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Research paper

Demystify the real time implementation of an aero pendulum with dSPACE to visualize and compare the results of PID and SMC

Ali Hassan Shah [1]*, Moazam Ali Siddiqui [2], Husnain Shahid [3]

[1] *School of Information Science and Technology, Fudan University, Shanghai 200433, China.*
[2] *School of Electrical and Computer Engineering, CIIT Abbottabad 22010, Pakistan*
[3] *School of Mechatronic Engineering and Automation, Shanghai University, Shanghai 20444, China*
**Corresponding author E-mail: hsali19@fudan.edu.cn*

Abstract

dSPACE is a real-time platform based on software and hardware in loop with MATLAB/Simulink. The real-time environment provides us a visual way to understand the actual real-time behaviour of the designed controller. This paper proposed a method to better understand the behaviour of a different de-signed controller in a real-time environment during learning. For application-specific we designed a pitch control hardware model for aero pendulum using single brushless dc motor (BLDC), position encoder and H-bridge in loop with MATLAB/Simulink and dSPACE hardware box. Different controllers (Proportional integral derivative (PID) and sliding mode controller (SMC)) are designed, then implemented to check its behaviour on the designed hardware in real-time. The performance is evaluated using overshoot, rise time, settling time peak time and disturbance rejection. Using the control desk software Graphics user interface (GUI) is developed not only to continuously monitor the behaviour but also to make changes into the system conditions during real-time.

Keywords: *Aero Pendulum; PID; SMC; Control Desk; dSPACE; Real-Time.*

1. Introduction

Hands-on practical hardware during a learning control sys-tem designing is necessary to fully understand and never forget the feel of the hardware its response and its characteristics, the influence of damping (D), Proportional (P) and the liveliness of the system due to the factor Integration (I) (van de Molengraft, Steinbuch et al. 2005). Although trends towards the internet and virtual based control system increased significantly (Overstreet and Tzes 1999). During the last few decades, the laboratories become more advanced, and the complexity level increased for basic entry-level students, but still, the laboratory has its own significance (Aburdene and El-Sharkawy 1989). Researchers used the GUI interface of MATLAB/Simulink and open-source platform for laboratory experiments and develop a set up to make things simpler for students to fully understand the behaviour of complex nonlinear systems and design their own controller (Enikov and Campa 2012, Shao, Zhang et al. 2012).

Being an undergraduate student it is difficult to understand the real-time behaviour of the system and design an appropriate control scheme for it. Lab manuals are designed to give us understanding about the system and its feedback control but most of them are used some external complex software unable to understand e.g. 3 DOF Helicopter or ball balancing on the plate, looks like black magic at that time. This will become the motivation to build a system that is quite simple and make things easier for newbies.

Hardware model of the pitch control of aero pendulum is implemented as the aero pendulum is the classical and benchmark example of the control system whereas the pitch is the basic and backbone for the aerospace industry/autopilot control system . To avoid the complexions in theoretical modelling, the aero pendulum is considered to be a rigid body having small deviations than normal conditions. Nonlinear behaviour and operating environment are two major challenges in the pitch control design of an aero pendulum, which leads to the selection of this system for designing our experimental equipment. Previously a lot of research work reported on pitch control and longitudinal dynamics (Chen and Khali 1990, M. Zugaj and Narkiewicz 2010, Qutbodin and Merging 2010, Wahid and M.F 2010). dSPACE (digital Signal Processing and Control Engineering) is a real-time control platform for data acquisition and surveillance based on software (Control desk) and hardware in the loop with MATLAB/Simulink automatically generated real-time C code and compiled over dSPACE hardware. Nowadays it is very popular in the industry as well as in an educational institute for modelling control systems controller (Shao, Zhang et al. 2012).

