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A Study on Development of ATCS for Automated Stacking Crane using Neural Network Predictive Control

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Abstract **– For a traveling crane, various control methods such as neural network predictive control and TDOFPID(Two Degree of Freedom Proportional Integral Derivative) are studied. So in this paper, we proposed improved navigation method to reduce transfer time and sway with anti-collision path for avoiding collision in its movement to the finial coordinate. And we constructed the NNPPID(Neural Network Predictive PID) controller to control the precise move and speedy navigation. The proposed predictive control system is composed of the neural network predictor, TDOFPID controller, and neural network self-tuner. We analyzed ASC(Automated Stacking Crane) system and showed some computer simulations to prove excellence of the proposed controller than other conventional controllers.**

I. INTRODUCTION

The current development of new automatic container terminal in many countries will reduce the main cost of transportation by sea. An ASC(Automated Stacking Crane) control system is required with highest productivity. Also, these tendencies may show the optimal way to solve the employment problems, the cost saving problems and the improvement of efficiency in port systems[1, 2]. To considering nonlinear elements of the transfer crane, we are to design a controller for crane automatic position and anti-sway. The PID controller has been widely used in actual industry because of its convenience and ordinary usage for user. As transfer crane has lots of dynamic characteristics, PID parameters must be changed in varying conditions automatically. Most of the engineers are progressing research using self-tuner and controller using NN(Neural Network). We will compose an identifier to design a predictor. In order to identification of the crane system was learned enough with input and output of the NN[3]. In these points, it is important to tune the parameters of the PID controller adaptively, so we tuned the PID(k_p, k_i, k_d) parameters using NN self-tuner. So we constructed PID controller one of TDOFPID controller as anti-sway and position controller. The techniques for unmanned traveling system of transfer crane are consisted of ATCS (Automatic Travel Control System), ALCS(Automatic Landing Control System) and UOS(Unmanned Operation System)[1]. ATCS is consisted of APS (Automatic Position System) that recognizes the position of the trolley, hoist and crane, and the technique of precisely navigational position control that travels to final goal by coordinate information, and the technique of anti-sway. In this paper, we would develop the ATCS with anti-sway above three techniques.

II. MODELING OF THE ASC

The ASC system is divided with the x-axis direction of trolley horizontal velocity control and the y-axis direction of rope control[1,2]. We supposed ASC system model as follow. Figure 1 is shown a transfer crane structure.

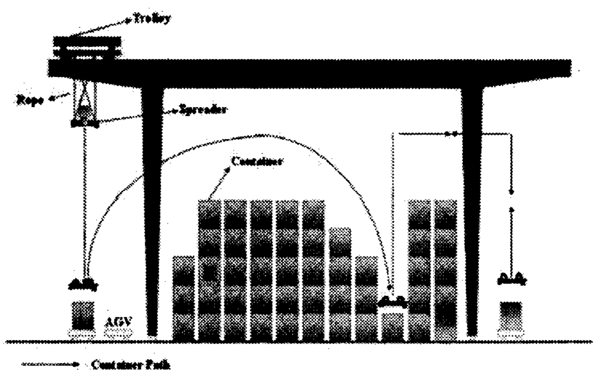


Fig. 1. Structure of the ASC

Table 1. Description of ASC system parameters

Parameters	Descriptions
x	Trolley position[m]
$\dot{x}$	Trolley's velocity[m/sec]
$\ddot{x}$	Trolley acceleration[m/sec^2]
θ	Oscillation angle[rad]
$\dot{\theta}$	Angle velocity[rad/sec]
$\ddot{\theta}$	Angle velocity[rad/sec^2]
l	Wire rope's length[m]
m	Trolley load[kg]
M	Container and spreader load[kg]
F_T	Force that act to trolley[kg]
F_H	Force that act to hoist[kg]
g	Gravity acceleration[m/sec^2]

$$F_T = (M+m)\ddot{x} + m\ddot{l}\sin\theta - ml\dot{\theta}^2\sin\theta + +2m\dot{l}\dot{\theta} + ml\ddot{\theta}\cos\theta \quad (1)$$

$$F_H = \frac{1}{2}m\ddot{x}\sin\theta + 2(M+\frac{1}{4}m)\ddot{l} - \frac{1}{2}ml\dot{\theta}^2 - \frac{1}{2}mg\cos\theta \quad (2)$$

$$0 = \ddot{x}\cos\theta + g\sin\theta + 2\dot{l}\dot{\theta} + l\ddot{\theta} \quad (3)$$

The length of the wire rope supposes that wire rope not changed and has been not fixed, system composed trolley to target point transfer container minimum oscillation. Where, if container's oscillation angle is very small θ, it is as follows :

