Active Vibration Control of Essential Tremor

Sri Sitaram Chowdary Lavu[1], Abhijit Gupta[1*]
[1] Department of Mechanical Engineering, Vibrations and Acoustics Center
Northern Illinois University, DeKalb, Illinois 60115, United States

[*] Corresponding author (email: gupta@ceet.niu.edu)

Abstract

Essential Tremor is the most common form of pathological tremor and is a major source of functional disability, affecting many of the daily living tasks. Essential tremor appears usually after the fourth decade and is slowly progressive. This paper is related to the active vibration control of the tremor of hand. Active vibration control has been successfully implemented in the past to control the vibrations of structures. In this study, a PID controller has been designed using MATLAB/SIMULINK. The PID controller has been loaded in the DS1104 processor. Experiments have been conducted on a beam and an artificial arm. A shaker is used to simulate the tremor signal and excite the artificial arm accordingly. An accelerometer attached to the arm gives the feedback to the controller. The controller takes the feedback from the accelerometer and produces the control (anti-vibration/anti-tremor) signal. This control signal is then sent to the actuator which is attached to the arm. Actuator exhibits the control signal on the arm to cancel the vibration due to tremor. Real-time experiment results can be visualized in the dSPACE control desk.

Keywords: Essential tremor, Matlab/Simulink, PID controller, DS1104 processor and dSPACE ControlDesk

1 Introduction & Objective

Essential Tremor is characterized by the involuntary oscillations of a part of the body. When severe it can be disabling and may result in difficulty in writing and in handling tools. Up to 25% of the patients with this condition retire or change jobs as a result of tremor. Essential Tremor (ET) causes adduction-abduction movement of the fingers and a flexion-extension movement of the hand. This paper is related to the flexion-extension movement of the hand. Frequency of the Essential Tremor is usually low which varies from 4.5 to 8 Hz [1]. It occurs due to the intentional movements. It can also affect other parts of the body like head, neck, legs, tongue, torso, voice. Some of the effects of ET are social embarrassment and depression. Everyday tasks and those requiring motor skills are difficult. People with this disease cannot comb their hair, cannot hold a cup of coffee without spilling which affects the quality of life [2]. Jack et al. [3] used a viscous beam which is a wearable tremor-suppression orthosis that applies resistance to motion of the wrist in flexion and extension movements. Active vibration control with appropriate actuators has been a challenging problem for both academic and industrial researchers for many years. Fei [4] used piezoelectric actuators to reduce the vibration of flexible steel cantilever beam with PID compensator using xPC Target real-time system. Stone et al. [5] explained the autotuning of a PID controller for an active vibration suppression device for the treatment of essential tremor. Mitra et al. [6] used piezoelectric actuators along with proportional-integral (PI) controller for the vibration control in a composite box beam. It may be noted that piezoelectric actuators are primarily suited for applications with low displacement and high frequency whereas essential tremor frequency involves low frequency and large displacement. Electrodynamic shakers have been successfully used in the past by Gupta et al. [7, 8] to control the vibration of structures. However shakers are heavy and bulky for essential tremor control application.

In this paper, Active Vibration Control has been implemented successfully to reduce the vibrations occurs similar to that due to the essential tremor. PID controller was developed in the Matlab/Simulink and was downloaded in the DS 1104 real-time processor. Offline simulations were done in Matlab/Simulink while developing the PID controller. Real-time experiments results and data acquisition were obtained from the dSPACE Control Desk software.

2 Theory

The PID control structure consists of three constituent components, the Proportional, Integral and Derivative part. In actual applications, different permutations of P, I and D components may be used depending mainly on the process and control requirements. P controller, PD controller, PI controller, and PID controller are the different permutations of the three components. PID controller is the most sophisticated continuous controller among those controllers. PID may give rapid response and exhibits no offset, but it is difficult to tune as there are three gains to adjust. As a result it s used only in a very small number of applications, and it often requires extensive and continuous adjustment to keep it properly tuned. It does, however, provide a very good control when appropriate parameters are implemented. In this paper, the parameters are taken as proportional gain $K_p = 0.05$, integral gain $K_i = 0.015$, derivative gain $K_d = 0.05$ to generate the control (anti-tremor) signal.

A model was built in Matlab/Simulink which includes PID controller. This model includes a function generator that provides the signal (simulating tremor) as input to the PID controller. Feedback is taken from the output of the PID which is utilized to calculate the error and the error is sent to the PID for further processing. The schematic of the model is shown in Figure 1.

