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Hybrid Control-based Model Reference Adaptive Control

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Introduction

The switched controller, which is a class of hybrid controller, has been researched in many control systems, such as an automated vehicles highway system [1], robotic control [2], chemical processes [3], traffic management [4], and adaptive control systems [5,6]. In this paper, we apply the switched controller as the adaptive controller to the well-known model reference adaptive control system (MRACS). The switched controller consists of a finite set of analog system and the switches which connect the member of analog system into the closed-loop system as shown in Fig.1. The set of analog controller C_1, C_2, ….C_N will be connected to or disconnected from the closed-loop path suitably by the switch $sw_i(t)$ which is controlled by the switching controller so as the error e(t) converges to an enough small value in reasonable sense beneath presence of parameter variation of the plant.

The proposed switched controller is implemented and applied to the speed control of one-link arm robot with variation of moment inertia of arm. The experiment results show that the rotation speed of one-link robot's arm is completely tracked to the desired output of reference model even the moment inertial of arm is varied.

In the next section, the 1st order plant will be considered and their simulation results will be discussed.

1st order plant

CASE I: Let's consider a first order plant as described in Eq.1 and the parameter K will be treated as variation parameter.

$$T\frac{dx(t)}{dt}+x(t)=Ku(t)\,. \qquad (1)$$

Here the two integral controllers will be used as the analog controller C_1 and C_2 in the switched controller. Then the controlled signal is calculated as follows.

$$u_i(t)=\int_0^t g_i sw_i(\tau)q(\tau)d\tau;\ i=1,2\,; \qquad (2)$$

where, g_i is a constant gain of analog controller *Ci* , $q(t)$ is the error signal and $sw_i(t)$ is two values (1 or 0) function and determined by switching controller as following equation.

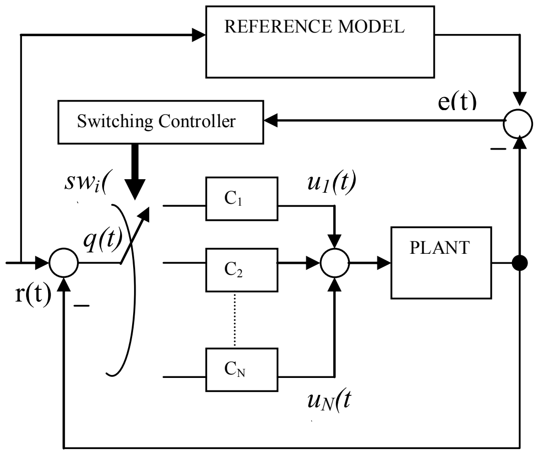

Fig. 1. MRACS with hybrid controller

$$sw_i(t)=\begin{cases}1\ ;C_i\ \text{is being connected,}\\ 0\ ;C_i\ \text{is being disconnected.}\end{cases} \qquad (3)$$

Thus $sw_i(t)$ can be considered as a pulse train function. If $\delta_i(t)$ and $\lambda_i(t)$ denotes its pulse width and period respectively. Let $h_i(t)$ denotes the duty rate of each $sw_i(t)$ then the $h_i(t)=\delta_i(t)/\lambda_i(t)$. If frequency of switching is higher than the frequency of control signal u(t) enough so then the control signal can be approximated as follows

$$u(t)\approx\int_0^t (h_1g_1+h_2g_2)q(\tau)d\tau \qquad (4)$$

where h_1 and h_2 are the duty rate of switch $sw_1(t)$ and $sw_2(t)$ mentioned above respectively. Using this control signal in Eq.4 to the plant in Eq.1 then the closed-loop adaptive control system can be described by below:

$$T\frac{d^2x(t)}{dt^2}+\frac{dx(t)}{dt}+(h_1g_1+h_2g_2)Kx(t)=$$
$$=(h_1g_1+h_2g_2)Kr(t)\,. \qquad (5)$$

