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Neurocontrol for a Rotary Crane System with Disturbance

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Abstract: In this paper we propose a neurocontroller (NC) for suppression of load swing with disturbance in a crane system rotating around the vertical axis. As in a nonholonomic system, the classical control method using a static continuous state feedback law cannot stabilize the load swing. It is necessary to design a time-varying feedback controller or a discontinuous feedback controller. Previous research had been successful in constructing the suppression controller of the load swing with a single initial rotation angle when disturbance occurred. In this paper, the performance of the NC optimized by genetic algorithm will be examined with three initial rotation angles.

Keyword: rotary crane, genetic algorithm, neurocontroller, disturbance

1 Introduction

Rotary crane systems are generally operated using both the rotation angle and the lean angle in order to suppress a load swing. However, by restricting the motion of the jib to the rotation around the vertical axis alone, the system becomes a nonholonomic system. This results in a complex control problem and it is necessary to design time-varying feedback or discontinuous control methods. When operating this rotary crane system, the most important control purpose is to suppress a load swing on the reference position. Usually, techniques for suppressing the load swing depends on skillful operator's experiences [1]. Therefore, it may be necessary to develop automatic control crane systems.

Many control methods for load swing suppression in a rotary crane system have been presented [1]-[6]. However, most of these control methods require knowledge of difficult control theories [1] - [4]. In contrast, it is easy to apply a neurocontroller which has simple structure and generalization ability as a controller [5], [6]. A neurocontroller optimized by an evolutionary computation technique, such as a genetic algorithm, is substantially simpler to realize than conventional control methods. In this paper, we propose a neurocontroller (NC) optimized by a genetic algorithm(GA). In real environment, the load of the rotary crane system may swing due to disturbance. For example, there are gust of wind and constant wind. Therefore, it is necessary to consider the disturbance. We previously reported that when the rotary crane system starts movement from single initial rotation angle, it is able to use the NC to suppress the load swing to the reference position even if the load swings suddenly [6].

In this paper, we propose the NC which has optimal control performance even if rotary crane systems start movement from several initial rotation angles with disturbance.

2 Model of rotary crane system

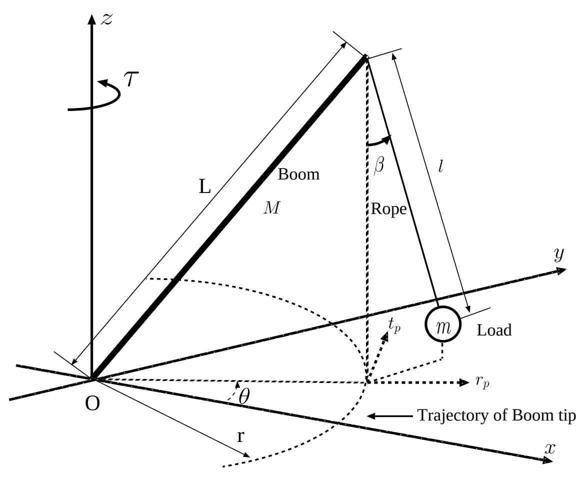

Fig. 1: Rotary crane system

Figure 1 shows the crane system rotating around the z axis. L is the jib arm length, m is the load mass, l is the wire length and r is the radius of rotation. θ is the rotation angle, α is angle of load lead, β is angle of load swing and τ is torque.

If the swing of the load is sufficiently small, we can consider the system in two-dimensional plane.

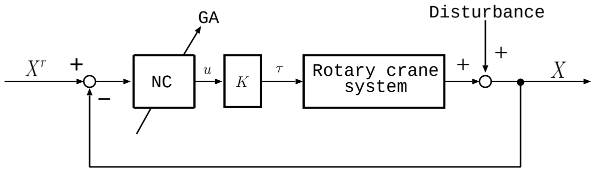

Fig. 2: Control system for rotary crane

Table 1: GA parameters

Parameter	Value/method
Initial parents NCs	100
Initial children NCs	50
Selection method	Ranking selection
Crossover	One-point crossover
Mutation rate	20%
Generation number	20000

Therefore, the dynamics and rotation movement of the system can approximately be described in terms of the following equations (1), (2) and (3)

$$\ddot{x} = \omega^2(r\cos\theta - x) \tag{1}$$

$$\ddot{y} = \omega^2(r\sin\theta - y) \tag{2}$$

$$\ddot{\theta} = Ku \tag{3}$$

where $\omega = \sqrt{g/l}$ is natural angular frequency. K is a constant value including the load mass and moment of inertia.

