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Parkinson's Tremor Suppression Using Active Vibration Control Method

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Abstract. Parkinson's disease is the second most common neuro-degenerative disorder. The hallmark symptom of Parkinson's disease known as tremor, affects the patients in carrying out most of their daily life activities. In this paper, a biodynamic model of human arm is used to imitate the behavior of Parkinson's tremor and suppression of this tremor is performed using a Proportional-Integral-Derivative (PID) controller which is optimized using Genetic Algorithm (GA) to obtain better performance. Active vibration controlling technique which incorporates sensors and actuators to detect and counteract the tremor is implemented with the help of PID controller.

1. Introduction

Parkinson's disease is a severe progressive neurodegenerative disorder with often disastrous symptoms that primarily affects older people. The disease was first described by James Parkinson in 1817 [1]. The disorder predominantly affects a particular region in the brain called substania nigra, which produces a neurotransmitter called dopamine. It acts as a messenger between the substania nigra and the corpus striatum to produce smooth coordinated movements. As a result of destruction of nerve cells in substania nigra, dopamine is no more produced thus affecting voluntary movements [2]. As a result, troublesome oscillations appear in different parts of the body such as hands, legs, jaw etc. This condition is called Parkinson's tremor (PT) [3]. As the tremor becomes more prominent the PD patients gradually develop difficulties in carrying out daily life activities such as writing, holding things, eating etc. The initial symptoms of PD occurs at the age of 50-60 years.

Tremor can be characterized as involuntary rhythmic oscillations that mainly affects hands. Treatment for PT includes pharmacotherapy i.e. intake of drugs such as levodopa, sinemet (combination of carbidopa-levodopa) etc. These drugs like any other causes negative impact on the patient's body such as muscle paralysis, speech impediments, hallucinations and depression. Deep Brain Stimulation (DBS) which is a neurosurgical procedure carried out to abate tremor can cause bleeding after surgeries or may cause device related infections. And also the surgery has to be carried out in well-established hospitals by expert surgeons, which may not be accessible for all patients [4]. These demerits led to the study for developing non-invasive devices that would help in reducing the effect of tremor. This paper introduces a simulation study for suppressing tremor which can be later used for building an anti-tremor device.

Currently in industries, the strategies used for suppressing vibrations include active as well as passive methods. Active vibration control method is a technique used for compensating tremor by actively applying equal and opposite forces and it includes sensors, actuators as well as feedback controls [5]. The sensors are used to detect the tremor and the feedback is given to the actuator to counteract the tremor. Passive methods does not use any external source to reduce tremor instead dampens itself by using biomechanical loads [6]. According to S. Kazi et.al [7] tremor suppression can be carried out using active control technique by incorporating a piezoelectric actuator in a specifically designed gloves and it was found that the actuator can act as a tremor resistive element by opposing the tremor force. A Proportional Derivative (PD) controller along with active force control method was investigated by A. As'Arry et.al to reduce tremor and the PD controller was optimized using signal constraint block available in the optimization toolbox of Simulink [8].

The rest of the paper is arranged as follows: Section 2 describes the methodology for carrying out the PT suppression. It explains about the dynamic model of human arm, PID controller as well as the GA for optimizing the PID controller parameters. Section 3 describes the simulation results and section 4 presents the conclusion.

2. Methodology

Figure 1 shows the block diagram for tremor suppression using the actuator with the help of feedback given by the PID controller.

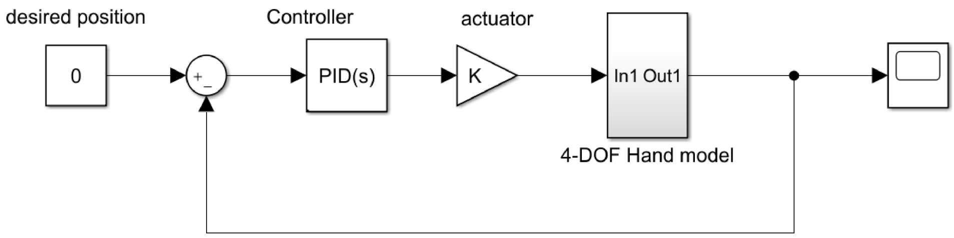

Figure 1. Block diagram for tremor suppression.