As above closed-loop system, that consists of 1st order plant and the integrator, the reference model should be 2nd order system described as follows

$$T\frac{d^2x_m(t)}{dt^2}+\frac{dx_m(t)}{dt}+L_m x_m(t)=L_m r(t)\,. \qquad (6)$$

By comparison Eq.6 with Eq.5, we can show that the error signal e(t) between the output of plant and reference model will be converged to zero asymptotically if the coefficient of both equations are the same or Eq.7 is satisfied.

$$(h_1 g_1 + h_2 g_2)k = L_m\,. \qquad (7)$$

To obtain the satisfaction in Eq.7 the switching controller will turn the switch to connect an analog controller to the closed loop path and disconnected the behind one from the loop logically by the following switching law. However the limitation of bandwidth frequency of switch and the analog controller is existed so then the considerable small boundary region of error εwill be applied to the switching law as the hysteresis width. δis the sampling time of switching controller.

Table 1. Switching law of switched controller

	e(t)> ε		e(t)<ε
	E(t)q(t) > 0	e(t) q(t) < 0	×
$SW_1(t)$	1	0	*$SW_1(t-\delta)$*
$SW_2(t)$	0	1	*$SW_2(t-\delta)$*

To investigate the above adaptive scheme a study case of simulation is performed. The following parameters condition is used for simulation.

Model: T = 0.35, Lm = 1.5.
Plant (DC motor): T = 0.35, K = 0.5.
Hybrid analog controller: C_1 = 10/s, C_2 = -10/s The simulation results, the step response of both model and plant are shown in Fig.3 and Fig.4 respectively. Furthermore, the control signal is shown in Fig.5.

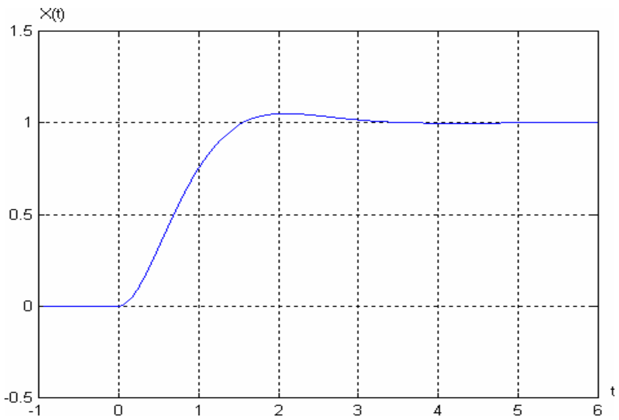

Fig. 2. A step response of the plant

These results verify that the two analog controllers C_1 and C_2 are switched by the switching controller suitably. Namely the duty rate satisfying Eq.7 are obtained. In the case II mentioned below will extend the use of hybrid analog controller to the plant with two varying parameters.

