Inverted Pendulum Teaching Experiment Platform Based on MATLAB-DSP

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Abstract. This paper presents a new teaching platform for the inverted pendulum based on MATLAB-DSP integrated development environment. The teaching platform shows some advantages, including high efficiency, low cost, friendly interface and the function of testing dynamic process and rework parameters on line. It plays an important role in the teaching of modern control theory. The experiment platform can convert Simulink model to DSP executable code automatically, so the students can specialize in the study control algorithm. After finish this experiment, students not only learn a lot of knowledge, but also lay a good foundation for the future research work.

Introduction

Inverted pendulum is a natural unstable object and a typical device of the study of control theory. It can effectively reflect many problems of the controlling process, such as nonlinear problems of system, robustness, stabilization and tracking problems. In university, it can help students master control theory through this experiment. It always takes a long time for students to accomplish the real-time control program in traditional control system experiment, so the effect of teaching can’t be guaranteed. This paper presents a new teaching platform for the inverted pendulum based on MATLAB-DSP integrated development environment. The process of system design, simulation and experiment could be conducted smoothly in one integration platform. After finish this experiment, students can learn a lot of knowledge, for example: MATLAB modeling and simulation, DSP TMS320F2812, CCS software, mathematical modeling and others.

Design of the Experiment Platform

The experimental platform combines MATLAB software and DSP development environment as a whole, it mainly used in the teaching work of undergraduate and graduate students. First of all, hardware and software platform of inverted pendulum control system must be settled up. The hardware design was based on DSP and CPLD, which could achieve data acquisition, control motor, protect system and other functions. The software design was based on MATLAB-DSP integrated development environment, and it needed to build the Simulink models and create custom device driver modules according to the hardware.

MATLAB-DSP integrated development environment can convert Simulink model to DSP executable code. The method is that Simulink model converted to C code first, which compiled into assembly code aimed at DSP target board, and then download the executable code to DSP. The design personnel need not care about how the MATLAB program convert to C code and how the C program convert to assembly code and the conversion step how to achieve. The reason is that these steps can be done by MATLAB automatically [1]. Especially for the people who specialize in the study control algorithm, they need not familiar with DSP hardware structure, function, DSP memory configuration and so on. In this integrated development environment, you can test the control algorithm in DSP target board directly [2].

A. The composition of the Experimental Platform

The hardware structure of the whole system is shown as Figure 1. Inverted pendulum car is powered by 12V DC motor through a conveyor, Displacement and angle signals were measured by the photoelectric encoder, then this signal were transferred to DSP. According to control algorithm we settled before, the DSP send the corresponding signals to Motor driver board and control the inverted pendulum car. Our experiment's target is the rod of pendulum can steadily upside down on the car.

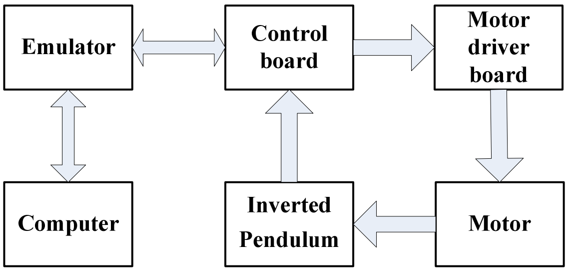

Fig.1. Block diagram of Platform

The experimental platform is mainly composed of hardware platform and software platform. The hardware platform is designed, which include three main parts: the DSP TMS320F2812, the incremental rotary encoder detection circuit based on CPLD and the motor drive circuit based on HIP4080; the software platform include windows XP, MATLAB2011, Code Composer Studio v3.3.

B. The generate of DSP code

The automatic generation of DSP code is the core of MATLAB-DSP integrated development environment, Developer's Kit for TI DSP is development kit based on Simulink and Real-Time Workshop belongs to MathWorks Company and Texas Instruments (TI) Company. With this Development Kit, the user can set the algorithm model of control system in Simulink environment [3].

The process of generating embedded code from rapid prototype is a key link based on the MATLAB-DSP integrated development environment. There are four stages for generating code automatically [4]:

a) Establish the model of MATLAB/Simulink model "model.mdl", Real-time Workshop read the model file and compiled into "model.rtw".

b) TLC target language read the information of "model.rtw" file, compiler the model into source code.

c) Generate the code of specified target.

d) Link to development environment of CCS which the program needed

The Design of the Controller and Simulation

The primary task is to build mathematical model in the study of inverted pendulum system. This is the foundation of controller and simulation. According to the principle of dynamics, we setup a mathematical model for the first level inverted pendulum with Newtonian mechanics method. Combining with the actual data of the inverted pendulum, we can get the state equation and output equation as shown below:

$$\begin{cases} \dot{X} = AX + Bu \\ Y = CX \end{cases}$$

$$A = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & -0.5382 & -0.6786 & 0.0276 \\ 0 & 51.7409 & 3.3930 & -2.6537 \end{bmatrix} B = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 1.1084 & -14.0832 \\ -5.5420 & 70.4160 \end{bmatrix}, C = eye(4)$$

The open loop characteristic root of first level inverted pendulum is [0,-8.6639, 5.9746, - 0.6430]. Therefore, there is a right half plane pole in a complex plane. We can conclude that the first level inverted pendulum system is unstable.

