Anti-swing Control Strategy Design of Container Crane Based on Fuzzy-Logic and LQR-PID Controller

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Abstract. With the development of world business and trade, effective anti-swing control strategy is vital to realize the automation of loading/unloading in ports. Based on the dynamic analysis of trolley movement, mathematical model of trolley motion system is established first. Then, a fuzzy control strategy combined with LQR-PID controller is proposed to decrease the swing of container crane. Finally, experiments were carried on based on the B&R trolley control system. The results show the validity of proposed control strategy.

Introduction

With the development of world business and trade, in order to promote the loading and unloading efficiency of container crane, it is very important to decrease the swing of container and spreader [1]. Electric anti-swing, as an active method, does not rely on the experience of the operator, but take the control of both anti-swing and movement of the trolley into account.

The process of loading/unloading with container crane is complicated and nonlinear. And there would be some affection of stochastic factors (e.g. wind) in ports. It is very difficult to control the anti-swing system by means of conventional control methods. Till now, several work has been taken to apply fuzzy logic in anti-swing control [2-4]. To get the best performance of anti-swing control system, it is effective to propose a new control strategy combined conventional methods with intelligent algorithm.

Mathematical Model of Container Crane Anti-swing System

During the container crane movement process, crane mainly has two degrees of freedom of movement: horizontal movement back and forth in the land and the sea side. The lifting direction will lift the container or down. The container is grasped by spreader, and joint between the sling and the trolley is through multiple sets of wire. In motion process, the spreader would produce swing, and natural attenuation would last for a long time, and seriously affect the efficiency and safety of cargo handling, so it leads to the anti-swing demand.

To establish the mathematical model of container crane, we made the following hypothesis:

(1) Under the condition of small angle swing, the crane and the load are connected by rigid connection;

(2) Ignoring friction and air resistance;

(3) Crane movement is limited to a single degree of freedom in the X direction;

(4) The length of the rope is unchanged under the state of motion.

Schematic diagram of anti-sway car system is as shown in Figure 1. The symbols in Figure 1mean:M stands for mass of trolley, m for mass of load, l for the length of rod, F for the traction force, T_d for the time constant, K for the Amplification factor.
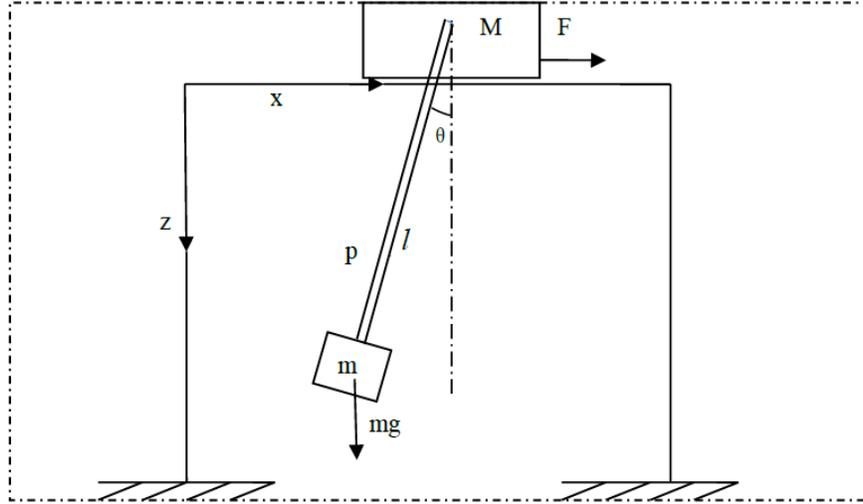
Figure 1. Schematic diagram of anti-sway car system.

