Application of PD and Genetic Algorithms for Control of two Overhead Cranes: a Virtual Approach

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***Abstract*- This paper presents the design and control of a new style overhead crane. The design approach is based on a modified traditional model of the overhead crane to allow the crane to move in three dimensions. Two overhead cranes acting in the same work space are designed to show the benefit of the proposed strategy. The modeling is done in the Visual Nastran (vn4d) software environment; and this is integrated with Matlab-Simulink for analysis and control purposes. The simulation results show that the proposed approach is effective with multiple cranes is acting in the same work space.**

Keywords- Overhead Crane; PD Control; Sways Suppression; 3DOF

I. INTRODUCTION

Overhead crane systems are used for material and product transportation and placement in industrial and manufacturing environments. The control challenge with such system is transportation of a payload with minimum sway, minimum vibration and accurate positioning at the target location. With multiple cranes, on the other hand, the additional requirement is to achieve collision free maneuvers. Many control methods have been studied for the overhead crane system [10]. Khalid et al. [1] implemented an input shaping controller on a gantry crane. They studied the actions of the operator driving the crane through the obstacles with and without the input shaping controller, and observed that the operator took an efficient maneuvering path when enabling the input shaping. Glossiotis et al. [2] presented an approach to minimize the sway of payload attached to a crane using digital filters. The scheme is simply based on pre-conditioning the command inputs by a well-designed finite impulse response (FIR) filter. From the simulation results it is clear that the sway can be suppressed effectively with this method. The method is simple to implement and doesn’t require any additional instruments. Gupta et al. [3] presented a computational approach that is less demanding and does not require any sway sensors. The technique was effective with a gantry crane, However it does not account for the effect of external disturbances such as wind and collision, Moreover the approach does not account for the initial sway created by jerky lifting of the load off the ground. Miyata et al. [4] applied a method which calculates the trolley travel pattern to stop the sway in advance. The calculated pattern is combined with feedback control. They showed how to set the trajectories to avoid collision. They assure that the method is safe and efficient. Piazzi et al. [5] proposed a feed forward/feedback approach based on a linearized model using an observer-based controller. The overshoot is reduced by increasing the travel time. Simulation results showed the effectiveness of the proposed scheme. Chi-Cheng et al. [6] developed a robust controller to minimize the sway during transport of the payload. They used a control approach which combined systematic feedback linearization for nonlinear systems, and the fast convergent characteristic of time delay control for unknown dynamics. A robust control performance has been indicated from the simulation results satisfying transient responses and excellent steady state properties. But there are two disadvantages associated with the scheme. The first is that the decoupling matrix in the linearization must satisfy a finite, known relative degree for the system, and the stable internal dynamics. The second disadvantage is the difficulty of measurement of state derivatives in practice. Benhidjeb et al. [7] applied two different approaches, namely, fuzzy control, and optimal control to control an experimental model of a crane . The experimental and simulation results indicated that the fuzzy controller was efficient for controlling the crane when the sway angle was difficult to measure. In addition to this, there is no need for a mathematical model when using fuzzy logic control (FLC). Moreno et al. [8] proposed a neural network (NN) based self-tuning controller. The inclusion of NN in the controller is to replace the identification part, and the controller decision part in the self-tuning scheme. The NN is trained online. By using NN no model assumptions are needed for the control algorithm. They applied the approach on an overhead crane system to suppress the oscillations during the operation of the crane. The comparison of simulation results of this method with these of the standard self- tuning algorithm demonstrated the advantage of the method. They have implemented the approach in real time on a prototype crane. Dedone et al. [9] proposed an open-loop control method based on phase-plane analysis of a linearized model. They designed three controllers, the first was based on linear analysis, the second and the third were based on nonlinear analysis. The results showed that the nonlinear scheme was very successful to suppress the system oscillation. However, the proposed method is an open loop technique, and does not account for any error in the process.

The traditional overhead crane has two degrees of freedom. The crane consists of a rail and a trolley both can move in one direction (say *X* direction). The trolley can move along the rail (say y direction). A hook hanging from the trolley on a pendulum-like lift line can be lowered and raised in vertical (z) direction for picking up and placing the payload. Therefore the hook and the payload attached to it can move freely in three dimensions, but the overhead crane itself can move only in two dimensions.

In a large number of applications, only one overhead crane acts in the work space. In some application using one crane is not enough if it is required to manipulate and place more than one payload at the same time. In such cases a multiple set of cranes will be required in which case it will be necessary to add a third degree of freedom to the dynamics of the cranes. This paper addresses the control of cranes with three degree of freedom (3DOF). Control of cooperative cranes is more difficult than controlling a single crane, although there are common features in the control approaches for multi-cranes and single crane systems. The added difficulty of a multi-crane system is that each crane may become a moving obstacle in the path of another crane. The control challenge in such a system is to avoid collision, achieve sway free motion, and accurate positioning of the payloads, thus with minimum vibration. The three main tasks to develop an efficient control system for a multi-crane system include; Accurate positioning of the cranes, minimum sway of the payloads, and Collision free motion of the cranes.

