Position Regulation And Sway Control Of A Nonlinear Gantry Crane System

Abdullah Cakan, Umit Onen

Abstract: This paper presents a controller design for position and sway control of nonlinear gantry crane system. Two-dimensional crane system is modelled by using MSC ADAMS. A realistic model is obtained since there is no simplification and linearization on the model. All mass and inertia properties of system components were taken into consideration as were in reality. The hoisting cable was treated as elastic and the first six modes are used in calculations. PD controllers are designed in MATLAB/Simulink for trolley position regulation and sway control of crane system. Performance of the proposed control scheme is tested for different inputs. Simulation results are given for evaluation and discussion.

Index Terms: Gantry crane, MSC Adams, position control, sway control, nonlinear system, PD control, simulation

1 Introduction

Cranes are commonly used for heavy material transportation in many area such as industry, construction and shipping. They can be classified according to their dynamics and mechanical structures. Although the physical structure of crane systems varies, flexible hoisting cable used for lifting and transporting the load is constant. Use of flexible hoisting ropes causes the reduction of the system mass and provides high motion speed, high payload ratio and low power consumption. While this element provides a main benefit of cranes, payload oscillations are the biggest problems in the crone systems. Gantry crane is used to transfer the payload from one position to desired position that is a common type of cranes. This type of cranes contain a trolley that is moving in a horizontal surface. The payload is mounted to the trolley with a cable, the length of cable can be change by pulley mechanism. During the transportation process, the load behaves like a pendulum and freely sway. If the sway reaches a critical limit, it must be absorbed or the process must be stopped until the sway is disappear. The goal of control of a crane system is transport the payload from one position to another as fast as possible without causing extreme sway. The gantry crane system is a typical model of a nonlinear underactuated system that has less control inputs than its number of degrees of freedom. This underactuation characteristic occurs an effect between the payload sway angle and the trolley position. Moreover, safety problems are appear in gantry crane systems because of uncontrolled payload swing dynamics that makes it more demanding to control them. Various control techniques were developed for sway control of cranes in many years. These techniques can be classified in two groups these are closed loop or open loop control.

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There are many control study based on open loop system in controlling cranes system. Earlier open loop optimal control strategies is used in the overhead cranes by many scientists [1-2]. Because of the open loop control is precision for the characteristics of system and can't suppress the disturbances poor results are came out. Input shaping control is another importance of open loop control strategy [3-7]. The input shaping controller is another open-loop control method. However, a lot of closed loop control methods applied to eliminate extreme sway motion effects of disturbances. Linear feedback control [8], nonlinear feedback control [9], closed-loop control based on root locus [10, 11], closed-loop controller based on LQR [12], PD [13-17] and PID control [18], Fuzzy Logic Control [19-22], Fuzzy - PID Control [23] and ANFIS control [24] are some of them.

2 Gantry Crane Model

A two-dimensional gantry crane system is considered in this study. The crane system is modelled by using MSC ADAMS instead of using mathematical equations. More realistic crane model is obtained since there is no simplification and linearization on the model. MSC ADAMS model of the crane is shown in Fig. 1.

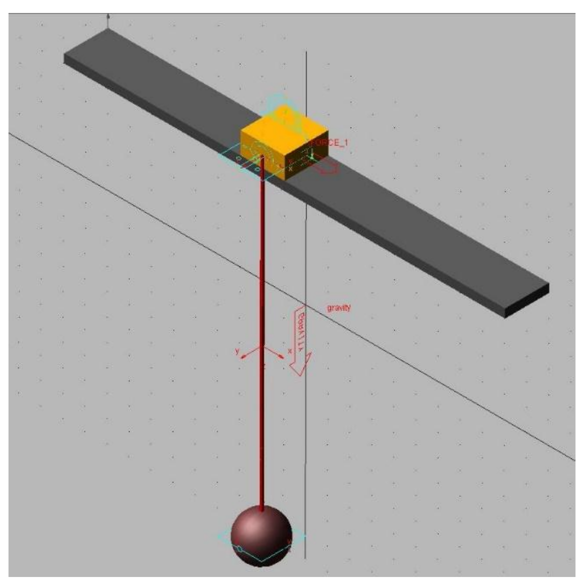

Figure 1. *MSC ADAMS model of gantry crane*

Gantry crane's simplified system model is shown in Figure 2. In this figure the trolley's motion direction *X*, the sway angle of the payload *θ(t)*, the position of the trolley *x(t)*, the elastic cable length *L*, the mass of trolley m_T, the mass of payload m_P and he control force that is applied to the trolley *F(t)* in the *X* direction shown respectively.

