Performance Evaluation of Smart Glove Applied to Experimental Rig to Control Human Hand Tremor for Parkinson disease

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Abstract: This paper focuses on the development of an experimental rig which was designed as an apparatus to induce vibration along the model of hand-arm to simulate the human postural tremor and proposed a smart glove incorporated with piezoelectric actuator for effective control over the tremor produced by the experimental rig. Intra Vernacular (IV) Training arm is used to represent the human hand-arm and two DC motors with unbalance masses are used as the source of excitation. Thus, this creates a quivering hand-arm model which represents the behavior of postural tremor phenomenon. The quantification assessment of human hand tremor and the experimental rig are measured and recorded at the palm. In this paper, the experimental results are divided into two parts; actual human hand tremor and model hand-arm tremor. Both experiments were done by wearing the glove to evaluate the effectiveness of the glove in reducing hand tremor. The displacement and acceleration are measured and recorded on the model using light-weight accelerometer and laser displacement sensor respectively. A piezoelectric actuator is employed as the main active element for the compensation of the disturbances. The results are 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 control strategies that is needed as an input for the piezoelectric actuator or in the design of a device that can suppress the hand tremor vibration. The presented system is notable for simplicity and low cost.

Key-words: Smart Glove, Human hand tremor, Piezoelectric Actuator, Experimental Rig

1 Introduction

Human hand motion can be broadly divided into two categories: voluntary and involuntary. Voluntary motion is intentional, such as throwing a baseball or changing the TV channel using a remote control. Involuntary motion is unintentional movement. One example of involuntary hand motion is the small vibrations in a person's hand when they are trying to keep their hand still, due to small imperfections in the human body's biomechanical feedback mechanisms. An important part of its mechanism is the loss of the neurotransmitter dopamine in a group of brain structures that control movements. Its major manifestations are variable but can include hand tremor, slowness of movements, limb stiffness, and difficulties with gait and balance. In healthy people this involuntary hand motion is small but those which are arising from neurological disorder, such as Parkinson's disease, there is a significant hand tremor movement which make difficult to the tremor patient to perform desired tasks especially for holding and writing.

Two types tremor always seen to the Parkinson's (PD) patient; there are resting tremor and postural tremor. Resting tremor occurs when muscle stay in relaxed and limb are supporting fully to gravity, such as when the hands are stay on the lap. Postural tremor appears when a part of the body is maintained in a fixed position and may also persist during movement [1]. Resting tremor occurs within the frequency range 3-7 Hz, occurs in up to 75% of individuals with PD [11]. Postural tremor is typically observed between 5 and 12 Hz and is symptomatic in around 60% of PD patients [12]. Previous research found that the acceleration amplitude for postural tremor at the range $\pm$ 10 m/s^2 [11,12] and displacement amplitude range $\pm$ 5 mm [2,4,5,6,12,13].

Tremor investigation mainly focused on the modeling of tremor and processed as random time series and spectral [6,7,9,10,11,12,17]. By measuring involuntary movement, loading the hand will increase the amplitude of tremor while decreasing the frequency. The acceleration of limb tremor movement is often measured with an accelerometer and acts as a transducer to convert mechanical movement or vibration to an electrical output, which can then be filtered and analyzed using available computer software. According to some researchers tremor is directly related to acceleration.

The use of gloves may be an economical and effective way of reducing the level of vibration that affects the hand and arm. The use of anti-vibration gloves is one possible solution to lower the vibration levels that are transmitted to the hand and arm area of humans. These gloves provide anti-vibration material in the finger and palm areas to absorb the vibration energy from the source in order to lower the level of vibration reaching the patient's hand. The effective use of the gloves should be evaluated as an economical means of reducing vibration, as a form of personal protection

In this paper, the postural type of tremor is selected to be studied because the frequency range of postural tremor is greater than the resting tremor. We attempt to solve the vibration control problem of the human hand with tremor using smart glove. The current study was motivated by the wish to develop a better understanding of potential mechanisms of the effects of deep brain stimulation on parkinsonian tremor by studying the tremor dynamics that occur during the onset and offset of high frequency deep brain stimulation in subjects with parkinsonian tremor.

2 Design Consideration

The experimental rig is designed for the purpose of data collection and measurement of a hand-arm model as shown in Fig. 1. Thus, it should minimize the behaviour of human hand-arm tremor. The test rig is designed to hold the hand-arm model (Intra Vernacular Training Arm) firmly in horizontal axis as to emulate the postural tremor condition. The PD patients' postural type of tremor was selected rather than resting tremor, because the frequency range of postural tremor is greater compared to the resting tremor [11,15]. By engaging unbalance mass to the DC motor, vibration can be induced onto the hand-arm model, hence, generating postural tremor behaviour. The test rig will be useful for further research especially in suppressing the postural tremor by measuring the tremor movement and developed the actuator such as piezoelectric actuator and/or developing the correct instruments using the anti-vibration gloves to compensate the tremor [3,4].

