DYNAMIC MODELLING AND CONTROL OF A REACTION WHEEL INVERTED PENDULUM USING MSC ADAMS AND MATLAB

Abdullah Çakan[1], Ümit Önen[2]
[1]Department of Mechanical Engineering, Faculty of Engineering and Natural Sciences,
Konya Technical University, Konya, Turkey
[2]Department of Mechatronics Engineering, Faculty of Engineering and Architecture,
Necmettin Erbakan University, Konya, Turkey
e-mail:acakan@ktun.edu.tr

Abstract: In this study, control of a reaction wheel inverted pendulum system is modelled in virtual prototyping environment is proposed. Virtual prototype of the reaction wheel inverted pendulum is created using several softwares. Firstly, the system is created by using SolidWorks and imported to MSC Adams, afterwards the control plant model is exported to MATLAB for design the controller and apply the system. A PID controller (Proportional-Integral-Derivative) is designed and applied for the purpose of balance control of the system. The results show that modelling and control the reaction wheel inverted pendulum is successfully achieved the control simulations. Results are given in the form of the graphics.

Key words: modelling, control, reaction wheel, inverted pendulum, simulink, mscadams, co-simulation.

INTRODUCTION

Inverted pendulum systems are widely studied in control systems area to compare control techniques as a benchmark problem. There are many different inverted pendulum types such as rotary inverted pendulum, single or double link cart pendulum systems and the reaction wheel inverted pendulum [1-4]. In this research, reactional wheel inverted pendulum system is studied. Reaction wheel is a flywheel that is used in many systems such as satellites attitude controls, drive the robots and vibration control systems [5-8]. The Reaction wheel inverted pendulum also known as inertia wheel inverted pendulum is a pendulum system consist of a rotating wheel on top and a simple inverted pendulum rotating about a pinned joint. Also, many control techniques are studied using these different type inverted pendulum systems [9-11]. PID controller is very comprehensive and effective that's why it is commonly used. Therefore, a PID controller is applied to balance the pendulum in this research. PID controller is implemented to the system by using MSC Adams and Matlabco-simulation. MSC Adams is an effective way to modelling the mechanical systems and exporting the control plant to the Matlab/Simulink [12].

MODELLING AND CONTROL

In this section modeling and control of the reaction wheel inverted pendulum system is described. CAD model of the system is designed on the basis of [13] by using SolidWorks. Designed reaction wheel inverted pendulum system is shown in Figure 1. and the system parameters are shown in Table 1.

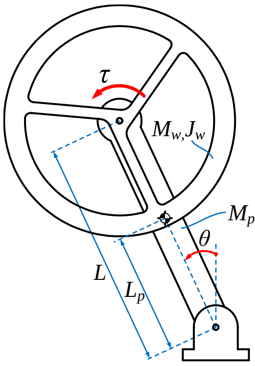


Fig. 1. Reaction wheel inverted pendulum system.

Table 1. Reaction wheel inverted pendulum system parameters.

M_w	Mass of reaction wheel	0.554 kg
M_p	Mass of pendulum	0.141 kg
J_w	Wheel mass moment of inertia	$4.36 \text{x} 10^{-3} \text{kgm}^2$
J_p	Pendulum mass moment of inertia	$0.69 \text{x} 10^{-3} \text{kgm}^2$
L	Pendulum length	0.21 m
L_p	Pendulum center of mass length	0.11 m
τ	Control torque	Nm
θ	Pendulum angle	degree

Designed CAD model is imported to MSC Adams that is a multi-body modeling software to build and simulate mechanical systems dynamic analysis. Therefore, equation of motion of the reaction wheel inverted pendulum is not used to simulate the system. The reaction (inertia) wheel inverted pendulum consist of a reaction wheel on top and a simple inverted pendulum rotating about a pinned joint. Control torqueis applied to the reaction wheel as input to balance the pendulum for the desired positionas output of control system using Matlab/Simulink and MSC Adams co-simulation. Pendulum angular velocity and wheel angular velocity values also defined as outputs of the system.Control system of the reaction wheel inverted pendulum is shown in Figure 2.