After finished the building of mechanical model using the methods of Newton mechanics, we should study the stabilization control technologies in order to achieve the control of inverted pendulum. A kind of stability controller was designed using LQR method, and a genetic algorithm was introduced to optimize the Q and R matrix optimization parameter, which improved the control effect.

After the corresponding calculation, we can get the globally optimal solution and the state feedback gain:

$$Q = \begin{bmatrix} 233.168 & 0 & 0 & 0 \\ 0 & 262.102 & 0 & 0 \\ 0 & 0 & 2.04 & 0 \\ 0 & 0 & 0 & 0.824 \end{bmatrix}, R = 0.926$$

$$K_{ga} = [\ -15.8682 \ \ -54.1644 \ \ -12.7614 \ \ -6.1252]$$

The Realization of Experiment

After completed the hardware platform, we must establish the rapid prototyping based on Simulink simulation model. The DSP automatic code generation model and simulation model have some differences ,it is need to add some related DSP hardware module to the former, Meanwhile, the MATLAB environment parameter setting and target system hardware module parameter settings are also needed.

We obtained the first level inverted pendulum model using LQR control method based on genetic algorithm optimization. The model is shown in Figure 2.It mainly includes the following functional modules: Target preference module, PWM and QEP hardware driver module, custom Target board module and the realization of function module, a key to achieve functional modules and others.

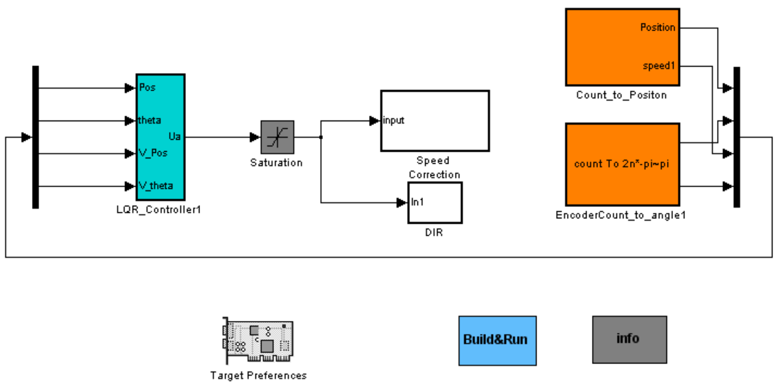

Fig.2. the first level inverted pendulum model

A. Target preference module

Target preference is mainly used to transfer the simulation model to DSP code rapid prototyping.

B. PWM and QEP hardware driver module

Hardware driver module is mainly composed of power control module (PWM output module) and the signal acquisition module. The signal acquisition part consists of two parts, QEP (Quadrature Encoder Pulse) module and CPLD module. In actual circuit connection, the signal acquisition module connected with the displacement signal encoder [5]. PWM output module and the QEP module can be added from the C281x processors support library.

C. Function module

Function module is mainly used for calculation and data processing, including: Displacement conversion module, Angle calculation module, Angle conversion module, Voltage converted to PWM duty ratio module.

D. A key to achieve functional modules

A key to achieve functional modules are composed of “Build & Run” module and code information module (info module) [6], Double-click on the “Build & Run” module will execute the script file ”system_script”, The function of the ’info” module is to display and modify the script file “system_script” .

“System_script” has the following functions:

e) Encapsulate the relevant code.

f) Link to the target board, generate the target code.

g) Compile and link to the executable file and run on independent development board.

h) Call GUI interface, achieve real-time control function.

E. The actual effect

From the real-time operation interface screenshots as shown in computer, we can see the first level inverted pendulum turns into a stable state quickly. The movement range of inverted pendulum car is less than 0.007 m, and the amplitude of the pendulum swing angle is less than 0.009 radians. If we give the car a slight disturbance, the system can return to balance position within 1 s.

Conclusion

This paper puts forth a new teaching platform for the inverted pendulum based on MATLAB-DSP integrated development environment. Practice shows that with the application of teaching platform, students can concentrate on the design of control algorithm. The platform is an innovation for the traditional experimental problems, and increases the interests of students. After finish this experiment, students not only learn a lot of knowledge, but also lay a good foundation for the future research work.

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