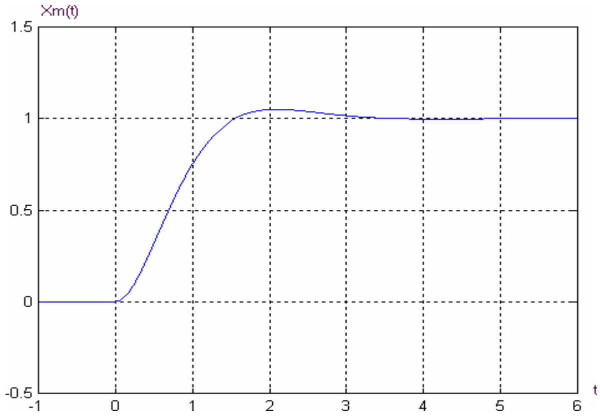

Fig. 3. A step response of the model reference

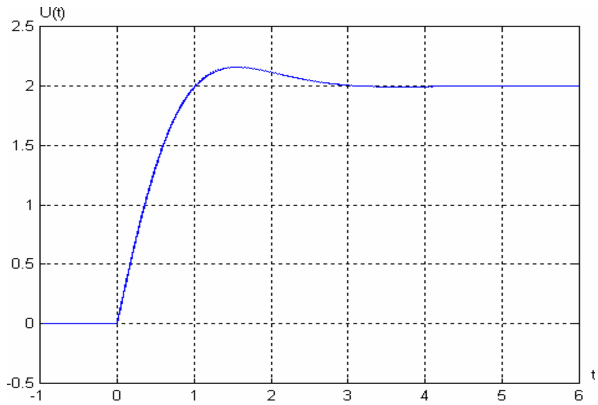

Fig. 4. A control signal of the plant

CASE II : In this case, the variation of both parameters T and K of plant in Eq.(1) will be considered. To obtain the response that coincides with the response of 2^{nd} order model described in Eq.6, the adaptation of the closed inner loop is needed. So then a hybrid adaptive controller is added to the adaptive control system as shown in Fig.5.

As Fig.5, the C_3 and C_4 are the proportional analog controller with constant gain g_3 and g_4 respectively. LPF is a low pass filter that rejects the high frequency signal occurred from switching. The switching law of the hybrid controller in the inner loop is shown in table.2.

Table 2. Switching law of switched controller

	e(t)> ε		e(t)<ε
	e(t) x(t) > 0	e(t) x(t) < 0	×
$SW_3(t)$	1	0	*$SW_3(t-\delta)$*
$SW_4(t)$	0	1	*$SW_4(t-\delta)$*

The simulation is performed by the following conditions:

Model: Tm = 0.35, Lm = 1.5.
Plant(DC motor): T = 2.0, K = 1.
Hybrid analog controller: C_1 = 10/s, C_2 = -10/s.
LPF: 1/(0.01s+1).

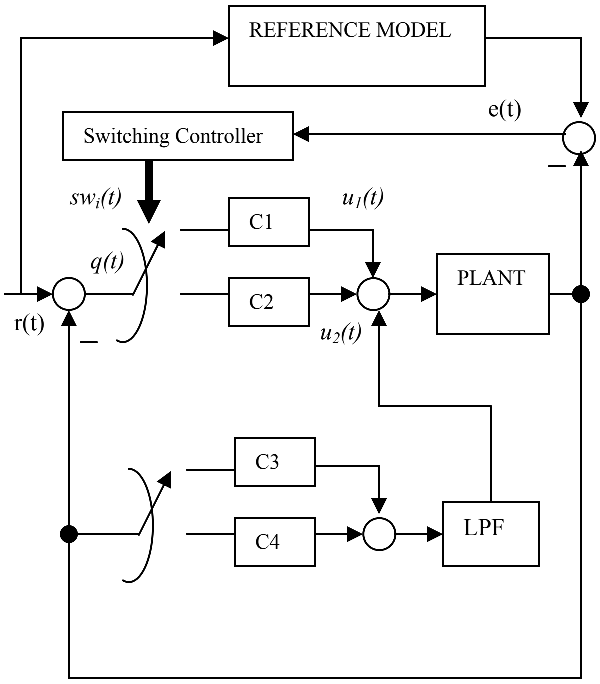

Fig. 5. MRAC using switched controller

The simulation results, the step response of both model and plant are shown in Fig.6 and Fig.7 respectively. Furthermore, the control signal is shown in Fig.8.

