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Research paper

Modeling and experimental study of a hand tremor suppression system

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ABSTRACT

Hand tremor is one of the most prevalent movement disorders. Nowadays, methods for suppressing the hand tremor, with fewer side effects, are interesting for researchers. In this study, an electro-mechanical device is designed to attenuate hand tremor of the Parkinson and the Essential tremor patients. This device is used as a spoon, which can suppress hand tremor in frequency range of 3–12 Hz. In this spoon, the piezoelectric devices are used as vibration sensor, energy harvester and vibration suppressor. To study application of the system, the governing electromechanical equations of motion are obtained and validated by experiment. Then to achieve best performance of the tremor suppressor, its parameters are justified concerning the tremor frequency. Furthermore, the electrical energy, which is harvested by the piezoelectric devices, is used to supply needed energy of electrical components of the device. Finally, it is shown that the designed spoon can effectively decrease the hand tremor and for frequency range of 3–12 Hz, this device is able to attenuate the tremor more than 80% during eating.

1. Introduction

Millions of people all over the world suffer from tremor, which is defined as an involuntary and oscillatory movement of the body or limbs [1]. Based on the movement situation of limbs, the tremor can be classified to rest tremor and action tremor. Oscillation of the body limb when the patient doesn't do any voluntary movement is rest tremor. Unlike the rest tremor, action tremor usually occurs during a voluntary movement. The most prevalent diseases that cause hand tremor are Essential tremor and Parkinson. The frequency range of tremor in the Essential tremor is between 5 Hz and 12 Hz and it usually effects on the upper limbs especially the hands [2]. Most common disease with the rest tremor is Parkinson disease, which its frequency range is between 3 Hz and 6 Hz and it commonly effects on hands and legs [2]. The hand tremor declines the patient's efficiency in daily life and the patients usually have difficulties in doing common tasks such as eating, drinking, writing, etc. The common treatments to control these diseases are drugs and surgery. Usually, patients have different responses to drugs. Furthermore, pharmacotherapy might cause different reverse effects such as depression, confusion, fatigue, weakness, etc. [3].

According to limitations of the discussed treatments, the importance of finding alternatives for attenuating the hand tremor with less adverse effects is obvious. Different alternative methods to suppress the hand tremor have been suggested. Several creative devices with passive or active control have been presented, which can be categorized into fixed and portable devices. The fixed devices should typically be installed on the ground, table or wheelchair and these devices are usually

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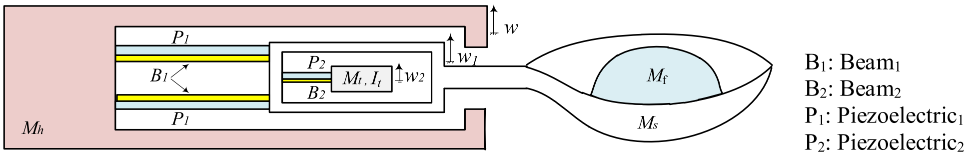

Fig. 1. Schematic of the passive hand tremor suppression system.

designed to help patients with hand tremor to do a special task such as writing, eating, etc. Controlled energy dissipation orthosis (CEDO) was designed to be mounted on a table or wheelchair frame to help patients with hand tremor [4]. Ohara et al. developed a helpful meal assistive robot, which actively suppresses the hand tremor during eating [5]. Mojica et al. designed a fixed mechanism with two links to assist people with hand tremor to write with less difficulty [6].

Wearable devices designed to attenuate the hand tremor can be categorized as portable devices in following sentences some of these devices are briefly explained. One of the methods to attenuate the hand tremor is adding mechanical loads to the patient's hand. Dahlin-Webb suggested a weighted wrist cuff, which is useful to suppress the hand tremor [7]. Hall designed a wearable glove, which uses the gyroscopic effect to attenuate the hand tremor [8]. Kotovsky and Rosen used an orthosis equipped with viscously damped beam to suppress the hand tremor [9]. Hashemi et al. used dynamic vibration absorber to decrease the rest tremor in Parkinson disease [10]. Rahnavard et al. studied the application of an optimized dynamic vibration absorber for suppressing the hand tremor in Parkinson patients [11]. A self-tunable dynamic vibration absorber was developed by Teixeria et al., which can adapt itself to changes of frequency of tremor [12]. To suppress the hand tremor, an orthosis with magnetorheological (MR) dampers was designed by Case et al. [13]. Then Taheri et al. developed its active control [14]. Also Zamanian and Richer suggested a permanent magnet linear motor as an actuator in an orthosis to suppress the pathological tremor and control it with adaptive disturbance rejection controller [15]. Also a variety of wearable robotic exoskeletons are suggested and developed to attenuate the hand tremor through passive and active control [16–18]. Some researchers also used functional electrical stimulation to suppress the tremor [19–21].

