International Journal of Automotive and Mechanical Engineering (IJAME)
ISSN: 2229-8649 (Print); ISSN: 2180-1606 (Online); Volume 8, pp. 1187-1196, July-December 2013

DOI: http://dx.doi.org/10.15282/ijame.8.2013.9.0097

EVALUATION ON AN ASSISTIVE DEVICE IN SUPPRESSING HAND TREMOR DURING WRITING

Z. M. Yusop[1], M.Z. Md. Zain[1], M. Hussein[1], A. R Musa[1], A. As'arry[1]

[1]Department of Dynamics System and Control,
Faculty of Mechanical Engineering,
Universiti Teknologi Malaysia,
81310, Skudai, Malaysia
Email: zul_12521@yahoo.com; zarhamdy@fkm.utm.my

ABSTRACT

This paper presents an evaluation of experimental results of a prototype assistive device in suppressing hand tremor during sitting and standing conditions. The handheld instrument is capable of sensing and suppressing hand tremor or other unpredicted movement during writing. The assistive device incorporates an accelerometer, allowing the movement of the hand to be captured and computed. The tremor suppressing instrument design is carried out by placing two springs between a handheld casing and pen-point at one end of the device. Decomposition of acceleration was analyzed using power spectral analysis to compare the data captured by attaching an accelerometer to a regular pen. The findings show that the proposed assistive device is able to improve the legibility of the handwriting of all the tested subjects by more than 16%.

Keywords**:** Assistive device; handheld instrument; power spectral analysis.

INTRODUCTION

The neurological disorder known as tremor is an involuntary or rhythmic uncontrollable oscillation of body parts that may be visible in patients with Parkinson's disease (PD). Tremor may happen to anyone (Pellegrini et al., 2004) and most PD patients do not care at the early stage of their tremor until the tremor becomes worse. From the literature, it was found that the tremor frequency range for Essential Tremor (ET) occurred between 4Hz and 12Hz (Charles et al., 1999) and ET is one of the classifications of tremor. The involuntary movement of a healthy person (physiological tremor) should be small and is clearly visible when a person encounters anxiety, anger, excessive cold and fear. However, for a person with a neurological disease such as Parkinson's disease there is a significant uncontrollable hand tremor movement (Hussein et al., 2009). Tremor may be caused by smoking habits, taking caffeine, alcohol, using certain drugs and in people with a family history of movement disorder (Ellingsen et al., 2006; Bain, 2007). Furthermore, most patient statistics show that tremor tends to occur in the hands more predominantly than in other body parts. People with this disease experience difficulties which interfere when performing personal activities, especially in writing. Even a simple handwriting task such as signing a document, or marking an exam paper for lecturers or teachers, can become a very difficult task for a tremor patient suffering from this disease. In addition, the persons may not only feel embarrassed to face other people but also, worse, may prefer to stay at home rather than go out. Consequently, it may have a negative impact on their quality of life, mood and independence (As'arry et al., 2006).

To prevent this movement disorder, some patients use modern treatments such as drug therapy, surgical treatment including thalamotomy and deep brain stimulation. These types of treatment may have their own weaknesses, especially for the long term effect on a patient's life, because the treatment involves using drugs and also the surgery is directly to the patient's brain. To reduce this kind of high-risk treatment, some other kinds of approach can be used to treat this disease. There are many studies and ideas from related fields, especially medicine and engineering, to help these kind of diseases. A micron-like intelligent active hand-held microsurgical instrument has become of great interest in the field of microsurgery, helping a surgeon perform better ophthalmological microsurgery procedures by counteracting the physiological tremor that may occur during operations (Ang, Riviere, & Khosla., 2001). The device senses the undesired motion and counters it with an equal but opposite deflection of the instrument's tip. MARo2 is a meal-assist robot developed by Ohara et al. (2009), where the human–machine interface makes it possible for the person with a tremor to manipulate the supporting robot without causing operability to deteriorate and without hazards arising from improper operation. This study introduces a non-invasive treatment by developing a passive instrument acting as a pen that can absorb hand vibration and improve the legibility of writing for patients with tremor (acting as anti-tremor), and also introduces a low cost method to collect the data from tremor patients to measure and investigate tremor handwriting behavior. The objective is to evaluate the performance of the proposed device to be used by volunteer subjects based on reduction of the coherence signal of power spectral density (PSD). The reduction of the coherence signal is very important to guarantee that the system applied is viable to improve the legibility of handwriting.

