Anti-sway and Position Control of Crane System

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Abstract: We developed a new crane control system that has an accurate position control function with anti-sway of the hung object. The control system consists of two blocks. One is for anti-sway control, and the other is for position control. Each output of the control blocks is calculated individually based on a proposed method and serves as a velocity reference for a trolley of the crane. The anti-sway control we realized was based on the simple impedance control method. The position control is carried out by following the pattern that is calculated so that the trolley stops smoothly at the predetermined standstill position. We confirmed the effect of this controller through experiments.

I . INTRODUCTION

Hoist cranes are widely used in material handling, and in the trend toward rationalized physical distribution featuring greater efficiency, labor-saving, and unmanned operation, they are expected to play a role as a constituent element in everything from conventional single systems to total physical distribution systems. Thus anti-sway and position control technology has become a requirement as a core technology for automated crane systems that are capable of flexible spatial automatic conveyance. Various control methods for anti-sway and position control have been proposed, such as status feedback and fuzzy control. Such systems must harmonize the operation of stopping at the desired position with the operation of controlling sway, requiring the adjustment of the parameters and membership function to achieve the desired precision.

To avoid these requirements, it was decided to consider position control and anti-sway control separately, as illustrated in Figure 1. This leads to a system having the following characteristics, which understood by those in charge of design and testing coordination and are easy to apply to actual equipment:

(1) The composition of the control system is simple and easy to understand.
(2) It is easy to make adjustments.
(3) Position control and the anti-sway function can be applied independently.

In Figure 1, both the output of the position controller and the output of the anti-sway controller are treated as velocity instructions for the trolley. The system is adjusted so that in position control the trolley is in the desired position, and so that to prevent swaying, the velocity response of the load with respect to changes in the velocity of the trolley is not oscillatory. In a crane, the position and sway angle interfere with each other: if the velocity of the trolley is varied to control the position, swaying arises, and if the trolley is moved so as to stop its swaying, positional error arises. While avoiding such interference, we have been able to adjust only the position control-related parameters so as to realize the goals of this system, namely:

(1) It stops at the desired position with the sway kept to no more than the permissible value.
(2) It takes as little time as possible to make the transition from travel at a constant velocity to standstill.
(3) The number of parameters to adjust is reduced.

The study described in this paper was made under the following conditions.

(1) Although actually it applies to a two-dimensional system, the method is considered one-dimensionally.
(2) The hoisting and lowering velocity is made small enough that differentiation of the wire length is negligible.
(3) The controller outputs trolley velocity instructions, and ideal velocity control of the trolley is achieved.

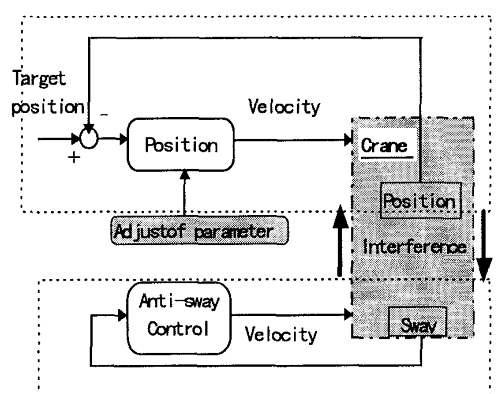

Figure 1. System configuration of automated crane.

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Ⅱ. SYSTEM CONFIGURATION

The configuration of an automatic crane is shown in figure2. The automatic crane tested this time is a scale model 1/10 actual size, and lateral travel, travel, and hoisting is done by a DC motor. The control computation is done with a personal computer, and velocity instructions are output to the motor driver via a digital-to-analog converter. The position of the trolley, length of the wire, and sway angle are detected, and the controller computes the velocity instructions so that the trolley stops at the desired position without swaying. The motor drivers controlle so that the trolley velocity and hoisting velocity keep prescribed value. In the experimental device, the position can be controlled in three dimensions (lateral travel, travel, hoisting) , but this time the basic properties were tested with respect to one dimension (travel).

