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A FUZZY LOGIC CONTROLLER FOR THE OPERATION OF AN OVERHEAD CRANE CONTROL PROBLEM

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Abstract - *Three-dimensional overhead crane is an extremely complicated operation with uncertain system parameters. The crane system is used for carrying payloads in industrial factories. Modern overhead cranes are operated in high speed for increase productivity. Three actuators are used in the system for trolley motion, bridge motion and cable length variation. Due to these motion, the control problem like cargo swing and cart motion instability will occurs, which cause inaccurate motion of crane mechanism leads to dangerous situation in operation zone. To eliminate the control problem, PID controller and Fuzzy logic controller are implemented in to the system. By comparing the output performance of the fuzzy logic controller shows the better performance when compared with PID controller. So, the fuzzy logic controller is proposed for the control operation of overhead crane system.*

Key Words: Overhead Crane, Lagrangian Approach, PID controller, Fuzzy logic controller, 3D Visualization

1.INTRODUCTION

Overhead crane are extensively used for lifting and carrying payloads in industrial factories Modern overhead cranes are usually operated at high speed to increase productivity. The fast motion of cranes without controls leads to large cargo swings, which cause inaccurate motions of crane mechanisms and lead to dangerous situations in operation zones.

Several papers that applied various types of control techniques have been published. Lee proposed a Lyapunov based controller comprising feed forward and non-linear PID control components, also designed motion planning scheme for two dimensional motion cranes and three dimensional crane system that are effective in high speed payload lifting. Sakawa and Sawodny proposed a linear control law by pole placement method. Giua promote a state feedback controller and an observer based on the parameter varying linear crane model. Sakawa promoted a optimal algorithm to minimize payload swing and track trolley.Gami studied an optimized nonlinear feedback controller that satisfies specified boundary conditions and functional constraints. Wang designed an optimal asymptotic linear quadratic controller with fixed gains during payload mass variation.

An adaptive controller for a three dimensional overhead crane proposed by yang hau. Omar, Giua and Corriga applied the gain scheduling approach to control tower and gantry crane.

Sliding mode control is a robust technique extensively applied in nonlinear system. Ngo proposes a payload sliding mode controller for container crane anti-swing.

To eliminate the control problem in the 3D crane system, proposes two types of controllers PID controller and Fuzzy logic controller. In the 3D crane system the cable length will varied for easy in system stability.
By comparing the output performance of the 3D overhead crane system, fuzzy logic controller posses better performance than other type of controllers.

2. SYSTEM DYNAMICS

The physical model of a three dimensional overhead crane can be represented as,

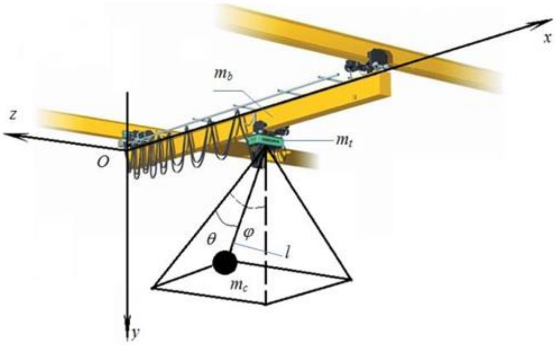

Fig. 1: Physical modeling of overhead crane

The crane system consist of four masses : trolley mass (m_t), bridge mass (m_b), equivalent mass of all rotating components of hoist (m_l) and cargo mass (m_c). The equivalent masses of trolley, hoist and cargo are represented as m_t, m_t and m_c. The system involves five degree of freedom corresponding to five generalized co-ordinates. *x(t)* for trolley displacement, *z(t)* for bridge motion, *l(t)*, *q(t)* and *j(t)* are the three generalized co-ordinates that determines cargo position. The inner friction of wipe rope is considered a linear damping element b_r, The frictions of trolley and bridge motions are characterized by b_t and b_b. The control signal ut, ub and ul denote the driving forces of trolley translation, bridge translation and cargo hoist translational motion.

3. SYSTEM MODELLING

In system modeling Euler-Lagrange formulation is considered in characterizing the dynamic behaviour of the crane system. To derive the dynamic equation of the system, the total energy associated with the crane system needs to be computed using Lagrangian approach.