The aim of this paper is to develop a hardware system that is effective for engineering and non-engineering students to visualize the effect of their designed controller for better understanding. Not only compare and track the performance of different controllers efficiently in a real-time environment but also hands-on laboratory equipment. Since proportional derivative integral (PID) controllers are extensively used throughout the industry, the aim is to demonstrate the different aspects and influence of all three (proportional, integral and deriv-

ative) gains on a system. These gains will be referred to as K_p; K_i and K_d respectively, also design some other controller like sliding mode control (SMC) and comparing its performance in a real-time designed environment on the designed hardware system.
There are different methods that can be chosen to determine the right values of the controller's parameters. First designed the controller according to the given parameters of the hard-ware model then implemented it on to our designed hardware make little changes in the calculated values to visualize the behaviour of the system followed by a hit and trial method. Real-time system behaviour is monitor by tracking continuously to aid the understanding of the impact of controller's parameters.

2. Hardware and software setup

2.1. Aero-pendulum

The overall hardware setup consists of 5 volts brushless Dc motor, rotary position encoder, H Bridge, current sensor and dSPACE hardware kit. Small DC Motor is fitted at the end of the plastic shaft. Another end of the plastic shaft is fitted on the adjustable moving aluminium support that is connected with the rotary optical encoder for position sensing. The plastic shaft moves freely and acts as a pendulum. The attachment with aluminium support is made flexible to make changes in the length of the pendulum also to add weight or add a new motor on the other side for further designing if necessary. PWM signal can be taken from the dSPACE hardware box and with the interaction of the GUI interface and optical rotary encoder pre-calibration is not necessary and can be changed to any default position at any time during the experiment. Fig.1 shows the real hardware implementation.

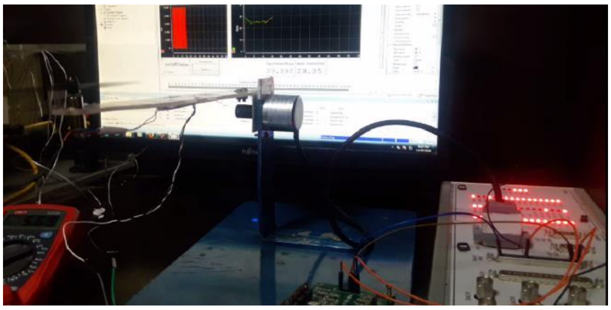

Fig. 1: Hardware Setup in A Real-Time Environment.

2.2. dSPACE

Digital signal processing and control engineering (dSPACE) is a single ds1104 R and D controller board that is designed for real-time implementation and simulation and plugged directly to the computer/desktop. Direct interfacing with MAT-LAB/SIMULINK makes things very simpler for students to design controller just drag and drop to observe the behaviour in a real environment [14]. For input and output during real-time implementation connector panel with Analogue to digital (ADC) and digital to analogue (DAC) are used with a resolution of 16 bits. Fig.2 shows the Connector panel for external connections.

Fig. 2: dSPACE Connector Board.

2.3. Simulink environment

To design the desired controller in MATLAB/Simulink environment build in dSPACE library is used." Encoder Master Setup Block" is placed that includes all the necessary paths for building a model in the RTI environment. Fig.3 shows the RTI model for the SMC controller. After designing the controller build the model to the external hardware, dSPACE itself creates the C code for the external hardware interface. Similarly for PID controller just used the build-in PID controller with desired values or design your PID controller in MATLAB and then implemented through the RTI interface to visualize the performance.

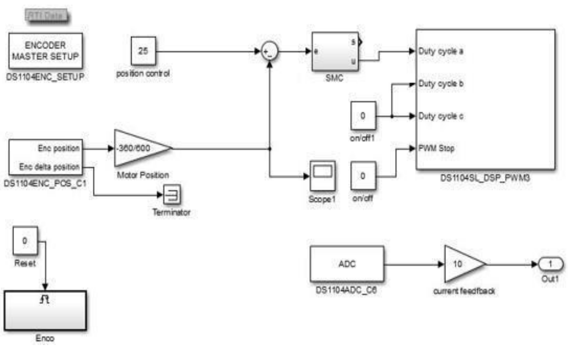

Fig. 3: Simulink Environment for Designing.

