Control of Jib Model Using Pid And Lqr Optimization

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Abstract – Crane is widely used in heavy loads transportation and hazardous material handling in industry to lift loads from one place to another. The transporting movement of heavy paylod causing n unwanted motion to the payload due to accelaraton and deceleration of crane trolley. To reduce these problems, a conventional Proportional-Integral-Derivative (PID) is proposed with Linear-Quadratic-Regulator (LQR) optimization enable the transfer the loads from one point to another as fast as possible and reducing the excessive movements to dissolve absolutely at the end of the load delivered point. In this method, LQR elements are used to generate and tune the PID controller gains according to the parameters given and desired specifications. Simulations are performed to demonstate the effectiveness of the proposed control scheme using MATLAB/SIMULINK software . The simulation results show that the designed controller is effective for load swing suppression and reduction of the excessive movements of the cart.

Nomenclature :

g	Gravitational acceleration constant	m/s^2
J_ψ	Jib motor equivalent moment of inertia	$kg.^{m2}$
$K_{t,j}$	Jib motor torque constant	N.m/A
l_p	Vertical distance of payload from jib arm	M
m_p	Mass of payload	kg
$m_{trolley}$	Mass of trolley	kg
$r_{j,\,pulley}$	Radius of trolley pulley from pivot to end of tooth	m

INTRODUCTION

A crane is a machine for lifting and lowering a load and moving it horizontally, with the hoisting mechanism an integral part of the machine. Cranes whether fixed or mobile are driven manually or by power. Cranes are widely used in the transportation and construction industry, ranging the application of light duty, small motion lift assistance to multiple ton, large motion payload placement which can be seen in construction operation [1]-[10]. The cranes supposedly transport the loads fastly and safely without involving in any excessive movements that will damage the loads. Figure 1 shows the lab-scale model of 3DOF Crane.

Swing of a payload suspended under a moving object is a problem which is considered in crane systems. During the transfer or when the load receives a disturbance, the load is free to swing in a pendulum-like motion. If the swing exceeds a proper limit, it may damage the load or threaten the life of the rescued person. Therefore, the purpose of this project is to develop a relatively simple controller that able to control the complete operation of jib subsystem without producing excessive movements and causing swinging motions of the payload so that the crane is stable and safer to be operated.

Figure 1: 3 DOF Crane

The remainder of the paper is arranged as follows. Section 3 provides the mathematical modelling of the experimental setup. Control schemes are devised in section 4. In section 5, simulation results are presented to illustrate the effectivess of proposed control schemes.

MODELING OF JIB PLANT

The jib is modeled as a two-dimensional linear gantry by assuming the payload is positioned at a fixed height and the angle is also fixed about the a gimble angle, which is the motion perpendicular to the jib length. Thus, it is assumed the payload only rotates about gimble angleg [11].

The jib is the horizontal member of 3 DOF crane. The trolley is suspended on a linear guide and is fastened to a motorized belt-pulley device. When the current in the DC motor, Im,j, is positive ampere the trolley moves away from the tower and towards the end of the jib and this is defined as positive velocity. Thus the position of the trolley, xj, increases positively as it goes towards the right of the freebody diagram shown in Figure 2.