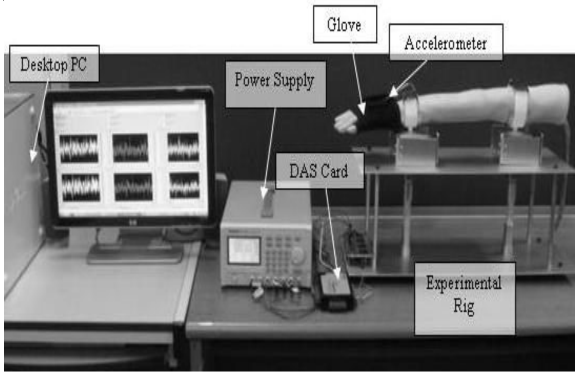

Fig. 1. The experimental setup

3 Biodynamic Model of the Human Hand

Many researchers have attempted to study the biodynamic response (BR) of the hand-arm in terms of its vibration transmissibility for the purpose of quantifying the nature of vibration transmitted to the different segments of the hand and arm. However, this study only focuses the biodynamic model at the palm of the human hand. The purpose is to investigate the BR distributed at the palm in the vertical plane (z-axis) in terms of acceleration, displacement and frequency behavior. Theoretically, human hand tremor occurred by its own without any external force that act at the hand. However, for simplicity of the biodynamic model, the external force is used to induce the vibration.

4 Dynamic Modeling of Piezoelectric Actuator

Piezoelectric actuators are becoming increasingly important in today's positioning technology and there has been a great deal of interest in getting better performance out of this technology, which in simple terms means getting increased actuator deflection out of smaller devices with lower input power. In the recent years, piezoelectric materials under computer control where made to act as actuators and sensors. The word "Piezo" is derived from the Greek word for pressure. Piezoelectric actuators convert electrical energy into mechanical energy, and mechanical energy into electrical energy or piezoelectric actuators convert voltage and charge into force and motion. Piezoelectric materials are a special type of dielectric materials. 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 piezoelectric actuator 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 [8].

Among the different actuator technologies, piezoelectric actuator 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.

The model shown in Fig.3 has been derived from the linear, coupled, electromechanical, constitutive equations ['Eqs. (8) and (9)'] between stress, strain, electric field and displacement.

$$D_3 = \varepsilon_{33} E_3 + d_{33} T_3 \tag{1}$$

$$S_3 = d_{33} E_3 + \frac{1}{Y_{33}} T_3 \tag{2}$$

Where:

D_3 Electric displacement or Polarization in actuator
S_3 Mechanical strain in actuator
D_{33} Piezoelectric charge coefficient of actuator
E_3 Electric field in actuator
Y_{33} Elastic modulus of actuator
T_3 Mechanical stress in actuator
v_a Instantaneous voltage across actuator
ε_{33} Dielectric permittivity of piezoelectric actuator material
N Number of layers
L Length of actuator
w Width of actuator
D Thickness of a one layer of actuator
Q Total charge in actuator
K^2 Electromechanical coupling coefficient

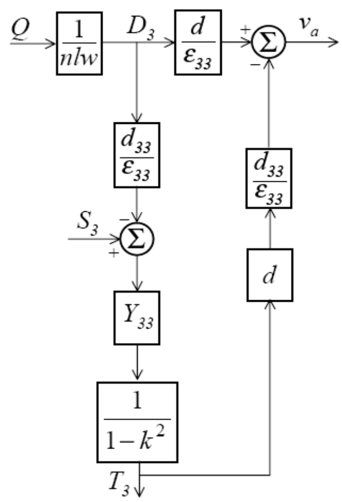

Fig. 2. Electromechanical model of piezoelectric actuator [16]

5 Results and Discussions

In this section, the experimental results are divided into two parts (a) actual human hand tremor (b) model hand-arm tremor. The oscillation readings of both the human hand tremor and IV Training Arm are taken at the left hand only quantified in the vertical plane as the plane of interest. The objective of the study is to determine the amplitude of vibration in terms of acceleration and displacement of tremble in time and frequency domain. The results can be used for further investigation of developing the anti-vibration glove to suppress or reduce tremor.

For every graph shown, there were two signals condition which are with piezoelectric actuator effect (red line color) and without piezoelectric effect (black line color). Figure 3 shows the acceleration response for actual human hand tremor behavior when wearing the Glove in time and frequency domain. In order to get the pure human hand tremor oscillation, the hand is measured without the effect of piezoelectric actuator, and it fluctuates between -3 m/s^2 to 2.85 m/s^2. It is also found that the coherence frequency occurred at 9Hz with magnitude of 0.623 $(m/s^2)^2$/Hz. Then, by applying piezoelectric actuator with the frequency at 7Hz, it is found that the acceleration signal changes and fluctuates between -3.85 m/s^2 and 3.85 m/s^2 as shown in Figure 3(a). The tremor frequency also observed at 9Hz with the magnitude decreased to 0.4081 $(m/s^2)^2$/Hz. Figure 3(b) illustrated the effect of piezoelectric actuator when applying the frequency at 8Hz. From the time domain figure, the acceleration signal vibrates within the range of -1.35 m/s^2 to 1.35 m/s^2. Meanwhile in the frequency domain, it is observed that the frequency occurred at 6Hz with magnitude at 0.1969 $(m/s^2)^2$/Hz. In Figure 3(c), the acceleration signal oscillates between -1.28 m/s^2 to 1.25 m/s^2 when the human hand tremor exposed with the piezoelectric actuator that vibrate at the frequency of 9Hz. In the frequency domain, the tremor frequency also observed at 9 Hz with the magnitude decreased to 0.1485 $(m/s^2)^2$/Hz.