The Euler equation can be written as,

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_k}\right)-\left(\frac{\partial L}{\partial q_k}\right)=Q_k \quad (1)$$

The Lagrangian approach can be defined as, the difference between kinetic energy and potential energy of the plant.

$$L=KE-PE \quad (2)$$

$$L=\frac{1}{2}\begin{pmatrix} m_t+m_b \\ +m_c \end{pmatrix}\dot{z}^2+\frac{1}{2}\begin{pmatrix} m_t+ \\ m_c \end{pmatrix}\dot{x}^2+\frac{1}{2}(m_c)\dot{l}^2 +\frac{1}{2}(m_c l^2\cos^2\theta)\dot{\phi}^2+\frac{1}{2}(m_c l^2)\dot{\theta}^2 +m_c\begin{pmatrix} \sin\phi\cos\theta\dot{l}+l\cos\phi\cos\theta\dot{\phi} \\ -l\sin\phi\sin\theta\dot{\theta} \end{pmatrix}\dot{z}+m_c\begin{pmatrix} \sin\theta\dot{l}+ \\ l\cos\theta\dot{\theta} \end{pmatrix}\dot{x} \quad (3)$$

To find Q_k in eq.(1), consider the general expression,

$$Q_k=\frac{\delta\omega}{\delta q_k} \quad (4)$$

In eq.(1) and (4)k varies as $[z \quad x \quad l \quad \phi \quad \theta]$, so the derived eq.(4) can be written in 5 different equations.

$$Q_z=f_z-b_b\dot{z}-f_{rz}-d_f\dot{x}_l \quad (5)$$

$$Q_x=f_x-b_t\dot{x}-f_{rx}-d_f\dot{y}_l \quad (6)$$

$$Q_l=f_l-d_l\dot{l}+m_c g\cos\phi\cos\theta-d_f\dot{x}_l\sin\phi\cos\theta -d_f\dot{y}_l\sin\theta+d_f\dot{z}_l\cos\phi\cos\theta \quad (7)$$

$$Q_\phi=-m_c gl\cos\theta\sin\phi-d_f\dot{x}_l l\cos\phi\cos\theta -d_f\dot{z}_l l\cos\theta\sin\phi \quad (8)$$

$$Q_\theta=-m_c gl\cos\phi\sin\theta+d_f\dot{x}_l l\sin\phi\sin\theta -d_f\dot{y}_l l\cos\theta-d_f\dot{z}_l l\cos\phi\sin\theta \quad (9)$$

By substituting the equation (3) in LHS of equation (1) and substituting equation (5), (6), (7), (8) and (9) in RHS of eq.(1), The five degree of equation of nonlinear dynamics of the crane system can be written as,

$$\begin{pmatrix} (m_t+m_b+m_c)\ddot{z}+m_c\sin\varphi\cos\theta\ddot{l}+m_c l\cos\varphi\cos\theta\ddot{\varphi} \\ -m_c l\sin\varphi\sin\theta\ddot{\theta}+b_b\dot{z}+2m_c\cos\varphi\cos\theta\dot{l}\dot{\varphi} \\ -2m_c\sin\varphi\sin\theta\dot{l}\dot{\theta}-2m_c l\cos\varphi\sin\theta\dot{\varphi}\dot{\theta} \\ -m_c\sin\varphi\cos\theta\dot{\varphi}^2-m_c l\sin\varphi\cos\theta\dot{\theta}^2 \end{pmatrix}=u_b \quad (10)$$

$$\begin{pmatrix} (m_t+m_c)\ddot{x}+m_c\sin\theta\ddot{l}+m_c l\cos\theta\ddot{\theta} \\ +b_t\dot{x}+2m_c\cos\theta\dot{l}\dot{\theta}-m_c l\sin\theta\dot{\theta}^2 \end{pmatrix}=u_t \quad (11)$$

$$\begin{pmatrix} (m_l+m_c)\ddot{l}+m_c\sin\theta\ddot{x}+m_c\sin\varphi\cos\theta\ddot{z} \\ +b_r\dot{l}-m_c l\dot{\theta}^2-m_c l\cos^2\theta\dot{\varphi}^2-m_c g\cos\varphi\cos\theta \end{pmatrix}=u_l \quad (12)$$

$$\begin{pmatrix} m_c l\cos\varphi\cos\theta\ddot{z}+m_c l^2\cos^2\theta\ddot{\varphi} \\ +2m_c l\cos^2\theta\dot{l}\dot{\varphi}-2m_c l^2\cos\theta\sin\theta\dot{\varphi}\dot{\theta}+m_c gl\sin\varphi\cos\theta \end{pmatrix}=0 \quad (13)$$

$$\begin{pmatrix} m_c l\cos\theta\ddot{x}-m_c l\sin\varphi\sin\theta\ddot{z}+m_c l^2\ddot{\theta} \\ +2m_c l\dot{l}\dot{\theta}+m_c l^2\cos\theta\sin\theta\dot{\varphi}^2+m_c gl\cos\varphi\sin\theta \end{pmatrix}=0 \quad (14)$$

By using the differential equation (10), (11), (12), (13) and (14), the crane system can be modeled.

