Experiments on IMC-Based PID Controller Design for a Two-link SCARA Robot

Sipaseuth SUVILATH [1], Taworn BENJANARSUTH [2], Noriyuki KOMINE[3] and Khamphong KHONGSOMBOUN [4]

[1] International College, King Mongkut's Institute of Technology Ladkrabang, Thailand
[2] Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang, Thailand
[3] School of Information and Telecommunication Engineering, Tokai University, Japan
[4] Faculty of Engineering, National University of Laos, Laos

1 Introduction

A SCARA robot (Selective Compliance Assembly Robot Arm) is a type of robots widely used in factory automation as assembly products robot, soldering robot and so on. In order to perform accurately and robustly, the robot controller should be designed suitably. Various schemes such as fuzzy logic [1], Neural network [2], IMC [3] and so on, have been proposed and applied to SCARA robot controller design. Among various controllers, PID controller is the most popular in industrial scene due to its simplicity and availability in the market. Mostly, PID parameters are determined by trial and error process by a skilled expert. So, in this paper, an easy IMC-Based PID method is applied to the Two-Link SCARA robot controller design.

In IMC controller design, it consists of 2 steps and its low-pass filter should be selected suitably because it affects the performance of the system. Many of filters have been selected for difference kind of models in [4] and [5] but those filters cannot be used as a filter for the SCARA robot model. So a suitable filter is selected in this paper. Then the IMC controller is approximated by Maclaurin series expansion to obtain PID parameters. Then, the parameters are simulated by Matlab/Simulink. Besides, they are also applied to controller coding in experiment.

2 Mathematical Model

The schematic diagram of the two-link robot manipulator considered in this paper is shown in Fig.1

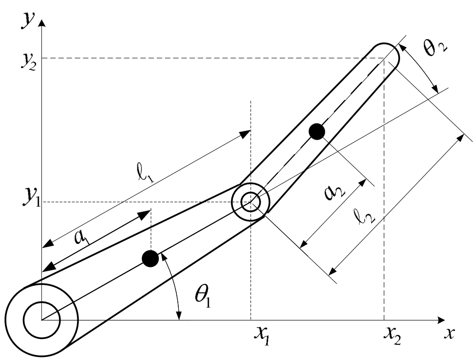

Fig. 1. SCARA Robot Diagram.

In order to design a controller by IMC technique, the nonlinear model [6], [7], is linearized. Then the linear transfer matrix can be derived as equation (1),

$$G(s)=\frac{\theta(s)}{E(s)}=\frac{1}{s^3+as^2+bs}\begin{bmatrix} a_{11}s+b_{11} & -a_{12}s \\ -a_{21}s & a_{22}s+b_{22} \end{bmatrix} \quad (1)$$

while $\{a,b,a_{11},a_{12},a_{21},a_{22},b_{11},b_{12}\}\in R^+$.

3 IMC-Based PID Controller Design

The structure of IMC control system is shown in Fig. 2, in which G is a controlled object, $\hat{G}$ is the model of the controlled object, C is an IMC controller.

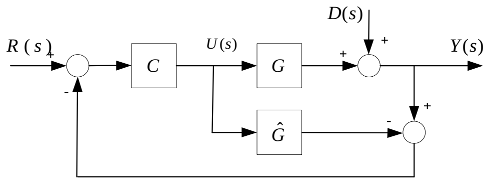

Fig.2. IMC control system.

In IMC controller design, it composes of two steps.

Step1: Divide the model of the controlled object $\hat{G}(s)$ into two parts as $\hat{G}(s)=\hat{G}_+(s)\hat{G}_-(s)$, where $\hat{G}_+(s)$ contains all the time delays and right-half-plane zeros. While $\hat{G}_-(s)$ is the transfer function with minimum phase characteristic and contains no predictive item.

Step2: To design the internal model controller, a low-pass filter $f(s)$ must be added to $\hat{G}_-(s)^{-1}$ to ensure the stability and robustness of the control system.

After rearrange the structure of IMC in Fig.2, the general closed loop control can be obtained as Fig.3.

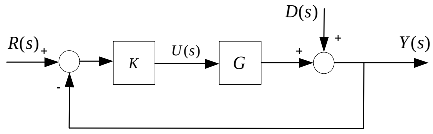

Fig. 3. General closed loop control.