Meanwhile, Figure 4 represents the displacement results for actual human hand tremor wearing Glove in time and frequency domain. Without effect of piezoelectric actuator, human hand tremor displace between -1.2 mm to 1.3 mm. It is also found that the coherence frequency occurred at 6Hz with magnitude of 0.07097 mm^2/Hz. Figure 4(a) shows the effect of piezoelectric actuator, when vibrates at 7Hz. In the time domain, human hand tremor amplitude is not in uniform distribution and ranges between -7.24 mm to 7.25 mm. In spectral measurement, the tremor was observed at 6Hz with magnitude of 0.08676. Figure 4(b) depicts the amplitude of human hand tremor when applying piezoelectric actuator at 8Hz oscillates between -1.3 mm and 1.2 mm. Meanwhile in frequency domain, the hand tremor was observed at 6Hz with magnitude of 0.04445 mm^2/Hz and decreases displacement magnitude peak from the human hand tremor. Lastly, Figure 4(c) illustrates the effect of piezoelectric actuator when it vibrates by applying frequency at 9Hz. From the time domain figure, the amplitude of displacement signal has the peak within -0.82mm to 0.82 mm. Meanwhile in the frequency domain, it is observed that the frequency occurred at 6Hz with magnitude reduced to 0.02533 mm^2/Hz.

Form the Glove result, human hand tremor proves excellent behaviour when the frequency magnitude of acceleration signals for all selected piezoelectric vibration frequency (7Hz, 8Hz and 9Hz) able to reduce human hand tremor. When applying piezoelectric at the glove and vibrate at 7Hz, it will reduce human hand tremor magnitude until 34.50%, for vibration at 8Hz, the magnitude peak decrease until 63.39% and for the last vibration at 9Hz, the acceleration magnitude peak reduce to 76.16%.

From displacement signal, the Glove results prove excellent reduction in human hand tremor magnitude peak reduces to 37.37% and 64.31%, when the piezoelectric vibrates at 8Hz and 9 Hz, respectively. The findings clearly show that Glove is better in reducing human hand tremor behavior.

Figure 5 shows three selected natural frequencies of DC motor analysis for acceleration behaviors in time and frequency domain. The acceleration amplitude exhibits in Figure 5(a) with the DC motor frequency at 67.91 Hz induce vibration within the range of -6.5 m/s^2 to 6.5 m/s^2 for the duration of 30 seconds excitation without the effect of piezoelectric actuator. After applied piezoelectric actuator, the acceleration signal vibrates within the range of -7 m/s^2 to 7.25 m/s^2. Without piezoelectric actuator, the magnitude is 0.852 $(m/s^2)^2$/Hz, meanwhile with piezoelectric actuator, the magnitude reduces to 0.7156 $(m/s^2)^2$/Hz.

Figure 5(b) presented the vibration when the DC motor frequency was 70.68 Hz. In time domain, without the effect of piezoelectric actuator, the acceleration signal oscillates between -11 m/s^2 and 10.5 m/s^2. Then, with piezoelectric actuator, the acceleration signal was found increased in the range -11.3 m/s^2 and 11.2 m/s^2. Meanwhile, the coherence frequency domain also occurred at 8Hz with the magnitude peak of piezoelectric (without piezoelectric effect) at 2.863 $(m/s^2)^2$/Hz and with piezoelectric effect at 2.92 $(m/s^2)^2$/Hz respectively. Lastly, Figure 5(c) shows the vibration of IV Training Arm at DC motors frequency of 77.80Hz with dynamic range between -12.14 m/s^2 to 12 m/s^2 without the effect of piezoelectric actuator. After applied piezoelectric effect, the dynamic range of acceleration was fluctuated between -11.5 m/s^2 to 12 m/s^2. The frequency of vibration occurred at 8 Hz with the magnitude of 3.22 $(m/s^2)^2$/Hz (without piezoelectric effect) and 3.041 $(m/s^2)^2$/Hz (with piezoelectric effect).

