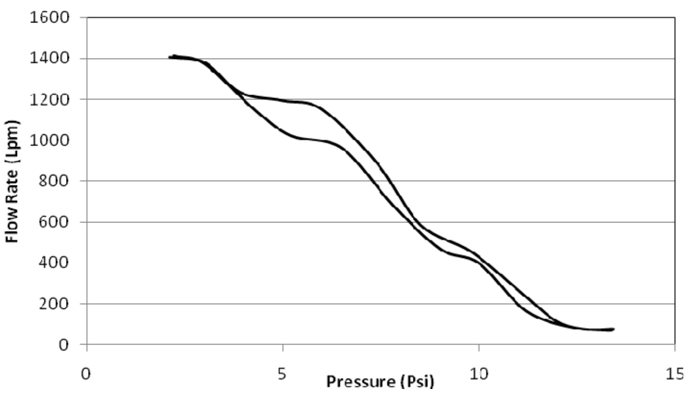


Fig. 3. Characteristic of Air Flow Control System.

3. Identification of Process

The model of the process is not needed for the design of DMRACs. Before implementing the control algorithm in real time, the designer has to observe the performance by various simulation studies. In order to design controllers through simulation, the actual process need to be modeled. Hence the procedure for identification of the nonlinear air flow process is outlined in this section. Identification refers to the process of selecting a model structure first, then estimating its parameters [23]. The general First Order plus Time Delay Process (FOPTD) is given by

$$G(s) = \frac{Ke^{-Ls}}{Ts+1}, \tag{1}$$

where K represents the steady-state gain of the process, L represents the time delay and T represents the time constant of the process. The process parameters for different operating condition are estimated by Two point Method [1]. Neglecting the time delay, the process model is approximated as First Order Process (FOP)

$$G(s) = \frac{K}{Ts+1} \tag{2}$$

The process parameters are determined as follows:

$$K = \frac{\Delta Y}{\Delta U}, \tag{3}$$

where ΔY is the change in output and ΔU is the change in input.

$$T = 1.5 * (T_2 - T_1), \tag{4}$$

where T_1 is the time taken by the process to reach 28.3 % of the final steady state value.T_2 is the time taken by the process to reach 63.2 % of the final steady state value. 50% of the collected real time data are used for modeling and the remaining 50 % are used for model validation [23].

The identified FOP models are given in Table I. The time domain validation of the model with the actual process is presented in Fig. 4. The obtained responses reveal the degree of closeness of the estimated FOP model with that of the actual process.

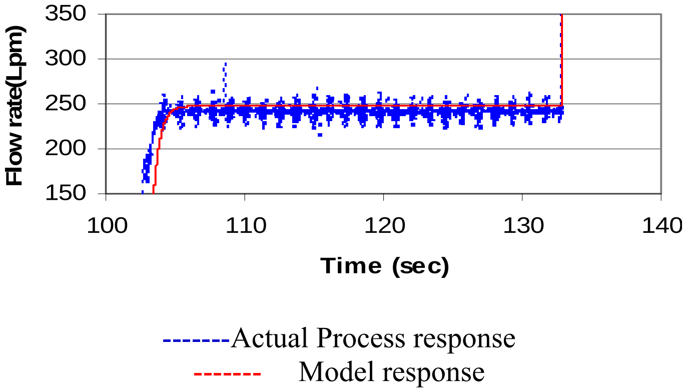


Fig. 4. Response of the identified Model and actual process.

Table I. Identified Models.

Flow rate (lpm)	**Identified Model**	**Flow rate (lpm)**	**Identified Model**	**Flow rate (lpm)**	**Identified Model**
5 – 134	$M_1(s)=\frac{0.01592}{0.475s+1}$	**872 – 1025**	$M_7(s)=\frac{1.3548}{0.475s+1}$	**872 – 725**	$M_{13}(s)=\frac{0.9168}{0.475s+1}$
134 – 280	$M_2(s)=\frac{0.0252}{0.475s+1}$	**1025 – 1170**	$M_8(s)=\frac{2.2488}{0.475s+1}$	**725 – 575**	$M_{14}(s)=\frac{0.5281}{0.475s+1}$
280 – 428	$M_3(s)=\frac{0.0683}{0.475s+1}$	**1170 – 1319**	$M_9(s)=\frac{4.0796}{0.475s+1}$	**575 – 428**	$M_{15}(s)=\frac{0.2654}{0.475s+1}$
428 – 575	$M_4(s)=\frac{0.2194}{0.475s+1}$	**1319 – 1170**	$M_{10}(s)=\frac{4.0768}{0.475s+1}$	**428 – 280**	$M_{16}(s)=\frac{0.0692}{0.475s+1}$
575 – 725	$M_5(s)=\frac{0.4188}{0.475s+1}$	**1170 – 1025**	$M_{11}(s)=\frac{2.5045}{0.475s+1}$	**280 – 134**	$M_{17}(s)=\frac{0.0505}{0.475s+1}$
725 – 872	$M_6(s)=\frac{0.8195}{0.475s+1}$	**1025 – 872**	$M_{12}(s)=\frac{1.4522}{0.475s+1}$	**134 – 15**	$M_{18}(s)=\frac{0.01536}{0.475s+1}$

4. Adaptive Control Algorithm

The Block Diagram Representation of DMRACs implemented in this work is presented in Fig. 5. The control system consists of two loops. The inner conventional feedback loop is composed of the process and the controller. The outer loop is for Parameter Adjustment Algorithm (PAA) with decision block. The decision, comparator in the figure decides input to the controller based on the input range (U_C) and stability condition (equation (31) and (32)). The PAA updates the controller parameters after satisfying the stability criterion for the specific range. The fixed gain controller block is placed in the conventional loop if PAA does not satisfy the stability criterion.