Ⅲ. CONTROL METHOD

Introducing the equations of motion for a one-dimensional model as shown in figure 3, we have the following.

$$x = X + u \tag{1}$$

$$z = -\sqrt{L^2 - u^2} \tag{2}$$

The equation of motion is expressed as follows from the Lagrangian.

$$\ddot{u} + \ddot{X} - \dot{u}z^{-1}\ddot{z} + 2uz^{-2}\dot{z}^2 + gz^{-1}u = 0 \tag{3}$$

Here, making the sway angle sufficiently small and setting

$$z^{-1} \approx L^{-1}$$

we have

$$M_x\ddot{X} + m\ddot{x} + D\dot{X} = f_x, \tag{4}$$

$$\ddot{u} + \ddot{X} + \frac{g}{L}u = 0, \tag{5}$$

$$\ddot{x} + \frac{g}{L}x = \frac{g}{L}X. \tag{6}$$

Here the wire length is constant and the mass is sufficiently smaller than the load.

As pictured in Figure 4, in the proposed system the controller generates the velocity instruction to control the trolley position, and so that for anti-sway the velocity response of the load with respect to changes in the velocity of the trolley is no longer oscillatory. Here, position control and anti-sway control are coordinated by adjusting

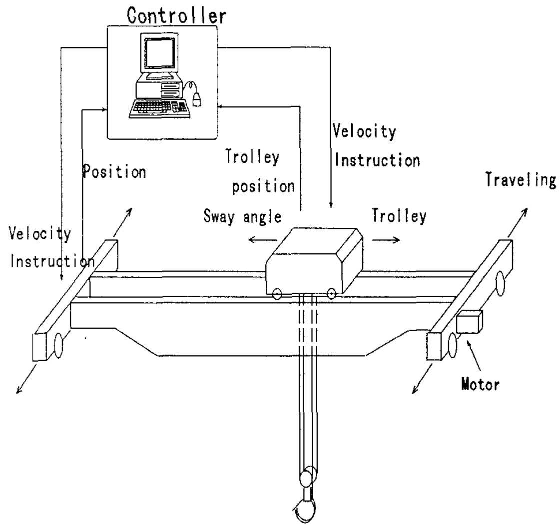


Figure 2. Overview of control system.

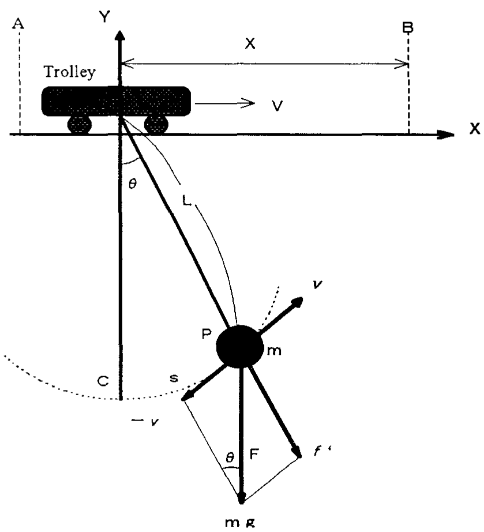


Figure 3. Crane model.

X : Trolley position	V : Trolley Velocity
x : Load position	v : Load Velocity
u : x-X	θ : Sway angle
L : Wire length	m : Load mass