Considerable amount of research has been conducted in field of collision avoidance. Durali, M. et al. [15] presented a scheme for motion control and collision avoidance of a vehicle. The method is based on designing a desired trajectory according to the distance between the vehicle and the fixing or moving obstacle. They used a sliding mode controller for controlling motion of the vehicle to track the desired trajectory. The approach was appropriate for real time implementation due to less expensive computations. Their Simulation results show the effectiveness of the scheme in avoiding the collision. Alexander H. et al. [16] Developed a low-cost, high-performance automated overhead Material transportation system for a variety of applications named ‘Magnebots’. The system consists of vehicles with magnetic wheels that move on trackless ferromagnetic walls and ceilings, the vehicles traffic is managed by a central computer that commands all the vehicles, computing each vehicle’s position. Proximity sensors on each vehicle are used to activate emergency stops or obstacle avoidance maneuvers using simple logic in the microcontroller program.

II. THE SYSTEM MODELLING

A. The Objectives

The objective is to design a multi overhead crane system comprising two overhead cranes. The task of each crane is to move and position its specific payload to a specific target location. The upper crane is modified to have a third degree of freedom to allow it to also move in the vertical (z) direction while the lower crane (crane-will remain to have two degrees of freedom (DOF).

The sequence of the system operation should be as follows:

1. Each crane is to move from rest to the location of its
2. Payloads.
3. The crane is to extend down and catch the payloads.
4. The crane is to hoist the payloads.
5. If crane1’s target location is far than crane2’s, then a swap process is required to avoid the Collision between the crane1 and the payload of crane2.
6. The swap process is achieved by moving crane2 upward for about one meter, and let crane one to move first.
7. The crane is to move to its target location at desired speed, minimum sway and avoiding collision with other crane.
8. The crane is to place down the payload at the target location with minimum vibration.

B. System Description

A system comprising two overhead cranes is designed using Vn4d. The cranes are designed in two layers; Figure 1 shows schematic drawing of the Crane 1. It consists of three rails and a trolley. Two fixed rails each with dimensions $10 \times 0.15 \times 0.1$ m are placed in parallel at certain height from the workspace floor. A third rail with dimensions $9.8 \times 0.15 \times 0.1$ m is connected perpendicular to the fixed rails using rigid joints on slot constraints (Figure 2). This will allow the perpendicular rail to move along the y axis.

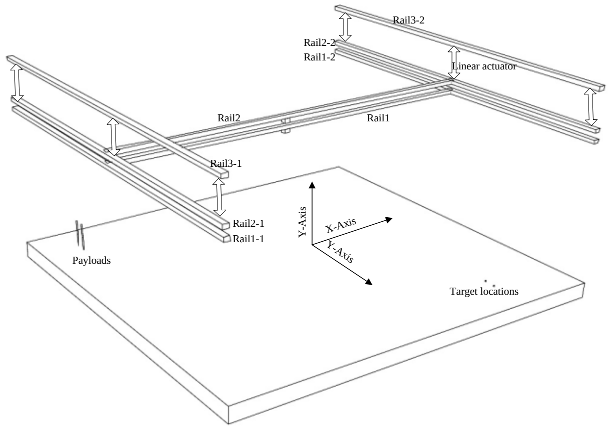


Fig. 1 Schematic diagram of the overhead crane with 3DOF

The cranes are required to move and position two payloads at the same time at specified target locations. The payloads are aluminum rods. Each overhead crane consists of a hook hanging from the trolley on a pendulum-like lift line. The hook is lowered and raised in the vertical (*z*) direction to hoist and place down the payloads, the hook is lowered and raised only when the crane reach the payload position and the target location respectively. Both the rail and the trolley can move in the y direction, the trolley can move along the rail in the x direction. In this way the trolley can move freely in two dimensions.

The upper crane (Crane 2) is modified by allowing the two rails (Rail 2-1, Rail 2-2) to move vertically up to 1 meter above its original position. This will permit the cranes to swap positions after picking up their payloads. The swap process is necessary if the payloads are desired to be placed differently from an initial arrangement, which will require a re-arrangement of the cranes, for which the control protocol will need to be modified so that collision-free motion is achieved.

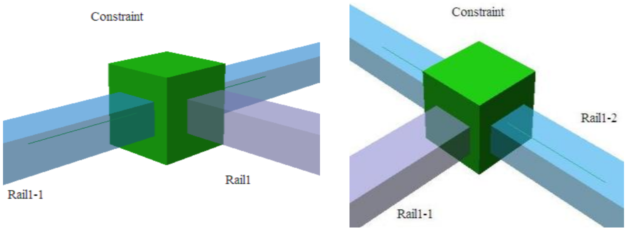


Fig. 2 Vn4D Rails constraints implementation

Six linear actuators are used to connect the Rails 2-1 and 2-2 with the new fixed Rails 3-1 and 3-2. The distance between the fixed and movable rails is set to 0.9 m. the task of the linear actuators is to move the Rails 2-1 and 2-2 upward. This will allow the whole crane to move vertically up to 1 meter above its original position. Figure 3 shows a screen capture of Visual Nastran model of the system. The model was integrated with Matlab-Simulink for analysis and control purposes (Figure 4).

