Developing a control for a double inverted pendulum with Siemens CNC

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Abstract

Introduction

Siemens Sinumerik 840d sl CNC control system is widely used for machine tools and other production machine applications, such as laser machining and handling systems [1]. Typical program of machine tools or production machines defines line by line instructions stating position of the axis for the upcoming state and what is the movement like during the motion [2]. Typically, g-code programs don't use any intelligence or feedback control loops in it. To test the performance of the Siemens CNC control system, a double inverted pendulum was implemented with it.

Inverted pendulum is a classical testing application for the different control systems and methods. Without control the inverted pendulum is unstable and it will fall from its upward position. Our research area includes usage of double inverted pendulum in balancing two rods which makes it more challenging to stabilize. Inverted pendulums are usually implemented with cart, belt, rotating DC motor and with simple microcontroller control, for example.[3] Depending on the system used and its dimensions, the response is different. However, working control for the inverted pendulum could stabilize the pendulum in less than 2 seconds, when magnitude of disturbance is around 20 degrees [4].

In this research project, Siemens Simotics L-1FN3 linear motor is used to move the pendulum. Typical fields of applications for this type of linear motor is high-performance machine tools and production machines [5]. Linear motor is optimal component for the double inverted pendulum. The pendulum needs precise and fast control and those are advantages of linear motors compared to other solutions. With linear motor the set-up of the system is also more robust, because of fewer amount of moving parts involved in it.

The application could be for demonstrating the capabilities of the Siemens' technologies. Also this research would help explore the applicability of G-codes for intelligent self-stabilizing ability of the linear motor. This could be useful for research and educational institutions for teaching purposes.

System description

Inverted pendulum

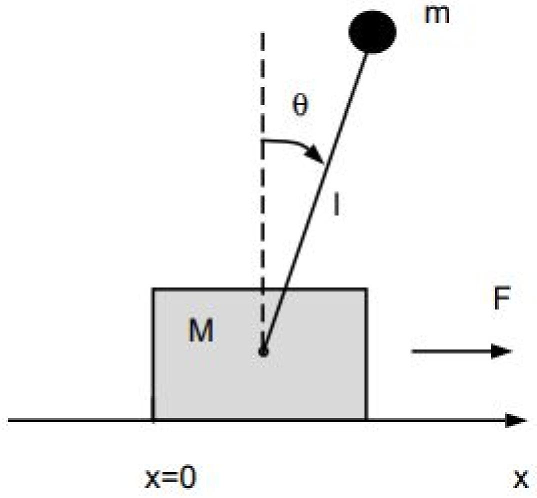

Figure 1. Model of inverted pendulum.

M: Mass of the linear motor's sledge
m: Mass point in pendulum's top
x: Position of the motor
θ: Angle of the pendulum
I: Inertia of the pendulum
F: Force from the motor

Siemens Sinumerik 840D sl

Sinumerik 840D sl is an industry standard for CNC machines' control system. It's capable to controlling 93 axes and up to 30 machining channels. In our application it is used to control the Simotics linear motor and the encoder data is also handled via the Sinumerik 840D sl. G-code is used to control the linear motor and eventually stabilizing the pendulum.

Siemens Simotics L-FN3 Linear motor

Simotics L-FN3 linear motors are very compact and they feature superior performance to force density. Accuracy and precision are the key features that linear motor can offer and these features are important to accomplish the inverted pendulum.

Mechanical design of the pendulum

First prototype of the pendulum and the bracket for it can be seen in the picture on the right. This bracket is functional but there is still some improvements to be made for the structural strength. Upgraded bracket will have couple of cross support to prevent the whole system wobbling when stabilizing the pendulum.

Control

Full state feedback controller was used for balancing the pendulum. It was developed using LQR (Linear Quadratic Regulation) method. First, the non-linear equations of the system dynamics were determined. Then those equations were linearized around the upward equilibrium position of the pendulum, and the state space model of the system was solved. Matlab was used to analyzing controllability of the system and for determining the control gain vector K. Weighting matrices Q and R were selected by trial and error. With vector K, the optimal control of the system y = -Kx could be determined.

Another option to control the pendulum is PID controller. The pendulum will be tuned with trial and error method. In the start the swingup function is used to swing the pendulum to upright position and after that the PID controller can take control of the pendulum.

Results

Discussion

Reference

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