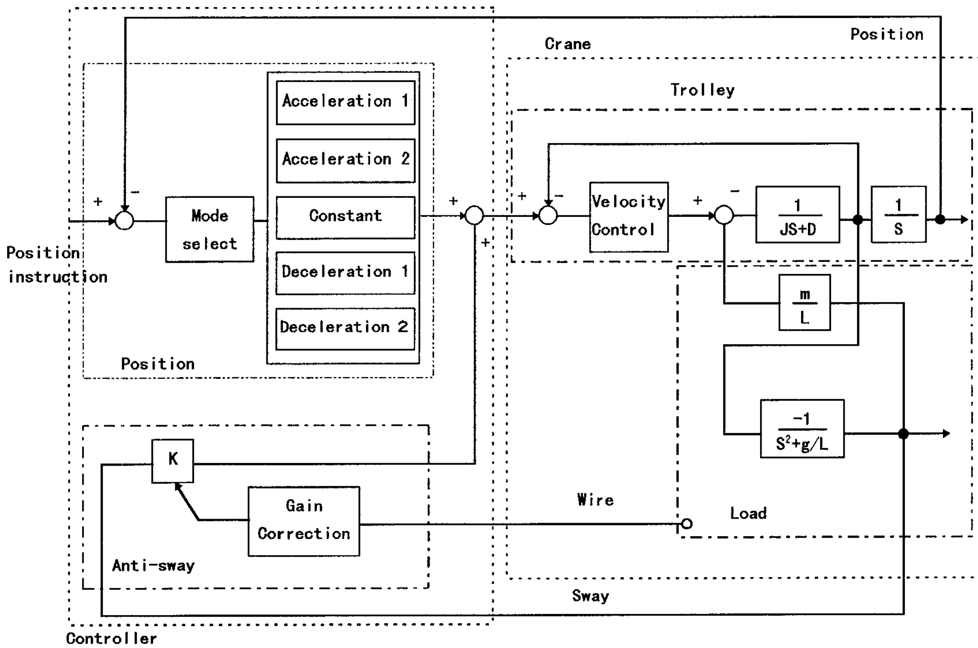


Figure 4 Control Block Diagram.

the values that are constrained by the differential value of the movement acceleration of the trolley.

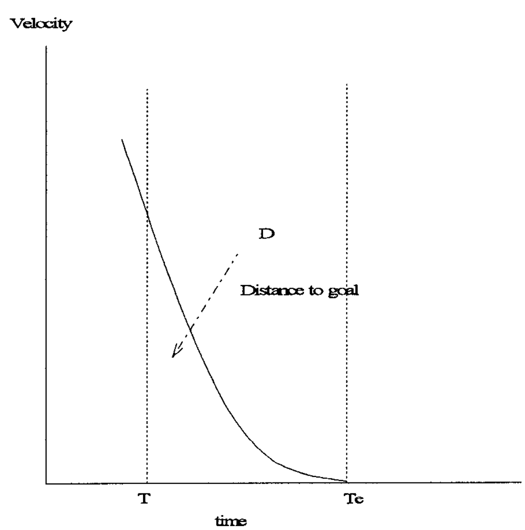


Figure 5 Position control.
(deceleration region 2)

A. Anti-sway control

Assuming anti-sway control is considered independently from the positioning control system, the equation of motion of an one-dimensional crane, simplified by making the sway angle small to approach linearity, is

$$\frac{d^2}{dt^2}u + \frac{g}{L}u = \frac{g}{L}X \,. \tag{7}$$

where u represents the position of the load, L is the length to the center of gravity of the load, and g is the gravitational acceleration.

Expressing the input to this system as the velocity of the crane, we have a following expression.

$$\frac{d^2}{dt^2}v + \frac{g}{L}v = \frac{g}{L}V_{ref} \tag{8}$$

The acceleration response of the load is a two-dimensional transfer function having no damping with respect to the velocity of movement of the trolley. Here the sway is thought of as a change in the velocity of the load, and with respect to the velocity of the load the control system is designed so that the velocity of movement does not become oscillatory, that is, so that the velocity response of the load does not become oscillatory even if there is a sway (a change in the relative position of the load with respect to the drive system). Therefore damping is added by feedback the sway angle to the velocity instructions, and the oscillation is suppressed by ensuring that the response of the velocity of movement of the load with respect to the velocity of movement of the trolley is not oscillatory.

If we set

$$V_{ref} = V - K\frac{d}{dt}v \qquad (9)$$

then we get

$$\frac{d^2}{dt^2}v + \frac{g}{L}K\frac{d}{dt}v + \frac{g}{L}v = \frac{g}{L}V \,. \qquad (10)$$

By setting K to the suitable value, the damping of this system can be increased and the oscillation in the velocity of the load can be suppressed.

To ensure that the damping coefficient is 1, K is set as follows.

$$K = 2\sqrt{\frac{L}{g}} \qquad (11)$$

Because it is often difficult to detect the acceleration of the load, the sway angle of the wire can be used instead of the acceleration from the next relationship.

$$\frac{d}{dt}v = \frac{d^2}{dt^2}u = -\frac{g}{L}u + \frac{g}{L}L_m \approx \frac{g}{L}L\theta = g\theta \qquad (12)$$

$$V_{ref} = V - Kg\theta \qquad (13)$$

θ : sway angle

Also, at this time, the value of L is detected and the feedback gain K is compensated for, ensuring that the system's damping is constant.

B. Positioning Control

Positioning is done with respect to the position of the trolley. In doing so, in order to stop smoothly at the target position, a velocity pattern is generated so that the velocity reaches zero at the target position. That is, we end up with a two-dimensional curve as the velocity instruction. The operational modes are partitioned as follows according to the state of the trolley, and velocity instructions are generated for each. Here we focus on the position and velocity of the trolley and take any operation concerning anti-sway to be a disturbance.

