Anti-swing Fuzzy Controller Design for a 3D Overhead Crane

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Abstract
This paper proposes a simple but efficient technique to control 3D overhead crane. Load must track a desired path and not sway more than a reasonable range.The proposed method uses PID control for trolley to track the desired path and fuzzy control compensation to eliminate the load swing. Only the projection of swing angle is applied to design the fuzzy controller. No plant information of crane is necessary in this approach. Therefore, the proposed method greatly reduces the computational efforts. Effectiveness of the proposed method is illustrated through a simulated example.

Keywords
Overhead crane, Swingangle, Fuzzy controller

1. Introduction

Overhead cranes are essential facilities in factories, harbor industry etc. They have been widely used for material transportation in many industrial fields, due to their low cost, easy assembly and maintenance.The need for faster cargo handling requires the control of the crane motion so that its dynamic performance is optimized. Automatic cranes are comparatively rare in the industrial practice, because of the relation between investment costs and achievable cost saving.Typically, skilled crane operators move a crane slowly to a desired position and make it stationary at the journey’s end. However, overhead cranes have some serious problems: crane acceleration or deceleration always induces undesirable load swing. Disturbances, such as wind and rain, also decrease the crane performance by adversely affecting the crane control. Furthermore, a crane operator may not effectively control a crane due to carelessness or lack of experience. Such problems decrease the work efficiency and in some cases cause damage to the loads and cause accidents. Thus, rapid and smooth automatic cargo handling requires effective and precise crane motion control. Since the swing of the payload depends on the acceleration of the trolley, minimizing the operation time and minimizing the payload swing are partially conflicting requirements. It is a big challenging for control society. The objective of the crane control is to transfer the load to the destination on a desired path as fast as possible; meanwhile, to minimize the swing during the transportation and to stop the trolley precisely at the destination. In this paper a fuzzy logic solution to the anti-swing control of a 3D crane is introduced.

Many people have studied to solve aforementioned problems.Minimal time control used to minimize the load swing [1]. An implicit gain-scheduling method applied in [2] to control the crane. Some researchers also used the dynamic model of the crane to design an optimal path and speed that minimized the load swing [3–7]. However, since the load swing depends on the movement and acceleration of the trolley, minimizing the cycle time and load swing are partially conflicting requirements. Some researchers also applied nonlinear control theory to analyze the properties of the crane system [8–10]. Besides, [11] also developed the modeling and energy-based nonlinear control of the crane lifter. These methods are too complex to implement for the industry use; meanwhile, they took much time to transfer the load smoothly and caused severe swing at the beginning of transportation. In addition, [12] proposed the real-time saturating control strategy for cranes.A centralized control system developed with coupling between the up-and-down and rotation directions to restrain the swing of a jib-type crane[14]. These researches focus the control on the suppression of load swing, but did not solve the problem of position error at the end of crane motion [15]. Some fuzzy-based methods [15–19] were also proposed to control the crane.

In this paper, a method is proposed to achieve the objectives of 3D crane control, including fast moving ofcrane tracking the desired path, anti-swing of the load, and concise designing procedures of controller. One uses PID controller to drive thetrolley in the first part of the control for tracking the desired pathand to apply the projection of swingangle to design the fuzzy controller. A simulated 3D crane example in Visual Nastran software and Simulink environment ofMatlab software is used to illustrate the effectiveness of proposed approach.This method does not use complex plant model of crane todesign the crane controller, but both the positioning andsway problems can be solved. So, the proposed fuzzycontrol method greatly helps to control the complex system.This paper is organized as follows. In section 2 a PID controller is designedfor path tracking and an anti-swing fuzzy controllerin section 3.In Section 4, simulation results are presented toillustrate the merits of the proposed approach. This paperconcludes with a summary in Section 5.

2. Path tracking controller

The physical system of the 3D crane system is composedof a trolley and a flexible cable ties the load, such as shown inFig. 1. Two AC motors drive the trolley along X- and Y-axes.The swing diagram of the load in 3D is shown in Fig. 2.Generally, the motion of the trolley will accompany withswing of load. When the trolley is driven forward, thebackward swing angle can be expected, and vice versa. Thatis, the direction of corresponding swing is contrary to thetrolley motion; meanwhile, the acceleration of trolley willalso cause the additional swing of load. Hence, fast and smooth transferringthe load in the meantime is not easy.Since one of the objectives of the crane control isto transfer the load as fast as possible; therefore, we utilizethe PID control for rapid transportation and path tracking of the load and the fuzzy controller to restrain the load swing.