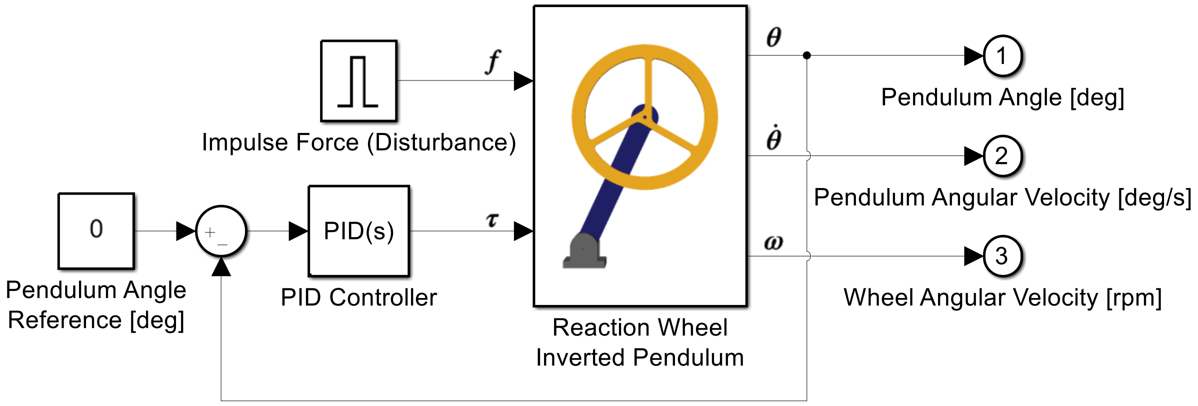


Fig. 2. Control block diagram of MSC Adams and Matlab co-simulation.

As seen in the control block diagram, an external force applied as disturbance in the4th second and the results are realized. Disturbance impulse value is 0.5 N-s and details of the disturbance shown in Figure 3.Initial position of the pendulum is -25 degree and pendulum angle is controlled to balance pendulum vertically using manually tuned (trial and error) PID controller, according to system response and PID constants determined as K_p=5, K_i=0.05and K_d=1.

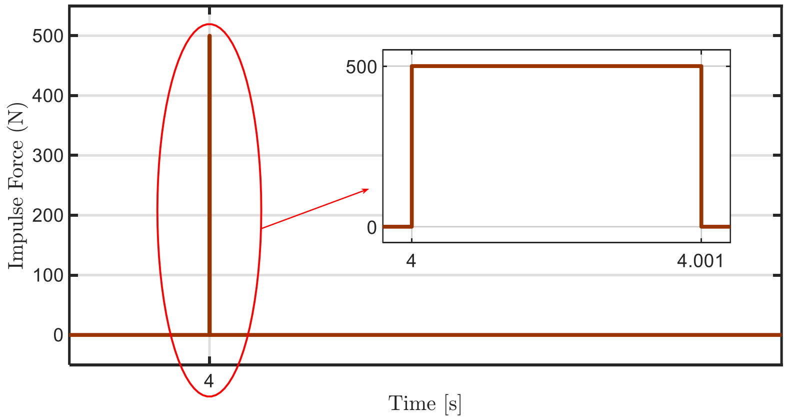


Fig. 3. 0.5 N-s impulse disturbance applied to the center of reaction wheel.

RESULTS AND DISCUSSION

Desired pendulum position is 0 degree both in the beginning of the simulation and in the 4th second when the disturbance is applied. PID Controlled pendulum position response is shown in Figure 4. As seen in the figure PID controller successfully achieved the desired position of the pendulum in less than one second. Moreover, Pendulum angular velocity and wheel angular velocity are also realized and given in Figure 5. and Figure 6. respectively. Control torque output of the PID controller (control input of the reaction wheel inverted pendulum system) is shown in Figure 7. Snapshots of the MSC Adams simulation is shown in Figure 8. In order to see the results clearly time axis of the figures are widened.