MATHEMATICAL MODELING

The mathematical modeling is based on a one-degree-of-freedom system that can be moved in a one direction axis. Since there is no external force to drive the system, the motion is designated as a free vibration. It is also un-damped, as there is no condition present which would inhibit the motion. Consider a free-body diagram of the mass in Figure 1, with the mass-less spring elongated from its rest, or equilibrium, position. The mass of the object is *m* and the stiffness of the spring is k_1 and k_2. Assuming that the mass moves on a frictionless surface along the x-axis direction, the only force acting on the mass in the x-axis direction is the spring force. As long as the motion of the spring does not exceed its linear range, the force, *F* in the *X* direction equals the product of mass and acceleration, with ∂ as a differentiation of direction, *x(t)* with respect of time, *t*. The equation of motion becomes (Tracy, 2009),

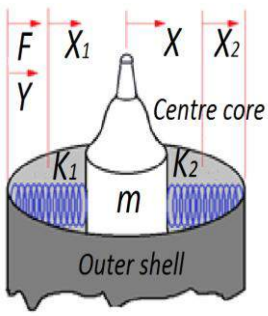


Figure 1. The mechanical system of an assistive writing device.

$$m\frac{\partial^2 x(t)}{\partial t^2} = -(k_1 + k_2)x(t) \tag{1}$$

$$\frac{\partial^2 x(t)}{\partial t^2} = \frac{-(k_1 + k_2)}{m}x(t) \tag{2}$$

One of the goals of vibration analysis is to be able to predict the response, or motion, of a vibration system. Thus it is desirable to calculate the solution to Eq. 1, which can be written as:

$$\frac{\partial^2 x(t)}{\partial t^2} + \frac{(k_1 + k_2)}{m}x(t) = 0 \tag{3}$$

$$\frac{\partial^2 x(t)}{\partial t^2} + \omega^2 x(t) = 0 \tag{4}$$

So natural frequency is defined as:

$$\omega = \sqrt{\frac{(k_1 + k_2)}{m}} \tag{5}$$

Assume that the outer shell on both sides of the central mass is free moving and labeled as the *Y* direction and the center mass is moving in the *X* direction. Thus, the transmissibility ratio, *TR*, is gained by the following equation:

$$TR = \frac{X}{Y} = \sqrt{\frac{1 + (2\xi r)^2}{(1 - r^2)^2 + (2\xi r)^2}} \tag{6}$$

where the damping ratio, $\xi = c / \sqrt{km}$, since it is assumed that the damping effect of the double spring is extremely small, thus the damping constant *c = 0*, which results in $\xi = 0$. Simplifying Eq. 6 gives

$$TR = \frac{X}{Y} = \sqrt{\frac{1}{(1 - r^2)^2}} \tag{7}$$

Rearranging Eq. 7, we determine frequency ratio, *r*:

$$r^2 = \pm\frac{1}{TR} + 1 \quad \text{and} \quad r = \frac{\omega}{\omega_n} \tag{8}$$

Note that ω_n is the natural frequency and ω is the excitation frequency. In this case study the transmissibility ratio (*TR*) is also known as the ratio of the vibration magnitude of the central mass *X* to the moving outer shell *Y*.

