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ADAPTIVE FUZZY SETTING REFERENCE MODEL FOR HOIST CRANE MOVEMENT

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Abstrak

Jurnal ini memaparkan tentang perancangan sistem kendali gerakan Hoist Crane menggunakan model reference Fuzzy Adaptive (*model reference adaptive fuzzy control*) untuk kendalian gerakan tak linier. Kendalian gerakan tak linier pada hoist crane yang dipilih untuk menguji efektifitas aturan kendali fuzzy adaptive melalui simulasi adalah model gerakan hoist crane tak linier yang pada dasarnya adalah tidak stabil. Aturan kendali fuzzy adaptive diturunkan menggunakan teori Lyapunov berdasarkan model linierisasi dari gerakan hoist crane. Model acuan yang dipilih adalah model linier yang telah distabilisasi. Kemudian dilakukan simulasi untuk mengamati kinerja MRAFC terhadap model tak linier. Jadi model tak linier dikendalikan menggunakan aturan kendali fuzzy adaptive yang diturunkan dari model linier. Kendali umpan-balik status (*full state feedback control*) melalui simulasi telah dibuktikan tak mampu menstabilkan gerakan hoist crane. MRAFC mampu melakukan dengan baik, bahkan untuk kasus dimana model parametrik kendali tidak diketahui secara pasti (*uncertainty*) atau berubah seiring waktu (*time-varying*). Hal yang perlu diperhatikan dalam perancangan adalah bagaimana memilih model acuan sebijaksana mungkin, karena hal ini mempengaruhi tingkat kestabilan sistem kendali.

Kata Kunci: Sistem Kendali Fuzzy Adaptive, Kendali Fuzzy Adaptive, Sistem Kendali Tak Linier, Linierisasi Model, Gerakan Hoist Crane.

Abstract

This journal describes control system designing of Hoist Crane movement using Adaptive Fuzzy Reference Model (Adaptive Fuzzy Control Reference Model) for non-linear movement controlling. Non linear movement controlling in hoist crane selected to test adaptive fuzzy control rule effectiveness through simulation is non linear hoist crane movement model which basically is unstable. Adaptive Fuzzy Control rule is derived using Lyapunov theory based on linearization model from hoist crane movement. Reference model selected was stabilized linear model. Then simulation was performed to observe MRAFC performance on non linear model. Full state feedback control through simulation has been shown not able to stabilize hoist crane movement. MRAFC is able to perform better, even for cases where controlling parametric model was uncertain or changing over time (time-varying). Point to note in the designing was how to select reference model as wise as possible because it affect control system stability level.

Keywords: Adaptive Fuzzy Control System, Adaptive Fuzzy Control, Non Linear Control, Model Linearization, Hoist Crane Movement.

I. INTRODUCTION

Full state variable feedback (full state feedback) control is a choice in designing control rule based on state space model. This control is able to control linear model resulted from hoist crane movement model linearization. But it is not proved having capability to control non linear origioanl model from the hoist crane movement. Therefore, this research is aimed to anticipate the problem by trying to use adaptive fuzzy control system.

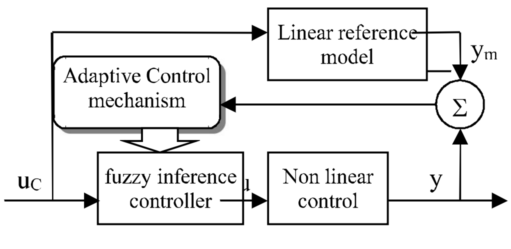

Fig.1. Block diagram of referene model adaptive fuzzy control with non linear controlling. [1].

Adaptive Fuzzy Control System is control system with capability to adapt with both external and internal environment changes to sustain system stability and performance. In general adaptive fuzzy control system consist of arious types including model referene adaptive fuzzy control, self tuning adaptive control, adaptive gain scheduling and dual adaptive control. [1]. For any reason, adaptive control type selected in this reesearch is reference model adaptive fuzzy control system (RMAFCS).

Reference model adaptive fuzzy control is ontorl system by controller with perimter that an adapt according to fixed adaptive control mode mechanism. This mechanism run in parralel with effort to force a control with poorer prformane (or even not stable) in order to follow a referene model behavior with better performane (and definitely stable) (2).