3 Control system for the rotary crane

3.1 Neurocontrol of the crane system

The control purposes to suppress the load swing movement from initial position (x_0, y_0), which is determined by several initial rotation angles, to the reference position (x^r, y^r) by rotating the jib arm. Figure 2 shows the control system using NC with GA. The state variable X and reference X^r are defined as follows :

$$X = [x, y, \theta, \dot{x}, \dot{y}, \dot{\theta}]^T \tag{4}$$

$$X^r = [x^r, y^r, \theta^r, \dot{x}^r, \dot{y}^r, \dot{\theta}^r]^T \tag{5}$$

The NC consists of three hierarchical layers with 6-12-1 structure. A linear function is used at the input layer and a sigmoid function is used for the hidden and the output layers. The NC receives the position error of the load, the velocity error, the rotation angle error, and the angular velocity error as inputs. And it outputs the control input u. Torque τ is calculated as the product of the control input u and constant value K.

This paper uses a simple GA as an optimization method for the NC. Table 1 shows the parameters of the GA. The performance of the NC is evaluated by a squared error function E which is defined with respect to the final state X^{end} and the reference X^r as following:

$$E = \sum_{p=1}^{P} (X^r - X_p^{end})^T Q (X^r - X_p^{end}) \tag{6}$$

Here, P is the number of initial rotation angles and Q is the unit matrix. In the GA evolutionary process, the connection weights of the NC are modified in order to minimize the error function E in Eq. (6)

3.2 Setting of disturbance condition

In general, the load of the system swings due to disturbance which is a gust of wind and a constant wind. In this paper, we assume the disturbance to be a gust of wind and we propose the NC which has optimal control performance even if the load swings suddenly. The disturbance is as follows: After t_{dis} second, the load position (x, y) suddenly moves to position $(x + \Delta x, y + \Delta y)$. The distance of disturbance Δx, Δy are determined by random numbers. Table 2 shows the parameters of the disturbance range and the times when it occurs.

Table 2: Parameters of disturbance

Parameters	Value
t_{dis} [s]	1.0 , 2.0 , 3.0 , 4.0
$(\Delta x, \Delta y)$ [m]	(0.05 , 0.05)

Table 3: Parameters and initial condition

Parameter	Value
Load mass : m [kg]	0.5
Rotation radius : r [m]	1.0
Length of wire : l [m]	2.0
Reference : X^r	(1,0,0,0,0,0)
Coefficient : K	5.0
Control time : T[s]	10.0
Initial rotation angle : θ_0 [deg]	90,120,150

4 Simulation results

Table 3 shows the parameters of the crane system and the initial conditions. The performance of the NC optimized by GA is verified using computer simulations. Runge-Kutta method is used for the system dynamic model, and sampling interval is 0.01 [s]. When the initial rotation angles are $\theta_0 = 90, 120, 150$ [deg], the evolutionary processes providing the best NCs are shown in Figure 3. Here, the position (x, y) of the load suddenly moves to $(x + \Delta x, y + \Delta y)$ at $t_{dis} = 1, 2, 3, 4$ [s]. The error function E decreases gradually until generation 20000. The result demonstrates that the GA evolutionary processes of the NCs is successful. Figure 5 shows the trajectory of the load mass in the $x - y$ plane and the movement of the rotary angle using the optimized NC with initial angles $\theta_0 = 120$ [deg], $t_{dis} = 3$ [s]. After t_{dis} second, the load is suddenly moved by disturbance, afterward, it converged and suppressed swing movement at the reference position. Figure 4 shows the movement of the rotary angle using the optimized NC with initial angles $\theta_0 = 90, 120, 150$ [deg], $t_{dis} = 3$ [s].