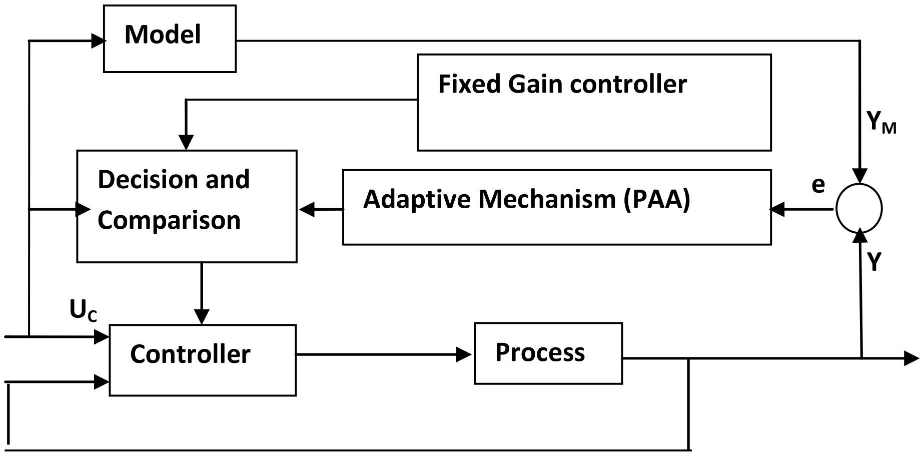


Fig. 5. Block Diagram Representation of Direct Model Reference Adaptive Control.

The outer loop adjusts the controller parameter in such a way that the model error (e), the difference between process output Y and model output Y_M is small

$$e = Y - Y_M \tag{5}$$

The controller parameters may be adjusted with the following loss function

$$J(\theta) = \frac{1}{2} e^2 \tag{6}$$

To minimize J, the parameters can be changed in the direction of negative gradient of J

$$\frac{d\theta}{dt} = -\gamma \frac{dJ}{d\theta} = -\gamma e \frac{\partial e}{\partial \theta} \tag{7}$$

The above parameter adjustment mechanism, called MIT algorithm is used to control the laboratory air flow control system. The quantity $\frac{\partial e}{\partial \theta}$ is the sensitivity derivative of the error with respect to controller parameter θ. The parameter γ determines the adaptation rate.

4.1. Adaptive MIT Controller [4]

Consider a system described by a model (equation 8)

$$\frac{Y}{U} = \frac{b}{p+a}, \tag{8}$$

where p=d/dt is the differential operator, U is the control variable and Y is the measured output. The control law is given by

$$U(t) \;\; = \theta_1 U_C(t) - \theta_2 Y(t) \tag{9}$$

The closed loop transfer function is given by equation (10)

$$\frac{Y}{U_C} = \frac{b\theta_1}{P + a + b\theta_2}, \tag{10}$$

where U_C is the command signal (input). The controller parameters are to be adapted such that process output follows the model output (equation 11)

$$\frac{Y_M}{U_C} = \frac{\alpha p + \beta}{p^2 + 2\delta\omega_n p + \omega_n^2} \tag{11}$$

Equation (10) and (11) are substituted in equation (5) to obtain modeling error.

$$e = \left[\frac{b\theta_1}{P + a + b\theta_2} - \frac{\alpha p + \beta}{p^2 + 2\delta\omega_n p + \omega_n^2} \right] * U_C \tag{12}$$

For perfect model following the controller parameters are to be chosen (when e=0) as in Equation (13) and (14).

$$\theta_1 = \frac{p\alpha + \beta}{b} \tag{13}$$

$$\theta_2 = \frac{p^2 + 2\delta\omega_n p + \omega_n^2 - p - a}{b} \tag{14}$$

As the process parameter a and b are not known, the following approximation based on the observation is applied for perfect model following. The sensitivity derivatives are obtained by taking partial derivatives of modelling error with respect to the controller parameters θ_1 and θ_2.

$$p + a + b\theta_2 = p^2 + 2\delta\omega_n p + \omega_n^2 \tag{15}$$

$$\frac{\partial e}{\partial \theta_1} = \frac{b}{p^2 + 2\delta\omega_n p + \omega_n^2} U_C \tag{16}$$

$$\frac{\partial e}{\partial \theta_2} = -Y \times \frac{b}{p^2 + 2\delta\omega_n p + \omega_n^2} \tag{17}$$

The controller parameters θ_1 and θ_2 are obtained by substituting equations (16) and (17) in MIT algorithm

$$\theta_1 = -\frac{\gamma'}{p}\left(\frac{1}{p^2 + 2\delta\omega_n p + \omega_n^2} \times U_C\right)e \tag{18}$$

$$\theta_2 = \frac{\gamma'}{p}\left(\frac{1}{p^2 + 2\delta\omega_n p + \omega_n^2} \times Y\right)e \tag{19}$$

$$\gamma' = \gamma b \tag{20}$$

4.2. Adaptive PI Control

An auto tuning method using model reference adaptive control (MRAC) based on MIT algorithm is proposed. The adaptation loop is simply switched for a period of time when tuning is required. Then the adaptation loop is disconnected and the system is left running with fixed controller parameters. The PI control law is given by equation (21)

$$U(t) = K_P(U_C(t) - Y(t)) + \frac{K_I}{p}(U_C(t) - Y(t)) \tag{21}$$

where K_P and K_I are the proportional and integral gains. The process transfer function considered for control is represented by equation (8). The closed loop transfer function is given by equation