Figure 6 shows the precise vibration displacement signals of IV Training Arm, after wearing the Glove. As shown in Figure 6(a), the amplitude is within the range of -0.65mm to 0.75mm (without piezoelectric effect) and -0.85mm to 0.85mm (with piezoelectric effect). Meanwhile in the frequency domain, it is observed at 7 Hz with the magnitude peak at 0.1525mm^2/Hz (without piezoelectric effect) and 0.1745 mm^2/Hz (with piezoelectric effect). In Figure 6(b), the IV Training Arm oscillated between -1.1 mm and 1.1 mm without piezoelectric effect. With the piezoelectric actuator, the acceleration signal was not in uniform distribution which the highest amplitude in the range -1.2 mm and 1.2 mm. This is due to the noise of the displacement signal while taking the measurement. Nevertheless, the frequency domain revealed the actual vibration reading at 8Hz and without the effect of piezoelectric, the magnitude is 0.3168 mm^2/Hz but with the piezoelectric, the magnitude is reduce a little bit to 0.3162 mm^2/Hz. Lastly, Figure 6(c) shows the high displacement range between -1.15 mm and 1.2 mm when disable piezoelectric effect while with piezoelectric it is between -1.3 mm and 1.35 mm respectively. In frequency domain, without piezoelectric actuator effect, the frequency was observed at 9Hz with magnitude peak at 0.3903 mm^2/Hz. By applied piezoelectric actuator, the frequency occurred at 8Hz with magnitude at 0.3219 mm^2/Hz.