SYSTEM OVERVIEW

The assistive device which is able to suppress unwanted motion is shown in Figure 2, and is designed to help people with hand tremor to perform writing tasks. Since hand tremor vibration tends to occur in the dominant direction (vibrating perpendicular to the forearm) during writing, the device is mainly focused to nullify vibration in that direction. It is obvious that the vibration occurs in the dominant direction rather than another direction from studying the quality of handwriting among Essential Tremor patients. This is done by having them draw Archimedes spirals. The design of the proposed writing device majors with two crucial parts by presenting two springs functioned to absorb the vibration and a center core acting as the mass of the system. The specification of the springs' stiffness should be correctly measured in order to eliminate the unwanted handwriting movement by absorbing it. In this study, the spring stiffness tested was 0.068 N/cm. Incorrect selection of the springs' stiffness may affect the performance of the writing instruments, by either not damping the unwanted motion if the stiffness is too high, or damping the unwanted motion if the stiffness is too low.

The center core, made of aluminum material with a weight of 0.02 kg, is placed inside the outer shell and functioned to hold the pen point. The pen point is filled inside a 4 mm diameter hole at the front end of the center core, with a 6 mm diameter hole at the back of center core. Two flange bearings are inserted into the hole to hold the center core with an outer shell. Besides that, these two bearings enhance the performance of the movement of the center core by providing less friction. The center core is divided into two sections with different diameters and a total of length of 102 mm. The diameter with a length of 42.25 mm from the front end of the center core needs to be reduced to 7 mm from its original diameter of 10 mm. The reduction is to provide adequate space and maximum clearance for the pen point to move inside the outer shell. The outer shell, which measures 134 mm long and 25 mm in diameter, is functioned to hold the two springs connected to a center core and acts as a holder for a hand grip while writing.

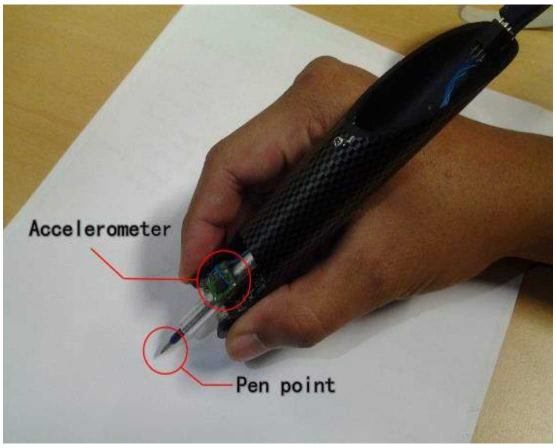


Figure 2. Assistive writing device mounted with an accelerometer.

SYSTEM VALIDATION

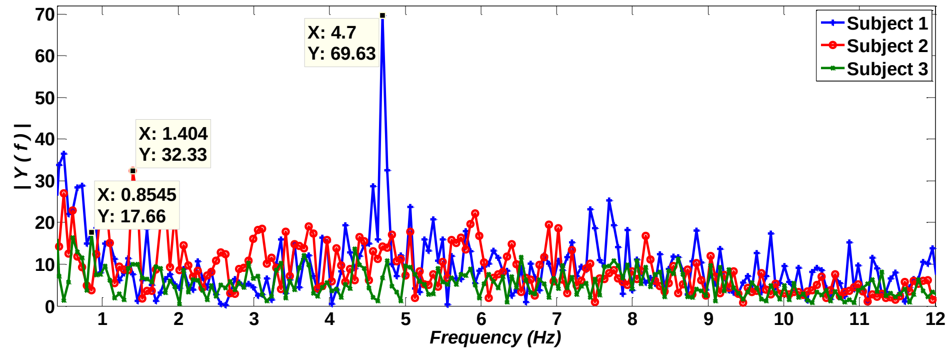
To validate the performance, the device was tested by an Essential Tremor patient diagnosed according to the clinical criteria, and two random healthy individual subjects (age 23–28). The experimental research focused on two conditions, the sitting condition where the subject is seated in a chair with his forearm resting on the table while performing a handwriting task (Figure 3 (a)), and the standing condition where the subject's forearm is prevented from resting on the table during writing (Figure 3 (b)). Each subject was required to perform both positions and to use two different types of handwriting instruments. The first instrument was an ordinary pen and the latter was the proposed assistive device. Both of these instruments were attached to an accelerometer ADXL330 to measure the acceleration of hand tremor during handwriting. The results from both instruments were compared to validate their performance, based on frequency spectral analysis and acceleration in time analysis. For each position, the subjects were required to perform two tasks: the first task, which is the most common way to diagnose Essential Tremor (ET), was to have the subject trace the Archimedes Spiral (Aguilar et al.) and the other task was to trace a few words.