$$\frac{Y}{U_C} = \frac{bpK_P + K_I}{p^2 + p(a + bK_P) + bK_I} \tag{22}$$

Consider the second order reference model given by equation (11). There is a real zero at $-\omega_n^2/\alpha$ $[\because \beta = \omega_n^2]$ in the reference model. This zero is introduced to match the structure of the equation (22). For perfect model matching

$$p^2 + p(a + bK_P) + bK_I = p^2 + 2\delta\omega_n p + \omega_n^2 \tag{23}$$

The adapted PI Controller parameters based on MIT algorithm are as follows

$$K_P = \left[\frac{-\gamma'}{p}\right] e \frac{p}{p^2 + 2\delta w_n p + w_n^2}(U_C - Y) \tag{24}$$

$$K_I = \left[\frac{-\gamma'}{p}\right] e \frac{1}{p^2 + 2\delta w_n p + w_n^2}(U_C - Y) \tag{25}$$

5. Stabilizing Range for Controllers

The control loop of the laboratory air flow control system is closed by adaptive MIT and adaptive PI controller. The conventional PI controller eliminates offsets and retains acceptable speed of response [16]. The complete range of stabilizing values for controllers for specified flow ranges are calculated and are given in Table II. The closed-loop characteristic equation of the system with adaptive MIT and Adaptive PI controller are given by equation (26) and (27).

$$\delta(s) = s + a + b\theta_2 \tag{26}$$

$$\delta(s) = s^2 + (bK_P + a)s + bK_I \tag{27}$$

The condition for closed loop stability of the process with Adaptive MIT control is given by

$$\theta_2 > -\frac{a}{b} \tag{28}$$

The following equations present the stability condition of the process with Adaptive PI controller

$$K_p > -\frac{a}{b} \text{ and } K_I > 0 \tag{29}$$

When the values of the controller parameters does not obey equations (30), Fixed Gain controller (FGC) is placed in the loop with gains $K_{FGC1}$from Table II and K_{FGC2} (0.475) by disconnecting the PAA loop.

Table II. Stability condition for various operating regions with two different controllers.

Model	K_p	θ_2	**Fixed gain controller** (K_{FGC1})	**Model**	K_p	θ_2	**Fixed gain controller**(K_{FGC1})
	$> -\frac{a}{b}$				$> -\frac{a}{b}$		
$M_1(s)$	> - 62.8141		62.8141	$M_{11}(s)$	> - 0.2453		0.2453
$M_2(s)$	> - 39.6825		39.6825	$M_{12}(s)$	> - 0.3993		0.3993
$M_3(s)$	> - 14.6413		14.6413	$M_{13}(s)$	> - 0.6886		0.6886
$M_4(s)$	> - 4.5579		4.5579	$M_{14}(s)$	> - 1.0908		1.0908
$M_5(s)$	> - 2.3878		2.3878	$M_{15}(s)$	> - 1.8936		1.8936
$M_6(s)$	> - 1.2203		1.2203	$M_{16}(s)$	> - 3.7679		3.7679
$M_7(s)$	> - 0.7381		0.7381	$M_{17}(s)$	> - 14.4509		14.4509
$M_8(s)$	> - 0.4447		0.4447	$M_{18}(s)$	> - 19.8020		19.8020
$M_{10}(s)$	> - 0.2451		0.2451	$M_{19}(s)$	> - 65.1042		65.1042

5.1. Adaptive MIT1 Controller

As long as input to the process and its output, $\{U(t)\}$ and $\{Y(t)\}$ respectively are bounded, closed loop stability is assured, when implementing Adaptive MIT or Adaptive PI controllers. In order to achieve BIBO stability a constant gain controller has been introduced in Adaptive MIT controller. The controller parameters from PAA are compared (Fig. 5). Whenever the parameter θ_2 of the Adaptive MIT becomes less than $-a/b$ (refer table II), a fixed gain controller provides the control action by eliminating the output from PAA. Once the condition reverses, adaptive mechanism is allowed to update the parameters of the inner loop controller again. This new strategy which accounts for stability is named as Adaptive MIT-1.

6. Results and Discussion

The process model is estimated from the data acquired from real time experimentation on the laboratory air flow control system. The DMRACs with Adaptive MIT, Adaptive MIT-1 and Adaptive PI controllers are designed with the same adaptation rate and implemented in simulation and in real time experimentation. Fig. 6 shows the tracking responses of the identified model $M_3(s)$ for the desired performance specification in simulation study. The adaptive PI controller with the identified model has lesser settling time when compared to model with adaptive MIT algorithm. The vanishing adaptive behavior of the controller can be inferred from Fig. 6(d) to 6(g). The response of the Adaptive MIT controller is smooth and takes more time to settle. The Adaptive PI controller responds very quickly to set point variations than the Adaptive MIT controller. The spans of controller parameters variations are large for Adaptive MIT than Adaptive PI for the same input variation.

The closed loop is disturbed at 41 and 42 sampling instants. The servo and regulatory responses of the process with Adaptive MIT, Adaptive MIT-1 and Adaptive PI are observed and plotted in Figs. 7(a) to 7(g). The loop with Adaptive MIT becomes unstable after 53 sampling instants. For the same disturbance the closed loop is made stable by Adaptive MIT-1 and Adaptive PI controllers. The Adaptive PI has acted to regulate the disturbance only at 41 and 42 sampling instants. After this the controller works for servo variation. The response shows the robustness of the Adaptive PI controller. The θ_2 variation of Adaptive MIT-1 is between -0.81 to -0.5 after the disturbance, thus maintaining the loop gain within bounds.