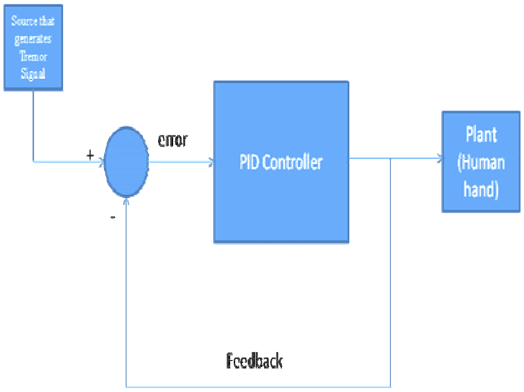

Figure 1: Schematic of the Matlab/Simulink model

Almost zero movement of the hand subjected to tremor was achieved in the offline simulation. This model was then built for real-time purpose by replacing source with DS1104ADC_C5 block which is the interface for DS1104 real-time processor. The response of tremor from accelerometer is sent to the processor through this block. Similarly, the output was replaced with DS1104DAC_C1 through which the control signal produced by the controller is sent to the actuator to counteract the tremor response. The real-time Matlab/Simulink model is shown in Figure 2.

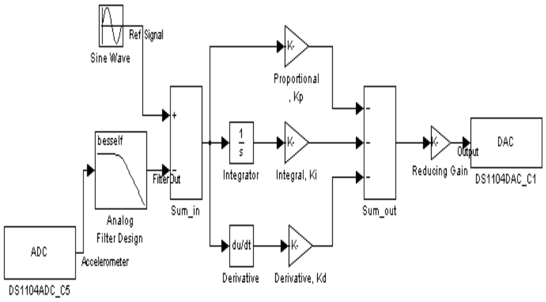

Figure 2: Matlab/Simulink real-time model

A low pass filter was used to avoid high frequency noise in the accelerometer signal. The model shown in Figure 2 was loaded in the real-time processor DS1104, which was placed in the PCI slot of the motherboard in the computer. Results and animation can be visualized in the dSPACE Control Desk environment.

3 Experimental setup

An experiment was setup to implement active vibration control on artificial arm which was subjected to the tremor signal with the help of a function generator. The schematic of the experimental setup is shown in Figure 3.

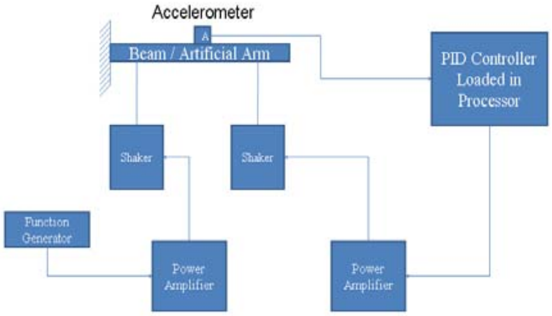

Figure 3: Schematic of the experimental setup

Tremor signal was generated by the function generator (Tektronix CFG253, 3 MHz) and sent to the power amplifier (B&K, Type 2706) which feeds that signal to the vibration exciter (B&K, Type 4809) to excite the artificial arm at tremor signal. The response of the artificial arm was measured by an accelerometer (B&K, Type 4507 B003) and sent to the PID controller developed in the Matlab/Simulink and loaded in the DS1104 real-time processor. Controller produced the control (anti-vibration/anti-tremor) signal to the response from the accelerometer and was sent to another power amplifier (B&K, Type 2706) which feeds that signal to the vibration exciter (B&K, Type 4809) used to control the vibrations occurred in the arm due to tremor signal.

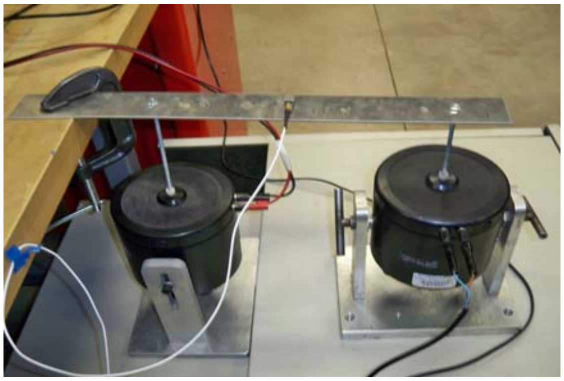

Figure 4: Experimental setup of aluminum beam using shaker for control

The setup and the control algorithm were tested by implementing the active vibration control on an aluminum beam. In this case shaker and piezoelectric actuator (PCB, model no. 713A01) were used to control the vibrations. Experimental setup with the aluminum beam when shaker was used for control is shown in Figure 4. Experimental setup with the aluminum beam when piezoelectric actuator was used for control is shown in Figure 5.

Figure 5: Experimental setup of aluminum beam with piezoelectric actuator for control

After successful implementation of active vibration control on the aluminum beam, it was implemented on an artificial arm with shaker. Experimental setup of artificial arm when shaker was used to control the vibrations is shown in Figure 6.