Designing order of fuzzy interferene control rule is firstly by decreasing non linear model control into linear. Next use reference model fuzzy sliding mode control from linear model in form of state space equation. The control rule is tested via return simulation on non linear model.

II. HOIST CRANE MOVEMENT MODEL

Hoist crane movement physial model is shown in figure 2. F force influene hoist crane movement in horizontla plane and also influence hoist crane upward movement angle position on vertical axis. Equation 1 shows the equation model is not linear from hoist crane movement. [3]. State variables of the equation are:

My= sling position in hoist in horizontal plane = y (m)
x_2 = hoist crane movement angle in vertical plane = θ (rad)
x_3 =hoist crane movement speed in horizontal plane (m/sec)
x_4 = hoist crane angle movement speed (rad/sec)

Table 1. Variable in hoist crane movement sling

Symbol	Explanation	Unit
ℓ	Length of sling hoist crane	Meter
F	Force that influence hoist crane movement sling position	Newton
θ	Position of hoist crane sling angle	Radian
M	Mass of hoist crane	Kilogram
m	Mass of sling	Kilogram
y	hoist crane position	Meter

g = earth gravity force = 9.8 m/sec^2.

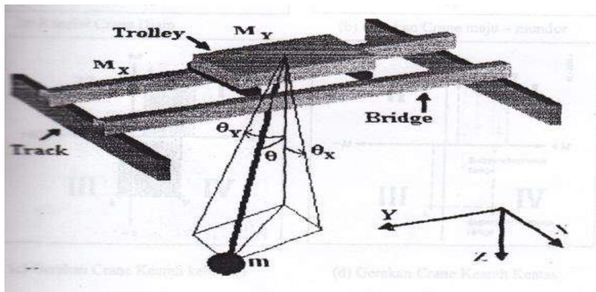

Fig- 2. Physical Model Of Hoist Crane Movement

$$\dot{x}_1 = x_3$$
$$\dot{x}_2 = x_4$$
$$\dot{x}_3 = \frac{u - \frac{1}{2} mg \sin 2x_2 + m\ell x_4 \sin x_2}{M + m \sin^2 x_2}$$
$$\dot{x}_4 = \frac{-u \cos x_2 + \frac{1}{2} mg \sin 2x_2 \cos x_2 - \frac{1}{2} m\ell x_4 \sin 2x_2 + Mg \sin x_2 + mg \sin^3 x_2}{M\ell + m\ell \sin^2 x_2}$$
(1)

I. REFERENCE MODEL ADAPTIVE FUZZY CONTROL

Note following state space equation model:

$$\frac{dx}{dt} = Ax + Bu$$
(2a)

It is expected to design control rule hence process model follows reference model behavior:

$$\frac{dx_m}{dt} = A_m x_m + B_m u_c$$
(2b)

Linear control general form is:

$$u = Mu_c - Lx$$
$$M = [\theta_1 \theta_2, \ldots, \theta_m]^T, \; L = [\theta_{m+1} \theta_{m+2} \theta_{\ell+m}]^T$$
(3)

In this case, m = number of input variable and ℓ = number of state variable. Next error equation and error equation derivation is written as follow:

$$e = x - x_m$$
$$\frac{de}{dt} = \frac{dx}{dt} - \frac{dx_m}{dt} = Ax + Bu - A_m x_m + B_m u_c$$
(4)

By adding and reducing with Amx in right side of equation (4) following can be obtained:

$$\frac{de}{dt} = A_m e + (A - A_m - BL)x + (BM - B_m)u_c$$

$$= A_m e + (A_c(\theta) - A_m)x + (B_c(\theta) - BM)u_c$$

$$= A_m e + \psi(\theta - \theta^\circ)$$

(5)

To obtain equality equation, it is suggested that condition for process model absolute similarity and reference model have been met. To decrease parameter adaptation rule, following Lyapunov function is introduced:

$$V(e,\theta) = \frac{1}{2}(\gamma e^T Pe + (\theta - \theta^\circ)^T(\theta - \theta^\circ))$$

(6)

Matrix P is positive definite matrix. Function V is positive definite function. To proof whether function V in (6) is Lyapunov's then we calculate V derivative total on the time.