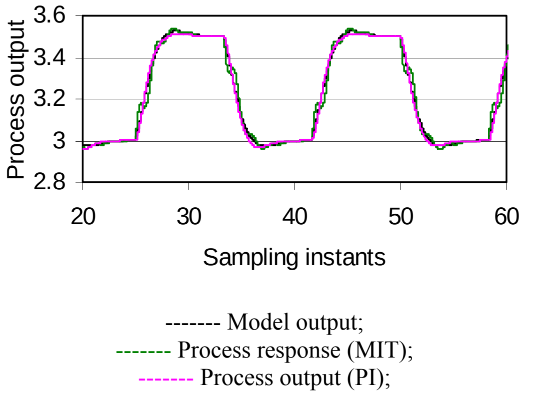


Fig. 6 (a). Response of Model and Process in Simulation.

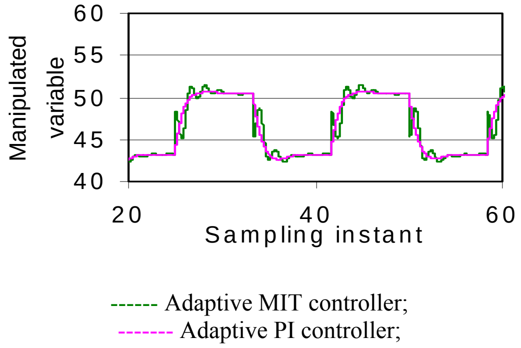


Fig. 6 (b). Response of the Controllers.

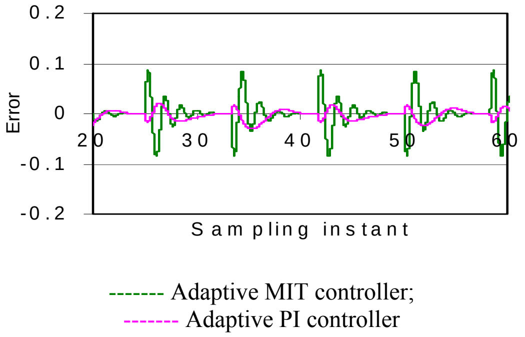


Fig. 6 (c). Response of Model Error.

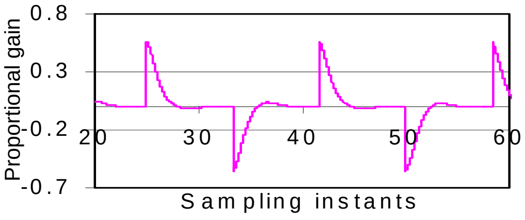


Fig. 6 (d). Adaptation of Proportional Gain.

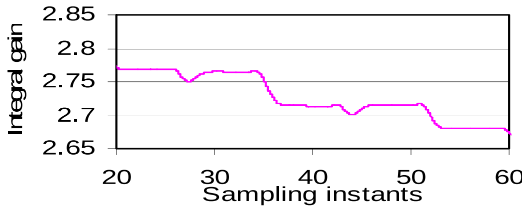


Fig. 6 (e). Adaptation of Integral Gain.

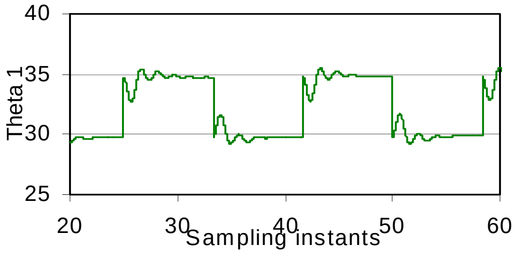


Fig. 6 (f). Adaptation of Theta 1.

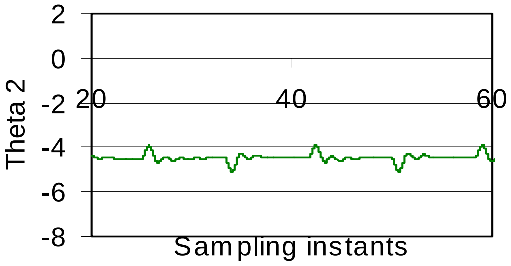


Fig. 6 (g). Adaptation of Theta 2.

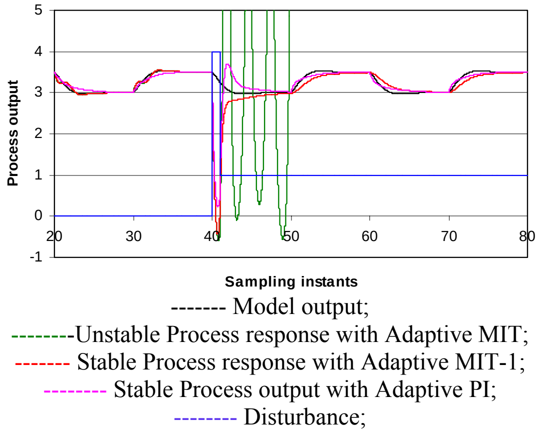


Fig. 7 (a). Response of Model and Process in Simulation (with disturbance).

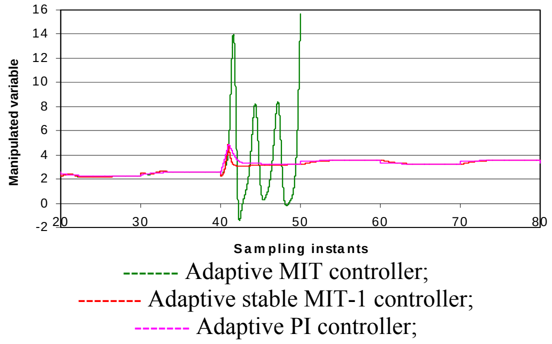


Fig. 7 (b). Response of the Controller.