2.4. Control desk environment

To visualize the response of the system in a real-time control desk is used. Designing a layout is simple just drag and drop it to the reference and by using the label from the Simulink environment connect them together. GUI interface not only helps to visualize the actual response of the system numerically but also graphically. Moreover, calibration and changes in default conditions of the system can be easily changed through a single click. Fig.4 shows the Designed Control desk GUI interface.

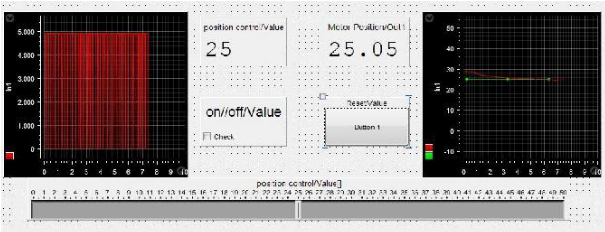

Fig. 4: Control Desk Environment.

3. Detail experiment

3.1. Theoretical modelling

A theoretical model is designed to identify the parameter of the plant. Fig. 5 shows a theoretical model of a pitch. After identifies the physical parameters of the pendulum used basic mathematical equations to develop a model. The response of the system is non-linear in nature clearly identifies from the developed model. We linearized the system to finally implement it to MATLAB/Simulink for its response Analysis.

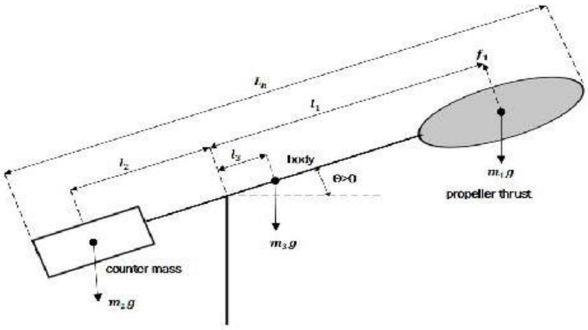

Fig. 5: Theoretical Model.

For an Equilibrium condition:

$$K_t I_m + m_2 g l_2 \cos\theta(t) - m_1 g l_1 \cos\theta(t) - m_3 g l_3 \cos\theta(t) = 0$$

$$\cos 0^{\circ} = 1$$

So,

$$K_t I_{eq} + m_2 g l_2 - m_1 g l_1 - m_3 g l_3 = 0$$

Linearize Model

$$\frac{K * L}{m * L + 2s^2 + cs} \qquad (1)$$

3.2. Simulation

First of all the designed system (Equation (4)) for the Pitch angle of the aero pendulum is implemented in a MAT-LAB/Simulink Environment. By using the built-in PID controller we check the response of the system. While a constant 25-degree input is given to the system. Fig. 6 shows the Modelling in MATLAB/Simulink, While Fig. 7 shows the ideal input behaviour of the system.

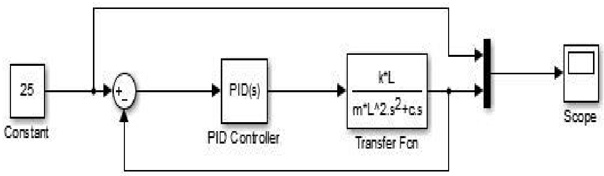

Fig. 6: Implementation of the Designed System.

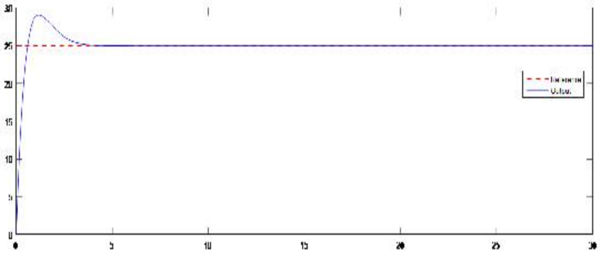

Fig. 7: Designed System Response with PID Controller.