$$\frac{dV}{dt} = -\frac{\gamma}{2}e^T Qe + \gamma(\theta - \theta^\circ)\psi^T Pe + (\theta - \theta^\circ)^T \frac{d\theta}{dt}$$

$$= -\frac{\gamma}{2}e^T Qe + (\theta - \theta^\circ)\left(\frac{d\theta}{dt} + \psi^T Pe\right)$$

(7)

Matrix Q is positive definite such that following relation is prevailed.

$$A_m P + PA_m = -Q$$

(8)

By bearing in mind Lyapunov theorem that positive definitE matrices P and Q will be always found if matrix Am is matrix that describe stable system. When control parameter adaptation rule is selected, then:

$$\frac{d\theta}{dt} = -\gamma\psi^T Pe$$

(9)

Where θ is vector with components ($\theta_1, \theta_2, ..., \theta_n, \theta_{n+\ell}$), then following is obtained (Note: n^{th} order sytem will have $n+\ell$ adaptation control parameter θ)

$$\frac{dV}{dt} = -\frac{\gamma}{2}e^T Qe$$

(10)

Equation (10) shows that Lyapunov function derivative is semi definite and not negative definite. Based on Lyapunov theory, it imply that for initial condition, value of adaptive fuzzy parameter ($\theta_1, \theta_2, ..., \theta_n, \theta_{n+\ell}$) need to be limited, where the limit ensure that $V(\theta,t) < V(e, \theta_1, \theta_2, ..., \theta_n, \theta_{n+\ell}, t)$ for every t > 0, or V Lyapunov function is positive definite.

IV. ADAPTIVE FUZZY CONTROL RULE

Hoist crane movement non linear control will be controlled by reference model adaptive fuzzy control derived from linear model. Hence system non linear model will be linearized into linear model. And selected reference model is also linier reference model that is stable and good performance model.

$$A = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & -\frac{mg}{M} & 0 & 0 \\ 0 & \frac{(M+m)g}{M\ell} & 0 & 0 \end{bmatrix}, \quad B = \begin{bmatrix} 0 \\ 0 \\ \frac{1}{M} \\ -\frac{1}{M\ell} \end{bmatrix}$$

(11a)

$$C = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix}$$

(11a)

State space equation model above is non stable. By taking controller gain value K

$$K = \begin{bmatrix} k_1 & k_2 & k_3 & k_4 \end{bmatrix}$$

(11b)

Reference model selected is:

$$A_m = A - BK$$

$$= \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ -\frac{k_1}{M} & -\frac{mg}{M} - \frac{k_2}{M} & -\frac{k_3}{M} & -\frac{k_4}{M} \\ \frac{k_1}{M\ell} & \frac{(M+m)g}{M\ell} + \frac{k_2}{M\ell} & \frac{k_3}{M\ell} & \frac{k_4}{M\ell} \end{bmatrix},$$

$$BK = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ \frac{1}{M}k_1 & \frac{1}{M}k_2 & \frac{1}{M}k_3 & \frac{1}{M}k_4 \\ -\frac{1}{M\ell}k_1 & -\frac{1}{M\ell}k_2 & -\frac{1}{M\ell}k_3 & -\frac{1}{M\ell}k_4 \end{bmatrix} \tag{12}$$

Reference model obtained from control linear model stabilized with pole placement technique (vector K is obtaned from pole placement technique). Signal and adaptive fuzzy control parameter is as in (3). Hence:

$$BL = \begin{bmatrix} 0 \\ 0 \\ \frac{1}{M} \\ -\frac{1}{M\ell} \end{bmatrix} [\theta_2 \quad \theta_3 \quad \theta_4 \quad \theta_5]$$

$$= \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ \frac{1}{M}\theta_2 & \frac{1}{M}\theta_3 & \frac{1}{M}\theta_4 & \frac{1}{M}\theta_5 \\ -\frac{1}{M\ell}\theta_2 & -\frac{1}{M\ell}\theta_3 & -\frac{1}{M\ell}\theta_4 & -\frac{1}{M\ell}\theta_5 \end{bmatrix} \tag{13}$$

$$A - BL = (Ac(\theta))$$

$$= \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ -\frac{\theta_2}{M} & -\frac{mg}{M} - \frac{\theta_3}{M} & -\frac{\theta_4}{M} & -\frac{\theta_5}{M} \\ \frac{\theta_2}{M\ell} & \frac{(M+m)g}{M\ell} + \frac{\theta_3}{M\ell} & \frac{\theta_4}{M\ell} & \frac{\theta_5}{M\ell} \end{bmatrix}$$