From the Glove results, by referring to the time and frequency domain, it shows that the acceleration of the IV Training Arm reduced when the DC motor rotates the unbalancing mass at 77.80Hz with 5.59% reduction. Meanwhile for the displacement signal, the glove is able to reduce tremor when the natural frequency of DC motor is also at 70.68Hz with 0.19% and at 77.80Hz with 17.52%. Thus, it clearly shows more effectiveness of the glove in reducing IV Training Arm tremor when the natural frequency of DC motor at 77.80Hz.

6 Conclusion

There were three selected natural frequencies of DC motor that can give vibration similar to human hand tremor which are 67.91 Hz, 70.68 Hz and 77.80 Hz. For IV Training Arm tremor, the smart glove is much better in reducing the tremor because it is able to give high percentage magnitude reduction for both acceleration and displacement signal.

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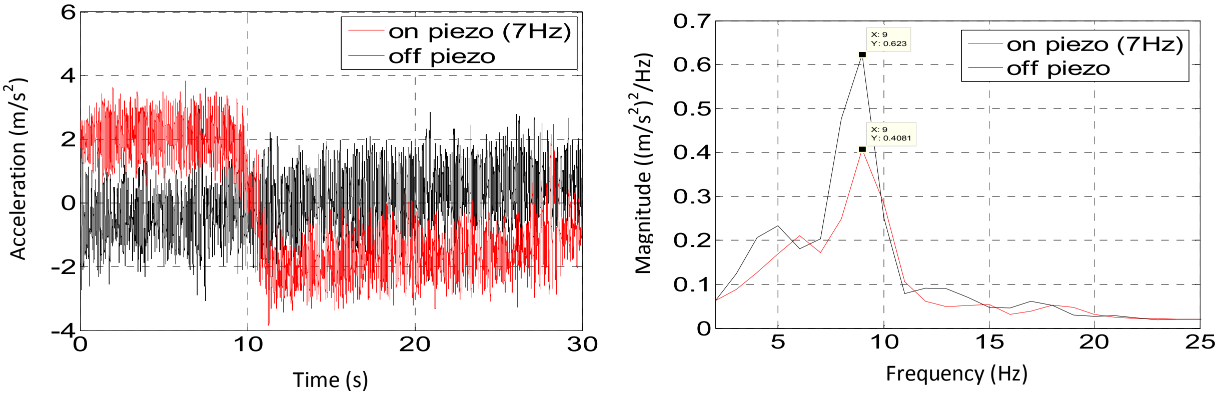
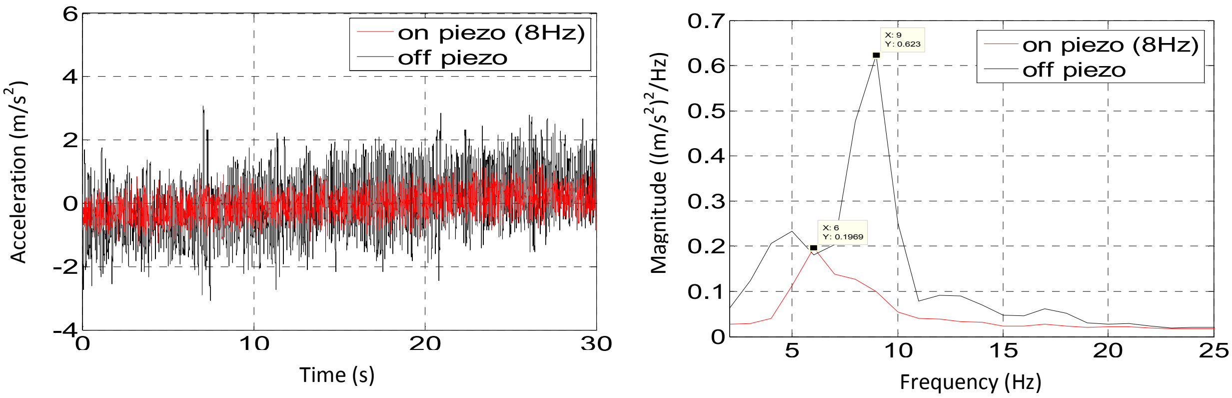
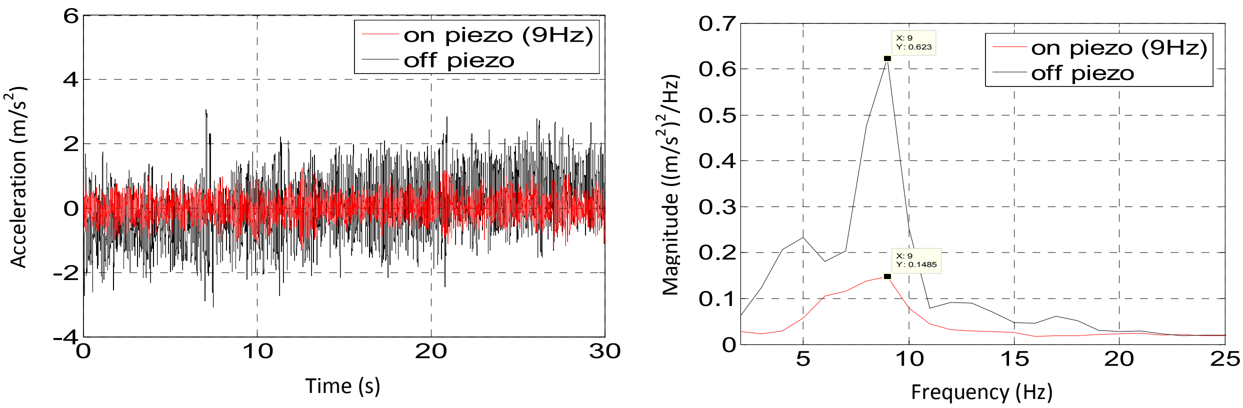