Fig.1. The physical apparatus of the 3D crane

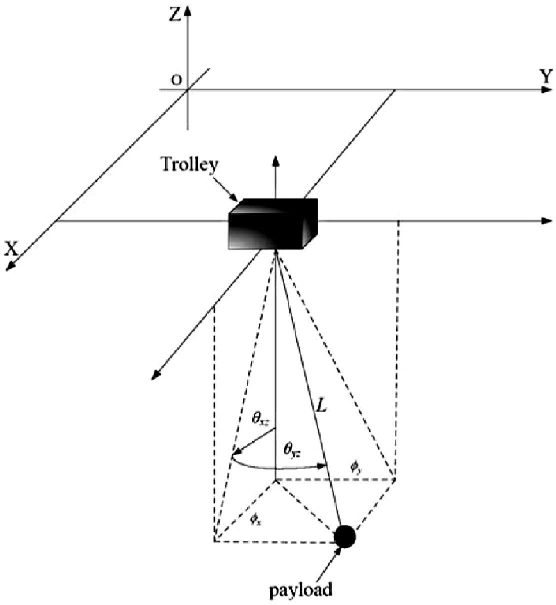


Fig.2. The swing diagram of the 3D crane

The block diagram of the fuzzy crane control system is shown in Fig. 3. The present position of the trolley on the XY-plane is $P \triangleq [p_x, p_y]\epsilon R^2$and the destination at every moment is $D \triangleq [d_x, d_y]\epsilon R^2$The PID control is $U_P = [u_{px}, u_{py}]$ where

$$U = \left(K_P + \frac{K_I}{s} + K_D s\right) E \tag{1}$$

The vector of the position error E is

$$E = D - P = \left[d_x - p_x, d_y - p_y\right] \triangleq [e_x, e_y]\epsilon R^2 \tag{2}$$

Where e_x and e_y are the components of the vector E in thedirections of X-axis and Y-axis, respectively. The constants $K_P = [k_{px}, k_{py}]$, $K_I = [k_{ix}, k_{iy}]$ and $K_D = \left[k_{dx}, k_{dy}\right]$in the PID controller are designed to track the desired path.

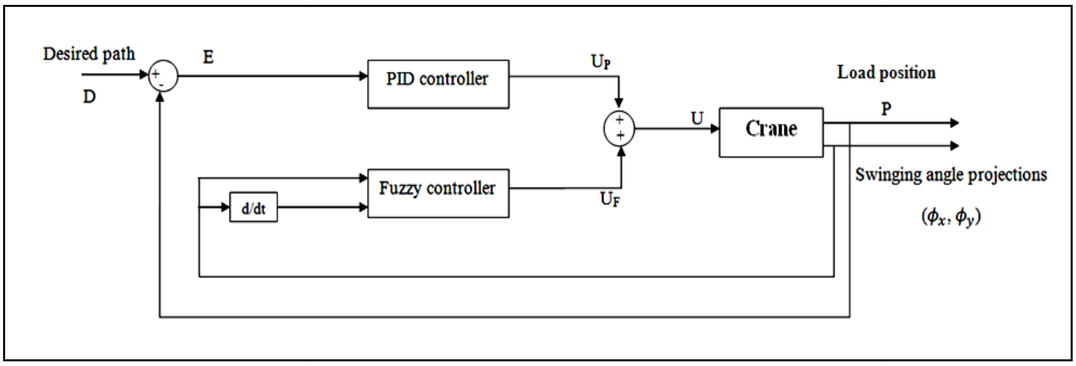


Fig.3. The block diagram of fuzzy crane control system

After the trolley has started to move, the load would swing.To eliminate this undesired swing, PIDcontrol input is compensated byanti-swing fuzzy control input. The proposedmethod utilizes the projection of the 3D swing angleto be the input variable of the fuzzy controller, shownin Fig. 4. The factor of swing angle is taken into considerationin this stage. One denotes the swing angle of theload in 3D space to be

$$\Psi = [\theta_{xz}, \theta_{yz}] \quad (3)$$

We use the projection of 3D swing angle on a 2D planeto present the level of load swing. The severer swing willlead to longer projection, and vice versa. Hence, the projectionof swing angle can be represented by $\phi \epsilon R^2$:

$$\phi = [\phi_x, \phi_y] \quad (4)$$

where ϕ_x and ϕ_y are the projections of swing with respectto the X-axis and Y-axis. Since the projection and theremaining distance are all in length, it is more reasonable toapply both the factors to design the fuzzy output at thesame time. The length of projections can be represented by

$$\phi_x = L\sin(\theta_{xz}) \quad (5)$$

$$\phi_y = L\sin(\theta_{yz}) \quad (6)$$

L is the fixed length of the flexible wire hanging the load.These projection vectors are depicted in Fig. 4.