1) Acceleration region 1 $(V < \frac{1}{2}V\,max)$

This interval is from the standstill state to 1/2 of the target velocity (constant travel velocity), and the rate of change of acceleration is accelerated as a constant. Velocity instruction V is generated.

$$V = \frac{1}{2}J \cdot t^2 \qquad (14)$$

where j is the rate of change of acceleration (jerk) and t is the time from start of motion.

2) Acceleration region2 $(\frac{1}{2}V\,max < V < V\,max)$

Until the target velocity is reached, the rate of change of acceleration is kept negative and constant, and the target velocity is reached at the peak of a quadratic curve.

$$V = \frac{1}{2}J(t - 2\cdot T_1)^2 + V\,max \qquad (15)$$

where T_1 is the time from acceleration region 1 to acceleration region 2.

3) Constant-velocity travel region $(L_d < L_m)$

Travel occurs at the target velocity until L_d before the target location.

$$V = V\,max \qquad (16)$$

where

L_m: distance to the target location,

L_d : distance from the start point to the end of the acceleration.

4) Deceleration region 1 $(\frac{1}{2}V\,max < V < V\,max)$

Deceleration takes place at a constant rate of change of acceleration until 1/2 of the target velocity.

$$V = -\frac{1}{2}J(t - T_2)^2 + V\,max \qquad (17)$$

where T_2 is the time from the constant-velocity travel region to deceleration region 1.

5) Deceleration region 2 $(0 < V < \frac{1}{2}V\,max)$

Speed instructions are given by a quadratic curve so that the velocity reaches 0 at the location that is taken as the target. At the target location, the velocity is made so that it reaches the minimum value of the quadratic curve.

Calling the current velocity V_n, rate of change of acceleration J_n, and time until stopping T_d, we have following equations.

$$V_n = \int_{Te}^{t} J_n t dt = \frac{1}{2} J_n T_d^2 \quad (18)$$

$$L_m = \int_{t}^{Te} V_n dt = \frac{1}{6} J_n T_d^3 \quad (19)$$

Then we have

$$T_d = \frac{3 \cdot L_m}{V_n}, \quad (20)$$

$$J_n = \frac{2 \cdot V_n}{T_d^2} = \frac{2 \cdot V_n^3}{9 \cdot L_m^2}. \quad (21)$$

Thus the velocity instruction for next time is calculated by the following formula.

$$V_{n+1} = \frac{1}{2} J_n (T_d - T_s)^2 \quad (22)$$

T_s : sampling time.

IV. EXPERIMENTAL RESULTS

Figure 6 gives the experimental results concerning travel when the trolley is moved to the target location; (a) is for when anti-sway control is performed, and (b) is for when anti-sway is not performed. It is clear from these results that with anti-sway control a smooth stop is possible without swaying. Figure 7 shows the relationship between the trolley velocity and load velocity when movement begins; in order to suppress the deflection, the acceleration of the trolley velocity varies during acceleration, but the velocity of the load increases linearly. Figure 8 shows the experimental results when a disturbance is added after movement begins. Because the load is set swaying during acceleration, the sway angle fluctuates greatly, but with anti-sway control the swaying is effectively stopped, and the trolley stops smoothly at the target position.

The value of the derivative of the acceleration of the motion of the trolley is adjusted in order to coordinate position control and anti-sway. This value is adjusted so that when the stopping position is reached, the deflection is no greater than the target value.

V. CONCLUSIONS

It has been confirmed that with the proposed system the crane can be stopped in the target position while the sway is suppressed. By considering position control and anti-sway separately, the control configuration becomes easy to understand and the design is simple, and since the physical meaning of the adjustment factors is clearly defined, the adjustment policy can be decided upon, test adjustments can be made easily, and this system becomes highly realizable as an actual system.

(1) The crane can move to the target position without swaying.

(2) By prescribing that the velocity response of the load shall not oscillate, it is possible that swaying prevention can be done that fits the natural oscillation of the load and does not overtax the drive system.

(3)By adjusting the feedback gain according to the wire length, swaying can be effectively suppressed in the same way as originally, even if hoisting or lowering is done during operation.

