Suppression of Hand Postural Tremor Via Active Force Control Method

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Abstract: - This paper presents the behavior and the effective way to suppress the human hand postural tremor using the active force control method. The main advantages of proposed method include; its simple control technique, practically applicable in real-time due to the much lesser computational burden and the extra robustness feature the method generates. The actual tremor data from a Parkinson disease patient is validated through an artificial vibration exciter to investigate a tremor suppression technique based on mechatronics approach in which a proportional-derivative (PD) with active force control (AFC) strategy is applied to a four degree-of-freedom (4-DOF) hand model. The acceleration and displacement dynamic responses on the human hand model were captured and recorded using the light-weight accelerometer and laser displacement sensor for validation purpose. The results may be considered as raw data that can be used for further analysis of human tremor especially for Parkinson's disease patients, which can later be used to assist in developing strategies in the design and development of a hand tremor suppression device. A piezoelectric actuator is employed as the main active element within the AFC-based system for the compensation of the disturbances. Simulation results show that the proposed AFC-based scheme is very robust compared to conventional PD counterpart.

Key-words: - Hand Postural Tremor; Tremor Suppression; Active Force Control

1 Introduction

Hand tremors are involuntary muscle movements of the hands. The involuntary hand tremor is a significant disability and those arising from a neurological disorder, can erode the quality of life. Physical tasks such as eating, drinking, reading, writing, walking, and proper personal care becomes difficult by the interference of tremor [1-4]. An effective way to attenuate the tremor could therefore improve the lives of the affected people.

Several research works have been carried out like medical, passive and kinematics to investigate and control the effect of human hand tremor. Medical treatments such as (drug), deep brain stimulation (DBS), a thalamic stimulator or else are used to reduce hand tremor. The available medicine treatment may lessen the tremor progress but most treatment methods have their inherent drawbacks. For example; drug therapy may cause a long term side effect whereas surgical therapy provides a high risk because it involves a brain operation. Thus, existing physical and drug therapies have not been very effective in tremor treatment, giving rise to the need of alternative approaches to solve the problem of tremor suppression.

Passive technologies are characterized by mechanical tremor reduction. These include; Viscous damping, added inertia, and gyroscopic stabilization and have been attempted by various researchers [5, 6]. Limited success has been obtained largely due to the fact that these methods seek to attenuate all motion, rather than just unintended motion. Other problems encountered with passive technologies include the increased muscle strength created with extended use of the dissipating element and fatigue associated with constantly "fighting" the passive device [6].

The kinematic measures of tremor include displacement, velocity, and acceleration. They can be measured with different techniques employing mechanical, optical or magnetic principles. The other measurements of tremor include force and electrical activity of muscles. Based on the measurements, the parameters that are used to analyze tremor are frequency, amplitude and waveform of the tremor [7].

An alternate way to control the hand tremor is known as Active Vibration (tremor) control. It is defined as a technique in which the vibration of a structure is reduced by applying counter force to the structure that is appropriately out of phase but equal in force and amplitude to the original vibration. As a result two opposing forces cancel each other, and structure essentially stops vibrating. An adaptive PID controller was developed for an active vibration suppression device for the treatment of essential tremor [8]. Adaptive mechanisms normally incorporated into the force control strategy to enhance the system's overall performance by introducing an automatic decision making facility in the control loop. One of such technique is active force control (AFC). AFC has been recognized to be simple, robust and effective as compared to conventional methods in controlling dynamical system [9, 10]. The AFC strategy selected as a controller has proven vibration cancellation capabilities either in simulation or experimental [11, 12]. Despite of several advantages of AFC, none of the researcher has employed piezoelectric actuator with AFC technique to control human hand tremor. Therefore, in this paper an AFC technique has been successfully implemented to reduce the vibration of postural hand tremor. The complete AFC scheme is designed in conjunction with the classical PD controller technique.