3.3. Real-time implementation

Digital signal processing and control engineering (dSPACE) setup environment and MATLAB/Simulink interface are being used for the real-time implementation of hardware. Fig. 8 shows the designed MATLAB/Simulink model with a real-time interface with 25 degrees.

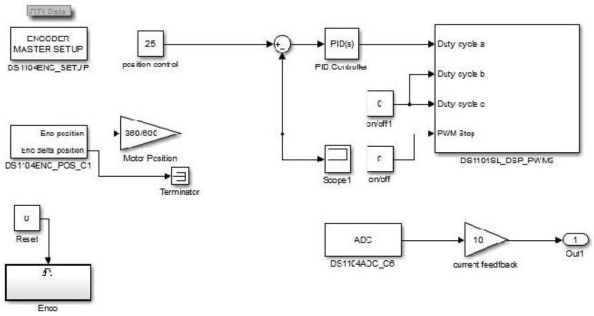

Fig. 8: Real Time Interface (RTI) Simulink Model.

3.4. Proportional controller

To check and visualize the impact of the controller first proportional (P) control scheme is implemented on a designed aero pendulum model in a real-time environment. Without the other two terms, there is no control over the effective response of the system since the K_p parameter acts as an amplifier and it just gives this sort of jump straight to the set point corresponding to the rising process by the arm. In this particular case, there is no overshoot since the turquoise line, which is the response after the influence of proportional integral and derivative (PID), is still under the desired value.

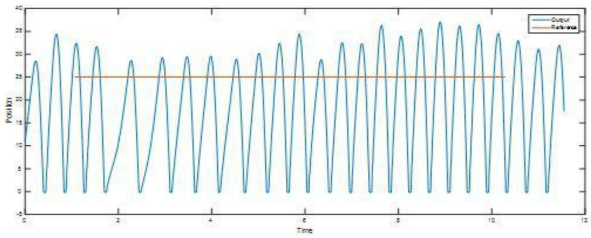

Fig. 9: Real-Time Response with Proportional (P) Controller.

By setting K_p to 1 and the K_i and K_d to 0, a sudden jump is noticed in the real system which is actually a current error. The real-time response is corrected by multiplying the error with the gain K_p value. Fig. 9 shows, an overshoot where the graph corresponding to the response of our system, overpasses the set point resulting in an unstable response. Noticed that, this type of response physically corresponds to harmonic oscillations of the arm in the real-time environment. When the K_p value is increased, the response is faster, meaning that the system would take less time to reach the set point (improved rising time), but the instability gets greater ending up with faster oscillations. Contrariwise if the proportional value is smaller, the rising time increases and the oscillations become slower. Hence it gives the true understanding of the P controller to an observer.

3.5. Proportional-derivative controller (PD)

To observe the effect of derivative term in the PID controller. The proportional derivative (PD) control scheme is implemented on a system in a real-time environment with the addition of the derivative term in the proportional controller the settling time is reduced. The hit and trial method are used to see the impact of D term on the system. If the value of K_d is too high a tremendous overshoot is observed.

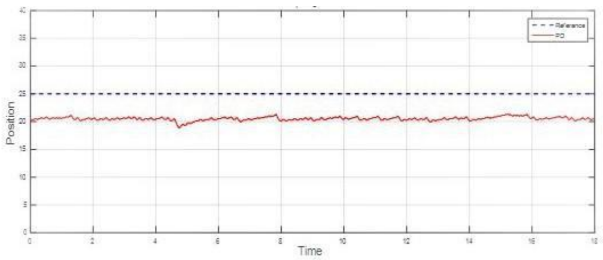

Fig. 10: Real-Time Response with Proportional- Derivative (PD) Controller.

Fig. 10 shows the PD controller response in a Real-time environment. The value of K_d used here is 3 and it eliminates the oscillations in the real system (eliminates the steady-state error) and accelerates the movement of the arm towards the base or set point (rise time).