1) $\theta^{\alpha}\theta^{\beta} = 0 (if : \alpha \geq 0, \beta \geq 0, \alpha + \beta \geq 2)$

2) $\cos\theta = 1, \sin\theta = \theta$

$$F_T = (M+m)\ddot{x} + ml\ddot{\theta} + 2m\dot{l}\dot{\theta} + m\ddot{l}\theta \quad (4)$$

$$F_H = \frac{1}{2}m\ddot{x} + 2(M+\frac{1}{4}m)\ddot{l} - \frac{1}{2}mg \quad (5)$$

$$0 = \ddot{x} + l\ddot{\theta} + g\theta + 2\dot{l}\dot{\theta} \quad (6)$$

III. PATH PLAN

The containers are did into the lattice format of a rectangular parallelepiped as size and shape of theirs, and after each unit-lattice is marked the characteristics coordinates (x_i, y_j) as shown figure 2. In the proposed methods, crane is controlled to have minimum time and minimum sway to objective shortest path.

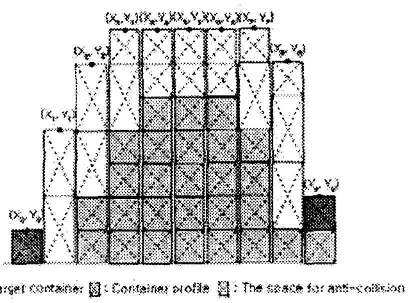


Fig. 2. Each transportation path of transfer crane

Figure 3 is shown transfer path of the container profile applied transfer crane.

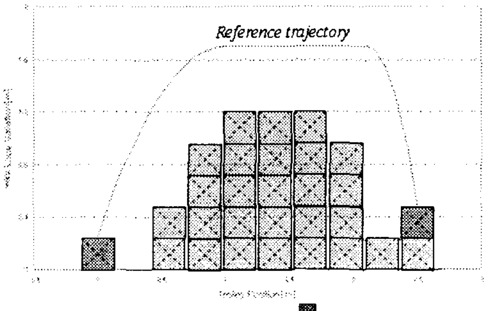


Fig. 3. The reference trajectory for container profile

IV. DESIGN OF THE NNPPID CONTROLLER

The predictive method need to identification of the system in some nonlinear dynamical system. The proposed structure of two-step neural network predictor is shown figure 4. The control parameters are trolley's position and angle. The predictive output is composed of the two NN predictors. In this paper, to control the transfer crane system we designed PID controller that has the ability to eliminate the disturbance and the performance to pursue the target. Figure 5 shows the block diagram of NNPPID controller.

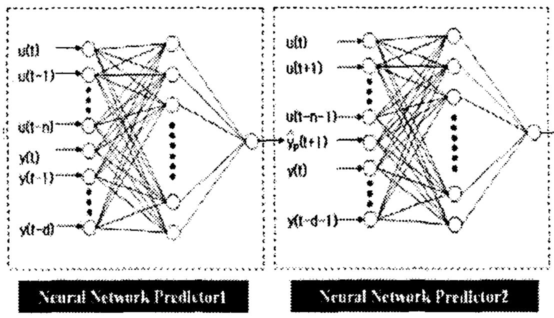


Fig. 4. A block diagram of NN predictor

In addition, we used the neural network algorithm to tune the parameters of TDOFPID controller in on-line manners. The figure 6 is shown the block diagram of TDOFPID controller. This system is consisted of the neural network predictor, TDOFPID controller and NN self-tuner. The disturbance considered wind that takes fixed cycle with equation (7).

$$F_W = ip(3\sin wt + 7\sin 2wt + 5\sin 3wt + 4\sin 4wt) \quad (7)$$

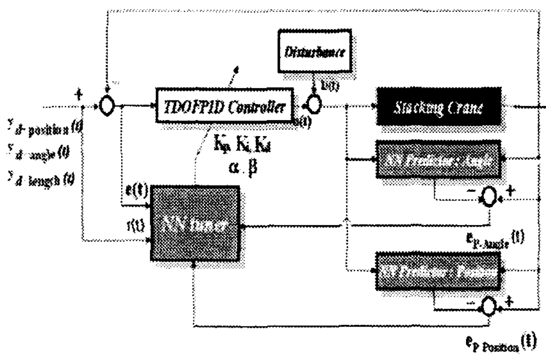


Fig. 5. A block diagram of NNPPID(proposed) controller

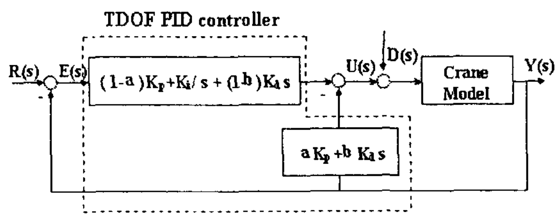


Fig. 6. A block diagram of TDOFPID controller

Figure 7 is shown the construction of NN tuner. Here, the momentum back propagation learning method and the input layer vector is composed of the error, the deviation of error, predictive trolley's position, angle output and the desired value. The activation functions of both hidden and output layers are sigmoid and linear function, respectively. Estimation function is used error function of equation(8). Error function E can be minimized by adjusting weight values. Error function E is found minimum values by gradient descent method.