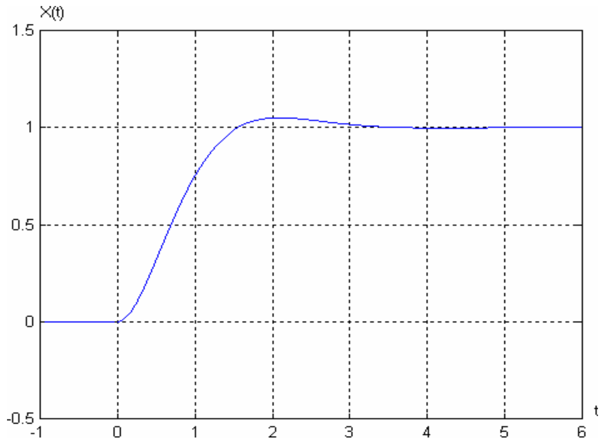

Fig.6. The step response of the plant

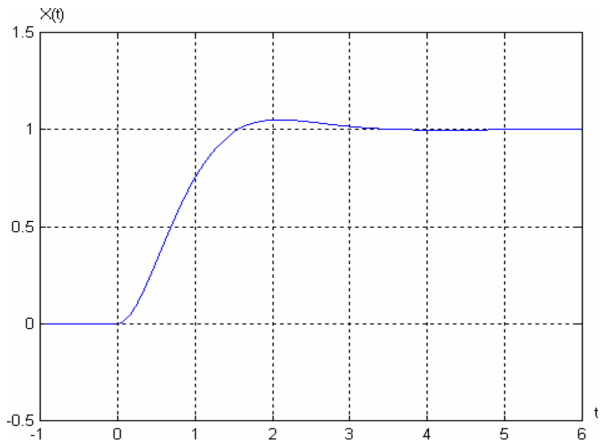

Fig.7. The step response of the model reference

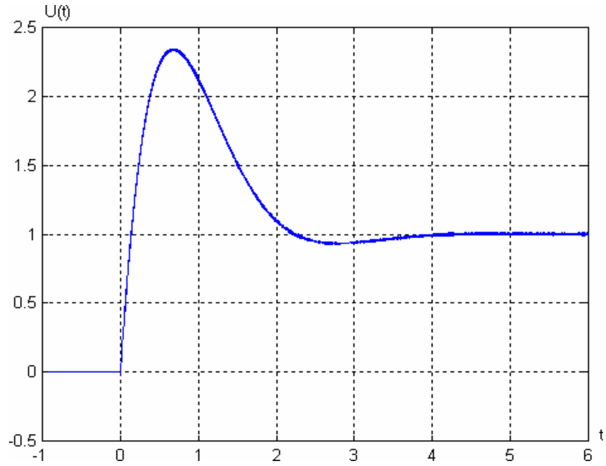

Fig. 8. The control signal of the plant

Experiments

The proposed switched controller is applied to speed control of one-link arm robot and its experiment is performed. The moment inertia of arm will be varied by changing the position of weight attached with the rotating arm. The configuration of experiment is shown as follows.

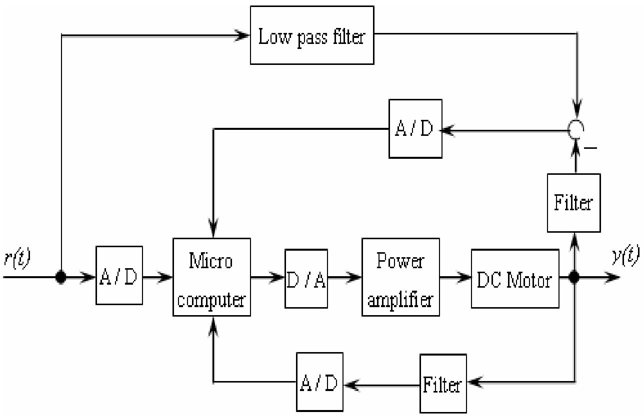

Fig.9. The configuration of experiment

In the experiment, the step response of rotating arm under two different conditions are investigated. Fig.3 shows the response when the arm's inertia is 1.6 [kg.cm2] and Fig.4 shows the response when the arm's inertia is 65.5 [kg.cm2]. As both results, the speed of rotating arm (lower) are tracked with the output of model (upper) well.

In the experiment, beneath variation of moment inertia of arm the step response of rotation speed are investigated. The specification of experiment is as follows.

Fig.10 shows the response when the arm's inertia is 1.6 [kg.cm^2] and Fig.11 shows the response when the arm's inertia is 65.5 [kg.cm^2]. As both results, the speed of rotating arm (lower) are tracked with the output of model (upper) well.

Conclusions

The switched controller applied to MRACS is presented. We show that the parameter adaptation can be done by switched controller. The proposed scheme is applied to the speed control of one-link robot's arm with existence of variation of moment inertia. The experiment results show that the rotation of arm is tracked to the desired speed generated by reference model very well.

