VOL. 11, NO. 10, MAY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

FEASIBILITY STUDY OF FINGER LOCALIZATION FEEDBACK FOR PROSTHETIC HAND USING VIBROTACTILE

Yusof bin Yunus, Yewguan Soo and Norhashimah bte Mohd Saad
Faculty of Electronic Engineering and Computer Engineering, Universiti Teknikal Malaysia Melaka, Malaysia
E-Mail: yusofyunus@gmail.com

ABSTRACT

This paper investigates the factor influencing the design of vibrotactile sensory substitution system for prosthetic hand. The coin motor is used as the vibrotactile stimulator because of its smaller size and cheaper price. This study is to develop a vibrotactile system to study the possibility for finger localization feedback. Three types of stimulator configurations and three level of vibratory frequency were tested in this study, which are vertical, rounded and u-shape configurations. Seven subjects were participating in the experiment and total of 255 stimuli were given to each subject. The results demonstrate that U-shape configuration and higher vibratory frequency is the best vibrotactile placement for finger localization feedback.

Keywords: vibrotactile sensory substitution, haptic, stimulator configurations.

INTRODUCTION

In recent years, the development of prosthetic hands has shown many improvements. All these hands are quite similar to natural hand as well as have similar appearance and function. The main problem that keeps new prostheses from being fully used is the cost of the end product. Many of the people who require prosthetic limbs are people who cannot afford the state of the art prostheses. In order to improve the problem, there are suggested improvements for prosthetic hand such as lower cost, fine control of fingers and provide sensory feedback.

However, the control capability between the user and the prosthetic hand is leak in term of sensory feedback from the prosthetic hand to the user. This is the major reasons on why the prosthetic hands cannot fully exhibit their capabilities. In addition, there is no commercially available sensory feedback system using non-invasive method for prosthetic hand today. Several sensory feedbacks modalities have been developed such as vibrotactile feedback, electrotactile feedback, mechanotactile feedback, invasive method and pressure tactile feedback. Among all of these modalities, non-invasive methods become the most chosen method rather than invasive method. The non-invasive methods are vibrotactile, electrotactile, mechanotactile and pressure feedback. Among all this non-invasive method, only three methods mostly use in research. There are vibrotactile, electrotactile and pressure. All this methods have shown improvements in sensory feedback for prosthetic hand.

Nowadays, vibrotactile feedback becomes the most popular method to restore perception of senses. Vibrotactile sensory feedback system is where a mechanical vibration of the skin used to convey the sensory information. Vibrotactile stimulation for feedback system is cheap, non-invasive and easily use into prosthetic technologies [1]. Compare to other modalities use as sensory feedback such as electrotactile and mechanotactile, still vibrotactile feedback become a famous modality among researchers to become the ideal sensory feedback substitution.

Vibrotactile substitution systems were applied on many type of application. Several researchers were use vibrotactile substitution system as a force feedback or slip feedback for prosthetic hand [2] [3] [4] [5]. Even the application was same, but there are still differences in term of type of actuator used, types of modulation applied and stimulation sites. The outcomes of this study shown the capability of vibrotactile substitution system have a better performances compare to no feedback situation [6]. But, there is still weakness in term of accuracy and effectiveness of the system. Another application is vibrotactile substitution system used to provide the visually disabled with sense of color [7]. This system able to completed color to tactile sensory substitution system and only need a few minutes of training for users to obtain accurate results. This system use pulse coded representation which map four colors per finger onto one actuator. The result of this research has shown the capabilities of vibrotactile substitution system.

Another application was applied using vibrotactile substitution system is for artificial touch sensors in multifingered prostheses [8]. This researcher uses a vibel which composed of three identical miniature motors as their stimulator. The outcome of this research is the system only able to discriminate three sensations to the user which is still not enough to cover up all sensation for natural hand. The vibrotactile substitution system also applied for virtual object manipulation [9]. These systems try to compare the performance of amplitude modulation and pulse train frequency modulation. The results shown that amplitude modulation provides better feedback for object manipulation. Vibrotactile substitution system outcome is compromising, but for each application depend on several factors such as type of actuator, stimulation site and modulation technique.