Then a controller $K(s)$ can be expressed as in equation (3).

$$K(s)=\frac{\hat{G}_-^{-1}(s)}{f^{-1}(s)-\hat{G}_+(s)} \quad (3)$$

With a suitable choice of $f(s)$, the controller $K(s)$ can possess the integral action and appear in the following form,

$$K(s) = \frac{1}{s} Q(s) \ . \tag{4}$$

By performing the Maclaurin series expansion for $Q(s)$, the controller $K(s)$ can be expressed as

$$K(s) \cong \frac{1}{s}\left[Q(0) + \dot{Q}(0)s + \frac{\ddot{Q}(0)s^2}{2!} + \ldots \right]. \tag{5}$$

By ignoring the higher order terms, the PID controller can be obtained as

$$K(s) \cong K_p + \frac{K_i}{s} + K_d s \ , \tag{6}$$

where its parameters are

$$K_p = \dot{Q}(0), K_i = Q(0) \text{ and } K_d = \ddot{Q}(0)/2 \ .$$

In this paper, the suitable filter is selected as equation (7).

$$f(s) = \frac{zs+1}{xs^3 + ys^2 + zs + 1} \tag{7}$$

4 Simulation and Experimental Results

Two closed loop PID controllers are designed independently to control each link as depicted in Fig. 4.

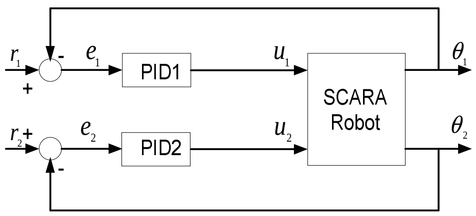

Fig. 4. Proposed control system structure.

The filter's parameters x, y and z are tuned and the corresponding PID parameters can be computed as in Table 1.

Table 1. The parameters both controllers

	x	y	z	K_p	K_i	K_d
PID1	15.10^{-5}	5.10^{-3}	5.10^{-1}	41	65	4
PID2	20.10^{-5}	4.10^{-3}	5.10^{-1}	46	73	4

The parameters in Table 1. are applied in both simulations and experiments as follows.

The step reference inputs at 45° are applied to both links separately until the outputs reach the desired positions and then the input disturbances at 4 volts are applied to both links at 4.5 seconds as shown in Fig. 5 and Fig. 6.

We can observe that the step output responses from both simulation and experimental results can attain to the set point rapidly and identically with overshoot about 14% but without steady-state error. Meanwhile, the system can reject the input disturbance and return to the set point within 2 seconds.

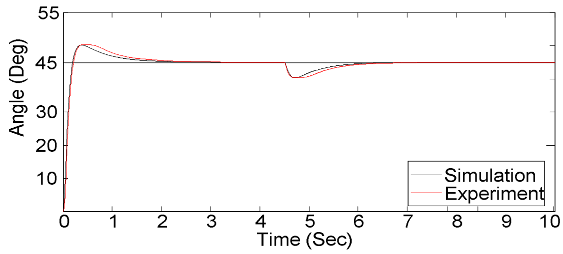

Fig. 5. Simulation and Experimental results for the first link.

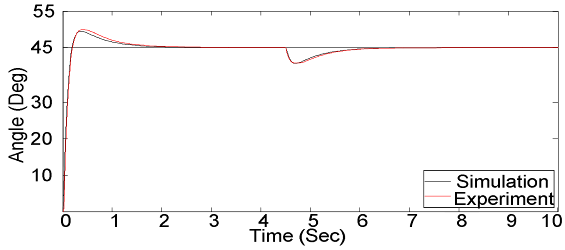

Fig. 6. Simulation and Experimental results for the second link.

5 Conclusion

In this paper, previous works, mathematical model, IMC-Based PID controller design method and simulation results are briefly reviewed. The PID parameters obtained in IMC-Based PID controller design are applied to the actual Two-Link SCARA robot. From the experiments, the results are nearly identical to the simulations. Both simulations and experiments demonstrate that the outputs of the proposed control system can track the reference inputs without steady-state error. Moreover, the effects of input disturbances can be rejected.

References

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