2.1. Dynamic model of Human Arm

In mechanics, any vibrating system can be modelled using mass, spring and damper system. Since tremor is similar to vibration, human arm can be configured using mass spring damper system. The parameters for emulating PT has been already determined [8]. A 4-Degree of Freedom (DOF) arm model is shown in figure 2, for studying the dynamic response of human arm when there is tremor. The biodynamic response can be defined as the response of human arm in terms of displacement, velocity, acceleration to a particular force acting on it [9]. In 4-DOF human arm model m_1, m_2, m_3 and m_4 are the masses of dermis, epidermis, subcutaneous tissue and muscle. The coupling between each of these skin layers is viscoelastic in nature and has been modelled using spring and damper [10]. It has been found that in Parkinson's disease the major source for carrying tremor from the brain to hand is through muscles, so it is considered to apply the input force at muscle m_4 in the arm model [6].

The variables q_1, q_2, q_3 and q_4 in Figure 2 denotes the displacements of each layer that is m_1, m_2, m_3 and m_4 respectively. The equations of motion for the 4-DOF model can be written as follows.

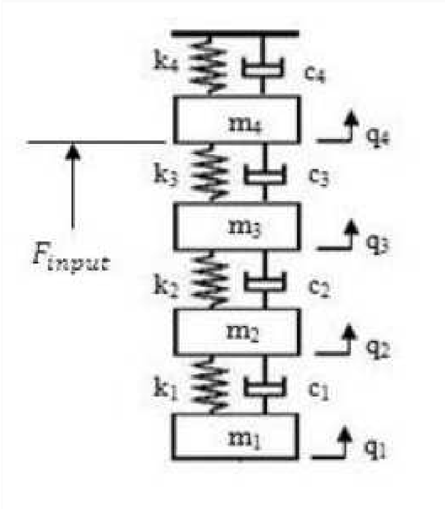

Figure 2. 4-DOF model for human arm.

$$m_1\ddot{q}_1 = -k_1(q_1 - q_2) - c_1(\dot{q}_1 - \dot{q}_2) \tag{1}$$

$$m_2\ddot{q}_2 = -k_1(q_2 - q_1) - c_1(\dot{q}_2 - \dot{q}_1) - k_2(q_2 - q_3) - c_2(\dot{q}_2 - \dot{q}_3) \tag{2}$$

$$m_3\ddot{q}_3 = -k_2(q_3 - q_2) - c_1(\dot{q}_3 - \dot{q}_2) - k_3(q_3 - q_4) - c_3(\dot{q}_3 - \dot{q}_4) \tag{3}$$

$$m_4\ddot{q}_4 = -k_3(q_4 - q_3) - c_1(\dot{q}_4 - \dot{q}_3) - k_4 q_4 - c_4(\dot{q}_4) + F_{input} \tag{4}$$

where k and c represents the spring and damper constant of different layers respectively.

Equations (1)-(4) which governs the PT of the hand can be rearranged and modelled in MATLAB and simulink for simulation. The parameters for the different layers of 4-DOF human arm are given in Table 1.

Table 1. Parameters for 4-DOF arm model.