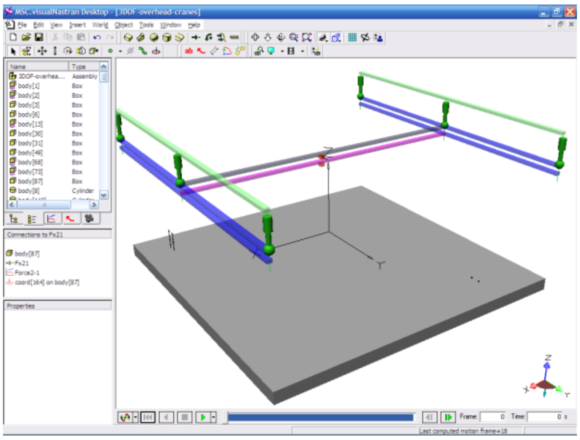


Fig. 3 Visual Nastran model of the system

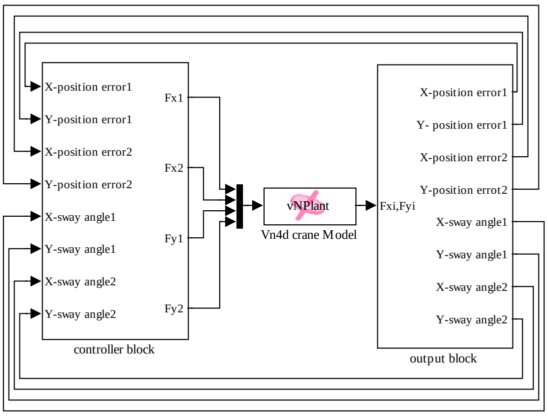


Fig. 4 Simulink implementation of the system

III. THE CONTROL SYSTEM DESIGN

The position error is calculated by measuring the distance between the trolley and the payload on the grabbing phase (x error1 and y error1) and then between the payload position and the target location in the dropping phase (x error2 and y error2). Conditional statements are set to feed back the appropriate position error to the control system, if a normal scenario is applied, the structure of the statements is:

If t<30 then (trolley – payload) else (trolley-target location), which means from the beginning of the simulation until t<30 seconds x error1 and y error1 is fed back to the position controllers, from t=30 seconds until the end of simulation x error2 and y error2 is fed back to the position controllers. If the swap process is required, the conditional statement will be: t<32 then (trolley – payload) else (trolley-target location). The 2 seconds delay is necessary to finish the swap process. Figure 5 illustrates how the position error is measured. and Figure 6 illustrates the Simulink implementation of the conditional statement.

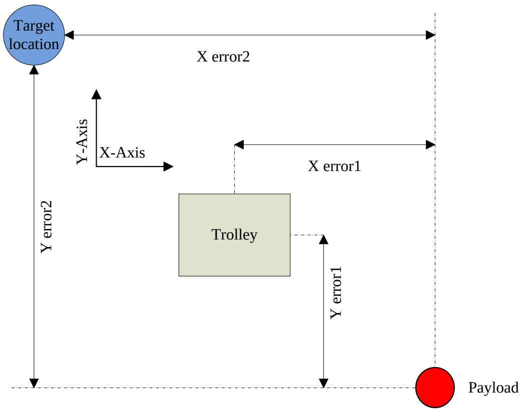


Fig. 5 Position error measurement

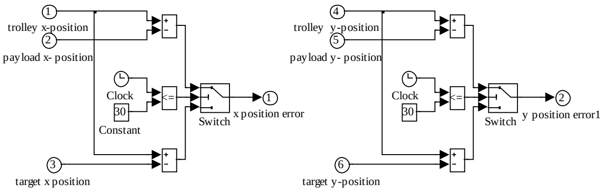
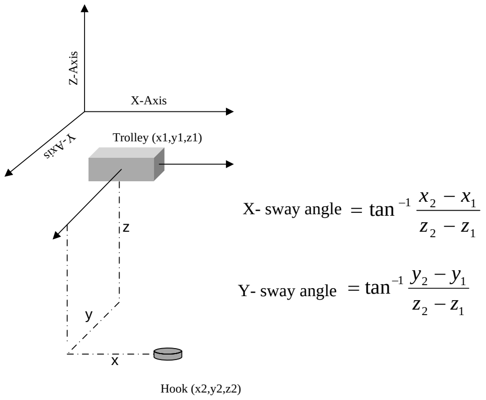


Fig. 6 Simulink implementation of the conditional statement

The sway angle (Figure 7) is calculated by measured the displacement of the hook with the trolley position. With Vn4d we can measure the position of anybody during the simulation, by measuring the positions of the trolley and the hook we can easily calculate the sway angles.



$$\text{X- sway angle} = \tan^{-1}\frac{x_2 - x_1}{z_2 - z_1}$$

$$\text{Y- sway angle} = \tan^{-1}\frac{y_2 - y_1}{z_2 - z_1}$$

Fig. 7 Sway angle measurement

Four independent PD controllers are used to control each crane (Figure 8): two for the positioning control (one for *x* direction and the other for *y* direction) and the other two for suppressing the sway (x and y directions). The objective of the anti-sway controller is to reduce the payload sway. The positioning controller aims to position the crane at the exact position of the payload during the grabbing phase, and at the destination position during the payload dropping phase. An additional PD controller is added in *Y* direction only to assure the collision free motion, this controller is active only if the distance in *y* direction between the two cranes is greater than the safe distance (0.3m).