(a) Subject during sitting condition (b) Subject during standing condition

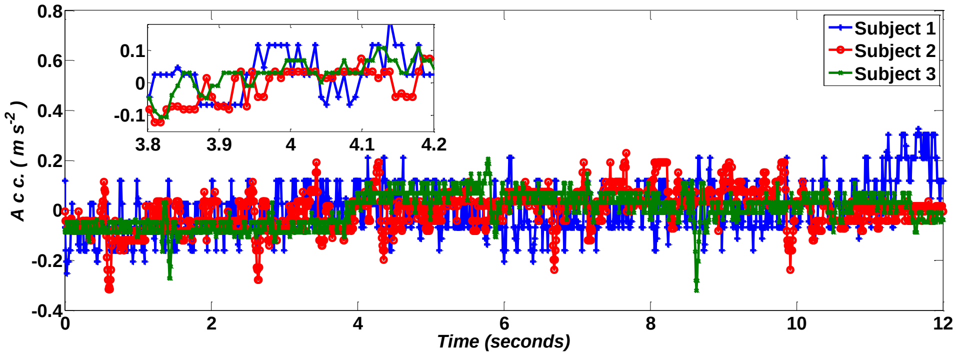
Figure 3. The two conditions of the subject when performing handwriting tasks.

RESULTS AND DISCUSSION

Figures 4 and 5 show the frequency response and acceleration in time response for the standing and sitting conditions when the subjects were using a regular pen. Each graph represents the results for all subjects and different colors represent the different subjects. From Figure 4 (a), subject 1 has the most dominant amplitude, 69.53 (4.7 Hz) followed by subject 2, 32.33 (1.404 Hz) and subject 3, 17.66 (0.8545 Hz). Figure 4 (b) shows the acceleration from all subjects with an average amplitude ±0. 2 m/s^2. From Figure 5 (a), subject 1 has the most dominant amplitude, 39.36 (4.639 Hz) followed by subject 3, 37.30 (0.8545 Hz) and subject 2, 19.52 (0.6104 Hz). Figure 5 (b) shows the acceleration from all subjects with an average amplitude of ±0.18m/s^2. Comparing both graphs, subject 2 has a random dominant amplitude in the range 0 Hz to 2.3 Hz in the standing condition and the result is more stable during the sitting condition, with a dominant amplitude of 19.52 (0.6104 Hz) . Meanwhile, for subject 3 the opposite condition was observed, with a random dominant amplitude in the range 0 Hz to 7.5 Hz during the sitting condition, while the subject performed better in the standing condition, judging from his frequency amplitudes. For subject 1, the dominant amplitude occurred at almost the same frequency for both graphs (Figure 4 (a)) and Figure 5 (b)), at 4.63 Hz, and the amplitude decreased by about 43.3% when the subject changed his writing position from standing to sitting.