4. CONTROLLER SCHEME DESIGN

A PID controller and Fuzzy logic controller are proposed to the system. The selection of controller is depends upon the better output performance of the system.

4.1 PID Controller

The first proposed controller is PID controller to move the trolley and the bridge from their initial positions to their destinations as fast as possible, to reduce cargo vibration during transfer, and to eliminate cargo swing at the trolley and bridge destinations.

In the PID controller tuning method, auto tuning method approach is to be achieved. By auto tuning the K_p, K_i and K_d will be 0.358, 0.572 and 0.746. By the use of PID controller, the elimination of control problem will be achieved.

4.2 Fuzzy Logic Controller

The Fuzzy Logic controller is one of the proposed controllers. Fuzzy control is a control method on fuzzy logic.

Input values of a fuzzy controller are positions of cart and payload in the direction z, x and l (y) – axis and angle φ and θ. The input set of positions deviations consists of five membership functions: negative large, target – desired position, near, medium and large – positive distance. The membership function for deviation in x and φ can be represented as,

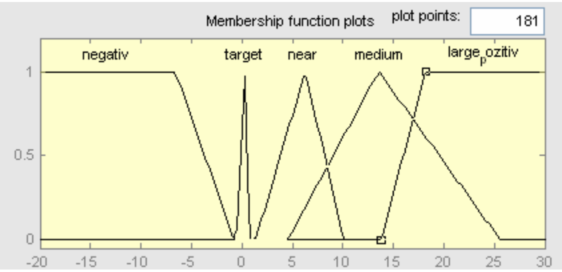

Fig.2 : Membership functions for deviation in x and φ,

The position of the payload is described by z and θ. The membership function: negative big, negative little, target, positive medium and positive large can be represented as,

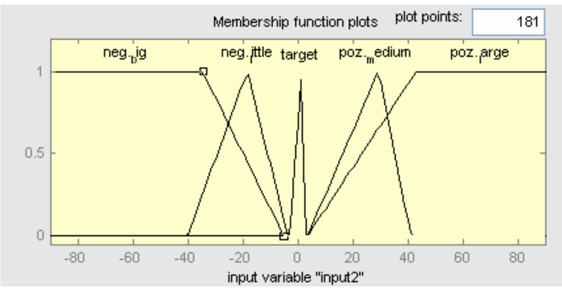

Fig.3 : Membership functions for deviation in z and θ.

An output value from fuzzy controller is voltage and is defined as a linguistic variable as follows: negative big, negative medium, target, positive medium and positive big.

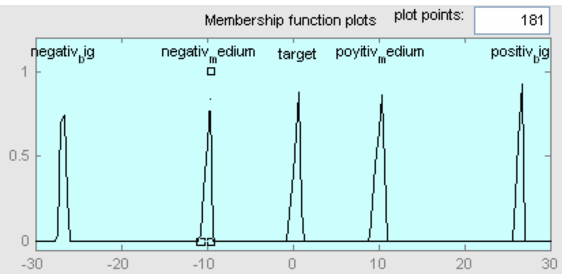

Fig.4 : Output functions from powers of DC motors

The fuzzy logic control is based on six rules, where the first input is distance, the second one is angles position and outputs are powers of DC motors:

The fuzzy logic control is based on six rules, where the first input is distance, the second one is angles position and outputs are powers of the DC motors:

1. If (input1 is negative) and (input2 is target) then (output1 is positive_medium),
2. If (input1 is large_positive) and (input2 is neg._little) then (output1 is positive_big),
3. If (input1 is medium) and (input2 is neg._little) then (output1 is negative_ medium),
4. If (input1 is medium) and (input2 is neg._little) then (output1 is positive_ medium),
5. If (input1 is near) and (input2 is target) then (output1 is positive_medium),
6. If (input1 is target) and (input2 is target) then (output1 is target).

5. SIMULATION& 3D VISUALIZATION

The first step is to evaluate the control problem and selection of controller with respect to the better output performance response.

5.1 Simulation

In this simulation study, the crane plant parameters are set as, Ra=2.6, La=0.012, B==1e-1, Kt=1e-2, Kv=3e-2, Kg=1e-3, J=0.1, m_head=100, Gamma=10 and g=9.806. The initial position of the cart position is x(0).

The major purpose of the simulation is to find the better output performance in the controllers of PID controller and Fuzzy logic controller, and verify the robustness of the system by using the method and its effectiveness for different move distances.