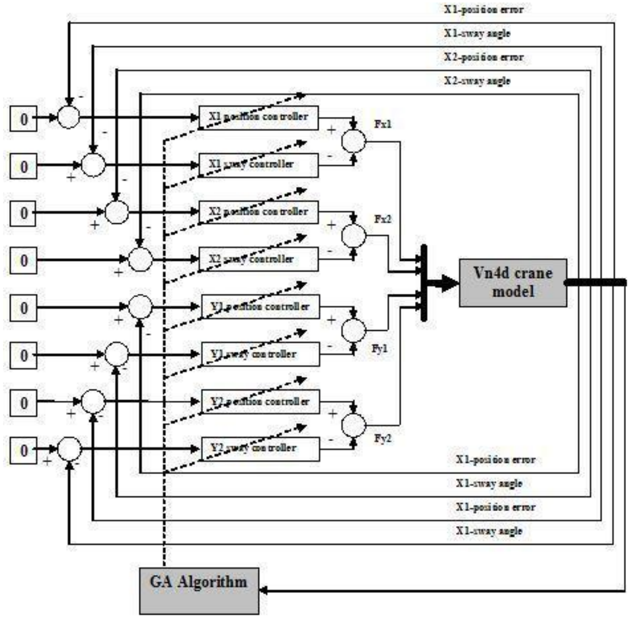


Fig. 8 Implementation of PD controllers

The signal of the sway controller is subtracted from the position controller in each direction [14], so each crane has two inputs: driving force in the *x* direction (Fx) and driving force in the *y* direction (Fy), where:

Fx= x position controller signal- x sway controller signal

Fy= y position controller signal- y sway controller signal

The controllers are tuned with the genetic algorithms (GA) technique, the GA process was encoded in Matlab script files, mean-squared-error (MSE) method is used to compute the objective function, an interfacing was made so that the Vn4d variables are passed to the Simulink , after finishing the simulation, the system response is passed again to the GA for the next computation. The GA was run for 100 generation with generation gap 0.8, Figure 9 illustrates the best value of the objective function, Optimal parameters obtained after a complete GA run are shown in Table 1.

TABLE I OPTIMAL CONTROLLERS PARAMETERS AFTER GA RUN

	Position controller		Sway controller	
	P	D	P	D
X direction	14.88	35.11	8.29	50.8
Y direction	49.9	285.28	49.68	460.95

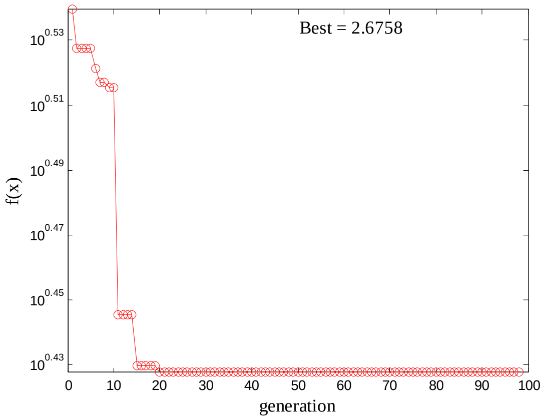
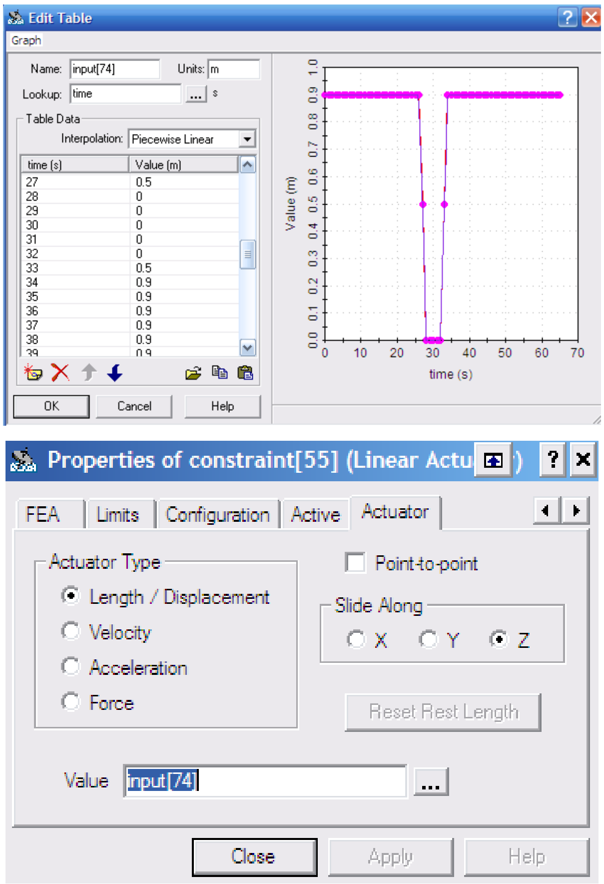


Fig. 9 The best value of the objective function

There are four main outputs. These are the actual positions of the cranes in the x and y directions, and the sway angles of the payloads in the x and y directions. These outputs are fed back into the control system to achieve the control objective.