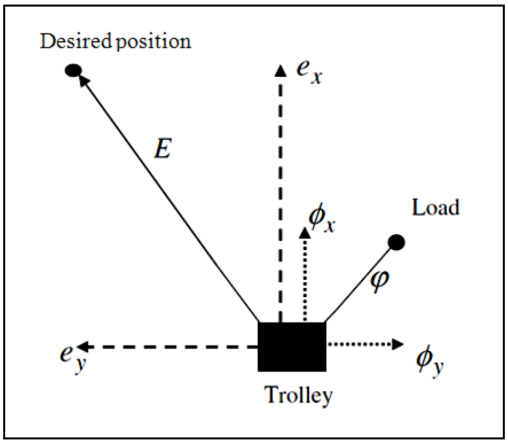


Fig.4. The concept of the projective method

3. Anti-swing fuzzy controller

Two motors for X- and Y-axes are used to drive thecrane. One uses ϕ_x and $\dot{\phi}_x$ to be theantecedents of fuzzycontroller to derive the fuzzy control for X-axis motor, andthe other applies ϕ_y and $\dot{\phi}_y$ to derive the control for Y-axismotor. Suppose that the output of the fuzzy controller isU_F, where the output acts as the fuzzy function of inputvariables,

$$U_F = (u_{fx}, u_{fy}) = (f_x(\phi_x, \dot{\phi}_x), f_y(\phi_y, \dot{\phi}_y)) \quad (7)$$

where $\phi_x, \dot{\phi}_x$ and $\phi_y, \dot{\phi}_y$ are the input variables, f_x and $f_y$represent for the functions of fuzzy controller, and u_{fx} andu_{fy} are the fuzzy output power to drive the X- and Y-axesmotors. In this case, we use nine linguistic states for eachinput variable ϕ_* and $\dot{\phi}_*$ to fuzzify the input variables anduse 9 states for output variables u_{f*}. The notation ‘‘*’’means ‘‘x’’ or ‘‘y’’ and the linguistic states are shown inFig.5. The dynamic ranges are [-1m,1m],[-1m/s,1m/s] and [-5000N,5000N] for ϕ_* , $\dot{\phi}_*$ and u_{f*}. Onenames the nine linguistic states of variables ϕ_* , $\dot{\phi}_*$ and u_{f*} as Negative Big_Big (-4), Negative Big (-3), Negative Middle (-2), Negative Small (-1), Zero (0),Positive Small (1), Positive Middle (2), Positive Big (3) and Positive Big_Big (4).