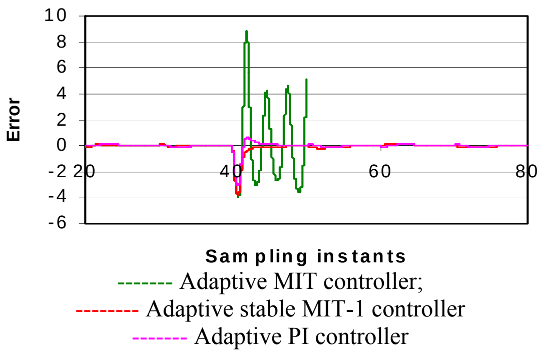


Fig. 7 (c). Response of Model Error.

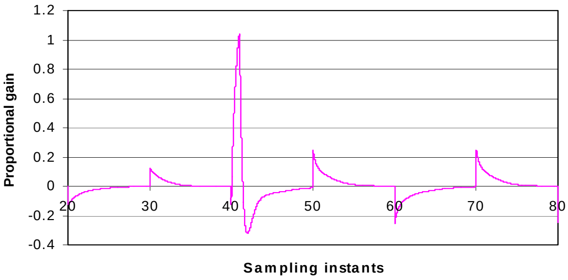


Fig 7 (d). Adaptation of Proportional Gain

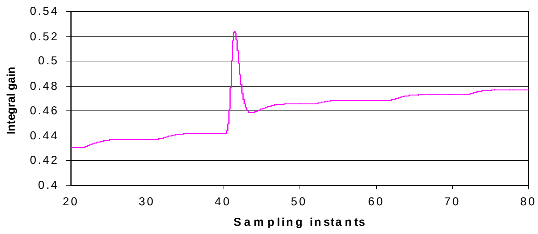


Fig. 7 (e). Adaptation of Integral Gain.

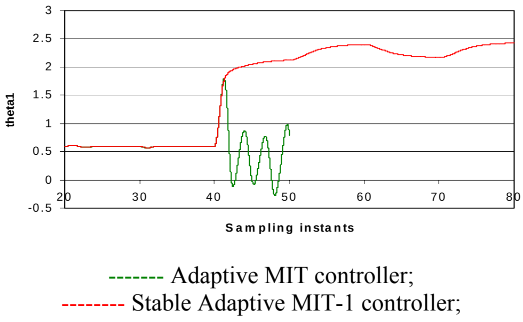


Fig. 7 (f). Adaptation of Theta 1.

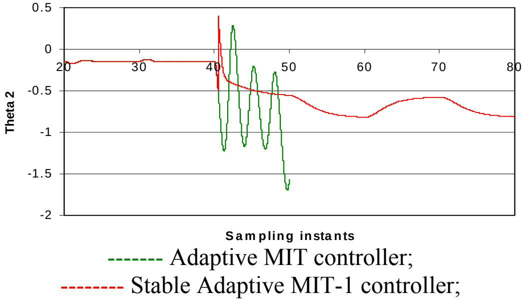


Fig. 7 (g). Adaptation of Theta 2.

The control of laboratory air flow control system in real time using dSPACE is presented in the following figures. Fig. 8(a) shows the laboratory air flow process. Fig. 8(b) displays the connection of the dSPACE, with the control system.

Fig. 8 (a). Laboratory Air Flow Control System.

Fig. 8 (b). Experimental Set up for Real Time Implementation of Adaptive Controllers.

The response of the nonlinear process in the range 872 to 1025 lpm is shown in Fig. 9 (a). The tracking ability of the process with adaptive PI controller is better when compared to process with adaptive MIT controller. Fig. 9 (b) displays the output of the controllers. The MIT controller has oscillatory output. But the output of the adaptive PI controller is very smooth. The spans of modelling error (Fig. 9 c) variations are large for the process with adaptive MIT controller. The adaptive PI controller adapts faster than the adaptive MIT controller. Vanishing adaptation can be visualized from the transient and steady state nature of the controller parameters (Figs. 9 (d) to 9 (g)).

Table III presents the range of adaptive gain variations of two different controllers. During experimentation theta1 (θ_1) parameter of the adaptive MIT controller varies from –0.05 to 0.91 and from - 0.3 to 1.61 for theta2 (θ_2) [Table III] for from 1170 to 134 lpm variation. The parameters of the adaptive PI controller various from – 0.017 to 0.017 for K_P and from 1.432 to 1.63 for K_I. The span of controller parameter variations is more for the adaptive MIT controller. Hence the amount of energy spent by the controller to bring the process output nearer to model output is more for the MIT controller. The Time Integral Performance Criteria [2] (Integral Square Error (ISE), Integral Absolute Error (IAE) and Integral Time Absolute Error (ITAE)) are tabulated (Table IV). The ISE, IAE and ITAE values are small when adaptive PI controller is placed in the control loop. From table IV, it is inferred that he parameter adaptation loop of the adaptive MIT controller has an increase of 9 % to 20 % in ISE, -35 % to 81 % in IAE and -54 % to 65 % in ITAE when compared to adaptive PI controller in simulation. Table V displays the various criteria for a stabilized system with two different controllers. Adaptive PI controller's performance is more satisfactory compared to Adaptive MIT-1 controller. The experimental time integral performance criteria for the laboratory nonlinear air flow control system are presented in Table VI.