4.1 The performance of the NC

Next, to verify the performance of the NC, it is tested with different initial positions $(x_0, y_0) = (\cos\theta_0 + \delta_x\ , \sin\theta_0 + \delta_y)$ which are varied from the trained position $(x_0, y_0) =(\cos\theta_0\ , \sin\theta_0)$. In this test, rotary angles are $\theta_0 = 90, 120, 150$, and the changes of the initial position (δ_x, δ_y) are set by random numbers in the range $(\delta_x, \delta_y) = [-0.03, 0.03]$. The criterion for success in control is when the squared error E_1 less than 0.0001 which is defined as :

$$E_1 = (X^r - X_1^{end})^T Q (X^r - X_1^{end}) \tag{7}$$

Table 4 shows the successful rate of control performance for the system through 1000 trials. Overall, when the rotary angle θ_0 is 90 [deg], good result is obtained. It shows that the latter time when disturbance occurs, the more difficult to the control system. Figure 5 shows an example of control result. Here, even if the control system started from the initial position, the load is moved with very little swing oscillation and it is suppressed to the reference position. It can be seen that the optimized NC has good control performance and has generalization ability.

Table 4: Success rate of control [%]

t_{dis} [s]	90[deg]	120[deg]	150[deg]
$t_{dis} = 1$	74.4	70.2	59.9
$t_{dis} = 2$	100.0	100.0	100.0
$t_{dis} = 3$	89.8	100.0	97.2
$t_{dis} = 4$	47.7	45.5	28.7

5 Conclusion

In this paper, we proposed a method to suppress the load swing movement from the initial positions, which is determined by three initial rotation angles, to the reference position by rotating the jib arm. As a result, simulations confirmed that the optimized NC by GA has good control performance. The NC suppress the load swing even if the load of the system is suddenly swung by disturbance, after the system started from several initial rotation angles. Moreover, to verify the performance of the NC, it is tested with different initial positions which are varied from the optimized position. We confirmed that the optimized NC has good control performance and has generalization ability.

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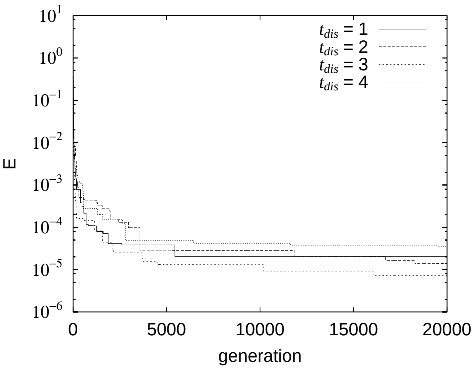
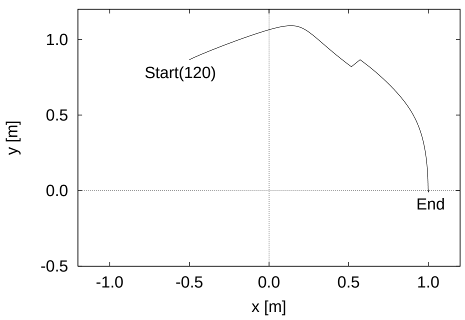
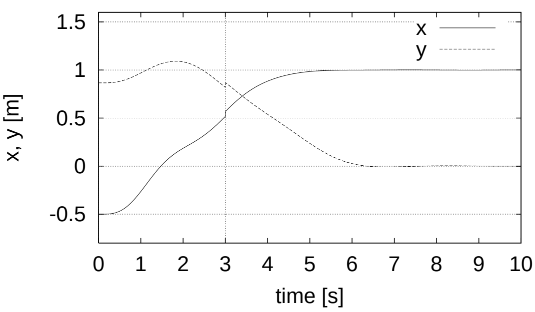