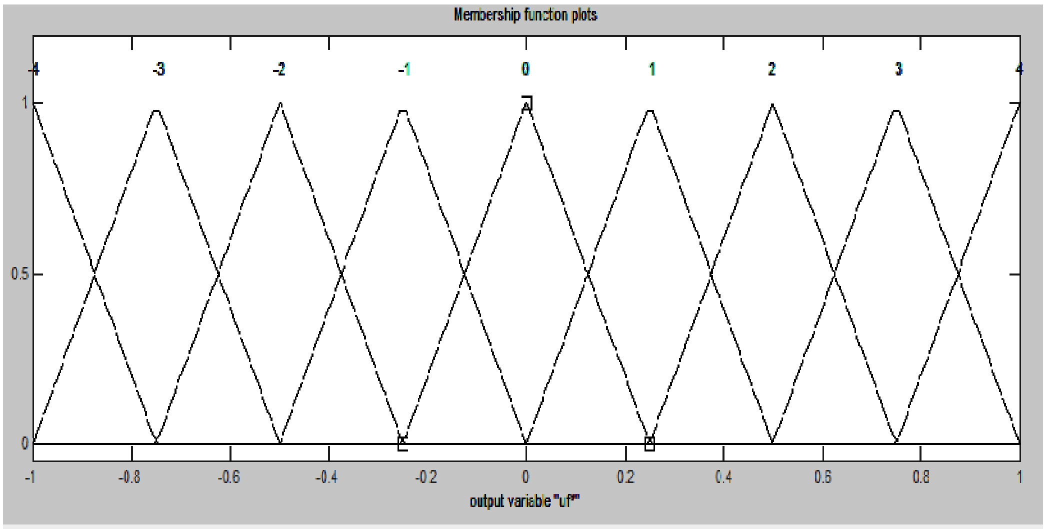


Fig.5. The linguistic state of fuzzy variables ϕ_* , $\dot{\phi}_*$ and u_{f*}

The output of the fuzzy controller U_F is obtained by combining the rules defined in Table 1 using minimum inference and centroid defuzzification [20]. We use the output signals to control the X- and Y-axes motors.

Table1. Rule base of the fuzzy controller

ϕ_*	$\dot{\phi}_*$								
	-4	**-3**	**-2**	**-1**	**0**	**1**	**2**	**3**	**4**
-4	-4	-4	-4	-4	-4	-3	-2	-1	0
-3	-4	-4	-4	-4	-3	-2	-1	0	1
-2	-4	-4	-4	-3	-2	-1	0	1	2
-1	-4	-4	-3	-2	-1	0	1	2	3
0	-4	-3	-2	-1	0	1	2	3	4
1	-3	-2	-1	0	1	2	3	4	4
2	-2	-1	0	1	2	3	4	4	4
3	-1	0	1	2	3	4	4	4	4
4	0	1	2	3	4	4	4	4	4

The control surface of the anti-swing fuzzy controller is shown in Fig.6.

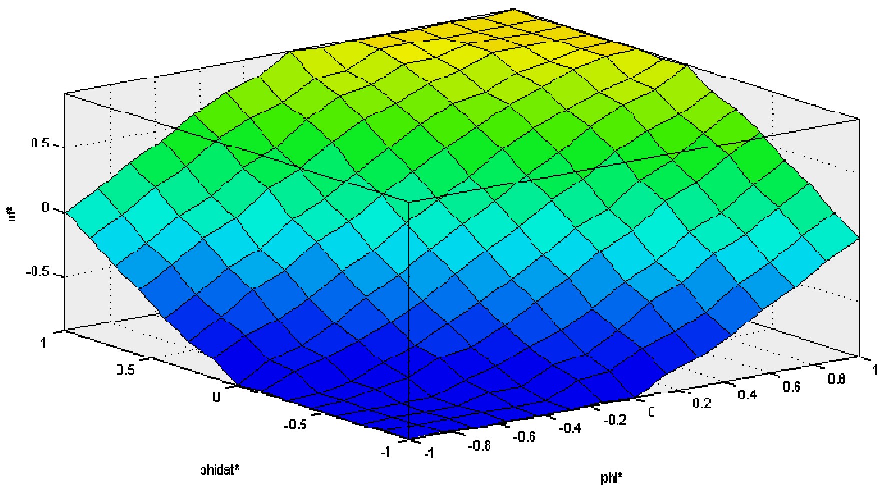


Fig.6. Control surface of the fuzzy controller

Since the factors to reach the destination and to eliminatethe swing are both taken into consideration to designthe fuzzy rule-based crane controller, the proposed methodguarantees that the swing is suppressed meanwhile thecrane is driven along the direction to track the desired path.The position error$E$ and swing level ϕ also present the objective of control. Thus, the purpose ofcrane control is to minimize E and ϕ.However, there is aflexible wire between the trolley and load. The control toeliminate E and ϕ is not on the same surface, and power isnot necessary to transfer completely from the trolley to theload. Therefore, some nonlinear properties will exhibit.Besides, the control through the flexible wire also increasesthe nonlinearity and complexity. Hence, nonlinear controllerwould be the more proper choice to design the cranecontroller. This is the main reason why the author chosefuzzy-based controller in this work.

4. Simulation results

A 3D crane model was built in the Nastran software to illustratethe effectiveness of the proposed method. This 3D model is shown in Fig.7. Two actuators for X- and Y-axes are applied to drive the overheadcrane system. Four sensors send the information ofthe present position (including the coordinates of X- and Y-axes)of the load and the swing angles projections of the load, ϕ_x andϕ_y to the controller. Controller was built in Simulinkenvironment of Matlab software and received data from Nastran and after calculating the control forces, sent them to the 3D simulation environment in Nastran.The load is a steel ball of radius 0.2 m and its weight is263Kg. The length of the hanging flexible cable is 2.55 m.

