A Study on Design of Anti-Sway Controller for ATC using Two Degree of Freedom PID Control

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Abstract: In this paper, an ATC(Automated Transfer Crane) control system is required rapid transportation to get highest productivity with low cost. Therefore, the container paths should be built in terms of the least time and least sway when container is transferred from the initial coordinate to the finial coordinate. So we applied the best-first search method for forming the container path, and calculated the anti-collision path for avoiding collision in its movement to the finial coordinate. And we constructed the neural network two degree of freedom PID (TDOFPID) controller to control the precise navigation. For simulation, we constructed the container profiles so that we analyzed the state of formed path and the performance of TDOFPID controller to the formatted path. Then we compared the performance of ES-tuned PID controller with our proposed controller in terms of trolley position, anti-sway, path change, disturbance, and the load of containers. The computer simulation results show that the proposed controller has better the other on the various conditions.

Keywords: Transfer Crane, Anti-Sway, Two Degree of Freedom PID, Neural Network, Predictive Control, Evolution Strategy

1. INTRODUCTION

Recently, the increase of quantity of goods transport is expected by Super Post-Panamax Vessel appearance. The growth of international container transport has led to increased demand for quay and terminal capacity in ports all over the world. Therefore, necessity of automation of container port handling equipments are risen to reduce of transfer logistics cost and improvement of terminal operation efficiency. The current development of new automatic container terminal in many countries will reduce the main cost of transportation by sea. An ATC(Automated Transfer 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].

To considering nonlinear elements of the transfer crane, we are to design a controller for crane automatic position and anti-sway. The PID(Proportional Integral Derivative) 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, 4, 5]. 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 (Two Degree of Freedom PID) 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 Automatic Position System (APIS) 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. The simulation results are shown that transfer crane system controlled by the proposed controller has better driving performances and anti-sway than the others.

2. MODELING OF THE ATC

The ATC system is divided with the x-axis direction of trolley horizontal velocity control and the y-axis direction of rope control[6, 7]. We supposed ATC system model as follow. Figure 1 is shown a transfer crane structure.

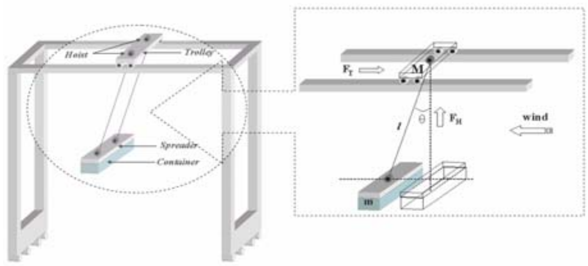


Fig. 1. Structure of the ATC

Table 1. Description of ATC system parameters

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

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

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

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

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

3. THE 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. We construct two dimensional maps that indicated the occupational area and non-occupational area by containers. The space for anti-collision established to avoid collision of the stack containers. In the proposed methods, crane is controlled to have minimum time and minimum sway to objective shortest path. Also we apply the best-first search method for searching the optimum path based on the sampled octree[8, 9, 10, 11]. Best-first search method use for evaluation function chose as follow.

$$f = \alpha_1 \cdot d_1 + \alpha_2 \cdot d_2 + \alpha_3 \cdot d_3 \quad (7)$$

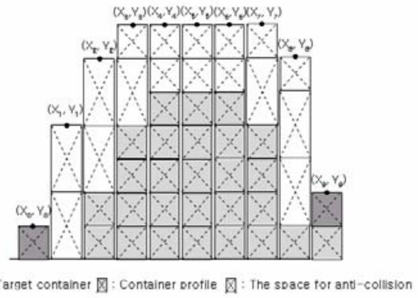


Fig. 2. Each transportation path of transfer crane

Where α_1, α_2 and α_3 are weight values. In this paper, the coordinate point of container profile could be set as follows:

- x_s, y_s : Start node coordinate value
- x_G, y_G : Target node of the container coordinate value
- x_n, y_n : Standard coordinate value of the current node
- x_t, y_t : Contiguity node from current node
- x_p, y_p : Standard node value

□ d_1: We define by value that reflect the XY-plane upper from removable contiguity node t to target node G.

$$d_1 = \sqrt{(x_G - x_t)^2 + (y_G - y_t)^2} \quad (8)$$

□ d_2: We define line segment that connect start node(S) and target node(G) in contiguity node t projected XY-plane upper to altitude. The straight line equation is same with equation (9) in X-Y plane.

$$\begin{aligned} & a\cdot x + b\cdot y + c = 0 \\ & a = y_G - y_s, b = x_s - x_G \\ & c = (x_G - x_s)\cdot y_s - (y_G - y_s)\cdot x_s \\ & d_2 = \frac{|a\cdot x_t + b\cdot y_t + c|}{\sqrt{a^2+b^2+c^2}} \end{aligned} \quad (9)$$

□ d_3: The equation of straight line L_1 and L_2 is shown equation (10). And the angle d_3 is shown equation (11).

$$\begin{aligned} & L_1 : \frac{x-x_p}{l_1} = \frac{y-y_p}{m_1} = \frac{z-z_p}{n_1} = t_1 \\ & L_2 : \frac{x-x_p}{l_2} = \frac{y-y_p}{m_2} = \frac{z-z_p}{n_2} = t_2 \end{aligned} \quad (10)$$

$$\cos(d_3) = \frac{l_1\cdot l_2 + m_1\cdot m_2 + n_1\cdot n_2}{\sqrt{l_1^2+m_1^2+n_1^2}\cdot\sqrt{l_2^2+m_2^2+n_2^2}} \quad (11)$$

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

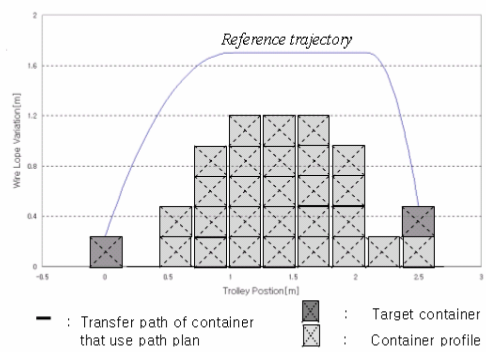


Fig. 3. The reference trajectory for container profile

4. 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 5. Here, the control parameter is trolley's position and angle. The predictive output is composed of the two NN predictors. The identification is performed with table 2 to do NN predictive control. In this paper, to control the stacking crane system we designed PID controller that has the ability to eliminate the disturbance and the performance to pursue the target. Figure 6 shows the block diagram of NNPPID controller.

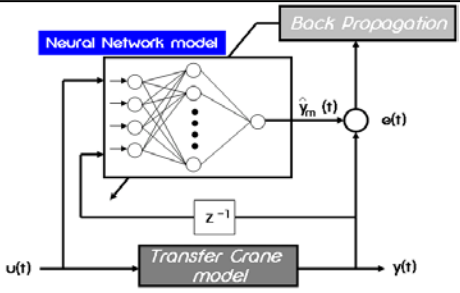


Fig. 4. A block diagram of NN identifier

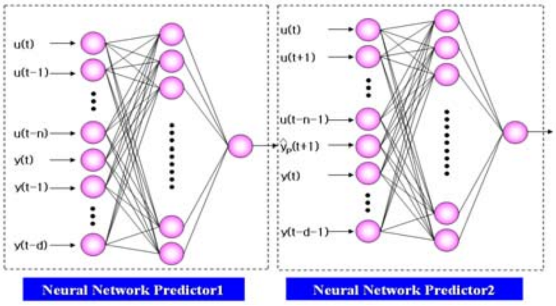


Fig. 5. A block diagram of NN predictor

Table 2. Parameters of the NN modeling

		Trolley position parts	Swing angle parts
Pattern No.		600	600
Node No.	Input No.	40	4
	Hidden No.	6	6
	Output No.	1	1
Learning ratio		0.09	0.09
Momentum factor		0.03	0.03
Input parameter		u(t), u(t-1), $\hat{y}(t)$, $\hat{y}(t-1)$	u(t), u(t-1), $\hat{y}(t)$, $\hat{y}(t-1)$