(a) Acceleration response when piezoelectric actuator vibrates at 7Hz

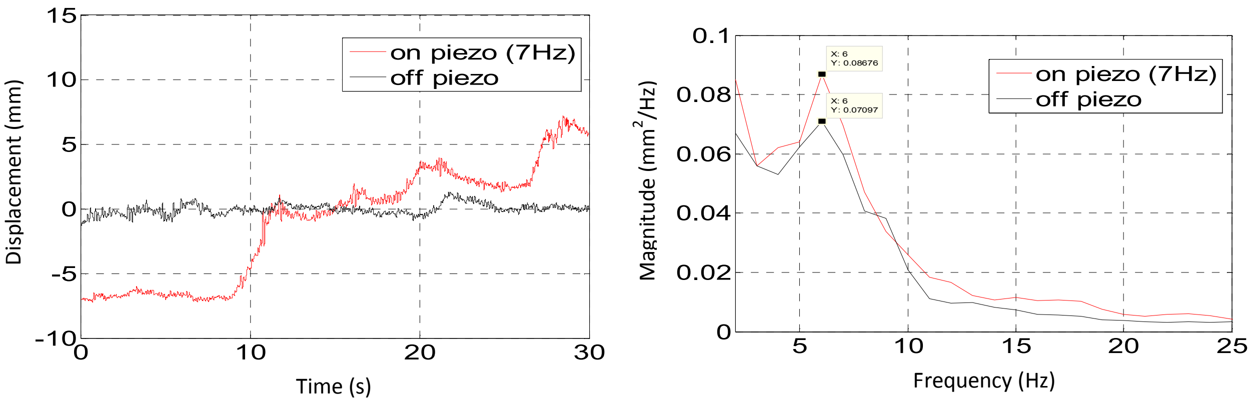


(b) Acceleration response when piezoelectric actuator vibrates at 8Hz

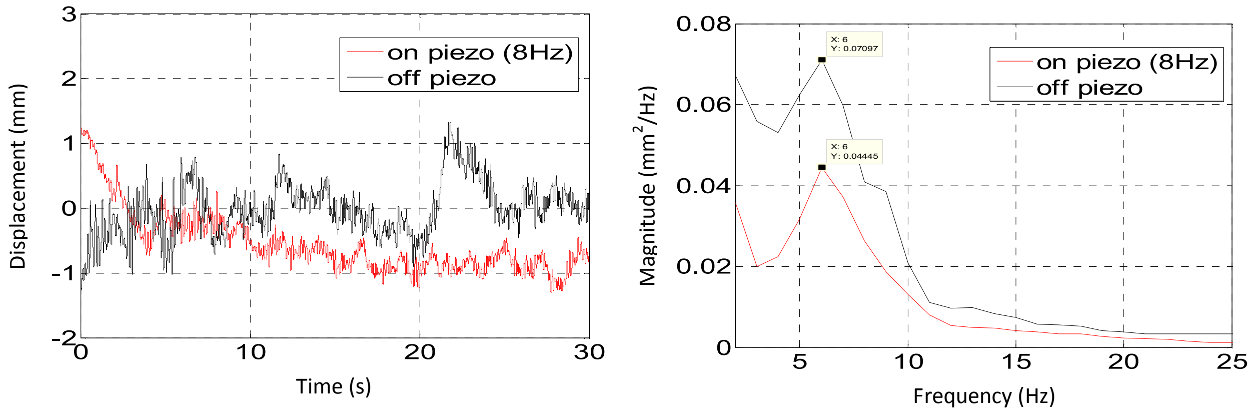


(c) Acceleration response when piezoelectric actuator vibrates at 9Hz

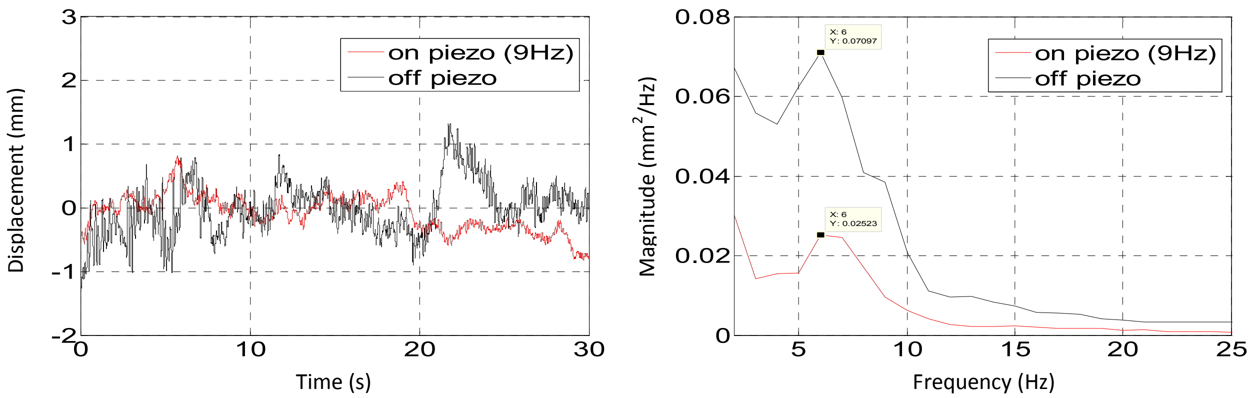
Fig. 3: Acceleration response for the Glove wear at human hand tremor