2 Background of Hand Tremor

Two types of hand tremor are generally seen in the patients suffering from Parkinson’s disease; namely resting and postural tremor. Resting tremor occurs when muscle stay relaxed and the limbs are supported fully to gravity. The frequency of resting tremor occurs within the range 3-7 Hz, and is found in up to 75% of individuals suffering from Parkinson’s disease [13]. Postural tremor appears when a part of the body is maintained in a fixed position and may also persist during movement [14]. It is found that the frequency of postural tremor in Parkinson’s disease occurred in the range of 5 to 12 Hz [15-17] and is symptomatic in around 60% of Parkinson’s disease patients [13]. The acceleration amplitude for postural tremor is in the range of + 10 m/s2 [13, 18] and displacement amplitude in the range of + 5 mm [18-23] and finally the tremor frequency at the range of 5 to 12 Hz. In this work, the postural type of tremor was selected because the frequency range of postural tremor is greater compared to the resting tremor [13, 16].

3 Dynamic Model of Human Hand

The human hand and arm mechanical (dynamic) models have been described in literature. A good description of the models can be found in [24]. One of them is described in greater detail in the following paragraph.

A human hand model can also be described as a four DOF lumped parameter model as shown in Figure. 1. The masses m1 and m2 have been attributed to mass due to dermis and epidermis and the coupling elements, k1 and b1 are considered to represent the viscoelastic properties of these tissues. The strong coupling between the dermis and the subcutaneous tissue has been associated with element k2 and b2 while m3 is attributed to that of the subcutaneous tissue. The elements k3 and b3 are considered to represent the weak coupling between the subcutaneous tissue and the muscle. The mass m4 is thus a representative of the hand muscle mass, while k4 and b4 relate to coupling between the muscle and the bones.

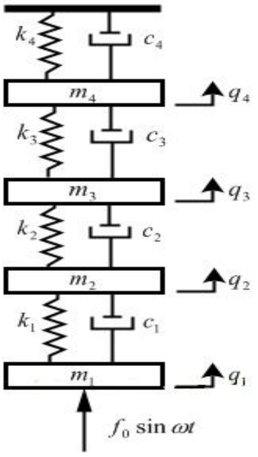


Fig.1 A 4 DOF human hand model subject to harmonic excitation

Table1 shows the parameters used to emulate the palm model and a higher order model is believed to yield a more accurate prediction of the biodynamic response of the human hand.

Table 1
Parameters used in 4-DOF [24] biodynamic response at the palm

Parameters	Mass (kg)	Damper (Ns/m)	Spring (N/m)
Palm	0.5	3.6	40
First Layer (Epidermis)	0.0043	88.8	678

Second Layer (Dermis)	0.105	1.5	185
Third Layer (Subcutaneous Tissue)	0.566	0.1	23.9
Fourth Layer (Muscle)	4.3	3.99	34.9

4 Dynamic Modeling of Piezoelectric Actuator

Piezoelectric actuators are becoming very effective in today’s positioning technology, due to the increased actuator deflection despite of the smaller sizes with lower input power. The word “Piezo” is derived from the Greek word known as pressure. These actuators convert electrical energy into mechanical energy and vice versa. For piezoelectric materials, an extremely applied force induces an electrical charge (Piezoelectric effect) and conversely, an applied electrical charge induces a force (inverse piezoelectric effect). There are many applications and fields where these actuators have been widely used, such as ultra-precise positioning, active vibration control, ultrasonic welding and machining, common rail diesel injection systems, and in the generation and handling of high forces or pressures in static and dynamic situations [25].

Among the different actuator technologies, piezoelectric devices offer a number of benefits for application in active control systems. Their high stiffness results in isotropic high actuator performance. The actuators are easily controlled, provide fast response, can have small dimension and weight, and can be simply driven by voltage.

Figure.2 depicts the piezo actuator model which derived from the linear, coupled, electromechanical, constitutive equations [Eqs. (1) and (2)] between stress, strain, electric field and displacement.