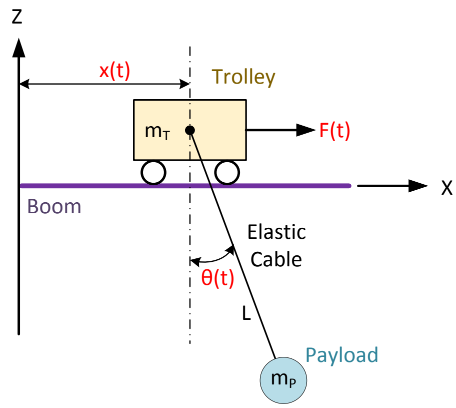

Figure 2. *Simplified gantry crane model*

3 Controller Design

Designed crane system has a single actuator for actuating two different variables. Horizontal position of the trolley and sway angle of the payload are the variables which are controlled by the horizontal movement of trolley. This crane system is a good example of underactuated systems. Control action becomes harder since two different variables are controlled with a single actuator. We have proposed a dual PD control scheme for tracking control and sway control of this gantry system. The controllers are designed by using MATLAB/Simulink software. The aim of the proposed control scheme is controlling the trolley position (X_{act}) so that it moves to the reference position (X_{ref}) as quickly as possible without extreme sway angle of the load (θ_{act}). Designed control scheme consists of a trolley controller and a sway controller and shown in Figure 3. Actual trolley position X_{act} is compared with the reference trolley position X_{ref} and resultant position error is attempted to be zero while the actual sway angle θ is attempted to be zero. Controller parameters given in Table 1 are determined by trial and error method.

Table 1. *Controller parameters*

	Kp	Kd
Trolley Controller	0.1	20
Sway Controller	2.2	1.2

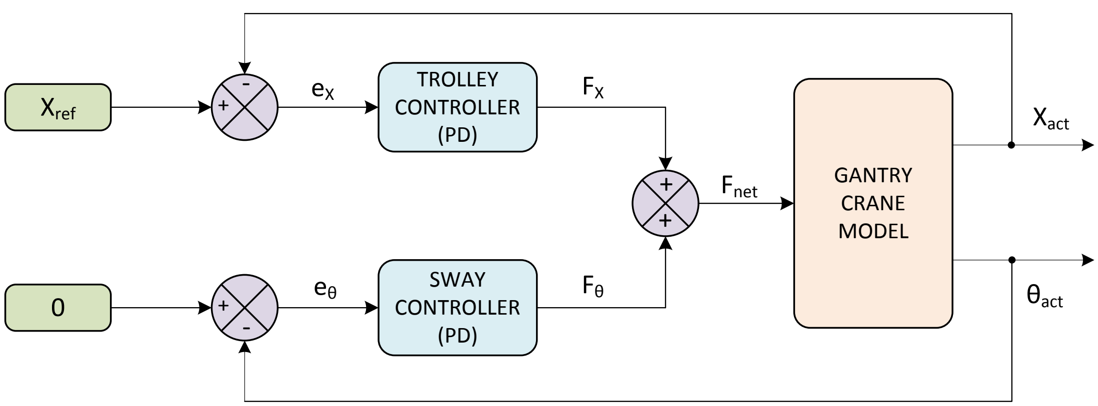

Figure 3. *Proposed Dual PD control scheme*

4 Simulations and Results

Gantry crane model created in MSC ADAMS was transferred to MATLAB/Simulink for controller design and simulations. All mass and inertia properties of system components were taken into consideration. The cable was treated as elastic and the first six modes are used in the calculations. Specifications of the model used in simulations are given in Table 2. Although the system is dimensionally smaller, it is very closer to real system in terms of system dynamics since it was modelled without any simplification and linearization. Tracking and sway control performances of proposed controller are tested for different step inputs. Simulation results are given in Figure 4 – Figure 6. As seen from these figures, proposed Dual PD controller can successfully control the sway of payload while tracing the reference trajectories in case of 0.2 m, 0.4 m and 1 m step inputs.

Table 2. *Specifications of System Components*

Mass of Trolley (m_T)	3.9 kg
Mass of Payload (m_P)	2.0 kg
Length of Elastic Cable (L)	0.75 m
Diameter of Elastic Cable (d)	0.005 m
Young's Module of Cable (E)	2×10^{11} N/m^2
Density of Cable (ρ)	7800 kg/m^3