3.6. Proportional integral derivative (PID)

After clearly observe the effect of K_d term and K_p terms integral term K_i is added to fully implement to observe the response and effect of the PID controller on a model in a real-time environment. Fig. 8 shows the real-time environment in Simulink with PID. The values of gains proportional K_p, derivative K_d and integral K_i are set according to system stability determined by hit and Trail method. Since the contribution of the integral term is directed to both, error and time (duration) of the error. By adding integral term the stability of the system increases in terms of faster rise time, faster settling time, decrease in steady-state error that can also be observed on the system response. Noticed in Fig. 11. Aero pendulum successively tacks the reference signal with very little deflection (error). Further tune the K_p, K_i and K_d terms to analyse the response of the system.

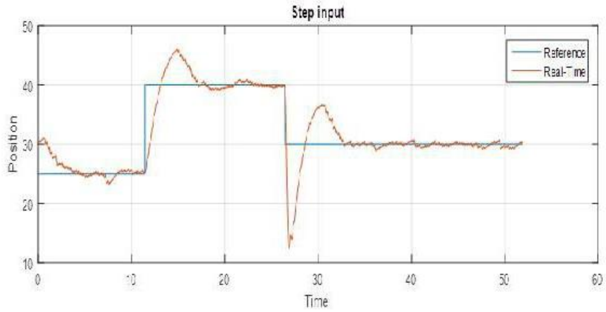

Fig. 11: Real Time Response Proportional- Derivative Integral (PID) Controller.

3.7. Sliding mode controller (SMC)

Sliding mode control (SMC) is a nonlinear controller. SMC changes the behaviour of a system by a discontinuous signal. When nonlinearities eliminate from the system it slides the system towards its normal or reference behaviour. Sliding mode control is a type of control method for variable structure control systems. After analysing the effect of the PID (K_p, K_i and K_d) controller. Using MATLAB/Design an SMC controller to observe its effect in a Real-time environment.

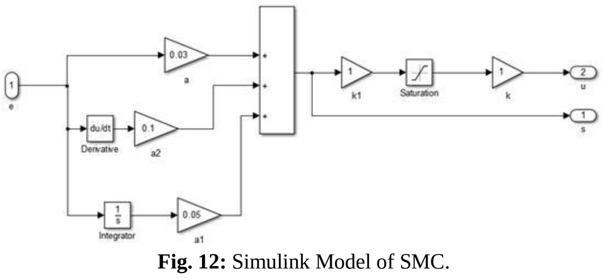

Fig. 12: Simulink Model of SMC.

Fig. 12 shows the design of the Simulink model of the sliding mode controller (SMC). Fig. 13 shows the Simulation result of the

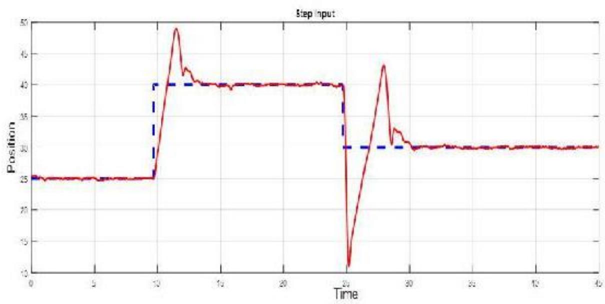

Fig. 13: Real-Time Output with Sliding Mode Controller.

A sliding mode controller for an aero pendulum, which perfectly tracked the desired angle (position) within 5 seconds after starting with a slight overshoot. Dotted lines represent the desired position and a solid line shows its real-time position.