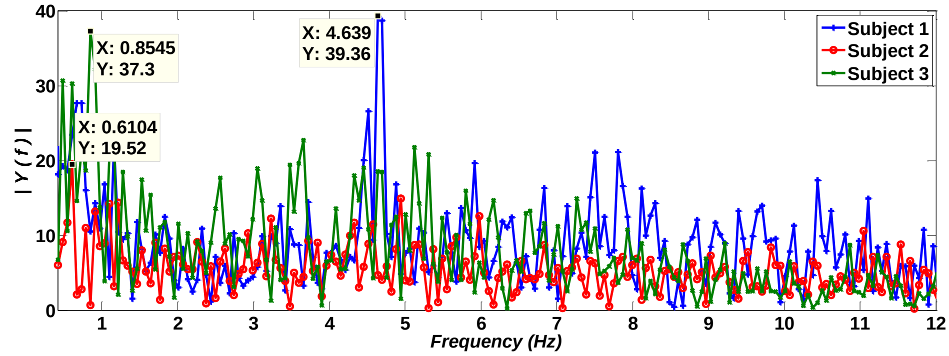


(a) Frequency analysis

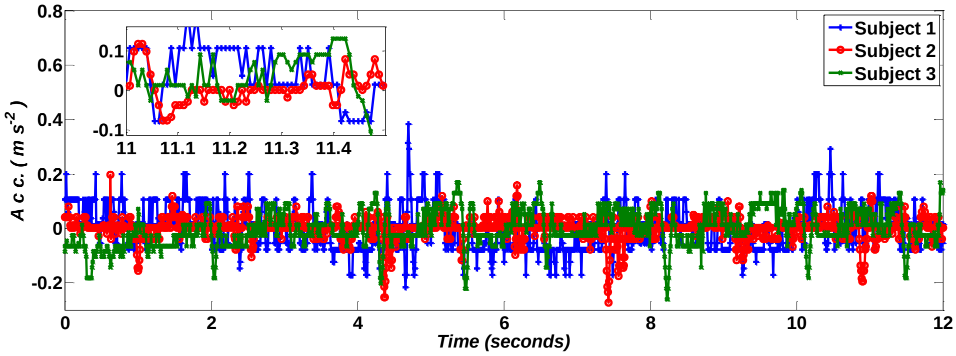


(b) Acceleration in time domain analysis

Figure 4. Standing condition using a common pen.



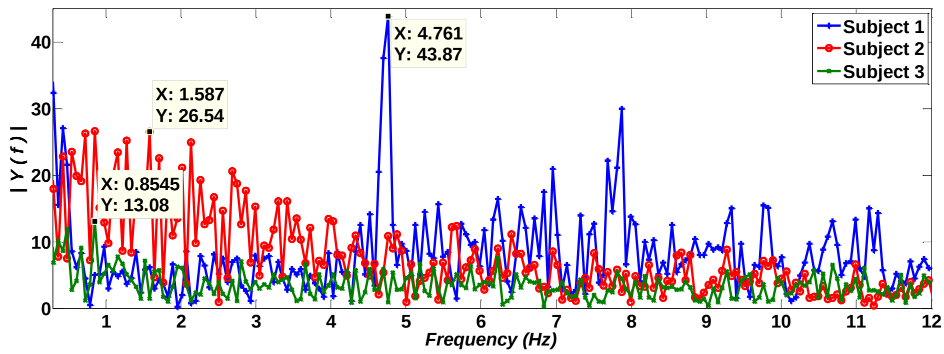
(a) Frequency analysis



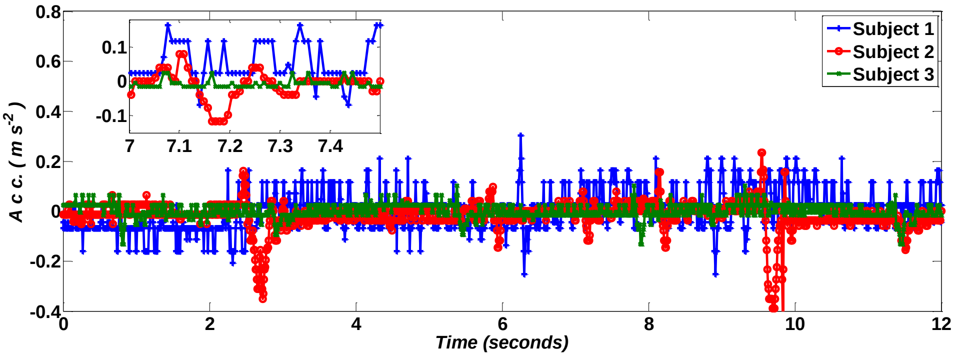
(b) Acceleration in time domain analysis

Figure 5. Sitting condition using a common pen.