In addition, we used the neural network algorithm to tune the parameters of TDOFPID controller in on-line manners. The discrete time version of the input of NNPPID controller is described by

$$\begin{aligned} u(t) = &\{(1-\alpha_p)k_{p\_p}(e(t)-e_p(t-1))+k_{i\_p}e_p(t) \\ &+(1-\beta_p)k_{d\_p}(e_p(t)-2e_p(t-1)+e_p(t-2)\} \\ &+\{(1-\alpha_a)k_{p\_a}(e(t)-e_a(t-1))+k_{i\_a}e_a(t) \\ &+(1-\beta_a)k_{d\_a}(e_a(t)-2e_a(t-1)+e_a(t-2)\} \\ &+\{(1-\alpha_l)k_{p\_l}(e(t)-e_l(t-1))+k_{i\_l}e_l(t) \\ &+(1-\beta_l)k_{d\_l}(e_l(t)-2e_l(t-1)+e_l(t-2)\} \\ &-\{\alpha_p k_{p\_p}(y_p(t)-y_p(t-1)) \\ &+\beta_p k_{d\_p}(y_p(t)-2y_p(t-1)+y_p(t-2))\} \\ &-\{\alpha_a k_{p\_a}(y_a(t)-y_a(t-1)) \\ &+\beta_a k_{d\_a}(y_a(t)-2y_a(t-1)+y_a(t-2))\} \\ &-\{\alpha_l k_{p\_l}(y_l(t)-y_l(t-1)) \\ &+\beta_l k_{d\_l}(y_l(t)-2y_l(t-1)+y_l(t-2))\} \end{aligned} \quad (12)$$

The figure 7 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 (13).

$$F_W = ip(3\sin wt + 7\sin 2wt + 5\sin 3wt + 4\sin 4wt) \quad (13)$$

Here, w is fundamental frequency of the wind and p is magnitudes of the wind.

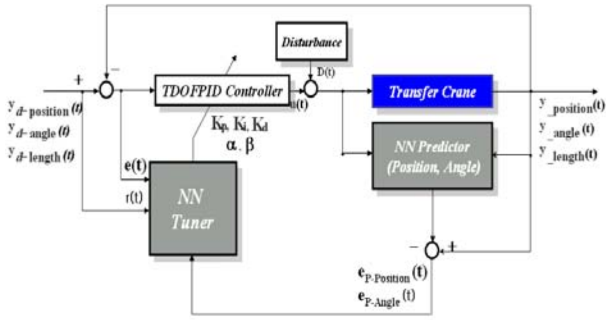


Fig. 6. A block diagram of NNPPID(proposed) controller

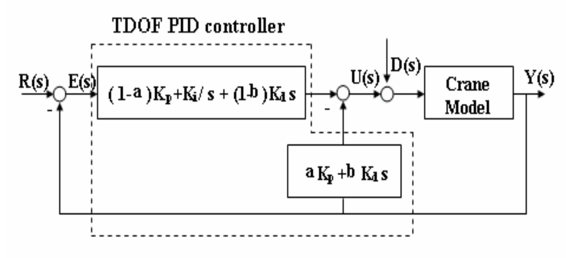


Fig. 7. A block diagram of TDOFPID controller

The proposed NNPPID controller is divided into two parts which are NN self-tuner and TDOFPID controller. Figure 8 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. Learning rate and momentum constant of the tuner is 0.9, 0.5, respectively. All weights are set initially 0.5 is chosen by trial and error. Estimation function is used error function of equation (14). Error function E can be minimized by adjusting weight values. Error function E is found minimum values by gradient descent method.