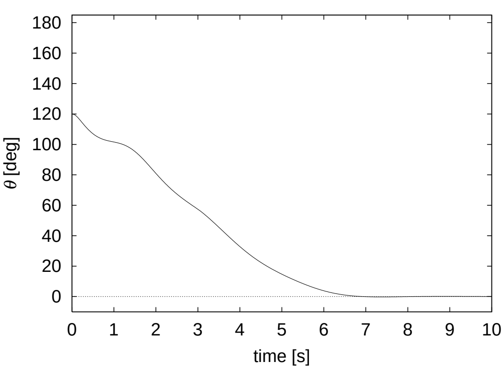
Fig. 3: Evolutionary processes



(a) Trajectory on x-y plane ($\theta_0 = 120$[deg])

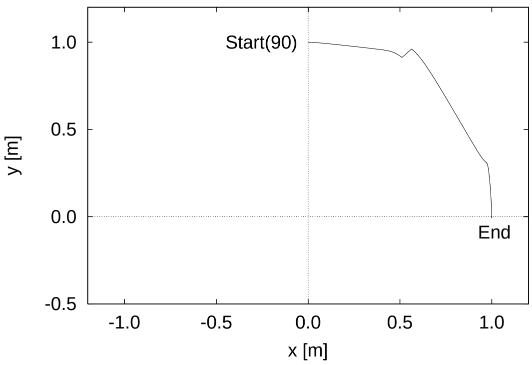


(b) Position x and y ($\theta_0 = 120$[deg])

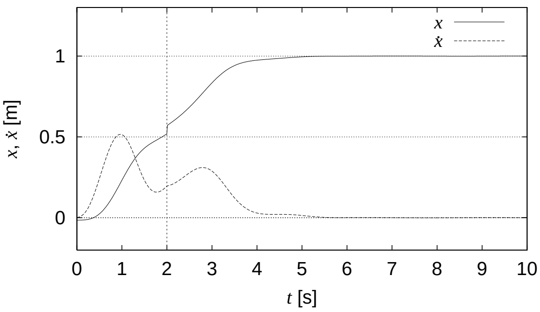


(c) Rotary angle θ ($\theta_0 = 120$[deg])

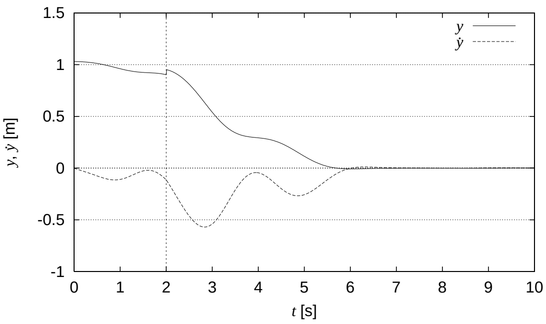
Fig. 4: Control results ($t_{dis} = 3$ [s])



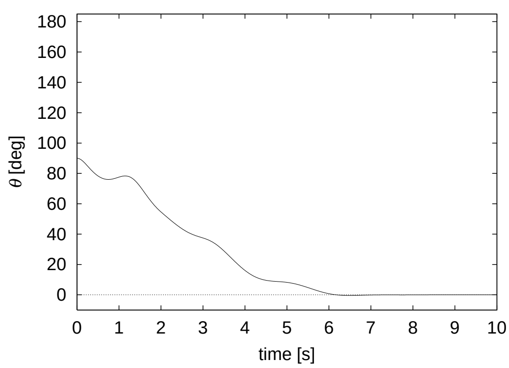
(a)Trajectory on x-y plane ($\theta_0 = 90$[deg])



(b) Position x and velocity $\dot{x}$ ($\theta_0 = 90$[deg])



(c) Position y and velocity $\dot{y}$ ($\theta_0 = 90$[deg])



(d) Rotation angle θ ($\theta_0 = 90$[deg])

Fig. 5: Control results (t_{dis}=2, (δ_x, δ_y)=(-1.5 , 3.0))