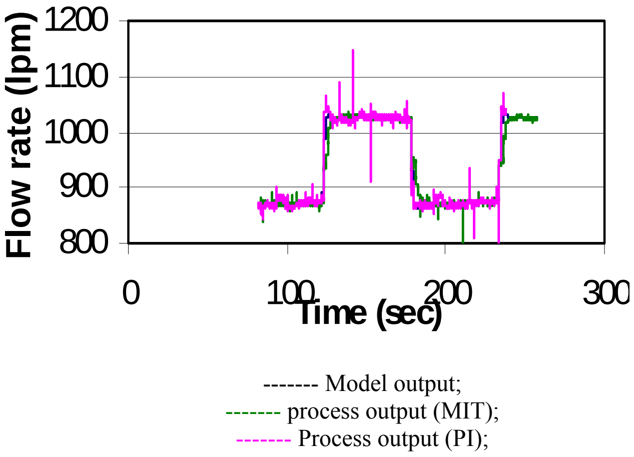


Fig. 9 (a). Response of Model and Process.

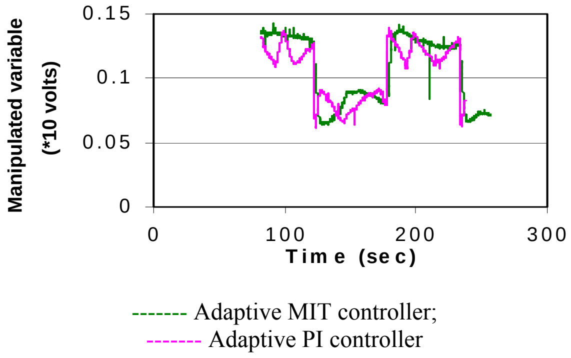


Fig. 9 (b). Response of the Controllers.

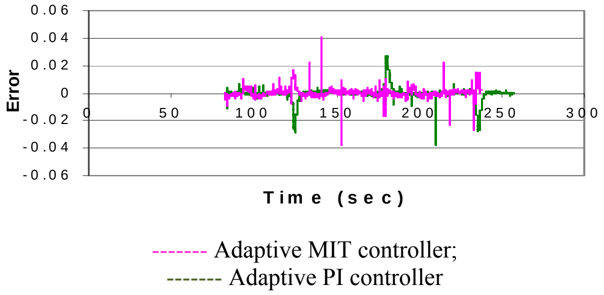


Fig. 9 (c). Response of Model Error.

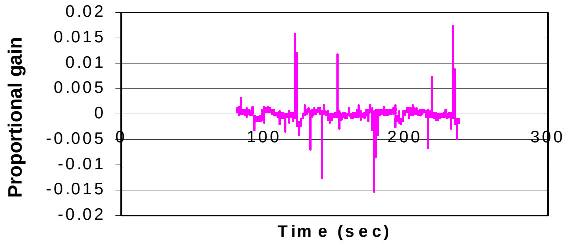


Fig. 9 (d). Adaptation of Proportional gain.

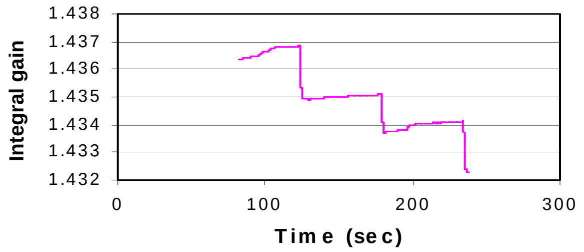


Fig. 9 (e). Adaptation of Integral gain.

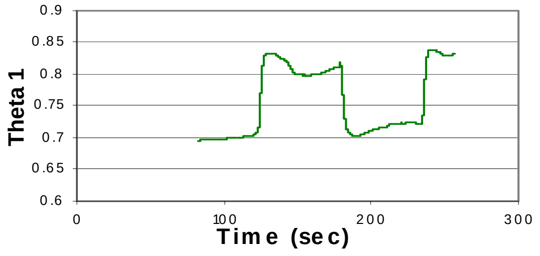


Fig. 9 (f). Adaptation of Theta 1.

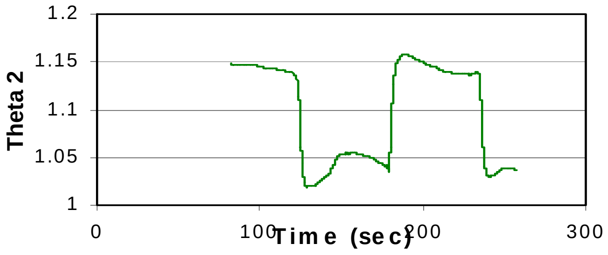


Fig. 9 (g). Adaptation of Theta 2.

Table III. Variation in Adaptation Gains for the Different Controllers.

Model	K_P		K_I		θ_1		θ_2	
	Max	Min	Max	Min		Min	Max	Min
$M_8(s)$ & $M_{11}(s)$	0.017	-0.017	1.4825	1.481	0.83	0.7	1.16	1.03
$M_7(s)$ & $M_{12}(s)$	0.015	-0.014	1.4765	1.4705	0.25	- 0.05	1.61	.25
$M_6(s)$ & $M_{13}(s)$	0.016	-0.016	1.467	1.461	0.52	0.29	1.39	.15
$M_5(s)$ & $M_{14}(s)$	0.007	-0.016	1.4583	1.4563	0.74	0.55	1.27	.07
M4(*s*) & M15(*s*)	0.015	-0.015	1.437	1.432	0.83	0.7	1.16	.03
M3(*s*) & M16(*s*)	0.002	-0.002	1.4437	1.44	0.91	0.82	1.07	.98
M2(*s*) & M17(*s*)	0.016	-0.014	1.63	1.54	2.4	0.09	1.1	-0.3

Table IV. Time Integral Performance Criteria (Simulation).