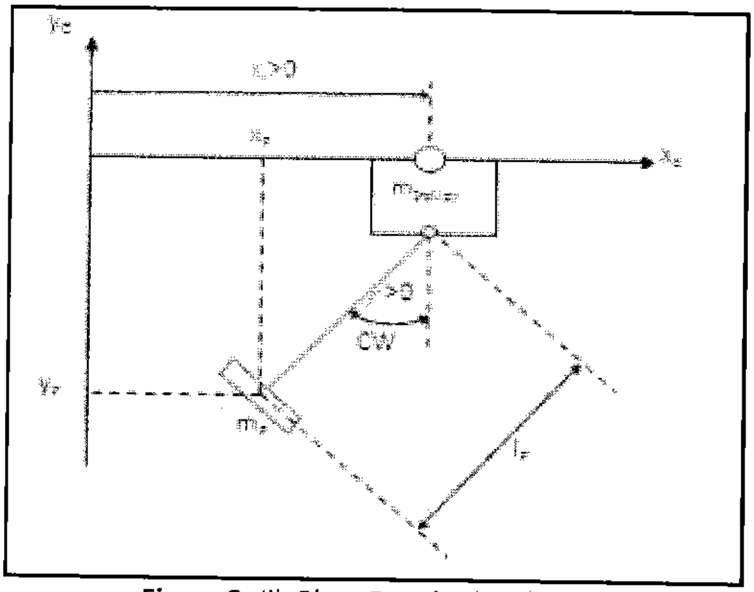

Figure 2: Jib Plant Free-body Diagram

The payload is connected to the trolley with a steel cable. Assuming the cable remains rigid, the payload is modeled as a suspended pendulum. As illustrated in Figure 2, when the trolley goes positive towards the right the pendulum angle , turns clockwise. This is defined as positive rotational velocity. From the Figure 2, the position of the payload's center of mass with the respect to the Cartesian coordinates system is [11]

$$x_p = x_j(t) - l_p \sin(\gamma(t)) \tag{1}$$

and

$$y_p = -l_p \cos(\gamma(t)) \tag{2}$$

The system is model as a cart with a suspended pendulum such as linear gantry plant. The Lagrange method is used to find the nonlinear dynamics of the system. The non-linear system equations are also linearized and represented in the state space format. When ignoring the rotational kinetic energy from the pendulum, the linear statespace system of the 3 DOF crane Jib system: [6]

$$\frac{\delta}{\delta t} x = Ax + Bu \tag{3}$$

$$y = Cx + Du \tag{4}$$

Where the x transpose:

$$x^T = \left[x_j(t), \gamma(t), \frac{d}{dt} x(t), \frac{d}{dt} \gamma(t) \right] \tag{5}$$

And the produce state space is

$$
A=\begin{bmatrix}
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1 \\
0 & \dfrac{m_p r_{j,pulley}^{2} g}{m_{trolley} r_{j,pulley}^{2} + J_{\psi} K_{g,j}^{2}} & 0 & 0 \\
0 & -\dfrac{g\left(m_{trolley} r_{j,pulley}^{2} + m_p r_{j,pulley}^{2} + J_{\psi} K_{g,j}^{2}\right)}{l_p\left(m_{trolley} r_{j,pulley}^{2} + J_{\psi} K_{g,j}^{2}\right)} & 0 & 0
\end{bmatrix} \qquad (6)
$$

$$
B=\begin{bmatrix}
0 \\
0 \\
\dfrac{r_{j,pulley}\eta_{g,j}K_{g,j}\eta_{m,j}K_{t,j}}{m_{trolley} r_{j,pulley}^{2} + J_{\psi} K_{g,j}^{2}} \\
\dfrac{r_{j,pulley}\eta_{g,j}K_{g,j}\eta_{m,j}K_{t,j}}{l_p\left(m_{trolley} r_{j,pulley}^{2} + J_{\psi} K_{g,j}^{2}\right)}
\end{bmatrix} \qquad (7)
$$

$$
C=\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix} \qquad (8)
$$

$$
D=\begin{bmatrix} 0 \\ 0 \end{bmatrix} \qquad (9)
$$

PID AND LQR OPTIMIZATION DESIGN

The structure of proposed controller for 3DOF Crane system is shown in the Figure 3 which is consists of PID controllers for both of position and anti-swing control respectively. The PID is designed into the crane plant for completed closed loop system.

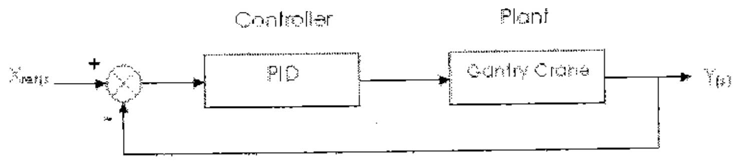

Figure 3: Block Diagram of 3DOF Crane Controller System Using PID

The continuous PID controller design is shown in Figure 4. The feedback loop used to control the position of the trolley while dampening the motions of the payload. A proportional-integral-derivative (PID) compensator is used to regulate the trolley position. The PID control gains are calculated by the full-state-feedback Linear Quadratic Regulator (LQR).