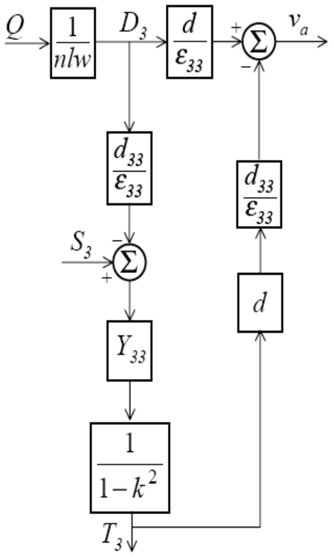


Fig.2 Electromechanical model of piezoelectric actuator [26]

Mathematically, the electro-mechanical equations of the actuator can be written as:

$$D_3 = \varepsilon_{33} E_3 + d_{33} T_3 \quad (1)$$

$$S_3 = d_{33} E_3 + \frac{1}{Y_{33}} T_3 \quad (2)$$

Where,

D3 is the Electric displacement or Polarization in actuator, S3 is the Mechanical strain in actuator, d33 is the Piezoelectric charge coefficient of actuator, E3 is the Electric field in actuator, Y33 is the Elastic modulus of actuator, T3 is the Mechanical stress in actuator, va is the Instantaneous voltage across actuator, ε 33 is the Dielectric permittivity of piezoelectric actuator material, n is the Number of layers, l is the Length of actuator, w is the Width of actuator, d is the Thickness of a one layer of actuator, Q is the Total charge in actuator and k2 is the Electromechanical coupling coefficient.

5 Active Force Control (AFC)

Active force control (AFC) scheme was first proposed by Hewit in the early 80’s in which a very robust system was achieved. The system remains stable and effective even in the presence of known/unknown disturbances, uncertainties and varied operating conditions.

In addition to previous work by Hewit[9], they applied AFC technique successfully to a robotic arm. They developed this AFC scheme by employing an internal force error feedback control scheme based on real-time acceleration and force measurements to compensate for the internal and external disturbances of a mechatronics/machinery system.

The concept of AFC is to use some measured and estimated values of the identified system parameters namely the actuated force, acceleration and the estimated mass of the body. The compensating action of AFC involves direct measurement of identifying parameters. Hence, a large number of mathematical and computational burdens can be reduced significantly. AFC can be shown to complement the basic Newton’s law of motion for translational and rotational system.

A number of implementations of the AFC schemes applied to robotic manipulator can be found in some studies that have been demonstrated in works by Mailah and co-workers [27, 28]. Some of their proposed modified AFC schemes were successfully implemented in real world applications. The general form of the AFC scheme is depicted in Figure.3.

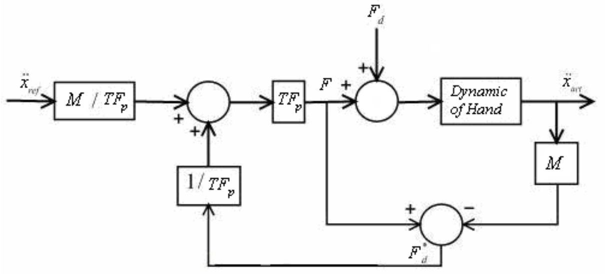


Fig.3 Typical AFC loop

The disturbance can be estimated according to the following expression:

$$F_d^* = F - M^* \ddot{x} \tag{3}$$

Where

M* : Estimated Mass matrix

$\boldsymbol{F_d^*}$: Estimated disturbance force

$\ddot{x}$: Measured acceleration signal

$\boldsymbol{F}$: Measured applied control force

The estimated mass used in the study can be obtained by a number of methods including AI techniques [11].

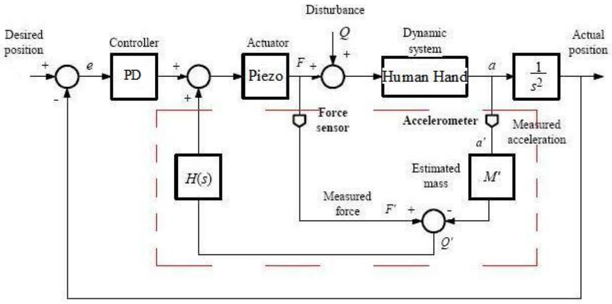


Fig. 4 The Proposed Scheme

From Figure.4, it is deduced that through this scheme, the output X can be made invariant with respect to the disturbance Q (which include the internal as well as the external disturbances). For a good control system performance, it is essential that the system output is made invariant with the disturbance.