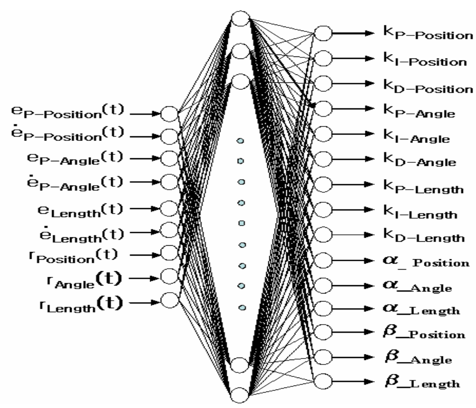


Fig. 8. NN self-tuner

$$E = \frac{1}{2}[y_{d-position}(t+1) - y_{p-position}(t+1)]^2$$
$$E = \frac{1}{2}[y_{d-Angle}(t+1) - y_{p-Angle}(t+1)]^2 \quad (14)$$
$$E = \frac{1}{2}[y_{d-length}(t) - y_{length}(t)]^2$$

The equation (15) is shown the weights of ΔW_{kj} and ΔW_{ji} using the gradient descent method.

$$\Delta W_{kj}(t+1) = -\eta \frac{\partial E}{\partial W_{kj}} + \varepsilon \Delta W_{kj}(t) \quad (15)$$
$$\Delta W_{ji}(t+1) = -\eta \frac{\partial E}{\partial W_{ji}} + \varepsilon \Delta W_{ji}(t)$$

$$\delta_k = -\frac{\partial E}{\partial net_k} = \frac{-\partial E}{\partial y(t+1)} \cdot \frac{\partial y(t+1)}{\partial u(t)} \cdot \frac{-\partial u(t)}{O(k)} \cdot \frac{-\partial O(k)}{\partial net_k} \quad (16)$$

$$o_{pj}(k) = f_j(net_{pj}) = f_j(\sum_i w_{ji} o_i) \quad (17)$$

Then using the chain rule, the update weights between hidden are

$$\Delta W_{jk}(t+1) = \eta \delta_k o_j + \varepsilon \Delta W_{jk}(t) \quad (18)$$

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. Figure 9 is shown the block diagram of the transfer crane system that is controlled by NNPID controller. Figure 10 is shown the block diagram of ES-tuned PID controller.

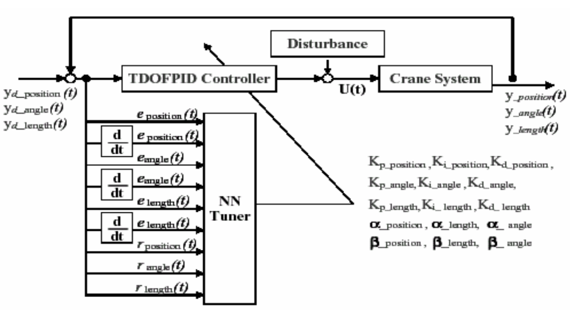


Fig. 9. A block diagram of NNPID controller

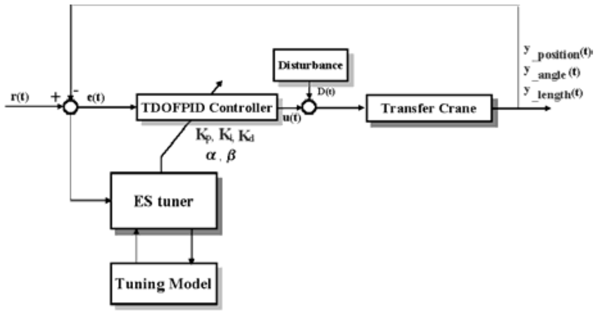


Fig. 10. A block diagram of ES-tuned PID controller

5. SIMULATION OF THE RESULTS

In this paper, we executed simulation about model of the ATC, 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 3 is shown parameters value of the transfer crane, and table 4 is shown parameters value of the ES(Evolution Strategy) algorithm. Figure 12 and 13 are shown performance identification of the crane system and identification error.