(14)

Further, it is obtained that:

$$A_c(\theta) - Am = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ \frac{k_1-\theta_2}{M} & \frac{k_2-\theta_3}{M} & \frac{k_3-\theta_4}{M} & \frac{k_4-\theta}{M}{}_5 \\ -\frac{k_1+\theta_2}{M\ell} & -\frac{k_2+\theta}{M\ell}{}_3 & -\frac{k_3+\theta_4}{M\ell} & -\frac{k_4+\theta_5}{M\ell} \end{bmatrix}$$

(15a)

$$BM - B_m = B_c(\theta) - B_m$$

$$= \begin{bmatrix} 0 \\ 0 \\ \frac{\theta_1}{M} \\ -\frac{\theta_1}{M\ell} \end{bmatrix} - \begin{bmatrix} 0 \\ 0 \\ \frac{1}{M} \\ -\frac{1}{M\ell} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \frac{\theta_1 - 1}{M} \\ -\frac{\theta_1 - 1}{M\ell} \end{bmatrix}$$

(15b)

$$\begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ \frac{u_c\theta_1 - u_c}{M} & \frac{x_1k_1 - x_1\theta_2}{M} & \frac{x_2k_2 - x_2\theta_3}{M} & \frac{x_3k_3 - x_3\theta_4}{M} & \frac{x_4k_4 - x_4\theta_5}{M} \\ \frac{-u_c\theta_1 + u_c}{M\ell} & \frac{-x_1k_1 + x_1\theta_2}{M\ell} & \frac{-x_2k_2 + x_2\theta_3}{M\ell} & \frac{-x_3k_3 + x_3\theta_4}{M\ell} & \frac{-x_4k_4 - x_4\theta_5}{M\ell} \end{bmatrix}$$

(16)

$$\begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ u_c & -x_1 & -x_2 & -x_3 & -x_4 \\ -u_c & x_1 & x_2 & x_3 & x_4 \end{bmatrix} \begin{bmatrix} \theta_1 - \mathring{\theta}_1 \\ \theta_2 - \mathring{\theta}_2 \\ \theta_3 - \mathring{\theta}_3 \\ \theta_4 - \mathring{\theta}_4 \\ \theta_5 - \mathring{\theta}_5 \end{bmatrix} + \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ \frac{-u_c}{M} & \frac{x_1k_1}{M} & \frac{x_2k_2}{M} & \frac{x_3k_3}{M} & \frac{x_4k_4}{M} \\ \frac{u_c}{M\ell} & \frac{-x_1k_1}{M\ell} & \frac{-x_2k_2}{M\ell} & \frac{-x_3k_3}{M\ell} & \frac{-x_4k_4}{M\ell} \end{bmatrix}$$

(17)

By augmenting both equations above then equation (16) is obtained. By splitting the equation above and changing vector θ with vectors **($\theta - \theta^0$), where θ^0** is convergent value from **θ** then equation (17) is obtained. Or in following form:

$$\Psi\left(\theta - \mathring{\theta}\right) + \Psi_a$$

(18)

Furthermore error derivative equation from (5) has been modified into:

$$\frac{de}{dt} = A_m e + \Psi\left(\theta - \mathring{\theta}\right) + \Psi_a$$

(19)

And by decreasing Lyapunov function candidate (6) and it derivative (7), then from control parameter adaptation rule equation (9), equation (20) is obtained. Right arm of equation (17) will be eliminated because it doesn't contain control parameter.

Matrix P is definite positive matrix obtained as in (8). So adaptive fuzzy rule in control parameters are shown in equation (21). It is clear in (21) there is no longer control parameter. So control rule is not depending on control parameters.

$$\frac{d\theta}{dt} = -\gamma\,\Psi^T Pe = -\gamma \begin{bmatrix} 0 & 0 & u_c & -u_c \\ 0 & 0 & -x_1 & x_1 \\ 0 & 0 & -x_2 & x_2 \\ 0 & 0 & -x_3 & x_3 \\ 0 & 0 & -x_4 & x_4 \end{bmatrix} \begin{bmatrix} p_1 & p_5 & p_8 & p_{10} \\ p_5 & p_2 & p_6 & p_9 \\ p_8 & p_6 & p_3 & p_7 \\ p_{10} & p_9 & p_7 & p_4 \end{bmatrix} \begin{bmatrix} e \\ e \\ e \\ e \end{bmatrix}$$