The linear actuators are derived via the Vn4d with the sort of data table, Figure 10, illustrate the data table that control the six linear actuator , the values are set to 0.9 m which means the actuators are expanded for 0.9m, during the swap process 27≤ t≤ 33 the actuators are slides to the 0 m , this will made Crane 2 to move up for 0.9m , it is clear that the actuators has been chosen to be length/displacement actuator , and they are set to slide along *z* axis.


Edit Table

Name: input[74] Units: m

Lookup: time s

Table Data

Interpolation: Piecewise Linear

time (s)	Value (m)
27	0.5
28	0
29	0
30	0
31	0
32	0
33	0.5
34	0.9
35	0.9
36	0.9
37	0.9
38	0.9
39	0.9

Properties of constraint[55] (Linear Actu)

Actuator Type: ● Length / Displacement ○ Velocity ○ Acceleration ○ Force

☐ Point-to-point

Slide Along: ○ X ○ Y ● Z

Value: input[74]

Fig. 10 Vn4d data table to derive the linear actuators

IV. SIMULATION RESULTS

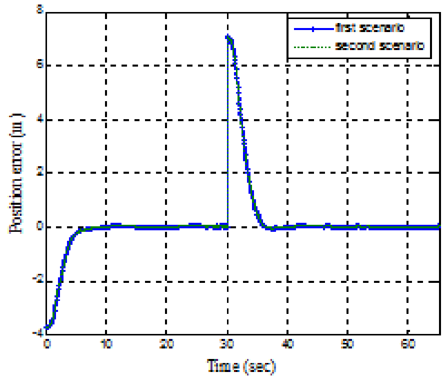
Two scenarios were investigated to demonstrate the performance of the system, namely when the payloads and the target locations has arrangement as shown in Figure 10 and when their arrangement is as shown in Figure 11. It should be noted here that with the first scenario there is no need for the swap process between the two cranes. However If it is desired that the payload arrangement at the target is as in Figure 11, then as the payloads are each 70 cm in length there is potential for collision as crane1 will need to cross Crane 2. To avoid such a potential problem the swap approach is proposed.

Fig. 10 First scenario arrangement

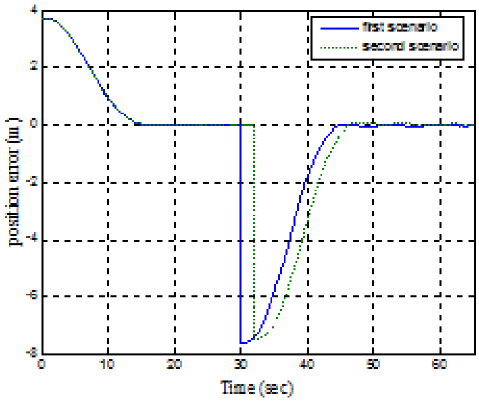
Fig. 11 Second scenario arrangement

Figure 12 shows results of the positioning controller for Crane 1, where the payload was initially positioned at x = 3.75 m, and y = 4 m. At the first scenario the controller evaluates the distance between the trolley and the payload during the first phase, and then between its position and the target location after catching the payload. The controller reference is set to zero, so that when the distance difference that evaluated is zero, the trolley reaches the required position. As can be seen from Figure 11, the crane reached the payload approximately in 20 sec where the hook then begins to extend down to catch and hoist the payload and then start the journey to the target location. The target location was set at x = 6.75 m, and y = 7.7 m . the excellent tracking of the crane is an indication for the stability of the system.

As noted in Figure 12, the crane began to travel to the target location at 30 sec, and the crane reached its target location in approximately 20 sec (50 seconds after the start of the simulation) at which point the hook extends down to place the payload. If the second scenario is apply, crane1 required to pass Crane 2 and its payload, this means the y position error for Crane 1 will be greater than the one of the first scenario, the new value will be 8 m . However the x position error is remaining same.