6 Simulation Results

Figure.5 shows the MATLAB-Simulink simulation model of the hand model used in this study. For the simulation, the acceleration and displacement results showed the emulate behavior of postural tremor by applying the harmonic force at the palm. The piezoelectric actuator model incorporated with 4-DOF of the hand model was used in the simulation. A sinusoidal disturbance with amplitude of 10 N and frequency of 10 Hz was applied to the dynamic system. The dynamic response of the system during 10 s was studied. A fixed sampling time of 0.01 was chosen in the simulation study.

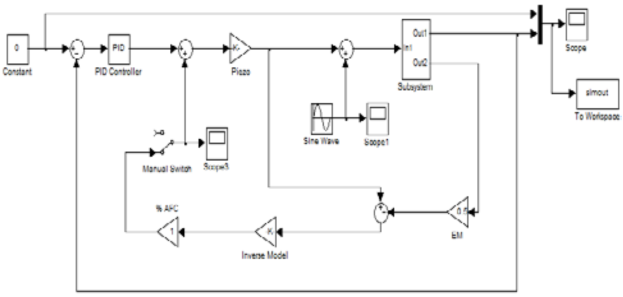


Fig. 5 MATLAB–Simulink simulation model for the Hand system

To implement the AFC scheme, the following control parameters are used in simulation:

For PD controller;

P=1000, D=10;

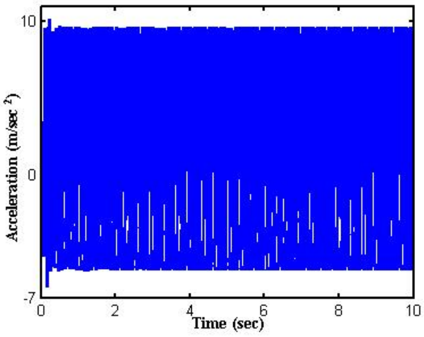
The piezoelectric actuator model incorporated with four degree-of-freedom (4-DOF) model was used in the simulation. A bimorph type piezoelectric actuator with transfer function of 0.006 was used for the simulation purpose [29]. Thus, the inverse model of the actuator would be 166.67. Using crude approximation, the suitable mass of the system was found to be 0.5.

d31= Piezoelectric charge constant = 190×10-12 mV-1
w = width = 0.0318 m
t = thickness = 0.0005 m
l = length = 0.0635 m
SE11=Elastic compliance (Stiffness) = 1.613×10-11m2N-1

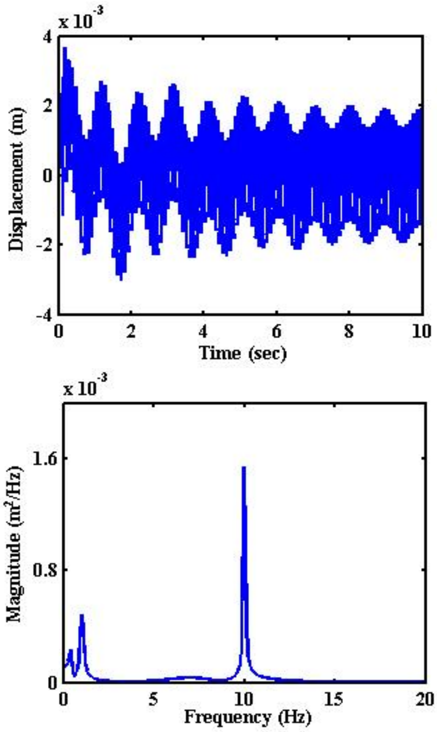
To evaluate the performance of the proposed method, comparison is made with the conventional PD controller and AFC-based Scheme.