Model	**Adaptive MIT**			**Adaptive PI**		
	ISE	**IAE**	**ITAE**	**ISE**	**IAE**	**ITAE**
$M_1(s)$	54.15	19.22	184.6	43.56	17.86	284.3
$M_2(s)$	38.6	15.91	173.1	32.69	15.55	258.1
$M_3(s)$	22.49	11.85	158.9	20.23	11.64	199.4
$M_4(s)$	13.02	0.942	180.5	11.81	8.457	156.1
$M_7\ (s)$	9.392	13.27	410.9	7.742	7.006	143.8
$M_{15}(s)$	12.95	10.49	207.6	11.2	8.082	149.2
$M_{16}(s)$	23.15	12 .0	157.5	20.16	11.6	198.6
$M_{17}(s)$	28.82	13.18	163.2	26.45	12.94	204.6
$M_{18}(s)$	55.15	19.55	186.4	44.04	18.03	288.3

Table V. Time Integral Performance Criteria for a Stabilized System (Simulation- Model M7).

Controller	**ISE**	**IAE**	**ITAE**
Adaptive MIT1	18.42	12.43	-246.1
Adaptive PI	14.06	10.88	-72.53

Table VI. Time Integral Performance Criteria (Real Time).

Flow Rate (lpm)	**Adaptive MIT**			**Adaptive PI**		
	ISE	**IAE**	**ITAE**	**ISE**	**IAE**	**ITAE**
575 – 725 & 725 – 575	0.0064	0.5541	85.16	0.00105	0.2358	23.9
1025 – 1170 & 1170 – 1025	0.6406	10.05	121.0	0.1056	1.916	109.9
872 – 1025 & 1025 – 872	0.09036	3.226	401.1	0.0044	0.6084	68.98
725 – 872 & 872 – 725	0.02113	1.017	97.52	0.0037	0.5133	48.9
428 – 575 & 575 – 428	0.0083	0.572	61.81	0.00819	0.5767	58.61
280 – 428 & 428 – 280	0.0048	0.4898	46.26	0.0054	0.6611	91.07
134 – 280 & 280 – 134	0.05178	2.208	229.5	0.0402	1.706	23.9

7. Conclusions

This paper has presented design of adaptive PI controller based on MIT algorithm and identification of the nonlinear Air Flow Control System using the data acquired in real time. The methodology of design and implementation of Adaptive controllers in simulation are discussed. The performance of Adaptive PI and MIT controllers are validated in real time by interfacing the laboratory Air Flow Control System through dSPACE interface Card and MATLAB. The overall system performance when employing Adaptive PI is observed to be better than that of the system with Adaptive MIT controller. The oscillations in the PI controller output are negligible when compared to MIT controller. It is inferred that there is an increase of -12 % to 95 % in ISE values, -34 % to 81 %, increase in IAE values for the Adaptive MIT controller from the comparison table VI. Further it is inferred that ITAE values of adaptive MIT controllers has an increase of -96 % to 90 % when compared to adaptive PI. So it can be concluded that except for flow ranges from 280 – 428 & 428 – 280 lpm the adaptive PI controller outperforms the adaptive MIT controller. Adaptive PI controller responds with 76.33 % lesser, 87.53 % lesser IAE and 29.47 % lesser ITAE (Table V) when compared to Adaptive MIT-1 controller. From the simulation and experimental responses it is found that the adaptive PI controller is a better controller for this airflow process.