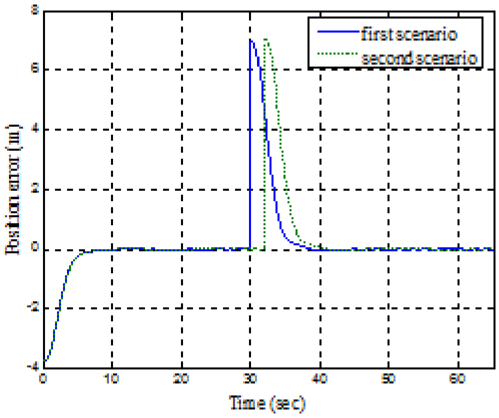


(a) x-direction

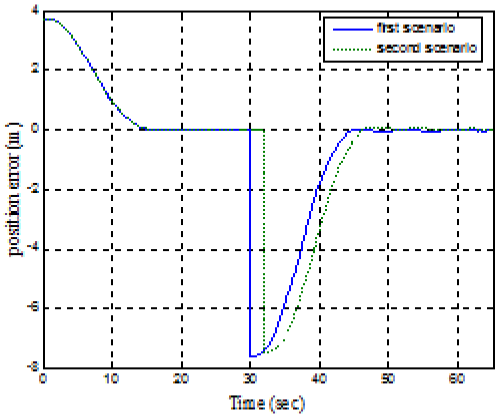


(b) y-direction

Fig. 12 Position error of Crane1



(a) x-direction

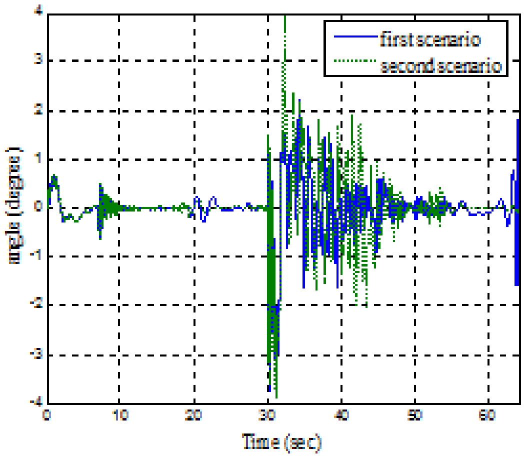


(b) y-direction

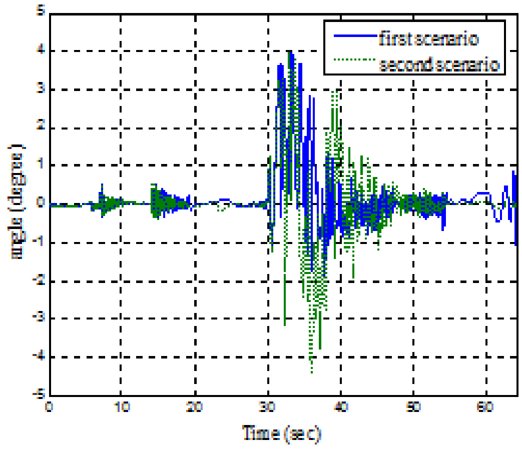
Fig. 13 Position error of Crane 2

Figures 13 shows similarly the poisoning control results for Crane 2, the crane began to travel to the target location at 30 sec after hoisting the payload without any sway or vibration. It reached its target location in approximately 20 sec (50 seconds after the start of the simulation) at which point the hook extends down to place the payload without any sway or vibration. In case of second scenario there is slight delay (2 sec) before the crane begins its journey to the target location. This is due to the swap process and to allow crane1 to move first.

Figure 14 illustrates the sway angle of the hook attached to crane1 in the *x* and *y* directions. The maximum angle in the *x* direction was less than one degree when the crane first moved from its parking position to where the payload is located. It is noted that the sway angle was damped to zero within 10 seconds. After picking up the payload it reached the target location in 30 seconds. It is noticed that the maximum sway angle was around 4 degrees and it reduced to zero within 30 seconds. It is noted that there was a slight sway at the end of simulation. This is due to the hook placing the payload at the target position. The sway angle in the *y* direction, as noted, was acceptable. The angle was around zero degrees during the first phase, and after picking up the payload and moving to the target location, the maximum sway angle in the y direction was about 5 degrees. This was suppressed in 30 seconds to around zero.