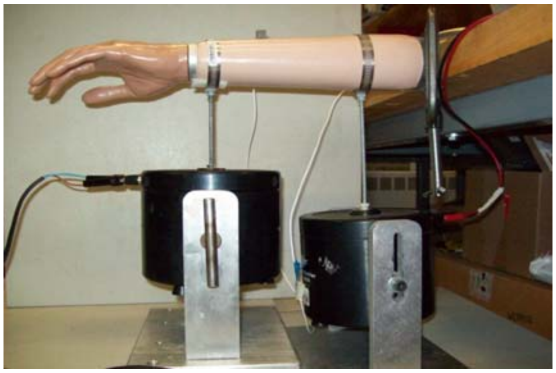

Figure 6: Experimental setup of artificial arm using shaker for control

	Control of Tremor Response with shaker	
	Aluminum beam	Artificial arm
Response Without Control	180 mV	120 mV
Response With Control	12 mV	54 mV
Reduction in Vibration	93.3%	55%

4 Results

Active vibration control results of the beam and the artificial arm are compared in Table 1. When shaker was used for control, vibrations of the beam were reduced by 93.3% and vibrations of the arm were reduced by 55% as the arm weighs more than beam. When piezoelectric actuator was used for control, vibrations of the beam were reduced by 83.3%.

Figure 7 shows the plot of the response of the artificial arm before and after control when subjected to tremor signal generated by the function generator.

Table 1: Active vibration control results of beam and artificial arm

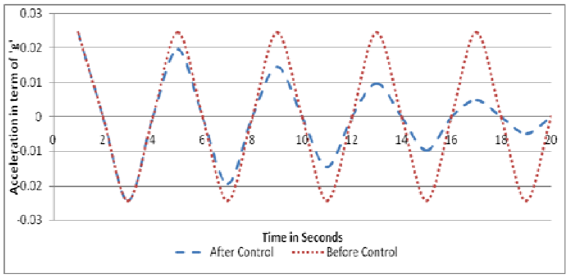

Figure 7: Response of artificial arm before and after control

5 Conclusions

A new control algorithm was developed in Matlab/Simulink for the implementation of active vibration control. This algorithm was used to reduce the vibrations induced in the aluminum beam and artificial arm when subjected to the tremor signal. Reduction of vibrations is more in the aluminum beam as it requires less force to control when compared to the artificial arm which weighs more than the aluminum beam. Piezoelectric actuator which is a light weight actuator was also used successfully to control the vibrations in the beam. This work is being continued using light weight actuators that can produce sufficient force to control the vibrations in the arm when subjected to the essential tremor.

Acknowledgment

The authors would like to thank the United States Department of Education for sponsoring this research and Dr. Promod vohra, Dean of CEET, NIU (Principal Investigator of this grant), and Mr. Gerald Stark of Fillauer Corporation for providing the artificial arm.

References

[1] M. Manto, M. Topping, M. Soede, J. Sanchez-Lacuesta, W. Harwin, J. Pons, J. Williams, S. Skaarup and L. Normie, “Dynamically Responsive Intervention for Tremor Suppression,” *Engineering in Medicine and Biology Magazine, IEEE*, pp. 120-132, 2003.

[2] W. Jason, B. Philip, A. Nikita, J. Jennifer, S. Ethan, T. Tang , “Wearable Essential Tremor Solution”, Presentation , Biomedical Engineering, University of Florida.

[3] K. Jack, J.R. Michael, ”A wearable tremor-suppression orthoses”, in Journal of Rehabilitation Research & Development, Vol. 35 No. 4, October 1998, pp. 373-387.

[4] J. Fei, “Active Vibration Control of Flexible Steel Cantilever Beam Using Piezoelectric Actuators”, in IEEE 2005.

[5] N. Stone, K. Kaiser, R.D. White, “Autotuning of a PID Controller for an Active Vibration Supression Device for the Treatment of Essential Tremor,” *ASME International Mechanical Engineering Congress and Exposition*, November 5-10, 2006.

[6] M. Mitra, S. Gopalkrishnan, M. Seetharama Bhat, “Vibration Control in a Composite Box Beam with Peizoelectric Actuators,” *Department of Aerospace Engineering, IISC, Bangalore*, pp 676-690, *May* 2004.

[7] A. Gupta, S. Yandamuri, and S. M. Kuo, “Active Vibration Control of a Structure by Implementating Filtered-X LMS Algorithm”, *Noise Control Engineering Journal*, **54**, pp 396-405, 2006.

[8] A. Gupta, S. Yandamuri, and S. M. Kuo, “Digital Implementation of Active Vibration Control of a Structure”, *Journal of Low Frequency Noise, Vibration and Active Control*, **26**, pp. 135-141, 2007.