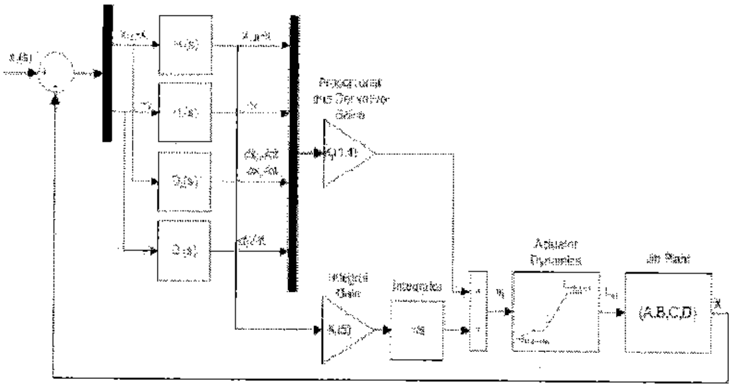

Figure 4: Closed-loop Feedback PID Control

The structure of designed controller for 3DOF Crane system consists of PID controllers for controlling both of position and anti-swing control respectively. The PID controller is controlled by three types of gains that can be classified as PD and PI controller gains. These tuning algorithms will measure the level of the ideal response from the desired design requirements. Linear Quadratic Regulator (LQR) was chosen to optimize the gain value for optimum performance, because of interdependency of controllers when used together. LQR system provides at least a phase margin of 60 degree and a gain margin of infinity by using robust LQR design method for determining controller. The purpose of this controller is to minimize the error signal from the input to output. In order to design a LQR controller for optimization of PID gains values, a linear state-space model of the Jib subsystem was obtained by linearising the mequations of motions of jib and the cart. Augment the jib system state in as follows: [5]

$$\zeta^T = \left[x_j(t), \gamma(t), \frac{d}{dt}x_j(t), \frac{d}{dt}\gamma(t), \int x_j(t)dt \right] \quad (10)$$

to include a cart position integrator. Next, using the control law:

$$u_j = K_j\zeta \quad (11)$$

The LQR method is used to minimize the cost function:

$$J = \int_0^\infty x(t)^T Qx(t) + u_j(t)^T Ru_{j(t)} dt \quad (12)$$

Where Q and R are weighting matrices and given that Q and R as:

$$Q = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (13)$$

and $R = 0.1$ (15)

However as previously mentioned, there are only two measured states in the jib system - the linear trolley position and the pendulum angular position. Therefore, the actual implemented controller is of the form

$$u_j = -K_j \zeta_{j,e}^{\ T} \qquad (16)$$

Where the estimated error state:

$$\zeta_{j,e}^{\ T} = \begin{bmatrix} x_{j,f}(t) - x_{j,df}(t), \gamma_f(t), \\ \left(\frac{d}{dt}x_{j,df}(t)\right) - \left(\frac{d}{dt}x_{j,df}(t)\right), \\ \frac{d}{dt}\gamma_j(t), \int x_{j,f}(t) - x_{j,df}(t)dt \end{bmatrix} \qquad (17)$$

Figure 5 below shows the closed loop PID controller block diagram that has the feedback loop which used to control the position of the trolley while dampening the motion of the payload. This control system will control both the trolley position and pendulum angle. The system consists of set point block, jib control system block, jib model block, jib observer block, and the scopes block set.

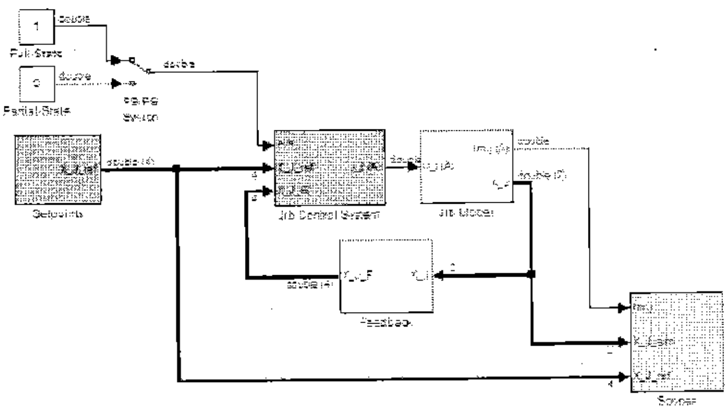

Figure 5: Jib Systems with LQR Controller

The jib control system block consists of proportionalderivative-integral (PID) compensator that used to regulate the trolley position. By assuming the system used the fullstate feedback, the linear-quadratic-regulator algorithm (LQR) is used to calculate the PID control gains.