(20)

$$\frac{d\theta}{dt} = -\gamma \begin{bmatrix} u_c(p_8-p_{10}) & u_c(p_6-p_9) & u_c(p_3-p_7) & u_c(p_7-p_4) \\ -x_1(p_8-p_{10}) & -x_1(p_6-p_9) & -x_1(p_3-p_7) & -x_1(p_7-p_4) \\ -x_2(p_8-p_{10}) & -x_2(p_6-p_9) & -x_2(p_3-p_7) & -x_2(p_7-p_4) \\ -x_3(p_8-p_{10}) & -x_3(p_6-p_9) & -x_3(p_3-p_7) & -x_3(p_7-p_4) \\ -x_4(p_8-p_{10}) & -x_4(p_6-p_9) & -x_4(p_3-p_7) & -x_4(p_7-p_4) \end{bmatrix}$$

(21)

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \\ \dot{x}_4 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & -\frac{mg}{M} & 0 & 0 \\ 0 & \frac{(M+m)g}{M\ell} & 0 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \frac{1}{M} \\ -\frac{1}{M\ell} \end{bmatrix} Mu_c - \begin{bmatrix} 0 \\ 0 \\ \frac{1}{M} \\ -\frac{1}{M\ell} \end{bmatrix} L \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix}$$

(21a)

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \\ \dot{x}_4 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & -\frac{mg}{M} & 0 & 0 \\ 0 & \frac{(M+m)g}{M\ell} & 0 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \frac{1}{M} \\ -\frac{1}{M\ell} \end{bmatrix} \theta_1 u_c - \begin{bmatrix} 0 \\ 0 \\ \frac{1}{M} \\ -\frac{1}{M\ell} \end{bmatrix} \begin{bmatrix} \theta_2 & \theta_3 & \theta_4 & \theta_5 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix}$$

(21b)

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \\ \dot{x}_4 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & \frac{mg}{M} & 0 & 0 \\ 0 & \frac{(M+m)g}{M\ell} & 0 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \frac{1}{M}\theta_1 u_c \\ -\frac{1}{M\ell}\theta_1 u_c \end{bmatrix} - \begin{bmatrix} 0 \\ 0 \\ \frac{1}{M}(\theta_2 x_1 + \theta_3 x_2 + \theta_4 x_3 + \theta_5 x_4) \\ -\frac{1}{M\ell}(\theta_2 x_1 + \theta_3 x_2 + \theta_4 x_3 + \theta_5 x_4) \end{bmatrix}$$

(21c)

V. STATE VARIABLE INTEGRATED MODEL AND CONTROL PARAMETER

Of the result above, then if we concern control system in general and "in linear, then basically there are three main block of the system that contain variable that can be considered as state variable. First is state space model block from reference model as stated in equation (2b). Second, linearized control block as shown in equation (2a) where u in (2a) is substituted by u in equation (3), hence equation (21a,b, c) is obtained. It is clear that the equation is non linear state equation by assumption that perimeters θ_1, θ_2, θ_3, θ_4, and θ_5 are state variables.

By assuming control parameters of θ_1, θ_2, θ_3, θ_4, and θ_5 are state variables, then (20) is also non linear equation where e = x –xm. Hence by integrating linear models surrounding original point (except for points $x_1^0=d$, and $x_{m1}^0=d_m$) and points $\theta_1^0=q_1$, $\theta_2^0=q_2$, $\theta_3^0=q_3$, $\theta_4^0=q_4$, and $\theta_5^0=q_5$ from equations (2b), (20) and (21c), then integrated linear state equation model is obtained from all control systems as shown in equation (22a-b).

Points $x_1^0=d$, and $x_{m1}^0=d_m$ selected as exception outside original point because basically the pendulum can stable along the hoist crane shift position movement. While for control parameters, basically the parameters are not always moving toward point 0 in steady state but it can move toward specific values.