(a) Displacement response when piezoelectric actuator vibrates at 7Hz

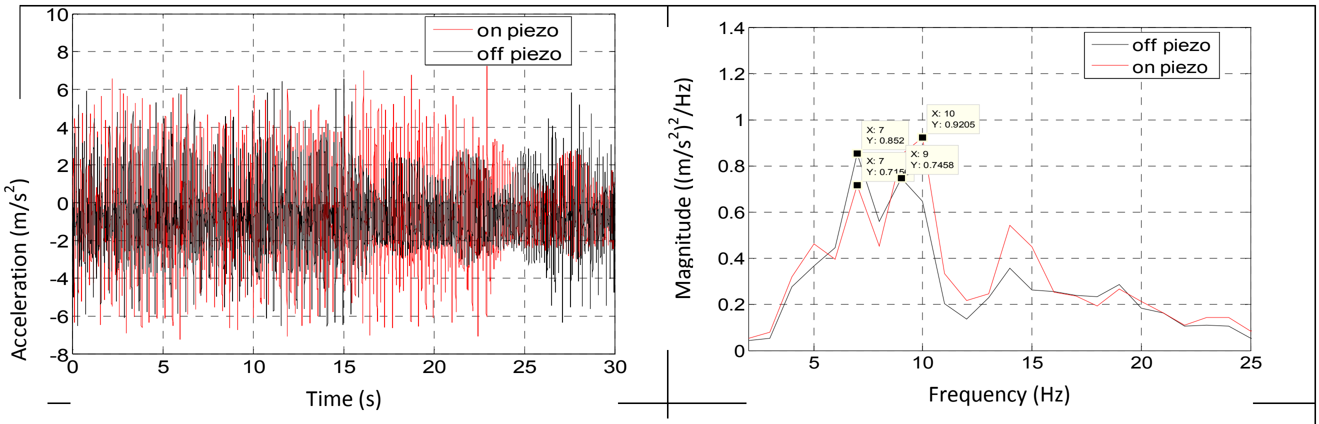


(b) Displacement response when piezoelectric actuator vibrates at 8Hz

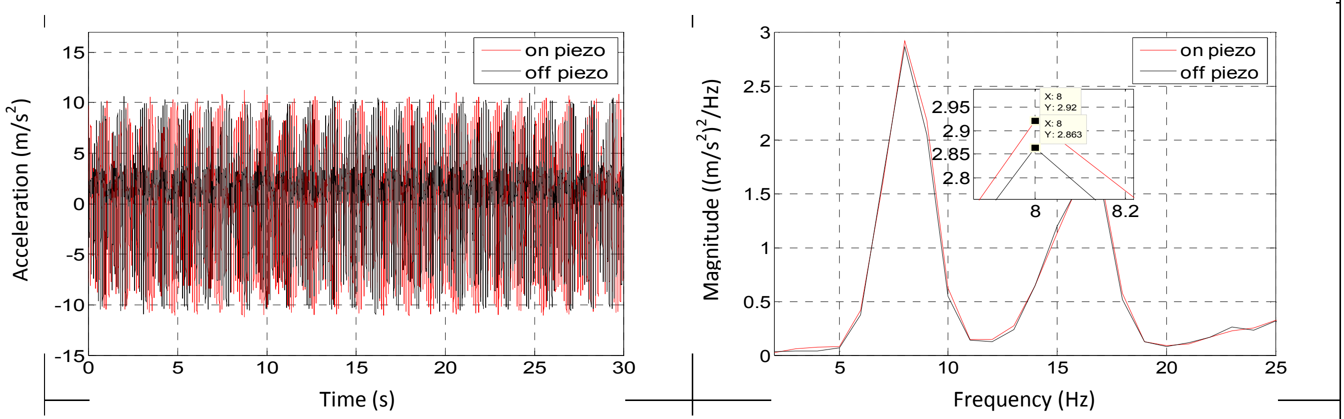


(c) Displacement response when piezoelectric actuator vibrates at 9Hz

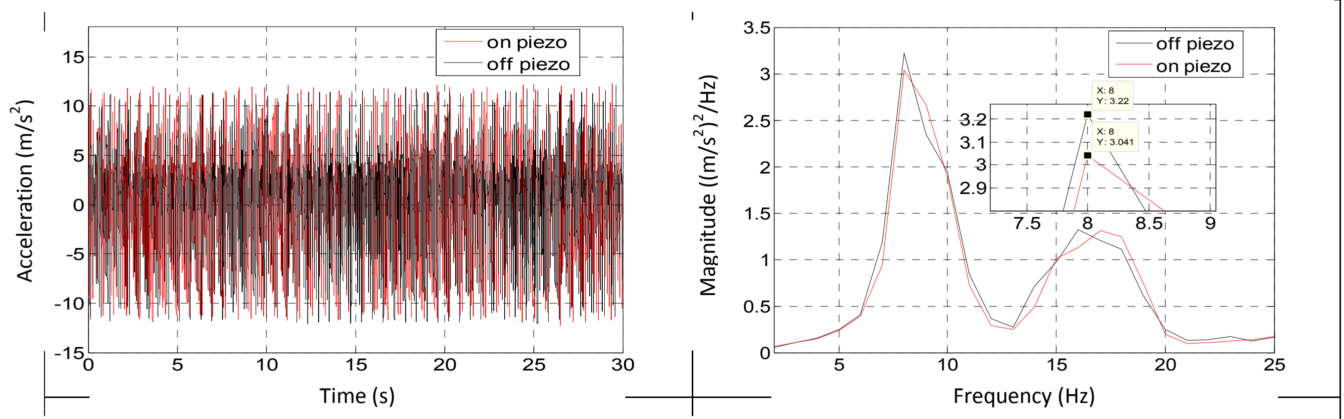
Fig. 4: Displacement response for the Glove wear at human hand tremor