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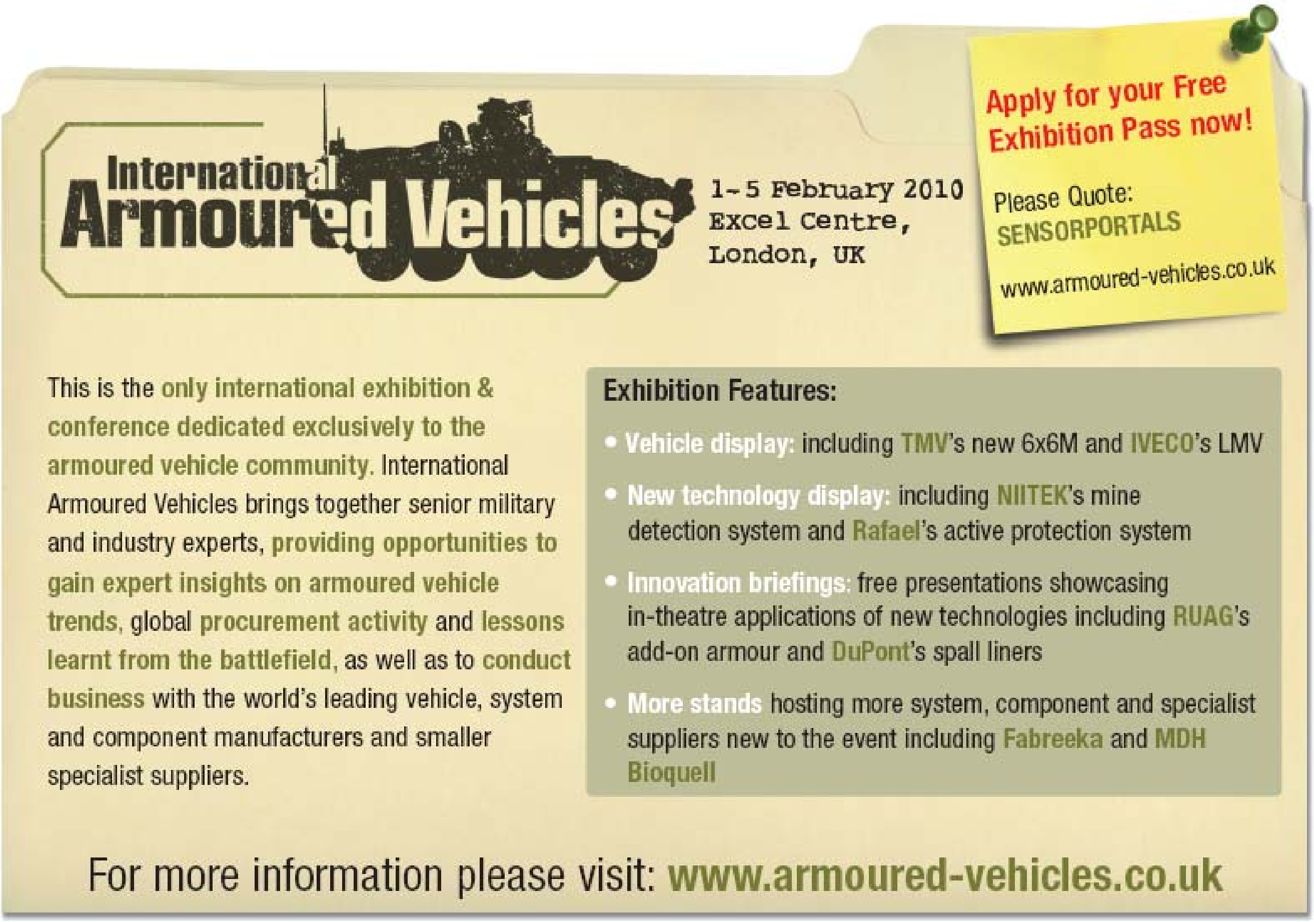

Guide for Contributors

Aims and Scope

Sensors & Transducers Journal (ISSN 1726-5479) provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because it is an open access, peer review international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per annual by International Frequency Association (IFSA). In additional, some special sponsored and conference issues published annually. *Sensors & Transducers Journal* is indexed and abstracted very quickly by Chemical Abstracts, IndexCopernicus Journals Master List, Open J-Gate, Google Scholar, etc.

Topics Covered

Contributions are invited on all aspects of research, development and application of the science and technology of sensors, transducers and sensor instrumentations. Topics include, but are not restricted to:

- Physical, chemical and biosensors;
- Digital, frequency, period, duty-cycle, time interval, PWM, pulse number output sensors and transducers;
- Theory, principles, effects, design, standardization and modeling;
- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
- Sensors interfaces, buses and networks;
- Signal processing;
- Frequency (period, duty-cycle)-to-digital converters, ADC;
- Technologies and materials;
- Nanosensors;
- Microsystems;
- Applications.

Submission of papers

Articles should be written in English. Authors are invited to submit by e-mail editor@sensorsportal.com 8-14 pages article (including abstract, illustrations (color or grayscale), photos and references) in both: MS Word (doc) and Acrobat (pdf) formats. Detailed preparation instructions, paper example and template of manuscript are available from the journal's webpage: http://www.sensorsportal.com/HTML/DIGEST/Submition.htm Authors must follow the instructions strictly when submitting their manuscripts.

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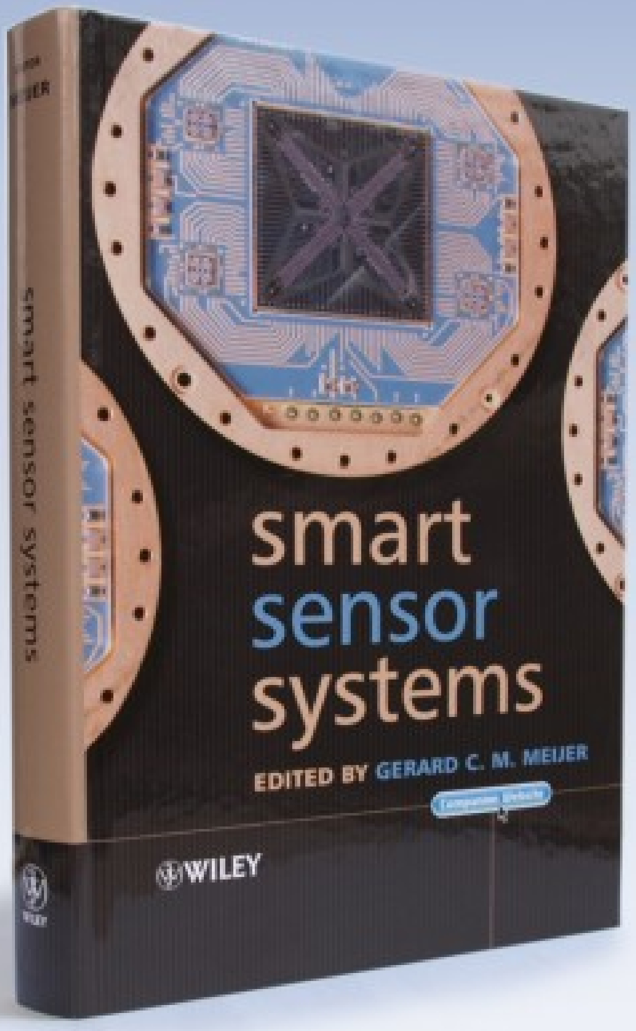
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