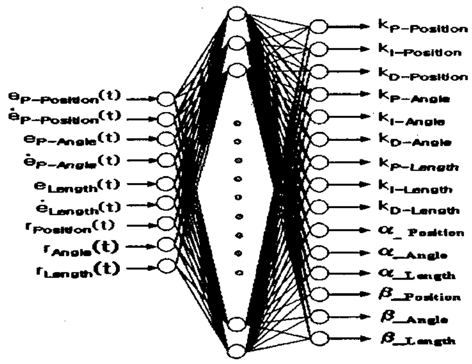


Fig. 7. NN self-tuner structure

$$E = \frac{1}{2}[y_{d-position}(t+1) - y_{p-position}(t+1)]^2$$
$$E = \frac{1}{2}[y_{d-Angle}(t+1) - y_{p-Angle}(t+1)]^2 \tag{8}$$
$$E = \frac{1}{2}[y_{d-length}(t) - y_{length}(t)]^2$$

The equation (9) is shown the weights of ΔW_{kj} and ΔW_{ji} using the gradient descent method.

$$\Delta W_{kj}(t+1) = -\eta \frac{\partial E}{\partial W_{kj}} + \varepsilon \Delta W_{kj}(t)$$
$$\Delta W_{ji}(t+1) = -\eta \frac{\partial E}{\partial W_{ji}} + \varepsilon \Delta W_{ji}(t) \tag{9}$$

$$\delta_k = -\frac{\partial E}{\partial net_k}$$
$$= \frac{-\partial E}{\partial y(t+1)} \cdot \frac{\partial y(t+1)}{\partial u(t)} \cdot \frac{-\partial u(t)}{O(k)} \cdot \frac{-\partial O(k)}{\partial net_k} \tag{10}$$

$$o_{pj}(k) = f_j(net_{pj}) = f_j(\sum_i w_{ji} o_i) \tag{11}$$

The system jacobian need $\frac{\partial \hat{y}(t+1)}{\partial u(t)}$ to calculate δ_k. f'(•) is the derivative equation of output layer for each neural network node, respectively.

V. Simulation of the Results

In this paper, we executed simulation about model of the ASC, and analyzed about container position, sway control, and change of the wire rope length using ES-tuned PID controller, NNPID controller, and proposed NNPPID. Table 2 is shown parameters value of the transfer crane, and table 3 is shown parameters value of the ES(Evolution Strategy) algorithm. Figure 9 and 10 are shown performance identification of the crane system and identification error.

Table 2. Parameters of the crane system

Parameters	Values
Gravity acceleration	9.8[m/sec^2]
Trolley load	4.2[kg]
Container load	10[kg]

Table 3. Parameter value of ES-algorithm

Parameters	Values
Population size	10
Total generation No.	10012
Mutation rate	50[%]

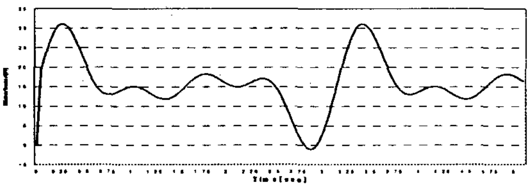


Fig. 8. Response characteristic of the disturbance

Simulation environment is same as follows.

- The final target of trolley: 2.5[m]
- The initial angle of sway: 0[rad]