(a) Vibration induced by DC Motor at 67.91Hz

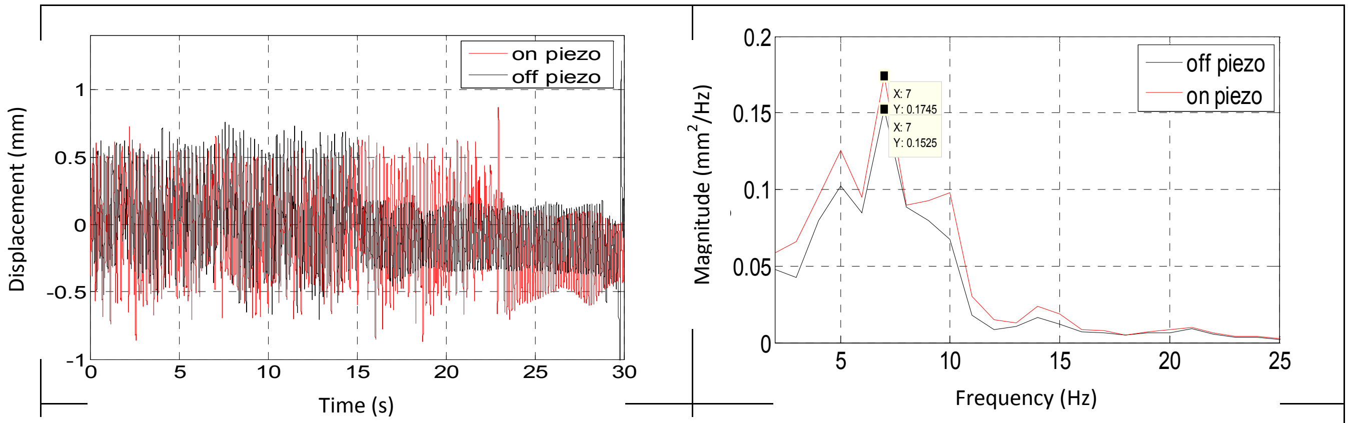


(b) Vibration induced by DC motor at 70.68 Hz

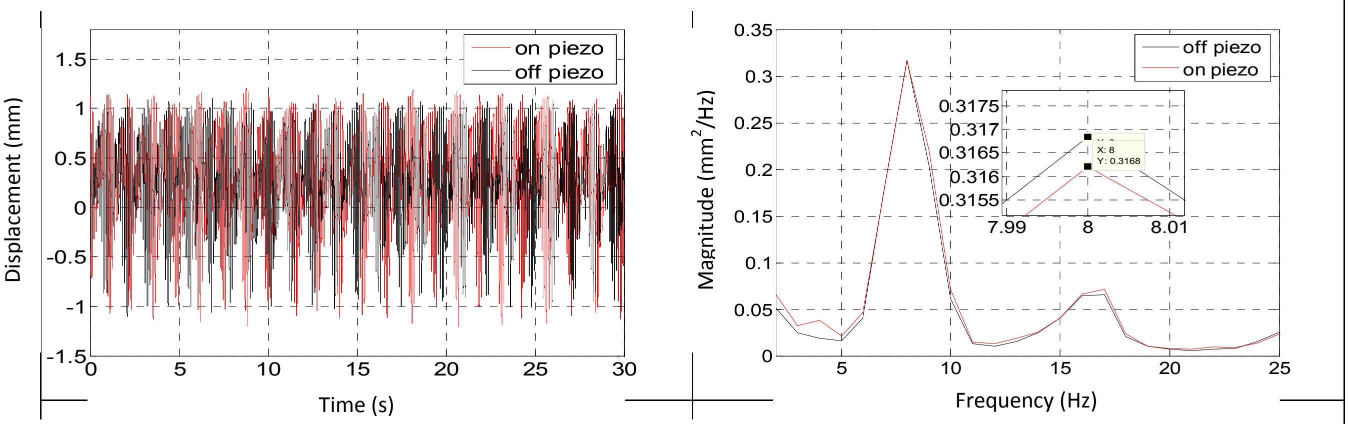


(c) Vibration induced by DC motor at 77.80 Hz

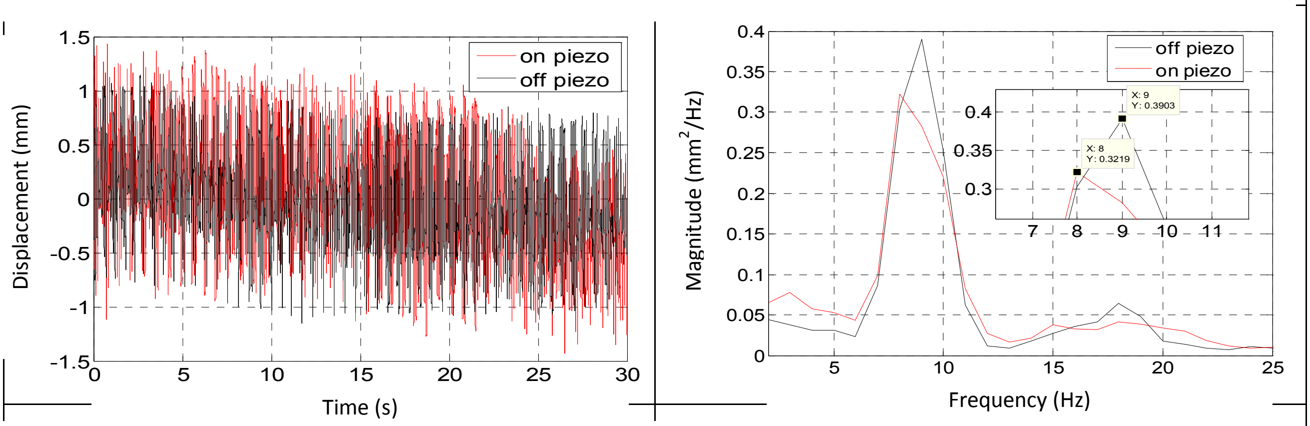
Fig. 5: Acceleration response of IV Training Arm when wearing Glove



(a) Vibration induced by DC Motor at 67.91Hz



(b) Vibration induced by DC motor at 70.68 Hz



(c) Vibration induced by DC motor at 77.80 Hz

Fig. 6: Displacement response of IV Training Arm when wearing Glove