State space equation model (22a) is very unique model. In the matrix there are changing parameters that is equilibrium points of d_1, d_{m1}, q_1, q_2, q_3, q_4, and q_5 that can be changed. However, if the system has been working then the equilibrium values have limited value along the stabilizing system. It is the uniqueness of the matrix. Fuzzy sliding mode control system stability is depending on equilibrium points value, and equilibrium values will be in bounded area along the stable control system.

Other part that influences fuzzy sliding mode control system stability is vector K elements (k_1, k_2, k_3 and k_4) and matrix P elements (p_3, p_4, p_6, p_7, p_8, p_9 and p_{10}). Matrix P elements are depending on vector K elements, and vector K is parameter formed from effort to stabilize non stable linear model from hoist crane movement control by pole placement technique. And this vector influences form of reference model being selected. So in other words control system stability is very depending on reference model to be selected. In this research various reference model have been tried and not all reference model forms can ensure fuzzy inference control system stability.

Stability analysis based on equation model (22) is not discussed in detail in this research. Here we have more focus on reference model fuzzy inference control rule design and control strategy effectiveness that have been designed is sowhn through simulation as discussed in following chapter.

VI. Simulation Result

Reference model adaptive fuzzy control system designing result based on Lyapunov theory is shown in figure 3 to 9. Simulation result shows RMAFC effectiveness to control hoist crane movement non linear controller. Simulation is performed by applying periodic command signal in control system input part. The periodic command signal functions to excite control parameters to move in optimum points.

Figure 3 and 4 are simulation result for state variable and control parameter for cases where parameter values M = 1 kg, m = 0,1 kg, g = 9,8m/$s^2$and l = 1 m. Simulation is performed by selecting constant γ = 6 and sling angle initial value x2 (0) = 0,1 rad. In simulation it is clear that all control state variables can be moved toward stable equilibrium point. It is shown that in figure 3 all state variables move toward original point. While in figure 4, all control system parameters move in bounded area. It is in parallel with as discussed in chapter V previously.

Adaptive Fuzzy Control still can control non linear controller well for cases where parameter values are changed: M = 1kg, m = 0,3 kg, g = 9.8 m/sec^2, amd ℓ=0.5m. Simulation is performed by selecting constant γ =4 and hoist crane movement pendulum angle initial value x2(0) = 0,1 rad. Figures 5 and 6 show simulation result for state variables and control parameters. Once more the state variables can move into original point and control parameters move on bounded area and finally toward specific steady states.

Figures 7, 8 and 9 are simulation results other than hoist crane parameter value M = 1 kg, m = 0,3 kg, g = 9,8 m/sec^2 and ℓ=1.2m. This simulation also provides satisfied result. Command signal period in this simulation is minimized (figure 9 above). Figure 9 in lower part is control signal resulted by fuzzy inference controller. It is clear that control signal works with amplitude and frequency greater in first work of control system.

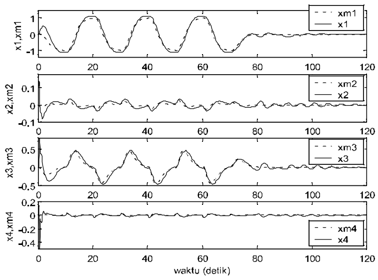

Fig-5, Variable Condition to M=1kg, m=0.3kg g=9.8 m/sec^2, ℓ= 0.5 m. γ =4. $x_2(0)$=0.1rad

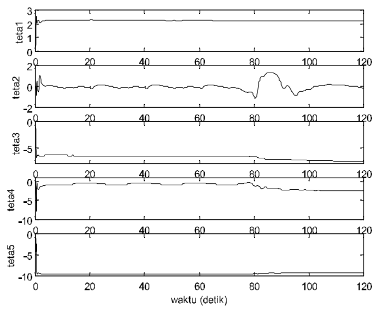

Fig-6, Control Parametre to M=1kg, m=0.3kg, g=9.8m/sec^2, ℓ=0.5m. γ=4. $x_2(0)$=0.1rad.

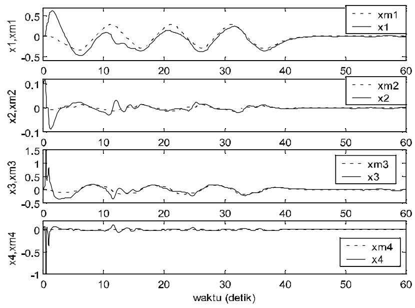

Fig-7, Variable Condition to M=1kg, m=0.3kg, g=9.8m/sec^2, ℓ=1.2m. γ=6. $x_2(0)$=0.1rad.