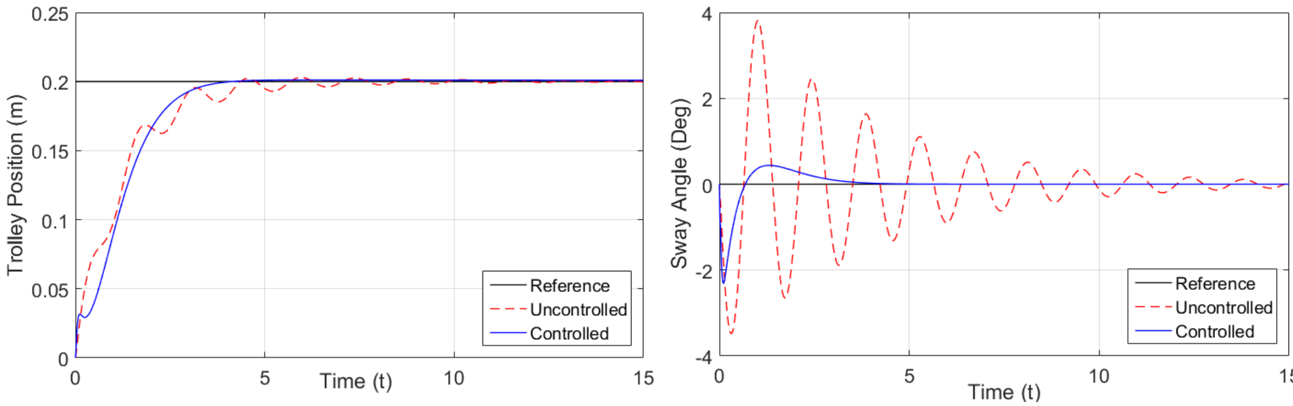

Figure 4. *Variation of trolley position and sway angle in case of 0.2 m step input*

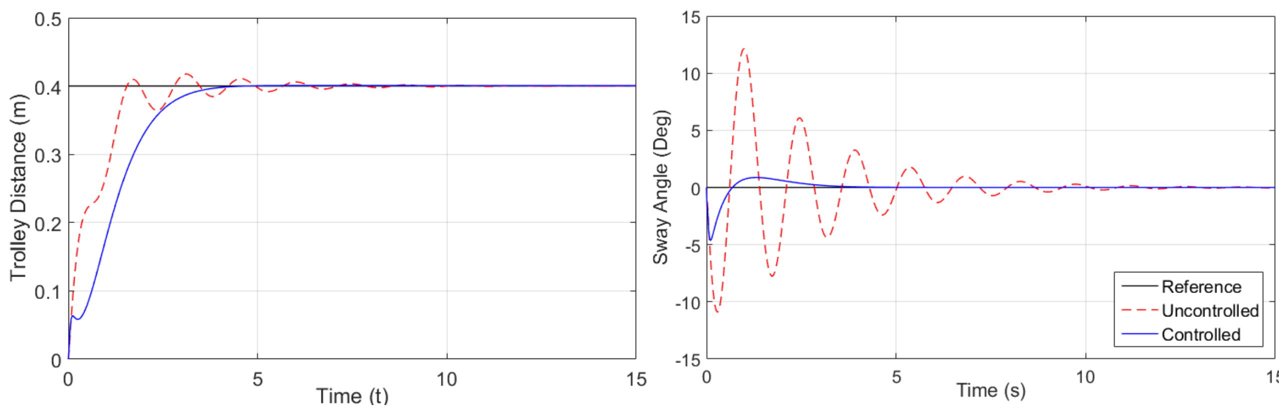

Figure 5. *Variation of trolley position and sway angle in case of 0.4 m step input*

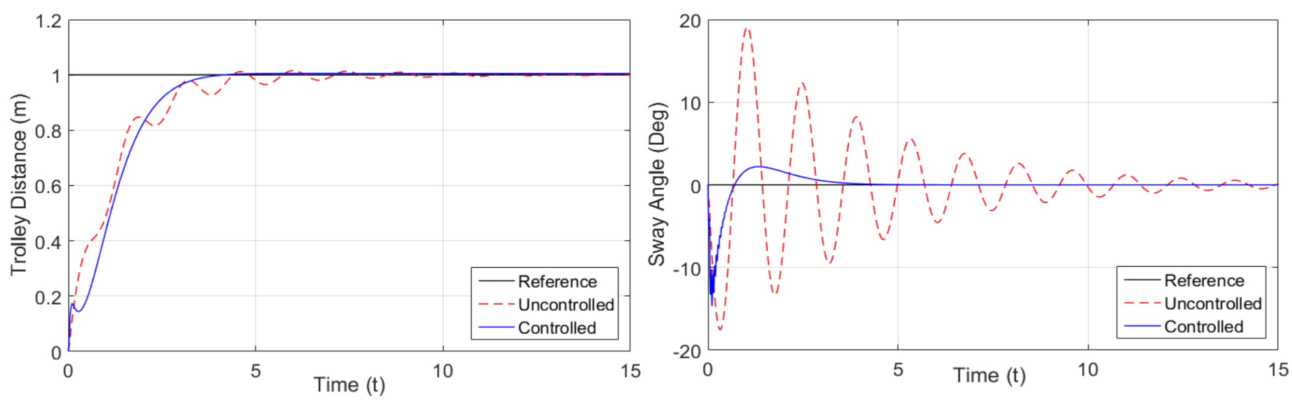

Figure 6. *Variation of trolley position and sway angle in case of 1 m step input*

4 Conclusion

A sway control of a nonlinear gantry crane model is investigated in this study. Unlike most of the studies in the literature, the crane model is not simplified and linearized. All mass and inertial properties of system components were taken into consideration as were in reality and the hoisting cable was treated as elastic. For such a nonlinear underactuated system, controller design is a challenging task. But, simulation results showed that designed controllers can provide a sufficient performance for tracking control and sway control. In future work, we will investigate the controller performance in case of disturbance. If the performance of PD control will be insufficient under disturbance, Fuzzy or ANFIS controllers will be designed.

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