4. Results and discussion

To visualize the effect of different controllers and their parameters in the real-time environment different signals can be designed not only visualize the effect by the naked eye but also graphically and compare the performance using simple calculations. Below in Fig.14, Fig.15, Fig.16 and Fig.17 response of PID and SMC on our designed system can be seen and compare the effect of control parameters on real hardware respectively. In our experiment, we use basic parameters i.e. overshoot, rise time, peak time and settling time to compare the effectiveness of the designed controller (PID and SMC) in the real environment.
The overall performance characteristics of both sliding mode controller (SMC) and proportional integral derivative (PID) is summed up in a Table. 1. And shown below. Apply controller in real-time environment attracts the attention of students to learn and explore more about the control system designing, and hand on equipment (hardware system) will help them to never forget the response of the parameters of the designed controller.

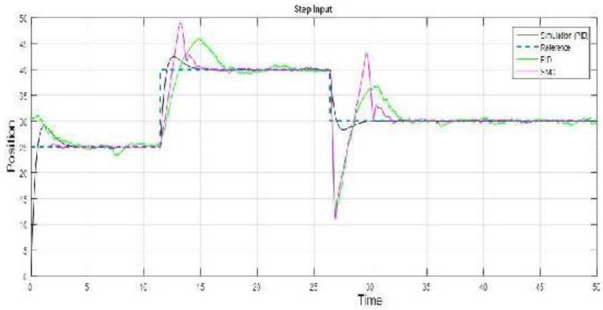

Fig. 14: Comparison between SMC and PID with the Step Signal.

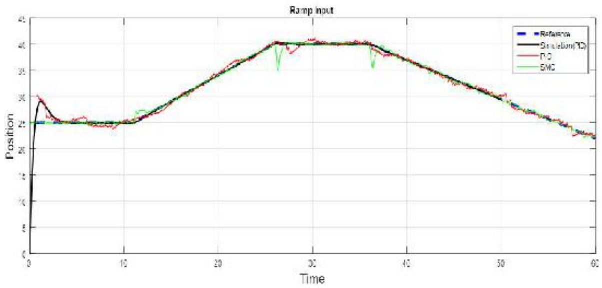

Fig. 15: Comparison between SMC And PID with the Ramp Signal.

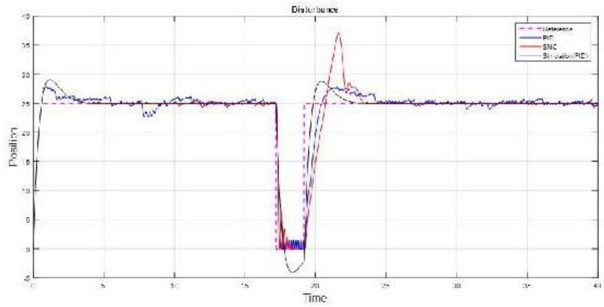

Fig. 16: Comparison Between SMC and PID with Disturbance Signal.

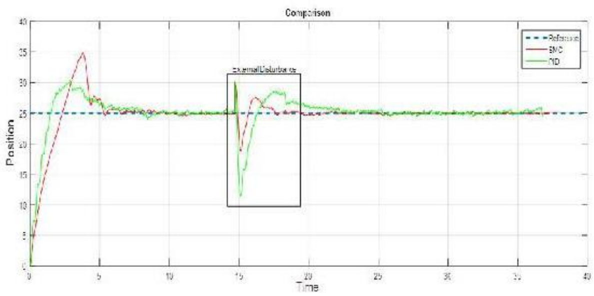

Fig. 17: Comparison Between SMC and PID with External Disturbance.

Table 1: Summary of Performance Characteristics of Pitch

Performance Metrics	PID	SMC
Overshoot *100	1.51	2.22
Rise Time in seconds	1.61	1.04
Peak Time in seconds	3.45	1.81
Settling Time in seconds	5.63	3.78

5. Conclusion

The designed RTI hardware system using dSPACE in the loop with MATLAB/Simulink helps to visualize the performance. Designing and learning of system response on different parameters get easy. Furthermore, the RTI interface will help to develop the interest of students towards the exploration of different features of the control system dSPACE and MATLAB for learning. In future before this setup is used in the laboratory gets students feedback and perspective to further improve its quality and application.

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