Preliminary Evaluation of Active Tremor Cancellation Spoon for Patients with Hand Tremor

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Abstract. Hand-arm tremor is common in Parkinson’s disease (PD) patients and essential tremor (ET) and can result in difficulty of carrying out daily tasks such as eating and writing. One of the approaches to overcome this is the application active tremor cancellation (ATC) to attenuate the vibration due to the hand tremor on the device held by the hand. There are several ATC spoons in the market which are meant to help the patient to eat however third-party evaluation of the effectiveness of this technology could not be found in the literature. This study evaluates Liftware, a spoon with ATC by measuring the acceleration performance of the spoon over the frequency range of 1-12 Hz which adequately covers both the PD and ET. In the first part of the study, the device was evaluated on the isolation index throughout the tested range of frequency along the vertical or gravitational, and the horizontal directions, the direction perpendicular to both gravitational and the longitudinal axis. Subsequently, the device was evaluated for the limit at which the food it contains start to spill. Solid food, typically boiled peas and liquid, namely curry was the food tested with the spoon. Ten measurements were carried out for each type of food and the average limits prior to spillage was presented. The results show that the isolation indices in vertical and horizontal directions range from 0.06 to 0.63 and 0.06 to 0.62 respectively at frequency range of 3-12Hz. The limits of the spoon in supporting the boiled peas and curry are 1.4g and 0.9g respectively. However, the preliminary study provides part of the knowledge useful for the potential users and researchers. Further study to subject the device under different conditions, especially in clinical settings is required.

1. Introduction

Parkinson’s disease (PD) is a central nervous system disorder caused by degeneration of basal ganglia resulting in the decrease in dopamine secretion. Essential tremor (ET) is another neurological disorder, which is twenty times more prevalent than Parkinson’s disease. The tremors of these two disorders can progress until the daily activities of the patients are affected. Essential daily tasks such as writing, dressing, eating and drinking can become difficult to be performed when the condition is severe [1]. Assistive devices that can be used to suppress or isolate tremor have been developed to ease the conditions of the patients.

One example of the assistive devices is the Neater Eater by Michaelis Engineering [2] where the device is required to be mounted on table. Tremor is isolated and absorbed by the tremor absorber in this device. This device solves the eating problem of people who have tremor or ataxia. The limitation of this device is that its usage is confined to a same place. The passive means of applying viscoelastic material in tremor dampening has been emerged to increase fine motor functions for ET
patients or individuals such that the patients are able to accurately touch an icon with an area of 1 inch by 1 inch square on a LCD panel [3].

The active tremor cancellation approach can be traced back to the research work carried out to overcome tremor in microsurgery due to physiological tremor. The obvious solution is to isolate the hand from the surgical tool by using robot assisted microsurgery which can overcome the problem of the tremor of the human hand as shown in the adoption of a dual arm six-degrees-of-freedom robot for master-slave teleoperating procedure [4].

The John Hopkins University steady-hand robot [5, 6] was designed to assist the surgeon in microsurgery. The positioning precision is reported to be approximately 5 microns. The system is further developed resulting in the second prototype with the capability of the robot to perform cannulation on approximately 80 μm outer diameter vein using biological model system [7].

Several active researches have been carried out on tremor cancellation mostly related to the cancellation of tremor in handheld microsurgical instrument which is pioneered by the study of the delicate retinal procedures where the data from the MEMS sensor and rate gyro were used to calculate the tip displacement error [8]. This method was further developed to compensate the oscillation at the instrument [9].

Saxena and Patel (2011) briefly described the expectations of a system to cancel hand tremor, particularly the need to respond in less than half of the sampling period [10] developed a device to compensate physiological tremor. The approach taken in the research to compensate microtremor of the hands in microsurgery paved the way for active tremor cancellation devices for patients with hand tremor, where in this case the tremor amplitude is larger (tens of millimeters compared to tens of microns in microtremor).