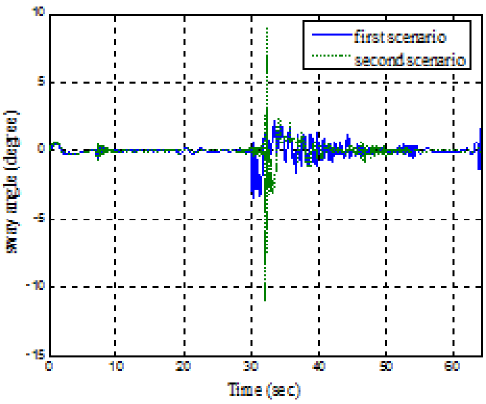
(a) x-direction



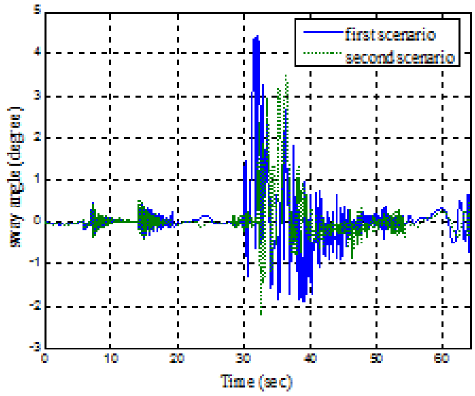
(b) y-direction

Fig. 14 Sway angle of Crane1

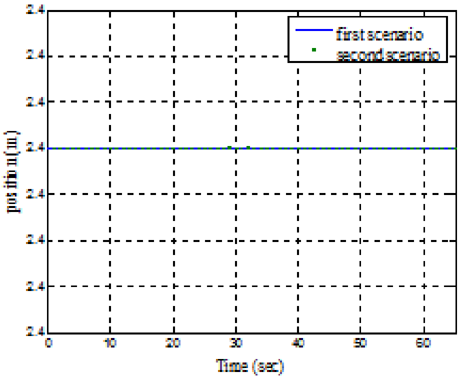
Similarly, Figure 15 shows the sway angle results for Crane 2. It is noted that there was a slight increase in the sway in the x direction at 32 sec. This is due to the initial maneuver of the Crane 2 to move towards the target position after the swap process. However, the results show that the controllers performed well in suppressing the sway of the associated hook and payload. The good payload sway damping ensures the stability of the system



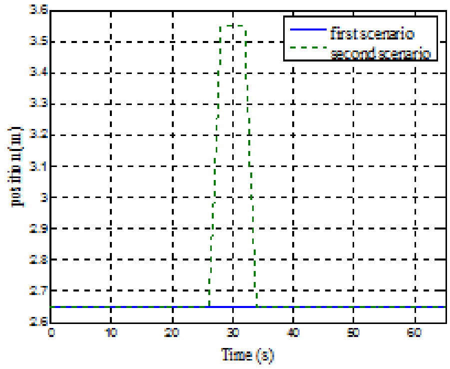
(a) x-direction
Fig. 15 Sway angle of Crane 2



(b) y-direction
Fig. 15 Sway angle of Crane 2



(a) Crane1



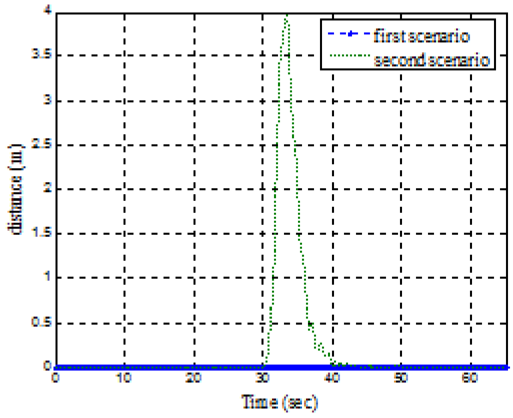
(b) Crane2

Fig. 16 Vertical position of the cranes

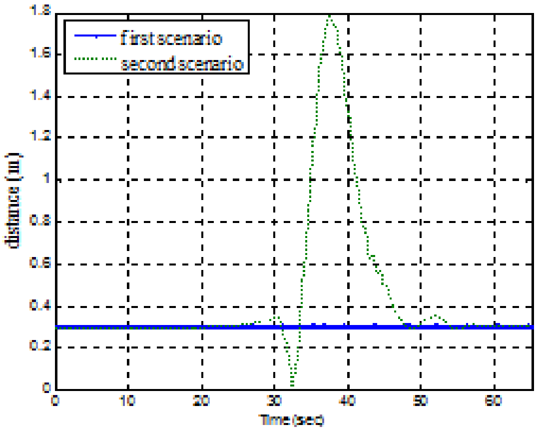
Figure 16 shows the positions of the cranes along the z axis. The normal positions of Crane 1 and Crane 2 in the z direction are 2.4 m, 2.65m; the idea of swap is to position the cranes at required height during the process of picking up the payloads in preparation for a collision-free travel to the target locations. Thus during the period 20 sec to 30 sec, Crane 2, will move upwards in the z direction by about 0.9 m and its movement to the target location will be delayed by 5 seconds. This will provide the system with sufficient clearance to allow Crane 1 to cross Crane 2 without collision. In this manner Crane 1 starts its journey at 30 seconds, while Crane 2 begins at 32 seconds after returning to its normal position.

Figure 17 show the closest distances between Payloads 1 and 2 in the x and y directions. It is noted that the distance remains constant during the first phase. As the swap process begins, a change in the distance is noted at around 30 sec. This corresponds to the time when the Crane 2 moves in the z-direction. The distance is around zero in the x direction after 40 sec, and 0.3m in the y direction after 40sec. However, as noted the distance between the payloads is maintained within the desired minimum safe value.

Figure 18 shows the distance between Crane 1 and Crane 2 in the y direction. It should be noted here that the distance at rest in the y direction is zero because all the cranes are designed in rows one over the other as shown in Figure 2.



(a) *x*-direction



(b) y-direction

Fig. 17 Distance between the payloads

A change in the distance is noted at around 28 sec. This corresponds to the time when the swap process begins. At around 32 sec the distance is noted as zero. This corresponds to the time when crane1 moves under Crane 2 and leads the journey to the target location. At the end a minimum safe distance (0.3m) is realized, and as noted in Figure 18 a collision-free maneuver was achieved.