Figure 6 and Figure 7 show the frequency response and acceleration response during the standing and sitting conditions when using the proposed assistive device. From Figure 6 (a), subject 1 has the most dominant amplitude with 43.87 (4.76 Hz) during the standing condition and the decrease was about 42.5% of amplitude with the same dominant frequency when the subject was in the seated position (Figure 7 (a)). From this point, subject 1 can be classified as having lessened hand tremor when seated compared to the standing condition, because the forearm was supported on the table while completing the writing task. For subject 3, when in the standing position the dominant amplitude occurred at a frequency of 0.8545 Hz with an amplitude of 13.08, but the results started to change when the subject was completing the task in sitting mode, for which the result shows that the dominant amplitude occurred at several points of frequency in the range of 0 Hz to 3.5 Hz. Subject 2 clearly had difficulty performing handwriting tasks in the standing condition compared with the sitting condition since the amplitude of the frequency response shows random amplitude peaks in the range of 0 Hz to 4 Hz, with an average amplitude of 23.0. Figure 6 (b) and Figure 7 (b) show the acceleration with average amplitude of ± 0.2 m/s² and ± 0.15 m/s² respectively.

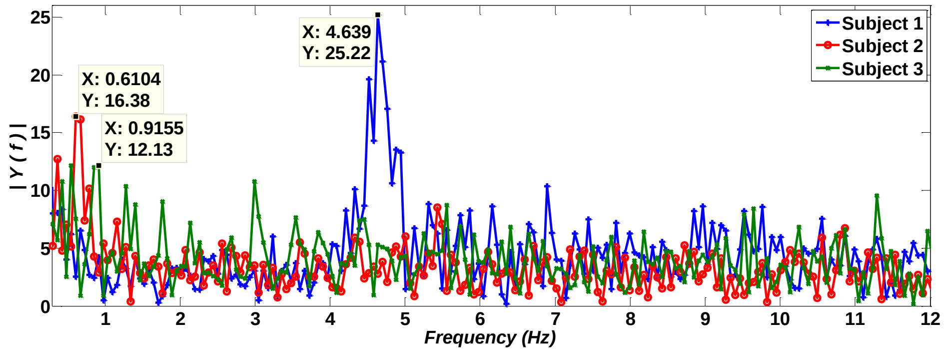


(a) Frequency analysis

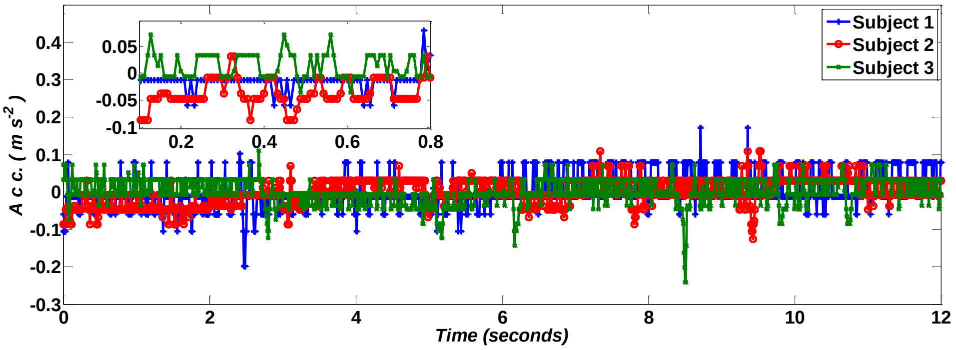


(b) Acceleration in time domain analysis

Figure 6. Standing condition using an assistive device.



(a) Frequency analysis



(b) Acceleration in time domain analysis

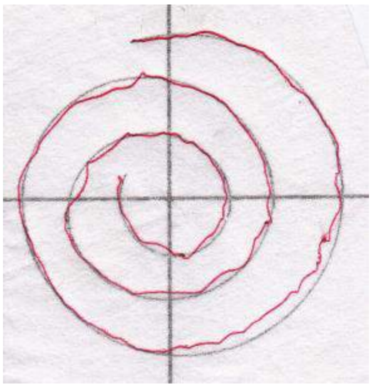
Figure 7. Sitting condition using an assistive device.

