Study of Active Force Control in Biodynamic Hand Model

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Abstract: - This simulation work provides the investigation of the performance active vibration method in suppressing human hand tremor. The Active Force Control (AFC) and classic Proportional-Derivative (PD) controller is proposed to control linear electromagnet actuator and applied at a 4-DOFs biodynamic model of human hand to investigate the performance of the controller. From the findings, the combination of AFC and classic PD controller shows excellent performance in reducing tremor error. The two degree of freedoms controller gives a significant improvement in tremor cancellation compared to merely using PD controller. The simulation work could be used as initial stage to study and develop anti tremor device.

Key-Words: - Active Force Control, Active Tremor Control

1 Introduction
Neurological disorder such as tremor is an involuntary or rhythmic uncontrollable oscillation of body parts that may visible for Parkinson Disease (PD) patient. The severe illness most commonly occurs at the hand and head. Tremor may happen to anyone [1] and most PD patient doesn’t care the early stage of their tremor until the tremor become worse. The involuntary movement for a healthy person (physiological tremor) should be small and clearly visible when a person encounters anxiety, furious, too cold and frightened. However, for a neurological diseases person, such as Parkinson’s disease there is a significant uncontrollable hand tremor movement [2]. Tremor may be caused by smoking habits, taking caffeine, alcohol, using certain drugs and a people with a family history of movement disorder [3-4].

There is no official statistical data available on people experiencing person severe Parkinson disease in Malaysia. According to Malaysian Parkinson’s Disease Association (MPDA), it is estimated that about 15,000 to 20,000 patients suffer from PD in Malaysia. While there is no cure for PD currently available and the fact that the proportion of elderly people in the population is increasing, the total number of PD patients is expected to rise to about 25,000 to 30,000 by the year 2020 [5].

The objective of this study is to investigate the performance of the active vibration method (linear electromagnet actuator and AFC controller) in suppressing human hand tremor. In this study, the Active Force Control (AFC) strategy will be applied as a controller [6] due to its simple control law and proven vibration cancellation capabilities either in simulation or experimental. From the literature, it was found that the tremor amplitude for a PD person in the range between ±10mm [7]. For the simulation model, biodynamic response (BR) will be used to generate 4-DOFs hand tremor and applying the proposed controller to reduce tremor error.

2 Biodynamic Model of the Human Hand
The biodynamic response (BR) of human hand is used to observe the relation between force and motion of human tremor. Thus, the mechanical model which is the combination of mass-spring-damper system is utilized to represent a 4-Degree of Freedoms (4-DOFs) model of human hand tremor, specifically at the palm.

In the 4-DOF model, masses $m_1$, $m_2$, $m_3$, and $m_4$ have been attributed to mass due to epidermis, dermis, subcutaneous tissue and the muscle, respectively. The coupling elements $k_1$ and $c_1$ are considered to represent the visco-elastic properties of epidermis and dermis tissue. The strong coupling between the dermis and the subcutaneous tissue has been related to element $k_2$ and $c_2$. However, the elements $k_3$ and $c_3$ are considered to represent weak coupling between the subcutaneous tissue and the
muscle. The element $k_4$ and $c_4$ relate to coupling between muscle and the bones [8].

Theoretically, human hand tremor exists due to the damage on human brain that disturbs the motor function (muscle) without any external force applied at the hand. Hence, in the simulation 4-DOFs model the source of force should be placed at the muscle (at $m_4$) and this can be called as ‘internal force’ that was used to induce the vibration. The applied force at the palm can be seen in the Figure 1.

Fig. 1: Four DOFs palm model.

The basic equation of motion of the 4-DOFs at the palm of human hand may be expressed as

$$m \ddot{q} + c \dot{q} + k q = f$$

(1)

where $m$, $c$ and $k$ represented mass, damping and stiffness element, respectively. The $\ddot{q}$, $\dot{q}$, $q$ and $f$ are parameter of acceleration, velocity, displacement response and force, respectively. Table 1 shows the parameters used to emulate the 4-DOFs hand tremor in the vertical plane.

Table 1. Parameters of skin anatomy at human hand [8].

<table>
<thead>
<tr>
<th>Skin Layer</th>
<th>Mass, m (kg)</th>
<th>Dampen, c (Ns/m)</th>
<th>Spring, k (N/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epidermis</td>
<td>0.0043</td>
<td>88.8</td>
<td>678</td>
</tr>
<tr>
<td>Dermis</td>
<td>0.105</td>
<td>1.5</td>
<td>185</td>
</tr>
<tr>
<td>Subcutaneous</td>
<td>0.566</td>
<td>0.1</td>
<td>23.9</td>
</tr>
<tr>
<td>Muscle</td>
<td>4.3</td>
<td>3.99</td>
<td>34.6</td>
</tr>
</tbody>
</table>