Table 3. The specification of experiment

Low pass filter (Reference Model)	$\frac{50}{3s^2 + 24s + 50}$
DC Motor	$\frac{100}{0.11s + 1}$
Arm's inertia	1.25.96.8 [kg.cm^2]
C_1 and C_2	$\frac{8\times10^{-2}}{s}$, $\frac{-8\times10^{-2}}{s}$
Microcomputer	SH7047
Power amplifier	100W
A/D Converter	10 bit
D/A Converter	10 bit
Anti-alias Filter	2nd order filter
Sampling time	1.13 ms

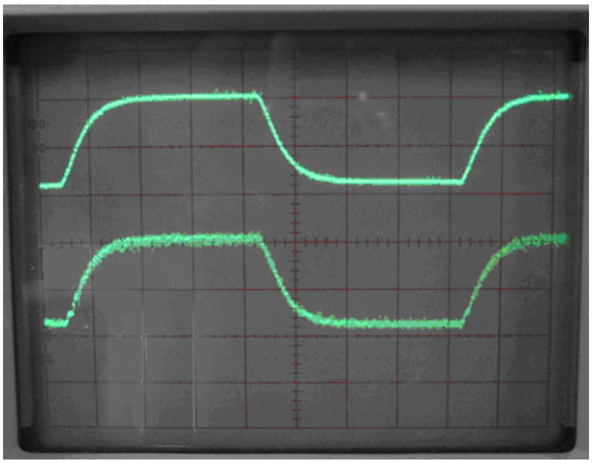

Fig.10. Condition: Arm's inertia: 1.6 [Kg*cm^2] (Upper: Output of model, Lower: Rotation Speed)

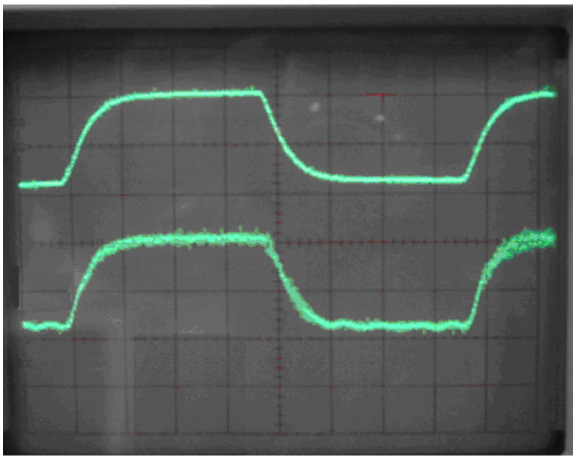

Fig. 11. Condition: Arm's inertia: 65.5 [Kg*cm^2] (Upper: Output of model, Lower: Rotation Speed)

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Pasiūlytas šiuolaikiškas kontroleris, kuris realizuotas ir pritaikytas valdyti robotą su vienos grandies petimi, kai kinta peties inercijos momentas. Gauti eksperimentiniai rezultatai rodo, kad roboto peties sukimosi greitis visiškai priartinamas norimo modelio išėjimo, net jei peties inercijos momentas kinta. Apibendrinti modeliavimo rezultatai. Il. 11, bibl. 6 (anglų kalba, santraukos lietuvių, anglų ir rusų k.).

S. Vichai, S. Hirai, M. Komura, S. Kuroki. Hybrid Control-based Model Reference Adaptive Control // Electronics and Electrical Engineering. – Kaunas: Technologija, 2005. – No. 3(59). – P. 5–8.

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С. Вихай, С. Хирай, М. Комура, С. Куроки. Гибридная модель адаптивного контроля // Электроника и электротехника. – Каунас: Технология, 2005. – № 3(59). – C.5-8.

Предложен современный контролер предназначенный для управления робота с плечом из одной цепи, когда момент инерции плеча меняется. Полученные результаты эксперимента показывают, что скорость вращения плеча робота полностью совпадает с заданной в выходе модели, даже тогда, когда меняется момент инерции плеча. Обобщены результаты моделирования. Ил. 11, библ. 6 (на английском языке; рефераты на литовском, английском и русском яз.).

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