Table 3. Parameters of the crane system

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

Table 4. Parameter value of ES-algorithm

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

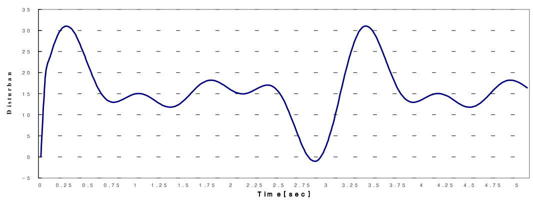


Fig. 11. Response characteristic of the disturbance

Simulation environment is same as follows.
•The final target of trolley: 2.5[m]
•The initial angle of sway: 0[rad]

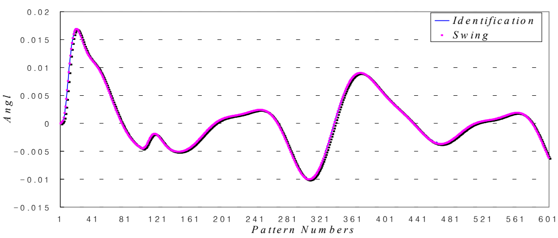


Fig. 12. Identification result of the crane system

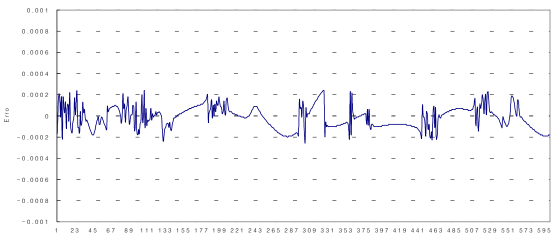


Fig. 13. Identification error of the crane system

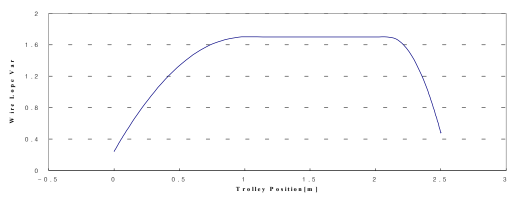
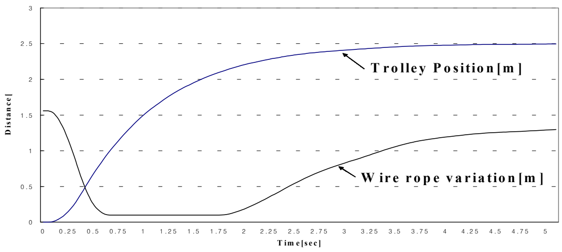
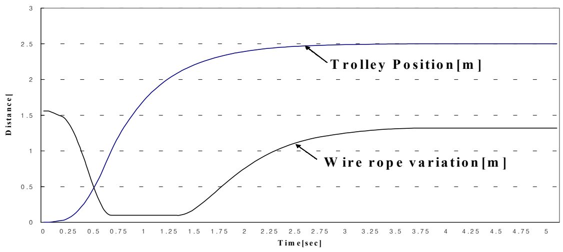


Fig. 14. Simulation result of the transfer path trajectory

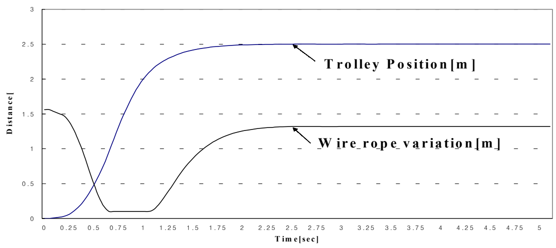
The length change of wire rope established to have trajectory of optimal path at trolley transfer from early position to target position with figure 14. We estimated about state of trolley position[m], trolley velocity[m/sec], angle[rad] and angle velocity[rad/sec]. Figure 15 is the result of trolley position[m] and wire rope variation[m] by driving characteristic of each controller.