Here, 3 stages of operation will take place, the stages can be written as follows,

1. z - Directional motion and corresponding swing angle φ will operates without cargo load. Other parameters are in rest.
2. z and x – Directional motion and corresponding swing angle φ and θ will operate with cargo load. Here, displacement of cargo load from current position to desired position will takes place.
3. z and x – Directional motion and corresponding swing angle φ and θ will operate without cargo load. Here, the crane set in the initial position.

5.1.1 PID Controller

By using PID controller, the output performance response of the five degree of motion overhead crane system can be represented as,

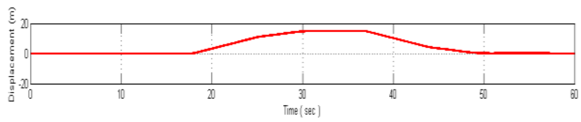

Fig.5 : Control operation in x-direction

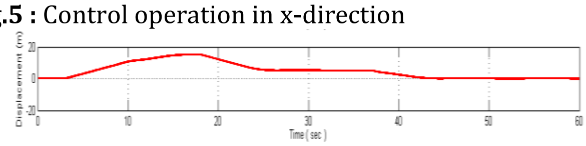

Fig.6 : Control operation in z-direction

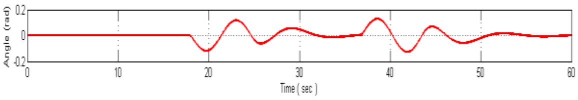

Fig.7 : Controlled swing angle θ

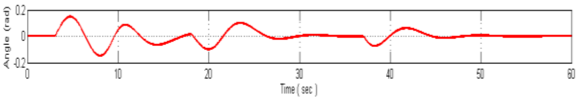

Fig.8 : Controlled swing angle φ

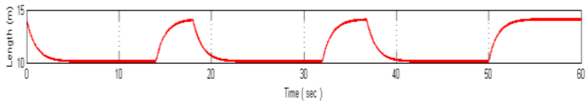

Fig.9 : Controlled hoist motion

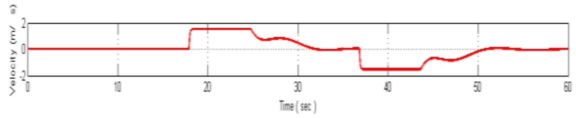

Fig.10 : Velocity in x-direction

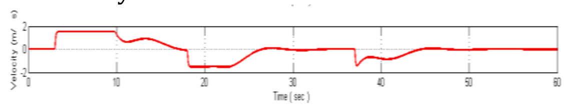

Fig.11 : Velocity in z-direction

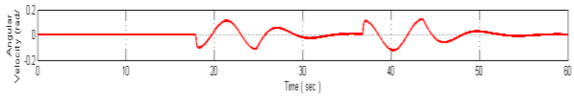

Fig.12 : Cargo swing velocity $\dot{\theta}$

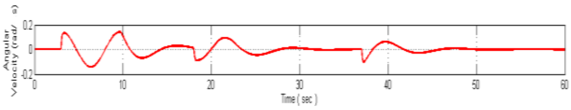

Fig.13 : Cargo swing velocity $\dot{\varphi}$

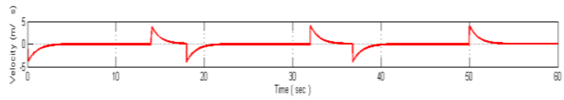

Fig.14 : cargo hoisting velocity

5.1.2 Fuzzy Logic Controller

By using the fuzzy logic controller, the output performance response of the five degree of motion overhead crane system can be represented as,