The more recent technology which managed to penetrate the market, making accessible by patients with hand tremor is a spoon that compensates tremor based on active-tremor cancellation (ATC) principle [11]. The assistive device in the form of spoon consists of sensors that measure the hand tremor of the user and microcontroller processes the data and drives the motors to produce movement of the attachment in the opposite direction of the tremor, in both the horizontal and vertical direction within the handle. Smith (2015) [12] highlighted the fact that limited evidence is available on the effectiveness of ATC spoon. To date, no published data by third-party on the frequency dependent performance, particularly the isolation capability of the active ATC spoon, are available.

This paper aims to close the information gap by establishing some baseline data of the effectiveness of the ATC spoon in the market. In this paper, the vibration acceleration isolation capability of an ATC spoon in two-dimensional linear vibration and the severity of tremor the spoon can support before spillage of food are presented.

2. Methodology
In this study the Liftware™, the self-stabilizing spoon that was developed by Lift Labs (Mountainview, California) to assist users with tremors to eat was evaluated. Isolation capability assessment without any load on the spoon bowl as well as evaluation on the limit the Liftware can hold without spillage were carried out.

2.1. Isolation capability assessment
The ability of the ATC spoon to isolate vibration was measured by isolation index. The isolation index is related to the transmissibility based on the following equations:

\[
\text{Transmissibility} = \frac{A_0}{A_1}
\]

\[
\text{Isolation index} = 1 - \text{Transmissibility}
\]

2
Isolation index = 1 - \frac{A_0}{A_i} \quad (3)

Isolation index = \frac{|A_i - A_0|}{A_i} \quad (4)

Where
A_0: Amplitude of vibration response
A_i: Amplitude of vibration input
|A_i - A_0|: Reduction in amplitude

The vibrational input and response were measured by using two uniaxial accelerometers (Dytran 3224A2, mass 0.2 gram) on the handle and bowl (also called spoon head) of the spoon respectively. The acquired accelerometers were connected to the National Instrument analogue input with two channels (model NI 9234), which was mounted on a data acquisition system (model NI cDAQ-9174).

Based on figure 1, the ATC spoon was mounted on a voice coil actuator (PBA System, model CVC 60-HF-20-C0.15) and driven by a signal generator (Stanford Research Systems, model DS 335) using sine swept function in the frequency range of 1-12Hz, which is adequate to cover the frequencies of tremor of PD and ET patients [13, 14]. In the experiment, the voice coil actuator acts as the shaker.

The signals were processed using fast Fourier transform (FFT) to obtain the acceleration spectrum before deriving the isolation index. The measurement was carried out in (1) the vertical direction (refer figure 1a), where the ATC spoon was shaken along the gravitational axis and (2) the horizontal direction where the ATC spoon was shaken along the axis perpendicular to both gravitational and spoon longitudinal axis. The process from acquiring the acceleration data to the attachment of isolation index was done in National instrument LabVIEW.

![Figure 1](image)

**Figure 1.** Experimental setup of the acceleration spectra measurement for transmissibility evaluation in (a)vertical and (b) horizontal direction

### 2.2. Limits of ATC spoon in holding food before spillage

The peak-peak response is taken as the parameter to measure the vibration level tolerable by the spoon. Acceleration data for spillage of different types of food is not readily available in the literature, thus this experiment serves to provide such values for the determination of the severity of tremor can be tolerated when consuming different types of food. The two common types of food tested are: boiled peas and curry gravy. The similar vibrational signal consisting of a sine swept function from
1-12 Hz was applied.

The level of acceleration was gradually increased by adjusting the gain on the amplifier and the acceleration level at which the food starts to spill was marked as the maximum tolerable limit of the spoon. The spillage test on each type of food was carried out for ten times. The limits in both vertical and horizontal directions were tested separately. The mean value and the standard deviation of the ten values of maximum limit were reported.

3. Results and discussion
The frequency spectra result of the input and output vibrations of the Liftware spoon when it was subjected to vertical oscillation were shown in figure 2(a) and 2(b) respectively. By referring to figure 2(a), the input vibration peaks at around 10.7Hz, with peak amplitudes of 0.08g. At the Liftware spoon bowl, (refer to figure 2b), the peak was shifted to 10Hz, and the amplitude was reduced to 0.05g.