7 Results and Discussions

Figures 6 (a) and (b) show the simulation response of acceleration and displacement of the 4-DOF model. Both responses are shown in time and frequency domain for a period of ten (10) sec and 15 sec respectively, where the individual is afflicted with Parkinson's disease. The frequency range associated with hand tremor is demonstrated by waveform, and it varies from 5-12 Hz. However, most of the tremor lies in the 10 Hz range. As shown in Figure. 6 (a), the acceleration amplitude and frequency fall in the targeted range of tremor i.e. -10 m/s2 to 10 m/s2 and 8-12 Hz [13,18] respectively. In Figure. 6 (b), the palm displaces with the small amplitude of +4mm, which is also in the targeted range of + 5 mm [19-23]. However, the behavior of output signal remains as sine wave input. Meanwhile, in Figure. 6 (b), the frequency coherence of tremor was observed at 10 Hz.



a) Simulation result of acceleration for 4-DOF model



b) Simulation Result of Displacement for 4-DOF Model

Fig.6 Simulation result for 4-DOF model

Figure. 7 and Figure. 8 show the acceleration and displacement result with uncontrolled vibration (UV), Proportional-Derivative (PD) controller and Proportional-Derivative with Active Force Control (PDAFC) scheme respectively. In Figure. 7, the result of UV (without any controller) was in the targeted range of -10 m/s2 to 10 m/s2 [13,18]. After applying the PD controller, the amplitude reduces to -4 m/s2 to 4 m/s2. From Figure 7, it is obvious that the PID controller is unable to control the hand tremor satisfactorily since it produces significant track error, though the performance is stable. However, when the same PD controller was upgraded to include the AFC-based scheme, the results drastically improve.

In Figure. 8, the result of UV was in the targeted range of + 4 mm [19-23]. After applying the PD controller, the hand displaces between + 1 mm. However, when the same PD controller was combined with the AFC-based scheme, the results significantly improve. The AFC-based schemes clearly demonstrate their robustness and effectiveness to control the hand system equipped with the highly non-linear piezoelectric actuator. The superiority and effectiveness of the AFC scheme over the PID counterpart was obvious from the results.

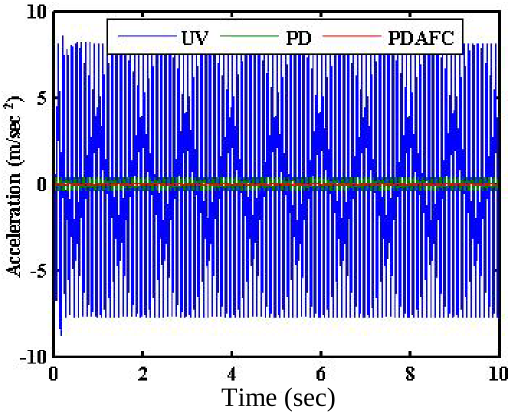


Fig.7 Control scheme of acceleration for the 4-DOF model

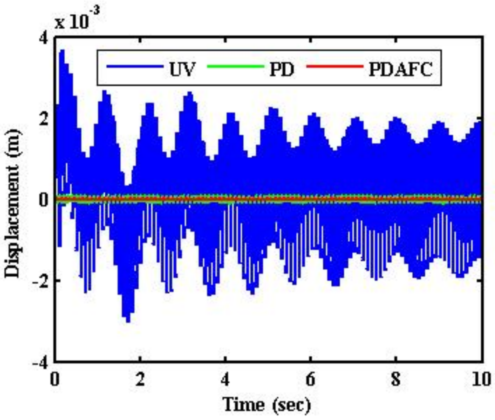


Fig.8 Control scheme of displacement for the 4-DOF model

8 Conclusion

The active force control (AFC) strategy has been successfully implemented to the hand system under vibratory (tremor) disturbances through simulation studies. The results clearly indicated that the AFC-based control scheme is robust and caused a significant improvement compared to PD controller in compensating the tremor present in the system. It is envisaged that the proposed work can be useful for medical application in reducing the tremor in Parkinson's disease.

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