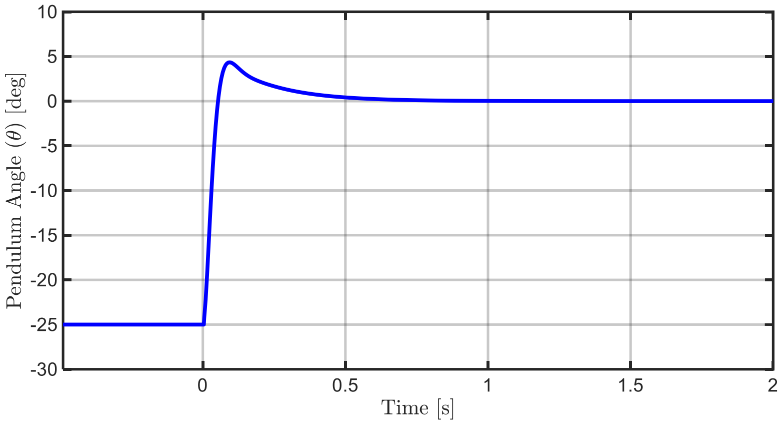


Fig. 4. Pendulum angle response of the system.

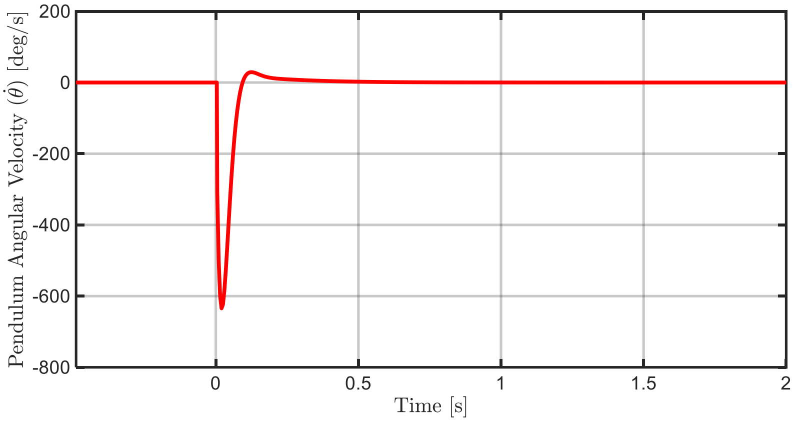


Fig. 5. Pendulum angular velocity response of the system.

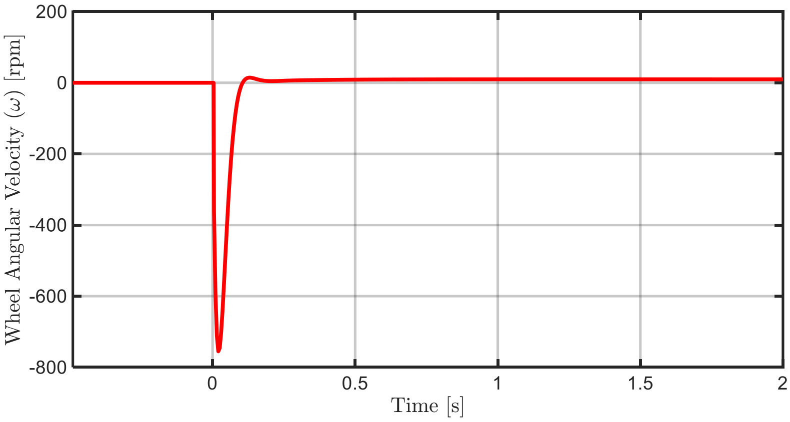


Fig. 6. Reaction wheel angular velocity response of the system.

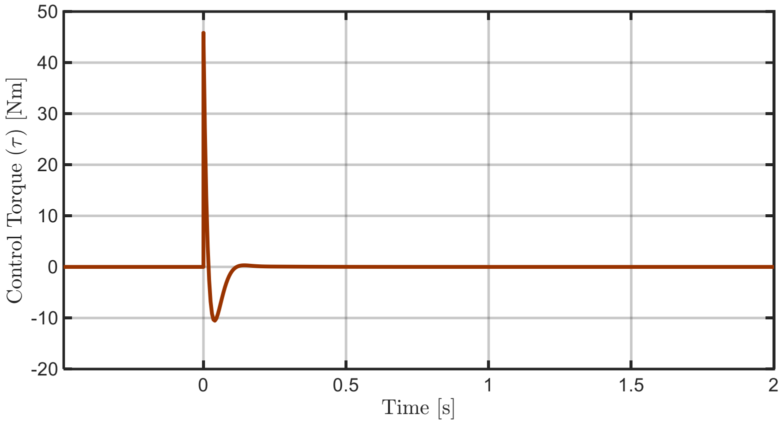
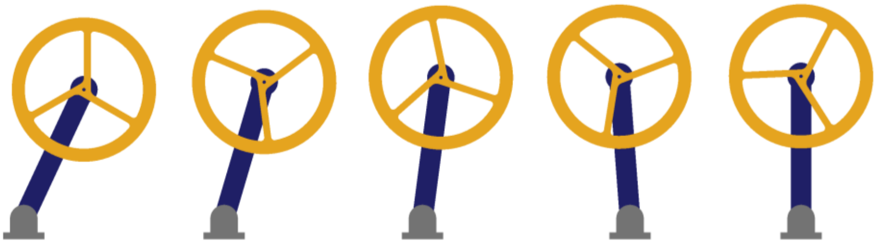