SIMULATIONS RESULT

In simulation, the parameters of the linear state space used are according to the nomenclature sections. All the results will be demonstrated below. The system performance without controller showed in Figure 6 and Figure 7, it illustrates that the jib system is unstable.

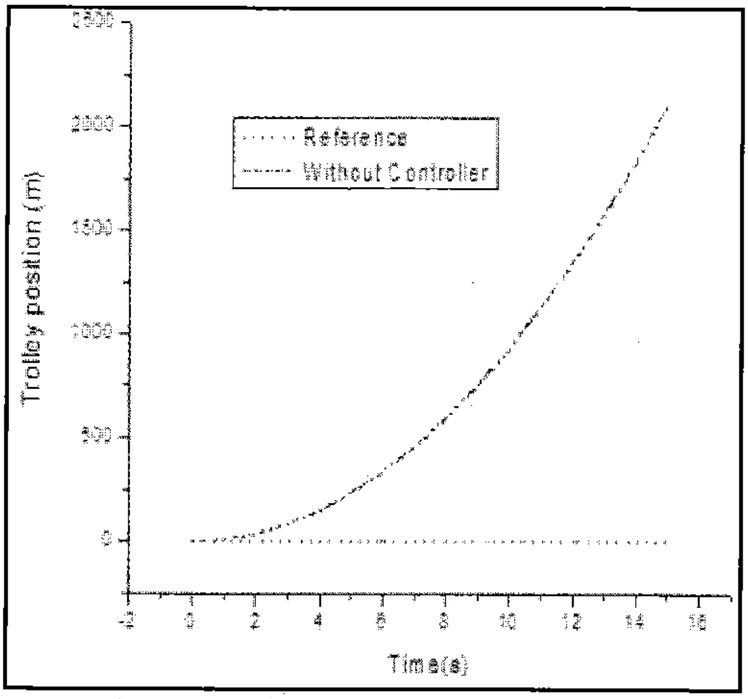

Figure 6: Trolley Position without Controller

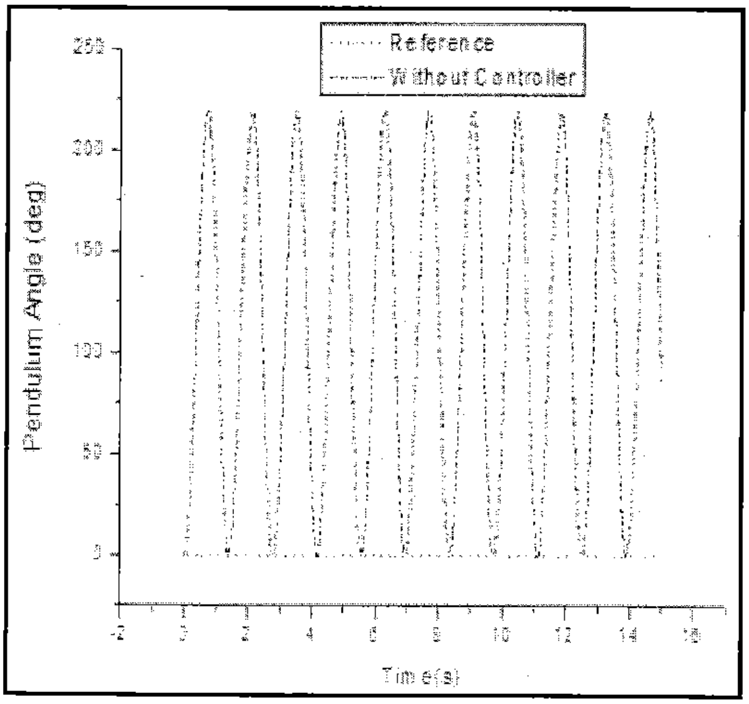

Figure 7: Pendulum Angle without Controller

A. System Performance with LQR Controller

The simulation is done with a closed loop PID controller which used to control the position of the trolley while dampening the motion of the payload is shown in Figure 8 and Figure 9 below.