It is considered thatthe desired path of the load is a sinusoid path that is determined in Fig.7, whilethe initial position of the load is at origin (0 m,0 m).

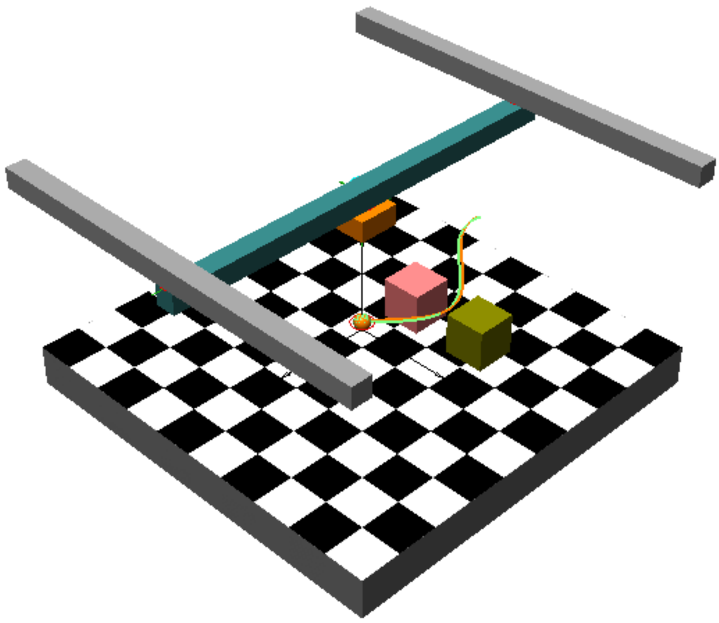
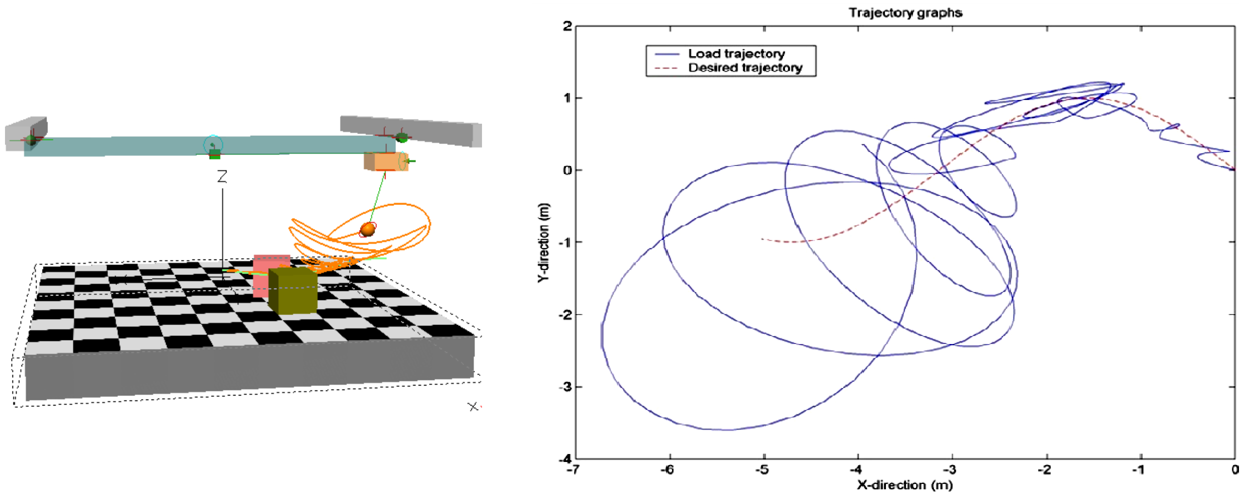


Fig.7. 3D crane model in Nastran software

The corresponding constants in the simulation are K_P = [2000, 2000], K_I = [0, 0], and K_D = [6000,6000].Fig. 8 shows the simulation results with only the PIDcontroller without the fuzzy compensator. Fig.8a shows the path traveled by the load in 3D view and Fig.8b in 2D view. Onecan find that the trolley is driven fast but with severe swing of the load.Fig. 9 shows the load trajectory with the proposed method. One can find that the load tracked its desired path.Meanwhile, the swing angles of the proposed method suppressed very well. Fig. 10 shows the swing angle projections ϕ_x and ϕ_y, which are very small in comparison with the ball radius. Maximum of swing angle projection is about 0.04 m and the ball radius is 0.2 m.



a.3D view b. 2D view

Fig.8. Load trajectory (PID controller and no fuzzy compensator)

Besides, the proposed fuzzy-based controller does not need to drive the trolley back and forth to control the swing, which also reduces the chance of load damage. No plant information applied to design the controller that helps to simplify the controller design.