According Newton second law, the mathematical model of container crane anti-swing system can be described by the following state space expression:

$$\dot{x} = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & -\dfrac{mg}{M} & 0 & \dfrac{1}{M} \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & -\dfrac{(M+m)g}{Ml} & 0 & \dfrac{1}{Ml} \\ 0 & 0 & 0 & 0 & -\dfrac{1}{T_d} \end{bmatrix} x + \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ \dfrac{K}{T_d} \end{bmatrix} u$$

$$y = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \end{bmatrix} x$$

Fuzzy-Logic and LQR-PID Based Container Crane Control Strategy

The anti-sway control system can be divided into two processes, namely, acceleration process and deceleration brake process. During the two processes, different control methods are adopted.

Acceleration Process

In this process, the speed of the trolley is taken as the control variable, the actual position of the trolley Position and the load swing angle Theta are used as the state variables, and the fuzzy-logic control algorithm is used to realize the optimal configuration of the speed VELOCITY and angle Theta. The control system block diagram is shown in Figure 2.

Fuzzy logic is widely used in machine control. The term "fuzzy" refers to the fact that the logic involved can deal with concepts that cannot be expressed as the "true" or "false" but rather as "partially true". Although alternative approaches such as genetic algorithms and neural networks can perform just as well as fuzzy logic in many cases, fuzzy logic has the advantage that the solution to the problem can be cast in terms that human operators can understand, so that their experience can be used in the design of the controller. This makes it easier to mechanize tasks that are already successfully performed by humans [5].
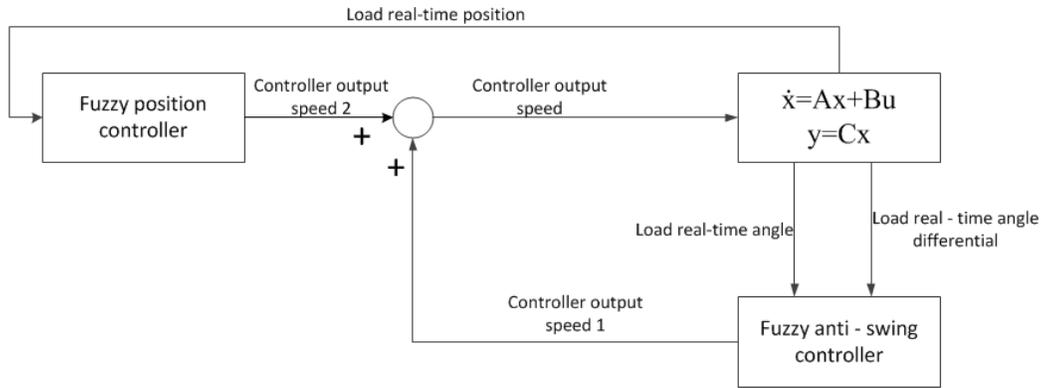
Figure 2. Fuzzy-Logic control block diagram during acceleration process.

Deceleration Process

This process is coordinated by LQR and PID controller. The car PID controller to the target position as a reference volume for 1 control variables, the car at a predetermined target point accurately stop; LQR controller to load swing angle as the input variables Theta 2, obtained 2 control variables, the rapid elimination of load swing. Two the controller makes the system reach the stable state quickly. The block diagram of the control system is shown in Figure 3, which can realize the optimal configuration of speed VELOCITY, position and angle Theta.