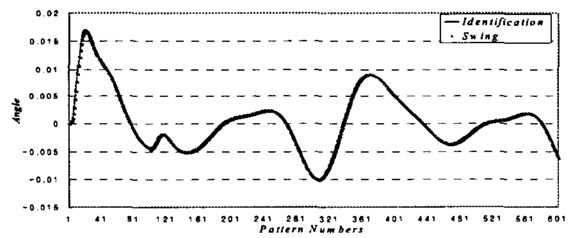


Fig. 9. Identification result of the crane system

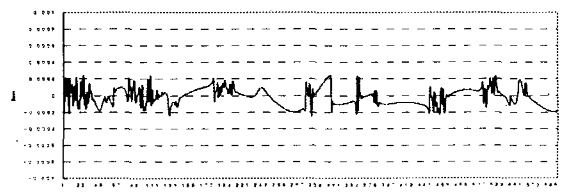


Fig. 10. Identification error of the crane system

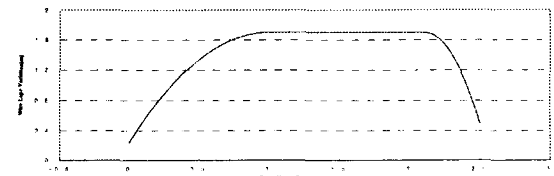
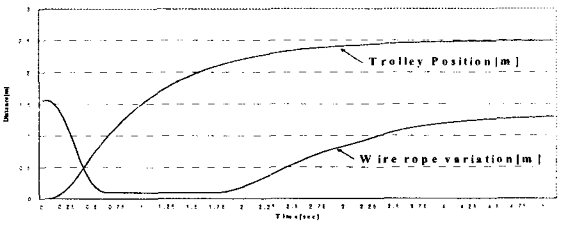
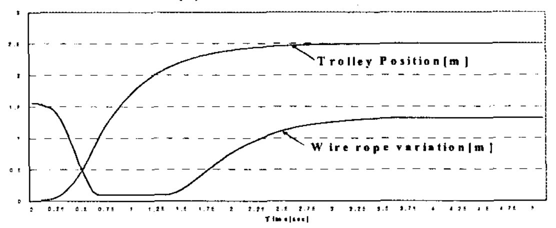


Fig. 11. Result of the transfer path trajectory

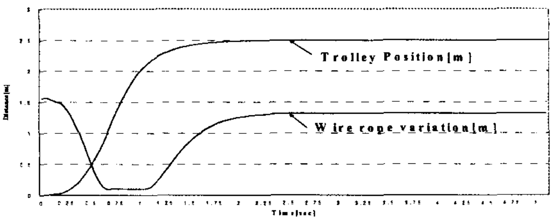
The length change of wire rope established to have trajectory of optimal path at trolley transfer from early position to target position with figure 11. We estimated about state of trolley position[m], trolley velocity[m/sec], angle[rad] and angle velocity[rad/sec]. Figure 12 is the result of trolley position[m] and wire rope variation[m] by driving characteristic of each controller.



(a) ES-tuned PID



(b) NNPID



(c) NNPPID

Fig. 12. Response characteristic of trolley position and wire rope variation

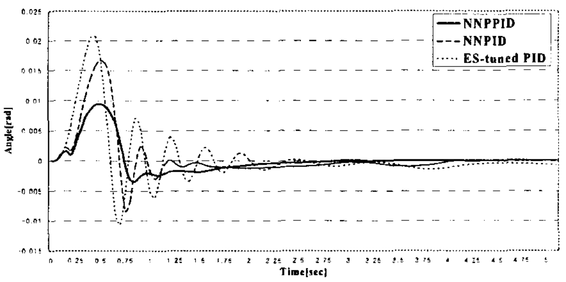


Fig. 13. Response characteristic of angle

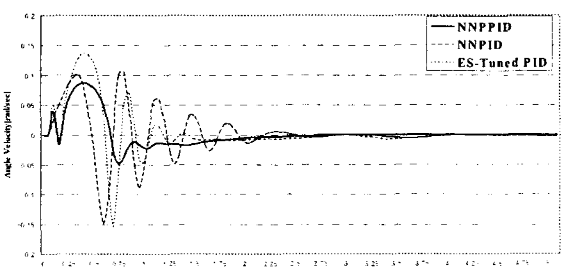


Fig. 14. Response characteristic of angle velocity

And figure 13 and 14 are shown the simulation results of angle[rad] and angle velocity[rad/sec]. The length change of wire rope did to change by 1.7[m]~0.24[m] to coordinate finally at initial coordinate. The table 4 are shown the simulation results.

Table 4. Comparison of each controller for crane system

Controller	The amplitude of trolley position[m]	The amplitude of swing angle[rad]
ES-tuned PID	2.4958~2.5040	0.0206~-0.01053
NNPID	2.4999~2.5094	0.0167~-0.00820
NNPPID	2.4998~2.5036	0.0094~-0.00349

VI. CONCLUSION

In this paper, we researched about develop of the ATCS with anti-sway in the techniques for ASC. The nonlinear ASC system applied NNPPID controller is proposed. Simulation result NNPPID about trolley position and angle was improved than NNPID. Trolley position and sway angle improved 60.12%, 48.28%. Also NNPPID was improved than ES-tuned PID controller. In case of trolley position and sway angle was improved 91.75%, 58.67% about each. This simulation result showed superior performance about trolley position, sway angle and settling time NNPPID than other controller. We researched about develop of the ATCS in the techniques for unmanned automation of the ASC. Besides, we designed the NNPPID controller using the NN predictor, and compared with the ES-tuned PID controller and NNPID controller. As result, the application of NNPPID controller is analyzed to have robustness about disturbance which is wind of fixed pattern- in the yard.

ACKNOWLEDGMENTS

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