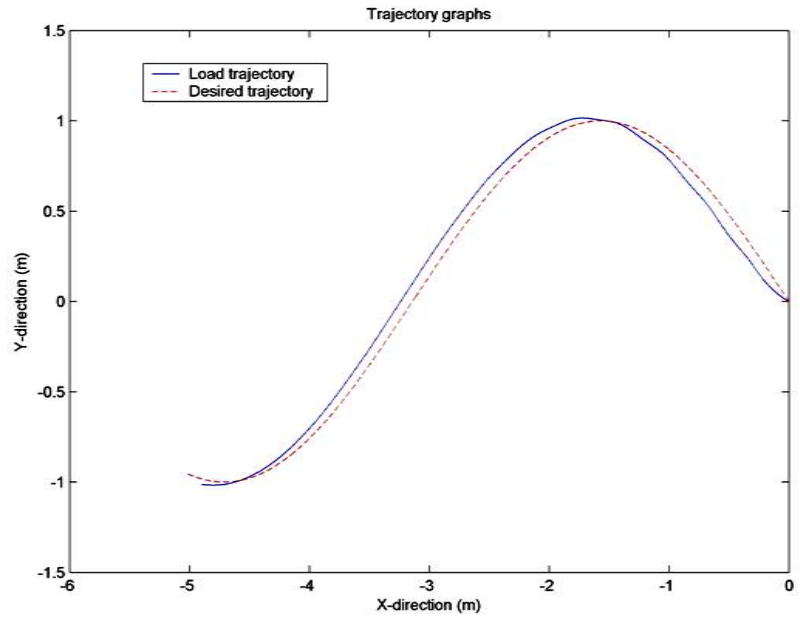


Fig.9. Load trajectory with proposed method

5. Conclusion

A simple but effective method is proposed to control the 3D crane system. This method is based on the position error and projection of the swing angle to design the crane controller. There are no complex dynamic equations of the crane that have to be taken into consideration in the controller design. Simulation results show that the proposed method can greatly restrain the swing without exposing the performance to fast traveling.

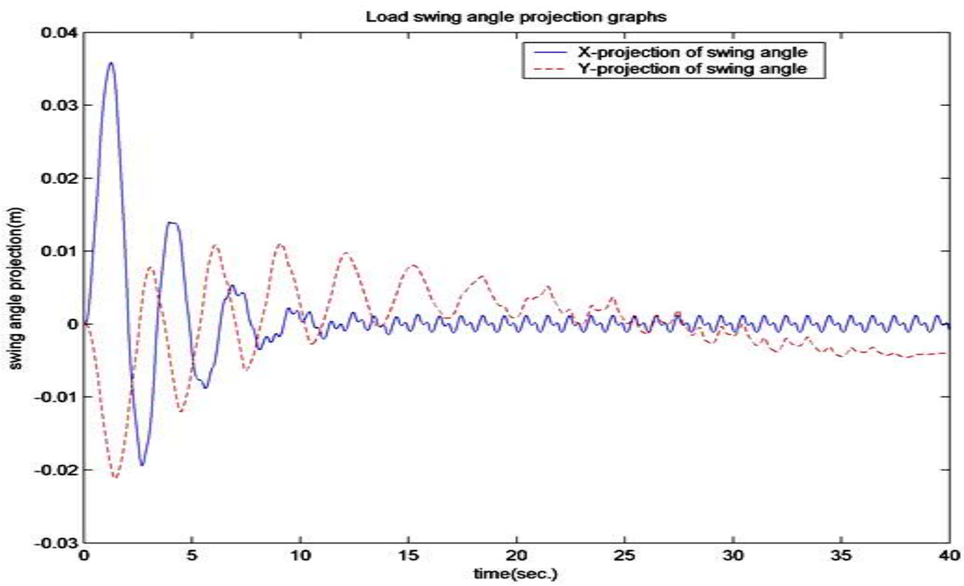


Fig.10. Swing angle projections with proposed method

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