Skin layer	Mass(kg)	Damper Constant(Ns/m)	Spring Constant(N/m)
Epidermis	0.0043	88.8	678
Dermis	0.105	1.5	185
Subcutaneous tissue	0.566	0.1	23.9
Muscle	4.3	3.99	34.6

2.2. PID Controller

PID controllers are the most commonly used controllers in industry. It performs proportional, integral and derivative actions to reduce the error. It is frequently used in control systems because of its robustness and simplicity. Tuning of PID controllers are very important in-order to obtain the exact parameters for reducing the error [11]. General equation for PID controller is given as,

$$u(t) = K_p * e(t) + K_i \int e(t) + K_d \frac{d(e(t))}{dt} \tag{5}$$

where u(t) is the control signal, K_p-proportional gain, K_i-integral gain, K_d-derivative gain, e(t) is the error signal.

A position sensor can be used to measure the displacement of the arm and the feedback is send to the controller. Ideally the tremor has to be suppressed completely therefore the desired position is set as zero. The difference between the desired position and the feedback signal is given to the actuator that generates anti-vibrations that cancels out tremor. The parameters K_p, K_i and K_d should be optimized so that the error is minimized.

2.3. Optimization using Genetic Algorithm

Genetic algorithm is a soft computing technique that is used for tuning PID controllers. Although PID controllers can be tuned manually, it is time consuming and tedious. The GA was proposed by John Holland which was based on Darwins theory known as survival of the fittest. The principle includes natural genetics and natural selection. The algorithm works by optimizing certain objective functions such as Integral Absolute Error (IAE), Integral Time multiplied by Absolute error (ITAE) and Integral Square Error (ISE) [12] [13]. The algorithm generates a population randomly according to the constraints and creates chromosomes/individuals that contains the PID parameters to be tuned. The algorithm then iterates which produces new generations based on the fitness function and based on different genetic operators known as selection, crossover, mutation, migration and reproduction. In each generation the fittest individual that is the one with minimum fitness value will survive and the weakest individuals get removed. In PID tuning the individuals/chromosomes i.e. K_p, K_i and K_d are encoded as real numbers. The equations for fitness functions are given below,

$$IAE = \int_0^\infty |e(t)|dt \tag{6}$$

$$ITAE = \int_0^\infty t|e(t)|dt \tag{7}$$

$$ISE = \int_0^\infty e^2(t)dt \tag{8}$$

The optimization of these fitness functions were carried out using the Genetic Algorithm toolbox in MATLAB by selecting a population size of 50, rank based fitness scaling, selection based on stochastic uniform sampling and arithmetic crossover. Figure 3 shows the flowchart diagram for GA optimization. In order to perform optimization using GA toolbox in MATLAB, transfer function of the 4-DOF hand model was necessary. Computation of the transfer function of the hand model was complex since it has 4 degree of freedom. Hence the model was linearized using Linear Analysis toolbox in MATLAB and the transfer function of the model was obtained as follows. Transfer function, H(s) obtained is given in equation (9).

$$H(s) = \frac{232.6}{s^2 + 951.2s + 13600} \tag{9}$$

Using this transfer function the PID parameters were tuned using IAE, ITAE and ISE as fitness functions.

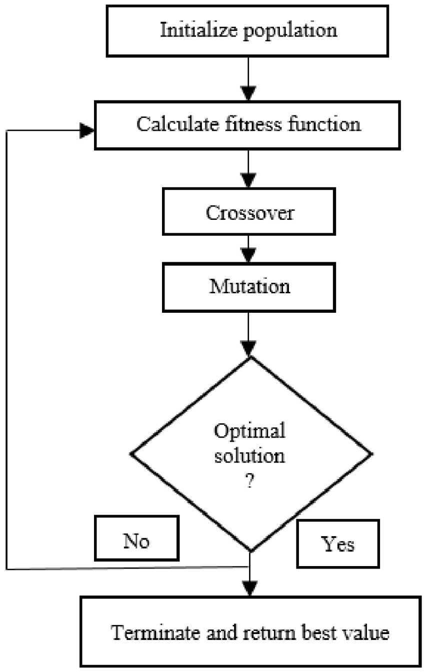

Figure 3. Flowchart for GA optimization.