Table 1 shows a side-by-side comparison between using a regular pen and the proposed assistive device for both standing and sitting conditions. The results clearly show that the dominant amplitude for all subjects is significantly reduced when the subjects change the writing instrument from a regular pen to the proposed assistive device. From the table, the error reduction (%) for subjects 1 and 2 differs slightly between both conditions, with percentage reductions of 1.1% and 1.9% respectively. Subject 3 presents a 67% error of reduction during the sitting condition, which means that the assistive device has a great impact on improving the legibility of his handwriting. The types of tremor suffered by each subject can be identified according to the dominant frequency.

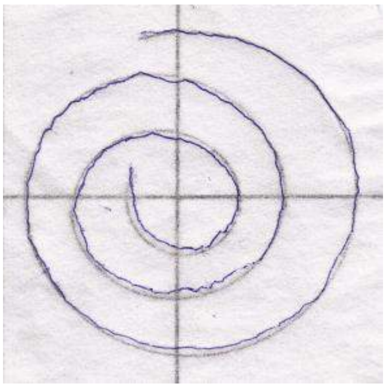
Figure 8 shows generally the samples of handwriting done by one of the interview subjects who was clinically proven to suffer from Essential Tremor. Figure 8 (b) and Figure 8 (d) clearly show that the subject improved his handwriting quality when using the proposed assistive device. The evaluation is based on visual observation of the smoothness of the words “HELLO WORLD” written in blue while using the proposed assistive device as compared with the quality of the red words when the subject was using a regular pen to trace the words. The current practice of neurologists in monitoring tremor patients’ handwriting capability is to observe the effect when the subjects draw the Archimedes spiral. The same approach was conducted in this research. As the result, Figure 8 (a) and Figure 8 (b) compare side-by-side the drawings done by the subject. The subject has difficulty using a regular pen to draw the spiral due to the trembling of his hand and he slightly missed tracing the correct line. Meanwhile, a significant improvement was observed when the subject used the proposed assistive device to trace the spiral.

Table 1. The results for all subjects in sitting and standing conditions using both types of writing instrument.

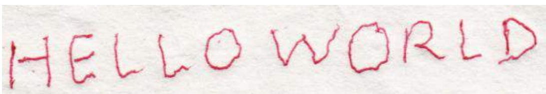
Position	Standing					Sitting				
	Regular pen		Assistive device		Error reduction (%)	Common pen		Assistive device		Error reduction (%)
Subjects	Freq. (Hz)	Amplitude	Freq. (Hz)	Amplitude		Freq. (Hz)	Amplitude	Freq. (Hz)	Amplitude	
1	4.70	69.63	4.760	43.87	37.0	4.639	39.36	4.639	25.22	35.9
2	1.404	32.33	1.587	26.54	18.0	0.610	19.52	0.6104	16.38	16.1
3	0.855	17.66	0.854	13.08	25.9	0.854	37.30	0.9155	12.13	67.0



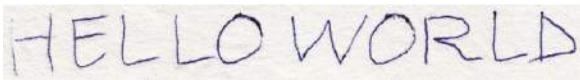
(a) Archimedes spiral drawn by subject using a regular pen.



(b) Archimedes spiral drawn by subject using an assistive device.



(c) Words written by subject using a common pen.



(d) Words written by subject using an assistive device.

Figure 8: Tracing of Archimedes spiral and words accomplished by the first subject during sitting condition.

CONCLUSIONS

This study provides the investigation of the performance feed forward method (passive) of suppressing human hand tremor while writing. The research was conducted with two different types of handwriting instrument to differentiate and validate the experimental results. The experimental results show that implementation of the proposed mechanical system in an assistive device creates a great potential for all subjects to improving the quality of their handwriting.

ACKNOWLEDGMENTS

The authors would like to thank the Universiti Teknologi Malaysia (UTM), especially the Department of System Dynamics and Control, Faculty of Mechanical Engineering for their continuous support in the research work.

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