In this paper, we demonstrate the feasibility of using vibrotactile to provide feedback for finger localization for prosthetic hand. Finger localization allows amputees to acknowledge the grip pressure from each individual finger of the prosthetic hand. If finger localization feedback is achieved, improvement on the

VOL. 11, NO. 10, MAY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

prosthetic hand such as slip detection and shape identification could be realized. The objective of this paper is to evaluate the performance of finger localization feedback for prosthetic hand using vibrotactile stimulation. Three different configurations of vibrotactile arrangements and three different vibratory frequencies are analyzed to investigate which is better for vibrotactile feedback.

METHODOLOGY

Experimental setup

A small coin/pancake motor (1 cm diameter, 0.3 cm height, iNEED (HK) Limited, Shenzhen, China) as shown in Figure-1 was used in this study. These pancake motors were chosen because it showed a good result [10]. All coin motors were driven at a constant voltage of 5V, which resulted in clearly tangible sensations and stimulation frequencies between 50 and 150 Hz. These motors generate the vibration by rotating an unbalanced mass. The coin motor rotates in a plane parallel to the surface. Since the perceived magnitude of the vibration mainly depends on the frequency, a frequency-chart was recorded. The maximum frequency of this coin motor can be achieved is 140 Hz. The frequency of this coin motor was measured by using accelerometer ADXL335. This accelerometer was a buffered +/- 3 G sensitivity range and operated in tri-axis mode (X, Y, and Z). The accelerometer had up to 360 mV/G sensitivity, as well as a bandwidth of 500Hz.

Figure-1. Coin/Pancake motor.

In total of five coin motors corresponds to each individual finger of a prosthetic hand were used in this study. Three types of configuration were designed in order to verify its performance as finger localization feedback for prosthetic hand. The configurations are vertical, rounded and U-shape configurations as shown in Figure-2. The distance between every coin motor for all configurations is kept constant at 3 cm. The stimulators placed on the upper arm by using double-sided tape with thickness 0.3mm.

Calibration

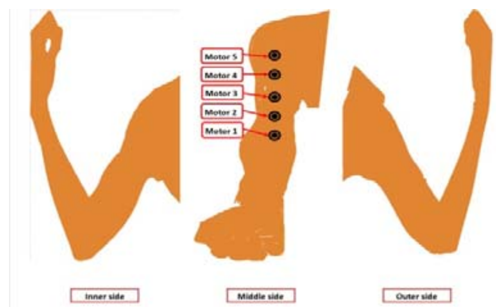
Calibration frequency of coin motor was done. At least 10 trials were performed to define the frequency interest (150 Hz, 130 Hz and 100 Hz). Verification of the frequency level was achieved by affixing the accelerometer directly on top of the coin motor and receiving data only in the z-axis of the accelerometer. Analog Discovery and WaveForms software from Digilent Inc. were used for this process that averaged over time a FFT analysis of the voltage signal from the accelerometer. This provided us with a frequency spectrum graph that showed us the vibratory frequency of coin motor. Figure-3 shows 3 vibratory frequencies used for this study.

Subjects

Experiments were performed on 7 healthy subjects (26 ± 3 years). All subjects did not have any experience before with vibrotactile stimulation and did not have any skin or sensory problem on upper arm.

Vibrotactile configuration

In this experiment, the accurate recognition of vibrotactile stimulation was assessed. The motivation of this experiment was to figure out the best configuration of stimulator of the upper arm's perimeter in distinguishable areas. 3 vibrotactile configurations were tested as shown in Figure-2.