Fig. 7. Control torque for the balance the system -25 degrees to 0.



t = 0 s , θ=-25° t = 0.02 s , θ=-16° t = 0.035 s , θ=-7° t = 0.095 s , θ=4° t = 1 s , θ=0°

Fig. 8. Snapshots of MSC Adams simulation -25 degrees to 0.

As mentioned in previous paragraphs 0.5 N-s impulse is applied to the center of wheel of the inverted pendulum system in the 4th second after the balanced from the initial position -25 degrees. Pendulum position response after the disturbance impulse is shown in Figure 9. and the snapshots of MSC Adams simulation is shown in Figure 10.

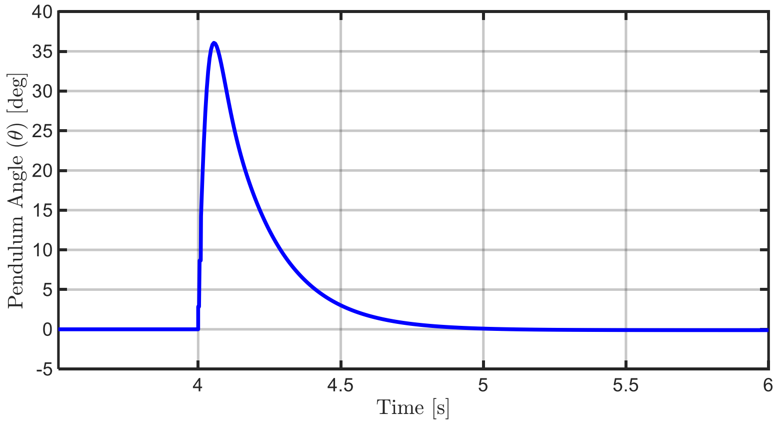
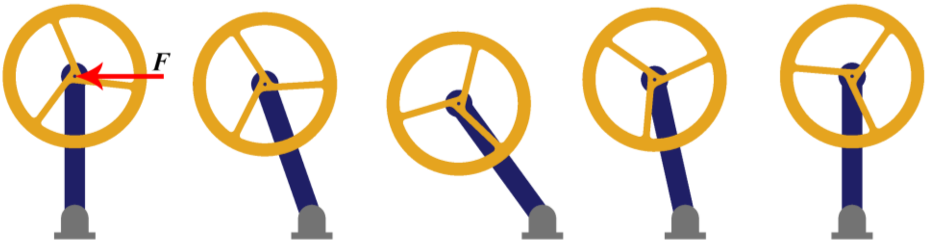


Fig. 9. Pendulum position response after the disturbance.



t = 4 s , θ=0° t = 4.015 s , θ=19° t = 4.055 s , θ=36° t = 4.25 s , θ=12° t = 5 s , θ=0°

Fig. 10. Snapshots of MSC Adams simulation after the disturbance.

CONCLUSION

The paper presents virtual prototyping approach of a reaction wheel inverted pendulum system. Virtual prototyping make easy modelling mechanical systems without using equation of motions. Designed system using SolidWorks is imported to MSC Adams, inputs are outputs are derived to create control plant and exported to the Matlab/Simulink to run combined model and apply PID controller. PID controller gains are manually tuned (trial and error) to balance the pendulum in the vertical position applied, (0 degree) both beginning of the simulation and after applied the disturbance impulse. Controller is successfully achieved desired pendulum position. According to results, co-simulation method is an effective and easy way to modelling the control systems. For the better results optimization algorithms can be used to determine PID gains or different control techniques can be used. Furthermore, this study can be a reference to the modelling and control studies of the mechanical systems especially different type of pendulum systems for the future works.

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