The LQR is an important part of the solution to the LQG (linear–quadratic–Gaussian) problem. The LQR algorithm reduces the amount of work done by the control systems engineer to optimize the controller. However, the engineer still needs to specify the cost function parameters, and compare the results with the specified design goals. Often this means that controller construction will be an iterative process in which the engineer judges the "optimal" controllers produced through simulation and then adjusts the parameters to produce a controller more consistent with design goals.
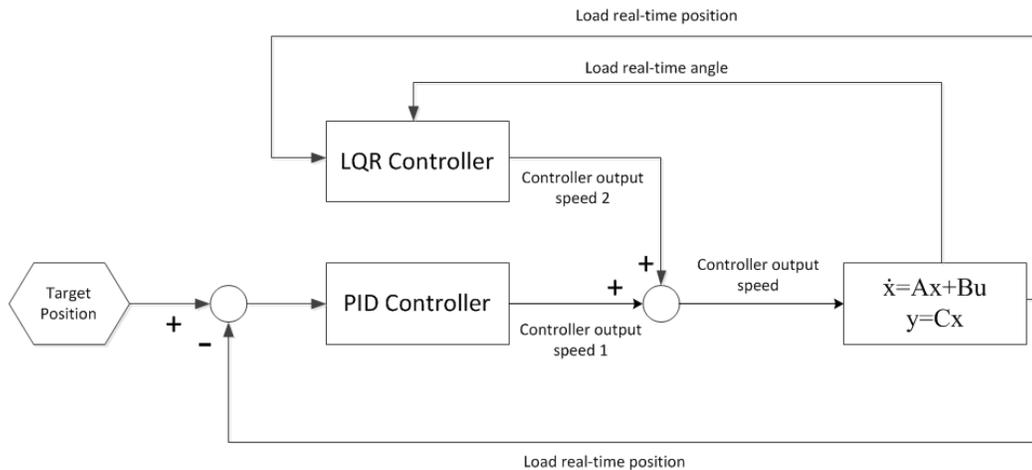

Figure 3. LQR-PID control block diagram during deceleration process.

Experimental Results and Analysis

In order to verify the validity of proposed control strategy, experiments were carried on based on the B&R trolley control system. After the testing to the experiment system, system parameters, such mass of trolley and load, the length of rod, were obtained. And the mathematical model of the experimental system is as follows:

$$\dot{x} = \begin{bmatrix} 0 & 1.0000 & 0 & 0 & 0 \\ 0 & 0 & -3.3000 & 0 & 3.3000 \\ 0 & 0 & 0 & 1.0000 & 0 \\ 0 & 0 & 102.5641 & 0 & 25.6410 \\ 0 & 0 & 0 & 0 & -1.0000 \end{bmatrix} x + \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 1 \end{bmatrix} u$$

$$y = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \end{bmatrix} x$$

After a number of parameters adjustment, considering the different effects of the movement time and the pendulum angle on the actual work, we get the results as shown in Figure 4:

Figure 4. Control performance using proposed strategy.

It is seen from Figure 4 that, the trolley system can accurately stop at the desired destination stability and small error.

Summary

A fuzzy control strategy combined with LQR-PID controller is proposed to solve the anti-swing problem of container crane in ports. Based on the mathematical model of trolley motion system, fuzzy-logic controller and LQR-PID controller are respectively adopted to control the anti-swing during the acceleration and deceleration process of trolley motion, which together constitute the control strategy. Finally, experiments carried on based on the B&R trolley control system show the validity of proposed control strategy.

Acknowledgement

References

[1] K. Huang, J.Q. Zheng and X. Li. Electronic anti-sway technology and its development of container crane[J]. Hoisting and Conveying Machinery. 12(2006)5-8.

[2] Nally M, Trabia M B. Control of Overhead Cranes Using a Fuzzy Logic Controller. Journal of Intelligent and Fuzzy Systems, 2000, 8 (1):7-18.

[3] Mahfouf M, Kee C H, Abbod M F, Linkens D A. Fuzzy Logic-Based Anti-Sway Control Design for Overhead cranes. Neural Computing & Applications, 2000 (9):38-43.

[4] Ho-Hoon Lee, Sung-Kun Cho. A new fuzzy logic anti-swing control for industrial three-dimensional overhead crane. Proc. of the 2001 IEEE International Conference on Robotics and Automation, 2001, 3, 2956-2961.

[5] Pedrycz, Witold (1993). Fuzzy control and fuzzy systems (2 ed.). Research Studies Press Ltd.

[6] Kwakernaak, Huibert & Sivan, Raphael (1972). Linear Optimal Control Systems. First Edition. Wiley-Interscience. ISBN 0-471-51110-2.