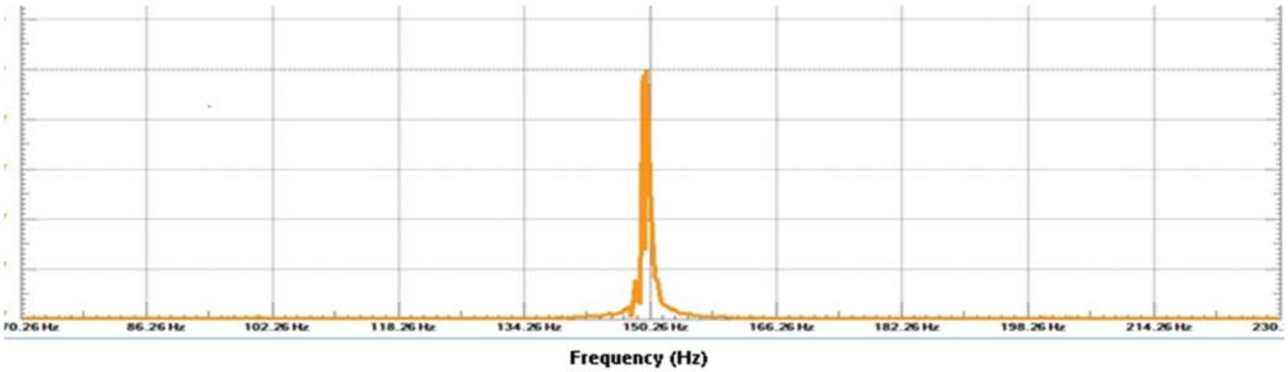
(a) Vertical Configuration

(b) Rounded Configuration

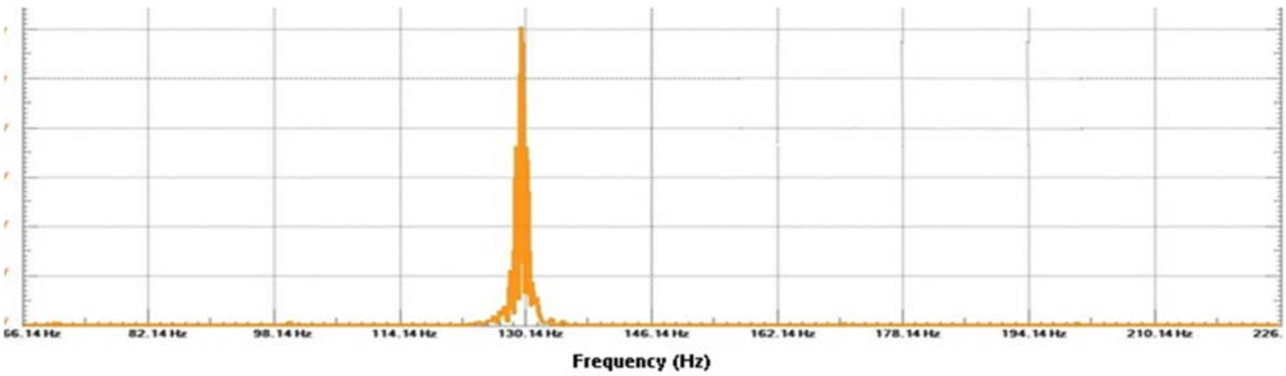
(c) U-Shaped Configuration

Figure-2. Different configuration of vibrotactile arrangement.