3. Results and Discussions

A method for active vibration control using an actuator for PT is introduced in this paper. The modelling as well as suppression of PT is simulated with the help of MATLAB and Simulink software. Using the equations of motion for 4-DOF arm the model was build and simulated. The input to the 4-DOF arm is a combination of sine wave and white noise signal which has been chosen to imitate the actual human tremor behavior, is shown in figure 4. The displacement response of the 4-DOF arm obtained lies between $\pm 10mm$, which corresponds to actual PT, is shown in figure 5.

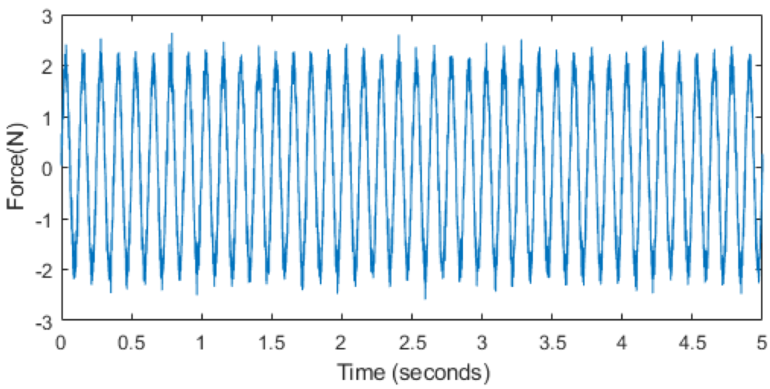

Figure 4. Input to excite 4-DOF arm model.

The PID controller parameters optimized using GA is shown in Table 2. Different fitness functions are used to compare the performance of the controller in suppressing tremor. The

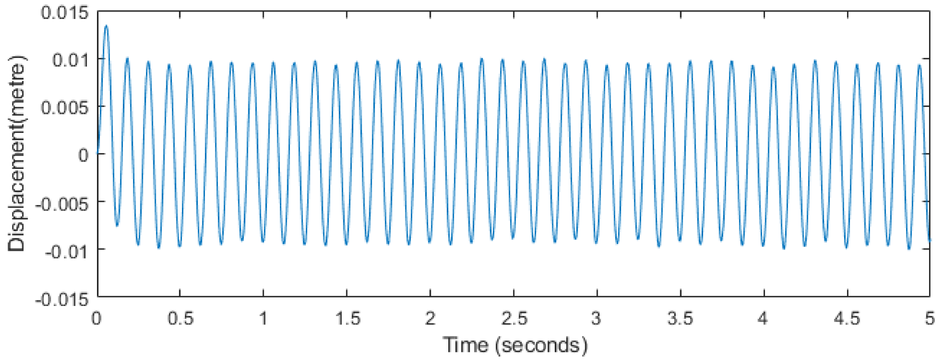

Figure 5. Displacement response of simulated tremor.

optimization using IAE, ITAE and ISE gave almost similar results. Figure 6 indicates the step response of the system using optimized K_p, K_i and K_d parameters. Figure 7 shows the displacement response of PT and suppressed PT.

Table 2. Optimized PID parameters.

Fitness function	Best value	Mean value	Iterations	Kp	Ki	Kd
ITAE	0.122	0.123	22	99.959	99.929	49.54
IAE	0.250	0.251	22	99.87	99.385	49.874
ISE	0.0725	0.0737	22	97.321	98.77	48.75