Figure 3 shows that isolation index varies over the spectrum. Under the tested condition, the vertical isolation index peaks at 7.9Hz and 12Hz. At these frequencies, the vibration can be isolated with Liftware for 62% and 54% respectively. At approximately 9.2Hz, the isolation index is the lowest, i.e., only 0.06. Based on the overall isolation index frequency spectrum, the Liftware can reduce 6% to 62% of tremor for the tested frequency of 3Hz or above. The performance in 3-12 Hz are more important since the PD and ET tremors [13, 14] were mainly reported in this range of frequency.

The FFT results of input and output vibrations oscillation (refer Fig. 4a and b respectively) when the Liftware was subjected to horizontal oscillation differ from those of vertical oscillation. The frequency of horizontal measurement peaks at around 10 Hz, with peak amplitude of 0.16g. At the spoon bowl, the peak occurred at around the similar frequency (figure 4b) but the amplitude was reduced to 0.11g. Figure 5 shows that the isolation index ranges from 0.06 (5.2Hz) to 0.63 (3.4Hz) for frequency above 3Hz.

The frequency spectra of the isolation index serve as design benchmark for further improvement in specific frequency range of interest, depending on the targeted tremor to isolate. The ability of the Liftware to hold 0.9g to 1.7g of vibration is reasonably usable by many patients.

When containing solid food, typically boiled peas of average 14.37gram in average, the limit of Liftware to handle vertical and horizontal vibration is approximately 17.24g and 1.42g in average of ten trials. When tested with curry gravy of 5ml, the limit of the acceleration the Liftware can handle to prevent spillage is reduced to 1.72g and 0.95g in vertical and horizontal directions in average of ten trials. The allowable limit before spillage in vertical direction is 1.2 to 1.8 times of that of horizontal direction.

Since the performance of the spoon varies in different directions, the way of gripping the spoon handle determines the superiority in isolating tremor in specific hand motion. For instance, for the case of users having tremor that is more dominant in wrist flexion-extension, it is suggested to group the Liftware by pronating the hand with palm facing down.

4. Conclusion
In conclusion, the frequency spectra of the isolation index and the limit of vibration level can be supported by Liftware before spillage provide the tangible performance of the ATC spoon. Comparison of other products and design improvement can be made based on the performance data presented.

The results were measured under the stated measurement conditions and tests on users with tremors and the measurement of the performance in three-dimensional angular parameters are required to provide a more comprehensive evaluation of the device. Nevertheless, the presented preliminary study has contributed part of the knowledge usable for the potential users and ATC
device researchers and designers.

![FFT results of (a) input and (b) output vibrations of the Liftware when it was subjected to vertical oscillation](a)

![Frequency spectrum of isolation index of Liftware when it was subjected to vertical vibration](b)

**Figure 2.** FFT results of (a) input and (b) output vibrations of the Liftware when it was subjected to vertical oscillation

**Figure 3.** Frequency spectrum of isolation index of Liftware when it was subjected to vertical vibration
Figure 4. FFT results of (a) input and (b) output vibrations of the Liftware when it was subjected to horizontal oscillation

Figure 5. Frequency spectrum of isolation index of Liftware when it was subjected to horizontal vibration
Table 1. Limit of acceleration at the handle of the spoon resulted in spillage. All data were the mean or standard deviation of the 10 repetitions.

| Food type   | Mean amount | Vertical acceleration mean and standard deviation (m/s²) | Horizontal acceleration mean and standard deviation (m/s²) |
|-------------|-------------|--------------------------------------------------------|----------------------------------------------------------|
| Boiled peas | 14.37 gram  | 17.24, 0.32                                           | 14.17, 1.44                                              |
| Soup        | 5ml         | 17.15, 3.99                                           | 9.45, 1.31                                               |

5. References

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Acknowledgement

This work was supported by the Ministry of Higher Education (MOHE) under Exploratory Research Grant Scheme ERGS (203/6730080) and Innovation Seed Fund USM (PMEKANIK AUPI00239).