3 Transfer Function of Linear Electromagnet Actuator

In this theoretical study, a linear motion electromagnet actuator is selected as the transducer to suppress human hand tremor. The electromagnet field (EMF) generated is proportional to the rate of change of the magnetic flux. The movement of the charge $q$ particle with a velocity $\dot{v}$ in an electromagnetic field will creates a current (electric field $\vec{E}$ and magnetic flux density $\vec{B}$). Thus, the occurrence force $\vec{F}$ on moving charge, also known as Lorentz Force can be represented by the equation,

$$\vec{F} = q(\vec{E} + \dot{v} \times \vec{B})$$

(2)

which consists of electric force and magnetic force. When a current is formed by a very large number of charged particles (the electrons) moving along the wire [9 – 10], the total force is given by integrating,

$$\vec{F} = i \int dl \times \vec{B}$$

(3)

Meanwhile, the Lorentz Force of the magnetic field acting on the element $dl = rd\theta$ of one turn of the coil with a current $i$. Thus,

$$F = i \int rd\theta \cdot B$$

(4)

The relationship of the electromagnet force $F$ and the current of the coil $i$ can be expresses as,

$$|F| = i \cdot 2 \pi nr \cdot B$$

(5)

For this simulation study, the parameters used for electromagnet actuator transfer function are; a) Outer diameter of the coil is 40 mm b) made into a 122-turn coil and 3) the magnetic flux density $B$ is 1.04 Tesla.

4 Active Force Control (AFC) and PD Control

Active force control (AFC) was firstly introduced by Hewit and is widely used since the last three decade [6], [11-12]. This robust controller is capable of managing a closed loop system with the introduction of disturbances, parameter uncertainties and changes to reduce error. The advantages of using AFC method include utilizing a simple control technique, low computational burden and proven capability in real-time application.

Figure 2 shows the proposed AFC control scheme incorporate with PD controller to control an electromagnet actuator for suppressing human hand tremor. The main AFC loop is shown in the dash line box. For theoretical simulation, it is assumed that the position sensor gives the perfect modeling ($H_s(s)=1$) and the noises in the sensors are totally neglected.
Meanwhile, the main AFC equation computed the Estimated Disturbance, \( Q' \) can be express as:

\[
Q' = F - M' \cdot \ddot{y} \tag{6}
\]

where,
- \( F \) : Applied force of the actuator.
- \( M' \) : Estimated mass vibration transmissibility.
- \( \ddot{y} \) : acceleration vibration transmissibility.

By using heuristic (try and error) method, the value of estimation mass \( M' = 0.001 \)kg. The computation of \( Q' \) is then passed through an inverse transfer function of the actuator and summed up with PD controller to give the ultimate AFC signal command embedded with an outer control loop. The scheme actually has a two degree-of-freedom controller (classic closed loop and AFC element) that offer an excellent overall system performance provided that the measurement and estimated parameters were appropriately acquired [12].

5 Results and Discussions
The proposed control scheme (AFC + PD control) is simulated to investigate the effectiveness of the controller in reducing tremor error. This simulation study is accomplished by using MATLAB and Simulink software. The results may be used for further investigation in real-time application. Figure 3 shows the input force signal which is a combination of sine wave and white noise signal. The combination signals have been selected to characterize the behaviour of real human hand tremor where the signal exhibits much closer to sinusoidal waveform, rhythm and regularity [13]. In order to get a realistic output displacement of human hand tremor, the value for sine wave signal and white noise signal have been tuned as follows,
- Sine wave – Amplitude [9N]; Frequency [50Hz]
- White noise – Noise Power [0.02]; Sample time [0.001]

As shown in Figure 3, the high input force value (±30N) is required to excite a 4-DOFs human palm hand due to the location of applying input force at the muscle (see Figure 1). The force energy will decrease from muscle to epidermis layer due to the absorption action of damper at each layer.

The displacement signal for human hand tremor when the input signal is applied at the 4-DOFs human palm hand can be seen in Figure 4 (labeled as Hand Tremor). Referring to the figure, the simulation reaction is between -8mm and 5mm which is still within the target displacement amplitude boundary since the actual human postural tremor behavior is within the range of ±10mm [14 - 15].

Figure 4 shows comparison of the performance of controller between classic PD controller and PD + AFC controller. During the 10-s simulation time, the displacement response of the human hand tremor was determined for the gap between the reference and PD controller oscillated between ± 2mm. By applying PD + AFC controller, the hand tremor error reduces to ± 20 micron. Overall, the findings conclude that when the AFC controller is applied, it gives a significant reduction in active vibration cancellation.
Theoretically, the findings prove that the AFC based scheme capable work with linear electromagnet actuator and manage to suppress human hand tremor. Hence, the outcomes of the study present an important finding and an initial stage that may assist researcher to design and develop anti tremor equipment utilizing linear electromagnet. Furthermore, the AFC controller has been proven to be effective in real time especially in vibration application, thus the idea to develop anti tremor device will be more realistic.

### 6 Conclusion

This study provides the investigation of the performance active vibration method in suppressing human hand tremor. From the findings, the combination of active force control (AFC) and classic PD controller shows excellent performance in reducing tremor. The two degree of freedoms controller gives a significant improvement in tremor cancellation compared to merely using PD controller. The simulation work could be used as initial stage to study and develop anti tremor device.

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