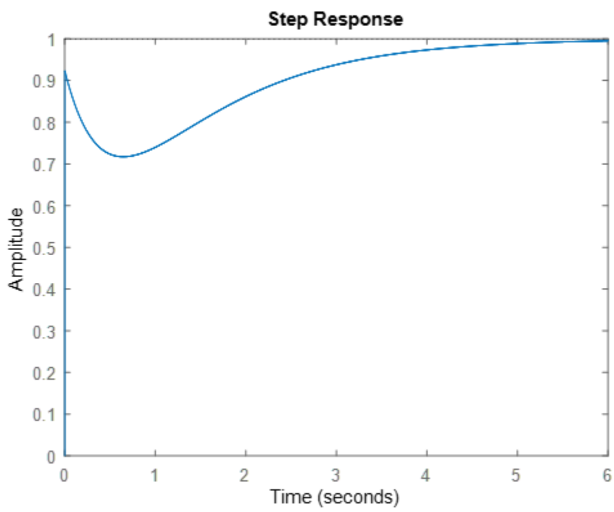

Figure 6. Step response of tuned PID controller.

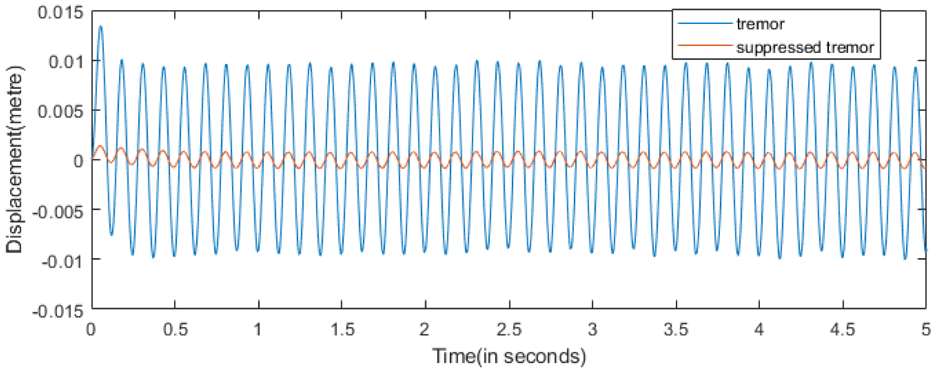

Figure 7. Displacement response of simulated and suppressed tremor.

Figure 8 shows the conversion of displacement response of simulated and suppressed tremor in frequency domain by applying Fast Fourier Transform (FFT). According to the studies, PT has a frequency range of 5-12 Hz. The results demonstrate that the simulated hand tremor occurred at 8.2 Hz which resembles PT. After suppressing the tremor using GA tuned PID controller the peak value at 8.2 Hz has reduced significantly.

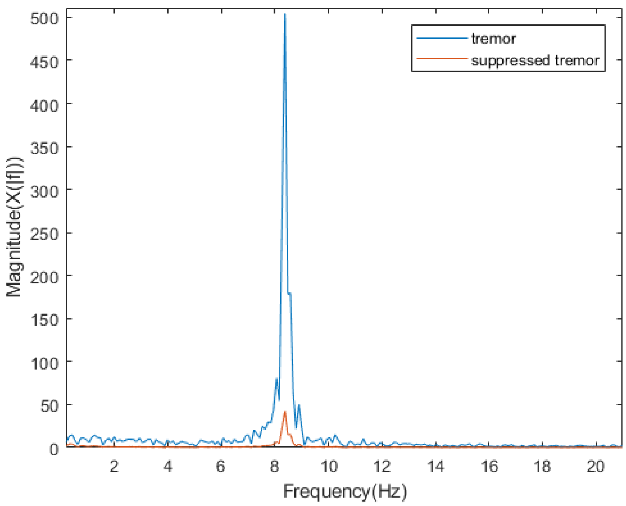

Figure 8. Displacement response in frequency domain.

4. Conclusion

This paper evaluates the performance of active vibration control technique which includes an actuator to suppress PT. An efficient approach for optimizing the PID controller was developed using GA. The simulation results reveal that the PT can be controlled by providing feedback to the hand with help of the actuator. As compared to the conventional methods, this offers a foundation to develop a prototype for providing non-invasive and economical means of reducing the tremor. Such an anti-tremor device could be modelled and developed to implement tremor suppression on patients more effectively.

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