Handheld devices can be used for special tasks are other group of portable hand tremor suppressor. A cup with gyroscopic stabilizer is suggested by Abbaszadeh to attenuate the hand tremor and help patients to drink with fewer problems [22]. In order to improve the handwriting of patients, a pen with active control was developed by Ou et al. [23]. Also the Liftware Steady, which is an innovative and practical spoon, was designed by LIFTWARE Company. This device, actively suppress the hand tremor up to 76% [24]. Arm Vibration Damping Device is a portable device is an US patent, which is designed to suppress the hand tremor [25]. This device includes a robotic mechanism, which uses the active control to attenuate the tremor. Abbasi et al. designed a device with two applications to attenuate the hand tremor with active control. This device can be used as a spoon and also as a pen for using of tablets and smartphones [26]. The mentioned device is a 2-dof robotic mechanism with active control, which can attenuate the effect of hand tremor. Unlike the mentioned studies, in the present investigation, a semi-active device with different mechanism is presented to suppress the hand tremor.

Passive control devices including base isolation, friction dampers, impact dampers, tuned mass dampers are well-known means for suppressing undesired vibrations [27,28]. In this study, vibration isolation and dynamic vibration absorber is used to reduce the hand tremor. This system is designed to attenuate the effect of hand tremor in both of the Parkinson and Essential tremor patients. Unlike previous studies, which are done in this research area, the designed system in this study is a semi-active device, which not only can effectively decrease the hand tremor but also it can generate its needed electrical energy.

2. Mathematical modeling

Considered hand tremor attenuation system, which is shown in Fig. (1). In this system, two clamped-guided piezoelectric beams (B_1 and P_1) are used to hold the spoon and a clamped piezoelectric beam (B_2 and P_2) is used as a dynamic vibration absorber. As shown in this system, w is the hand motion that consists of tremor and intentional movement, and the oscillations of first and second beams are respectively shown with w_1 and w_2. Furthermore, in Fig. (1), M_h, M_s, M_f, M_t and I_t are respectively the handle mass, the spoon mass, food mass, the tip mass and the tip mass moment of inertia. To facilitate eating food for the patients, rotation of spoon should be avoided. In the present study, the tip of spoon is connected to two parallel beams, which behave as clamped-guided beams. Therefore, the spoon cannot rotate and it only moves linearly.

The potential energy of the system can be calculated as shown in Eq. (1). Where L_{B1}, $L_{B2,}$ and L_e are the length of beams B_1, $B_{2,}$ and equivalent length, respectively. EI_B and EI_P are the beam and piezoelectric flexural stiffness, respectively. Furthermore, V_1 and V_2 are the output electrical voltage of P_1 and $P_{2,}$ respectively. The kinetic energy of the system can be written as shown in Eq. (2):

$$\begin{aligned}\pi = &\int_0^{L_{B1}} EI_{B1}\left(\frac{\partial^2 w_1}{\partial x^2}\right)^2 dx + \int_0^{L_{B1}} EI_{p1}\left(\frac{\partial^2 w_1}{\partial x^2}\right)^2 dx + \int_0^{L_e} E_{p1} w_{p1} V_1 d_{31}\left(-z\frac{\partial^2 w_1}{\partial x^2}\right) dx\\ &+ \frac{1}{2}\int_0^{L_{B2}} EI_{B2}\left(\frac{\partial^2 w_2}{\partial x^2}\right)^2 dx + \frac{1}{2}\int_0^{L_{B2}} \left\{EI_{p2}\left(\frac{\partial^2 w_2}{\partial x^2}\right)^2 + E_{p2} w_{p2} V_2 d_{31}\left(-z\frac{\partial^2 w_2}{\partial x^2}\right)\right\} dx\end{aligned} \tag{1}$$