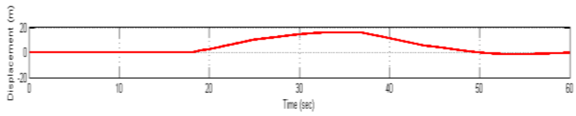

Fig.15 : Control operation in x-direction

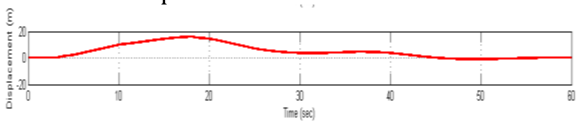

Fig.16 : Control operation in z-direction

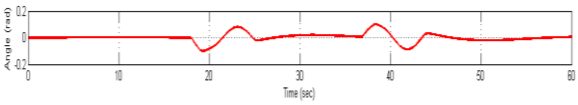

Fig.17 : Controlled swing angle θ

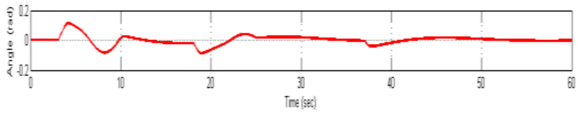

Fig.18 : Controlled swing angle φ

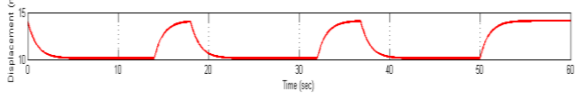

Fig.19 : Controlled hoist motion

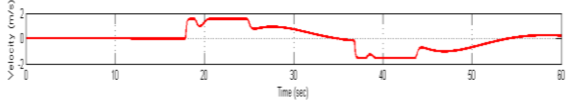

Fig.20 : Velocity in x-direction

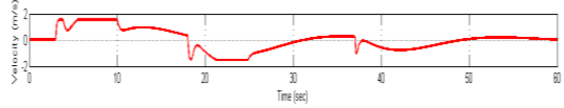

Fig.21 : Velocity in z-direction

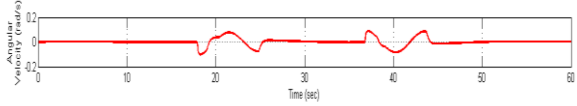

Fig.22 : Cargo swing velocity $\dot{\theta}$

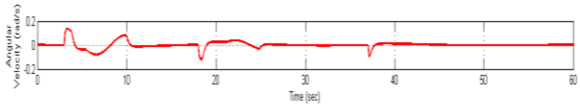

Fig.23 : Cargo swing velocity $\dot{\varphi}$

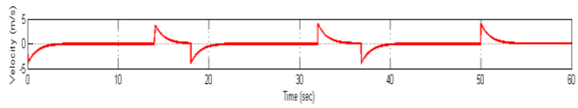

Fig.24 : cargo hoisting velocity

5.2 3D Visualization

The 3D visualization is the best way of communication of the operating overhead crane system. The three dimensional diagram is designed by using the vrealm software, this software is attached with MATLAB.

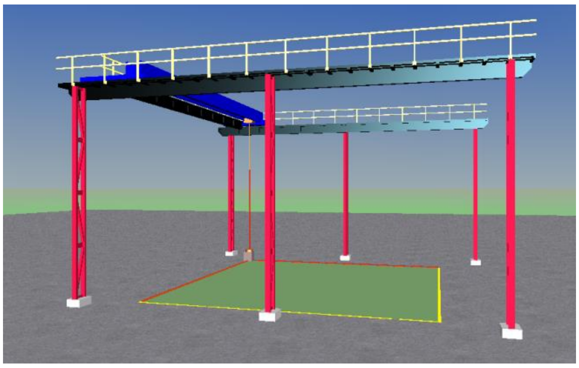

Fig.25 : 3D view of overhead crane

The designed model is attached to the VR sink block in the simulink and selects the required ports for the movement of the crane. Connect the VR sink block to the modeled system.

While run the simulink model, the 3D operation will be executed. So, the system output performance can be clearly identified.

5.3 COMPARISION

By comparing the performance of the controller in 3 stages of operation,

1. Stage – 1

Controller	Swing Angle	Rise Time	Peak Time	Settiling Time	Peak Overshoot
PID	φ	-	-	-	-
	θ	-	4.7s	16s	0.19
Fuzzy	φ	-	-	-	-
	θ	-	4.4s	11.5s	0.16

2. Stage – 2

Controller	Swing Angle	Rise Time	Peak Time	Settiling Time	Peak Overshoot
PID	φ	-	23.2s	32.4s	0.18
	θ	-	23.5s	27.8s	0.18
Fuzzy	φ	-	19.8s	27.5s	0.149
	θ	-	18.8s	25.3s	0.145

3. Stage – 3

Controller	Swing Angle	Rise Time	Peak Time	Settiling Time	Peak Overshoot
PID	φ	-	38.8s	49.4s	0.185
	θ	-	41.7s	45.3s	0.143
Fuzzy	φ	-	38.4s	46.5s	0.165
	θ	-	37.9s	44.9s	0.136

6. CONCLUSION

In this work, proposed three types of controllers, PID controller and fuzzy logic controller. Here, want to use a better performance controller for the control problem elimination. By comparing the output response of the controller from the simulation results, better output response will generated by the fuzzy logic controller. The fuzzy logic controller was improved the performance in a complicated operation in which cargo lifting, trolley motion and bridge motion by comparing with other controllers. Here, the control problems of the system like swing angle elimination and system stability will be achieved.

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