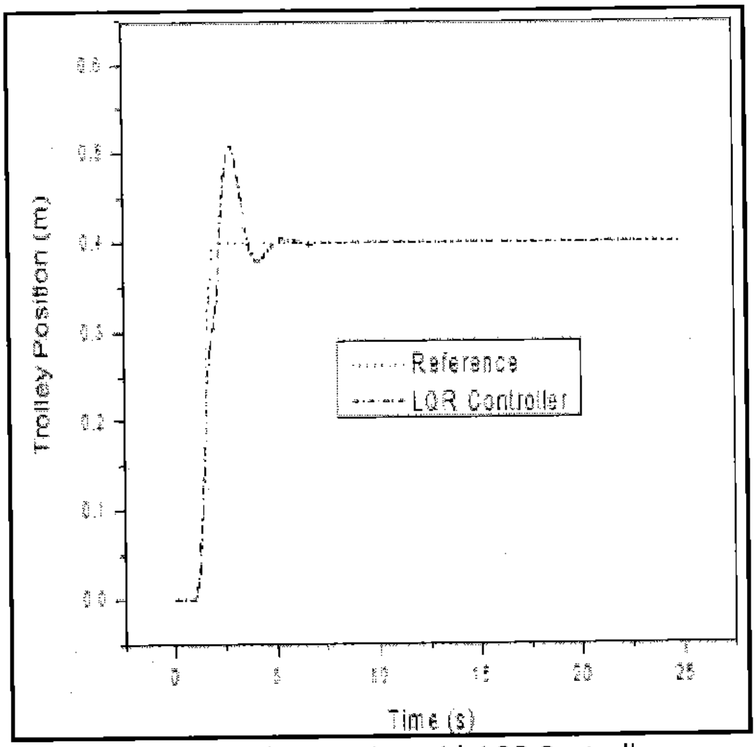

Figure 8: Trolley Position with LQR Controller

Figure 8 shows the simulated result for positioning control. The performance of PID control. The result shows about 27.4087% of overshoot, very fast rise time and settling time. That means the trolley have injected with higher current and speeding in very fast motion in controlling the trolley movement. At 4.711sec, the trolley displacement was achieved the desired position (0.4m) and at this condition, there no current was supplied to the motor and make the trolley freeze.

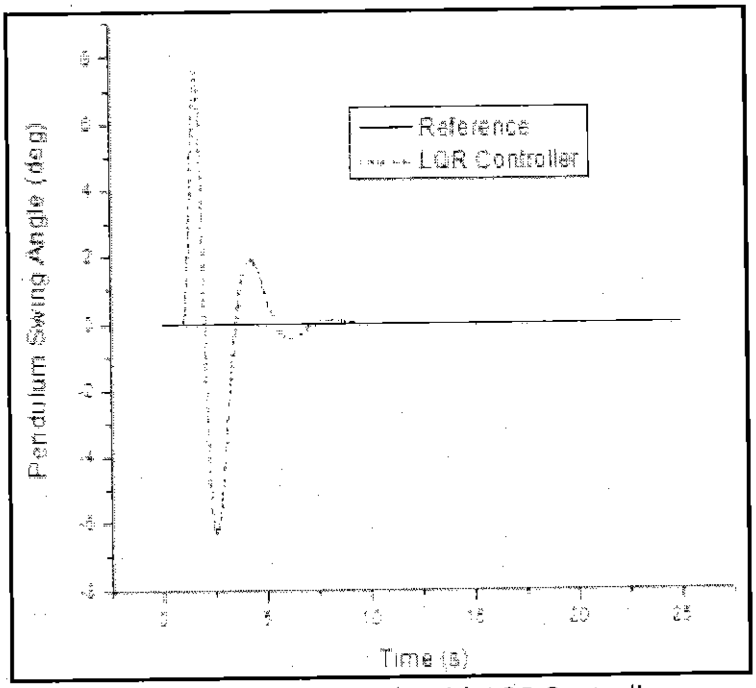

Figure 9: Pendulum Angle with LQR Controller

Figure 9 shows the simulated result for swing angle control performance of PID control. The result shows the maximum angle is about 7.7745 deg and the minimum angle is -6.261 deg. The pendulum is stopped from swinging at 15.13 sec.

CONCLUSION

We have presented our simulation investigtion of PID controller using LQR optimization. We demonstrated that the proposed control scheme able to reduce and give minimum swing angle and settling time. Optimal control tuning, (LQR) is the best way to tuning the proportional, integral and derivative of PID gains until the ideal response is produced [12] thus minimizing time while using the heuristic /classical method for PID controller of obtaining the best gain value. [13]

ACKNOWLEDGEMENT

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