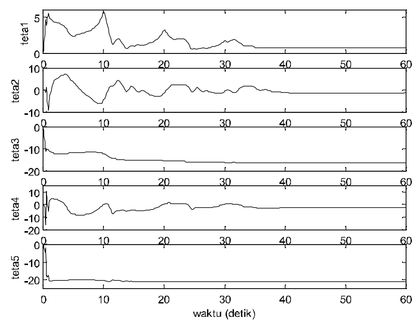

Fig-8, Control Parametre to M=1kg, m=0.3kg, g=9.8m/sec^2, ℓ=1.2m. γ=6. $x_2(0)$=0.1rad.

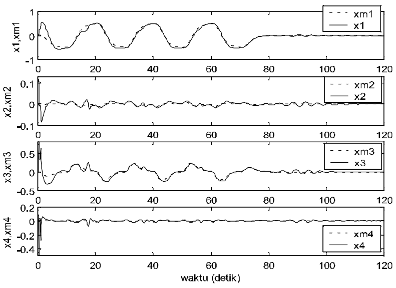

Fig-3, Variable Condition to M=1kg, m=0.1kg, g=9.8 m/sec^2, ℓ=1m. γ=6. $x_2(0)$=0.1rad

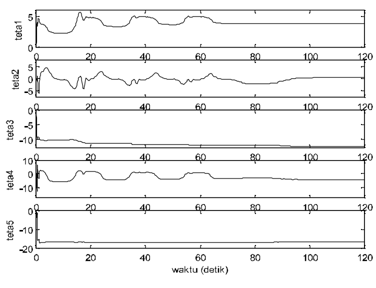

Fig-4, Control Parametre to M=1kg, m=0.1kg, g = 9.8m/sec^2, ℓ=1m. γ=6. $x_2(0)$=0.1rad.

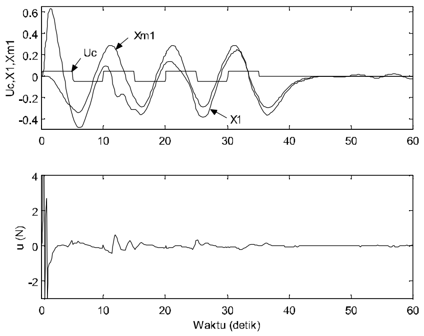

Fig-9, Toward Signal u_C, x_1 and x_{m1} (atas), and control signal u (low) to M=1kg, m=0.3kg, g=9.8m/sec^2, ℓ=1.2m. γ=6. $x_2(0)$=0.1rad

VII. Close

7.1. Conclusion

This Reference is not to Hoist Crane movement, So this reference to conveyor system movement .

Reference model adaptive fuzzy control system designed using Lyapunov theory based on control linearization are able to stabilize hoist crane movement non linear control in better way even for case where control parameter values are uncertain (parameter uncertainty) or change over time (time varying).

Convergence speed of algorithm adaptive fuzzy Control is depending on adaptive fuzzy velocity constant. The greater constant γ value is, the faster control system into stable equilibrium point. However the value selection should be as wise as possible because greater γ value tend to decrease the reference model adaptive fuzzy control system stability level.

Main contribution of this paper is providing new approach line to design reference model adaptive fuzzy control system for non linear control. Approach to be used is selecting linear reference model from non linear model linearization result and stabilizing it by pole placement technique if the linear model is not stable. Next step the control strategy is designed using Lyapunov theory.

7.2. Further Research

This research can be developed to gain more analytic information concerning with control system stability limit. In addition, further research that reaches fuzzy inference control rule realization as obtained into electronic tools and to apply it in real plant is very interesting work to do.

Fuzzy inference control system implementation into FSMM chip has been performed. FPGA is chip that consists of tens to hundred thousands logic gates that can be programmed into specific application using hardware description language (HDL). Designing is performed by hardware-software co-design approach. That is controller hardware is designed with HDL, while control algorithm is written into Assembly language or C language. The controller series consist of main controller block (CSP – control system processor) and control parameter adaptation algorithm. Selective research result will be tried in maglev-levitation system.

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