(a) ES-tuned PID



(b) NNPID



(c) NNPPID

Fig. 15. Response characteristic of trolley position and wire rope variation

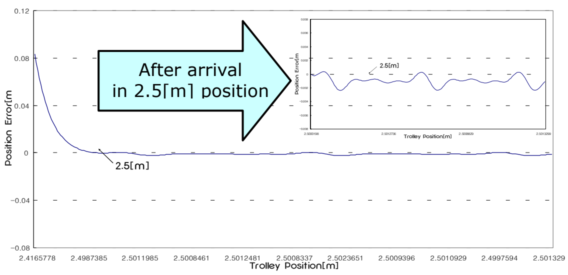


Fig. 16. Response characteristic of trolley position error(After 2.5[m])

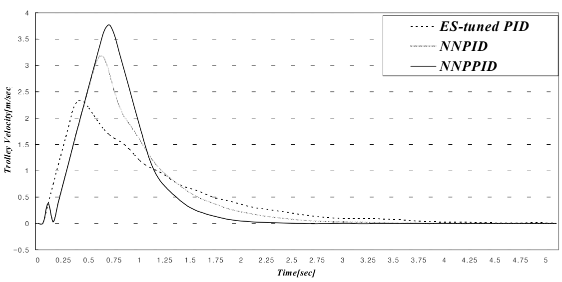


Fig. 17. Response characteristic of trolley velocity

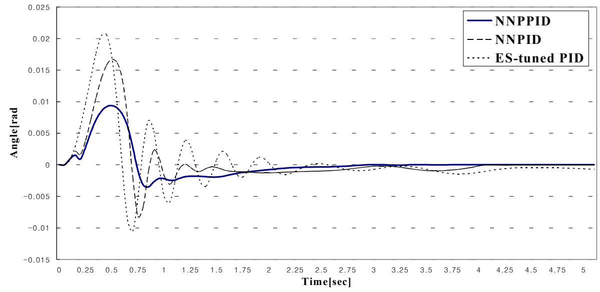


Fig. 18. Response characteristic of angle

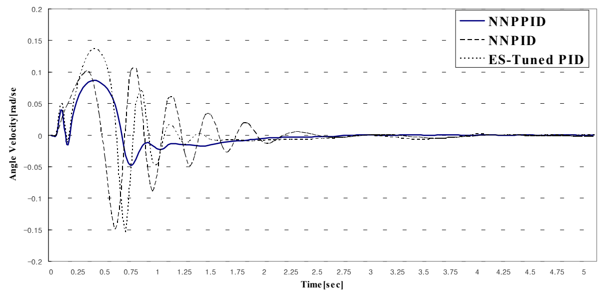


Fig. 19. Response characteristic of angle velocity

Figure 15 and 17 are shown the simulation results of trolley position[m] and trolley velocity[m/sec]. And figure 18 and 19 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 5, 6 are shown the simulation results.

Table 5. 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

Table 6. Comparison of each controller for crane system (when trolley reached 2.5[m])

Controller	Angle[rad]	Angle Velocity [rad/sec]	Reaching time[sec]
ES-tuned PID	-0.000716	-0.00172	5.65
NNPID	-0.000815	-0.00440	3.75
NNPPID	-0.000327	-0.00261	2.55

6. CONCLUSION

In this paper, we researched about develop of the ATCS with anti-sway in the techniques for ATC. For this, we developed the algorithm that builds the container path and calculates the anti-collision path for avoiding collision in its movement to the finial coordinate, and constructed TDOFPID controller for transferring the container in the least time. Also, the various simulation of transfer path is executed about container profile. The nonlinear ATC 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 ATC. 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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