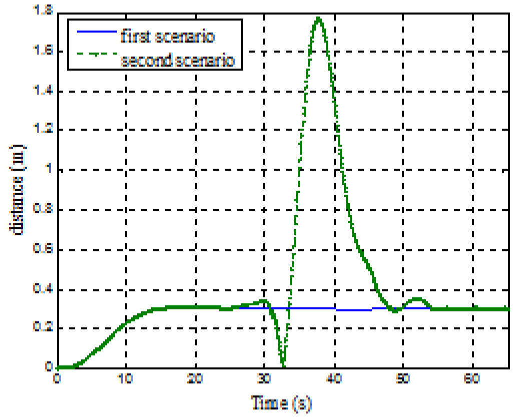


Fig. 18 Distance between cranes in the *y* direction

V. CONCLUSION

An overhead crane with three degrees of freedom has been designed and control strategy to achieve collision free maneuvers has been presented. A second crane has been installed in the same workspace to demonstrate the effectiveness of the developed control system. The modeling has been done using Visual Nastran (vn4d) software environment; this has been integrated with Matlab-Simulink for analysis and control purposes. Four independent PD controllers have been designed for positioning each crane and controlling of sway angle of the payloads. The input commands that drive the overhead cranes have been preconditioned using low pass filters. The simulation results have demonstrated that the new proposed crane design is advantageous when more than one crane is acting in the same work space.

REFERENCES

[1] Khalid, A., Singhose, W., Huey, Lawrence J., and Frakes, J. , D. (2004). “Study of operator behavior, learning, and performance using an input-Shaped bridge crane,” Proceedings of the 2004 IEEE International Conference on Control Applications, Volume: 1, pp. 759- 764, Vol.1.

[2] Glossiotis, G. and Antoniadis, I. (2003). “Payload sways suppression in rotary crane using digital filters,” Proceedings of the Institution of Mechanical Engineers, Journal of Multi-body Dynamics, V. 217. Number 2 / 2003 pp. 99 – 109.

[3] Gupta, S., Bhowal, P. (2004). “Simplified open-loop anti-sway technique,” Proceedings of the IEEE INDICON India Annual Conference, pp. 225- 228.

[4] Miyata, N., Nishioka, M., Ukita, T., Monzen, T., Tokyohara, T. (2001). “Development of Feedforward Anti-Sway Control for highly efficient and safety crane operation,” Mitsubishi Heavy industries Ltd., Technical review Vol. 38, No. 2.

[5] Piazzi, A., Visioli, A. (2002) “optimal dynamic-inversion-based control of an overhead crane,” Control Theory and Applications, IEE Proceedings, Volume: 149, Issue: 5, pp. 405- 411.

[6] Chi-Cheng, C. and Cheng-YI C. (1996). “Controller design for an overhead crane system with uncertainty,” Control Engineering Practice, Volume 4, Number 5, pp. 645-653(9).

[7] Benhidjeb, A. and Gissinger, G. L. (1995) “Fuzzy control of an over head crane performance comparison with classic control,” Control eng. Practice, Vol. 3, No 12, pp. 1687-1696.

[8] Moreno, L., Costa, L., Méndez, J.A. Méndez, S. Torres, A. Hamilton, and Marichal, G. N. (1998).” A self- tuning neuromorphic controller: application to the crane problem,” Control Eng. Practice 6, pp. 1475-1483.

[9] Dadone, P., Vanlandingham, H. F. (2002). “Load transfer control for a gentry crane with arbitrary delay constraints,” Journal of Vibration and control, 8, pp. 135-158.

[10] Burananda, A., Ngamwiwit, J., Panaudomsup, S., Benjanarasuth, T., Komine, N. (2002) “Neural network based self-tuning control for overhead crane systems,” Proceedings of the 41st SICE Annual Conference, Volume 3, pp. 1944 – 1947.

[11] Mohamed z, and Tokhi M. O. (2002),” Vibration control of a single-link flexible manipulator using command shaping techniques”, Proc. Instn. Mech. Engrs., Vol 216, part I: J.

[12] “Signal processing toolbox, for use with simulink users guide,” V. 6, 2006. The Mathworks Incorporated, Natick, Massachusetts.

[13] URL: http://www.atnet.it/lista/support.htm , Lista studio srl, [last accessed on December 2007].

[14] Wahyudi; J. Jalani, R. Muhida and M. J. E. Salami1 (2007) “Control Strategy for Automatic Gantry Crane Systems,” A Practical and Intelligent Approach.International Journal of Advanced Robotic Systems, Vol. 4, No. 4 , pp. 447-456.

[15] Durali, M., Javid, G.A., Kasaiezadeh, A. (2006), “Collision avoidance maneuver for an autonomous vehicle,” 9th IEEE International Workshop on Advanced Motion Control, pp. 249-254.

[16] Slocum, A.H., Awtar, S. and Hart, A.J., 2002, “Magnebots - A Magnetic Wheels based Overhead Transportation Concept”, Proc. 2nd IFAC Conference on Mechatronic Systems, Berkeley, CA.