Finally, the stopping precision is improved by determining to offset of the sway angle.

REFERENCES

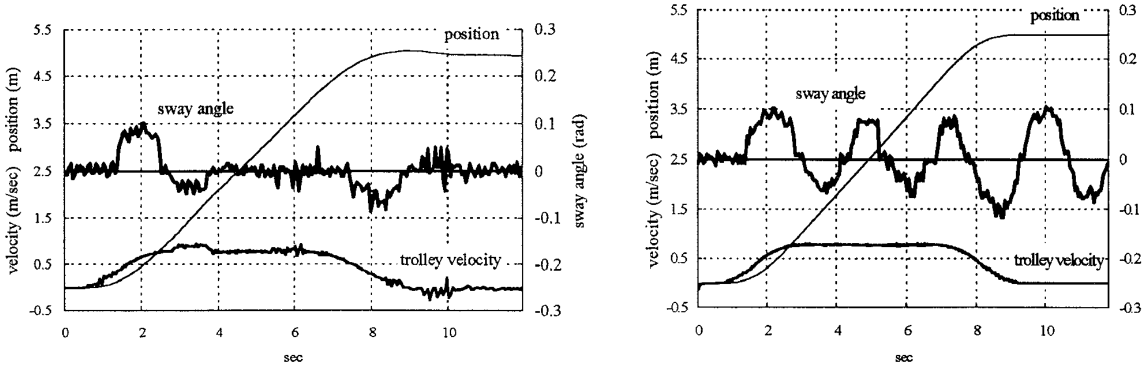
(1) Itoh, Migita, Itoh, Irie: "Application of Fuzzy Logic Control to Automatic Crane Operation", Journal of Japan Society for Fuzzy Theory and Systems,994/4,VOL.16 No2,P172–P181

(2) Murata, Nakajima:" Automatic Control System of Container Crane", Transaction of the Japan Society of Mechanical Engineers (C),Vol.59,No.564,93/8,p137–143

(3) Watanabe, Ichihashi :" Iterative Fuzzy Modeling using Membership Functions of Degree n and its application to a Crane Control", Journal of Japan Society for Fuzzy Theory and Systems, 91/5, VOL.3, No.2, P347~356

(4) Ishide, Uchida, Miyakawa: " Application of a Fuzzy Neural Network in the Automation of Roof Crane System", 9th Fuzzy System Symposium,93/5,P29–32

(5) Shibata, Takeguchi, Tsutsui, Kasahara: "Special Issue on Industrial Control Systems. Anti-sway Control System for Cranes", Yaskawa Technical Review,VOL.57, No.4, P289-297



(a) Experimental result with anti-sway control.

(b) Experimental result without anti-sway control.

Figure 6. Effect of anti-sway control.

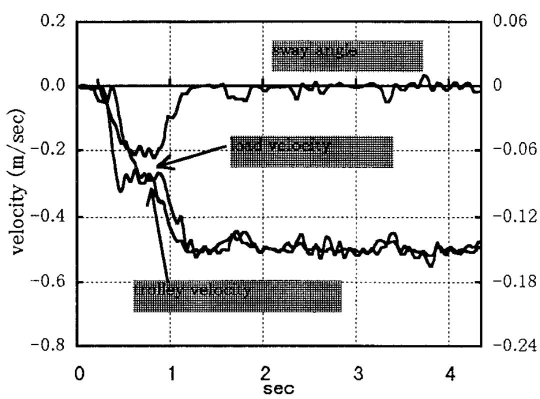


Figure 7. Trolley and load velocity.

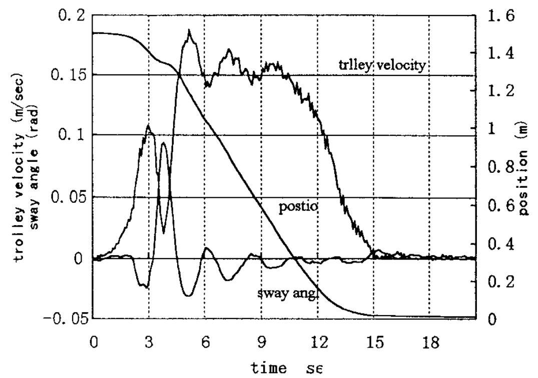


Figure 8. Effect of anti-sway control for disturbance ce.