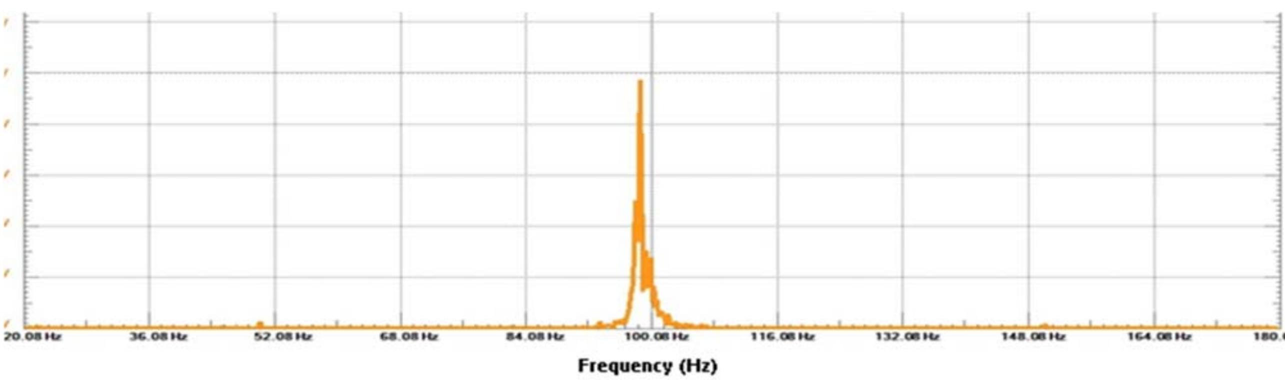
VOL. 11, NO. 10, MAY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences



(a) 150 Hz frequency



(b) 130 Hz frequency



(c) 100 Hz frequency

Figure-3. Different vibratory frequencies.

Table-1. Nine sessions experiment.

Session	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Vibratory Frequency (Hz)	150Hz	130Hz	100Hz	150Hz	130Hz	100Hz	150Hz	130Hz	100Hz
Vibrotactile configuration	Vertical configuration			Rounded configuration			U-shaped configuration		

Experimental procedures

Each subject will undergo 9 session of experiment with different vibratory frequency and different vibrotactile configuration. Table-1 shows the flow of the experiment. Each session was use one type of vibrotactile configuration and one types of vibratory frequency.

In the experiment, one of the five vibrotactile is activated for 3 seconds and the subject is required to distinguish and clearly perceive where the feedback

VOL. 11, NO. 10, MAY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

stimulus is originating from. Total of 25 stimuli were given for each session. Total of 75 stimuli were given for each configuration configurations and three vibratory frequencies. In summary, 225 stimuli were given to each subject. The sequence of the vibrotactile to be activated is randomly generated during the experiment.

Performance index

The number of stimuli that was correctly identified by the subject is computed. At the end of the experiment, the accuracy (in percentage of 100) is calculated for each configuration. Finally, the average of the accuracy for all the subjects is compared among three different configurations.

RESULT AND DISCUSSIONS

Objective evaluation

Figure-4 shows the result for the whole experiment. For vertical configuration, the 150 Hz vibratory frequency score 81.71±14.76%, while the 130 Hz and 100 Hz vibratory frequencies score 80±15.49% and 73.14±16.93%. As expected, the 150Hz vibratory frequency performed better than the 130Hz and 100 Hz vibratory frequencies. For rounded configuration, the score was almost same with vertical configuration. The 150 Hz vibratory frequency score 86.29±9.48%, while the 130 Hz and 100 Hz vibratory frequencies score 82.86± 16.28% and 80.57±16.56%. The score show that the larger the vibratory frequency, the better the performance. Rounded configuration performs more accurate than vertical configuration. For U-shaped configuration, the score is slightly different from previous configurations. The 100 Hz vibratory configuration score the best result, 90.29±10.29% compare to 130Hz and 150Hz vibratory frequency which score 84.57±12.95% and 85.71±14.58%. This result shows that, by using U-shaped configuration, the vibratory frequency was not a major factor to evaluate the accuracy of this system.

Figure-5 shows the result for different frequency. This result corresponds to the investigation from other researcher [11] that conclude that the larger the vibratory frequency, the more accurate the system. The score for 150 Hz vibratory frequency is 84.57±12.68% while the 130 Hz and 100 Hz vibratory frequency score were 82.47 ±14.34% and 81.33±15.87%.

Figure-6 shows the performance of the system by using different vibrotactile configuration. Among those configurations, vertical configuration demonstrates lowest performance where only 78.29±15.42% of the stimuli was accurately distinguished by the subjects. On the other hand, in average accuracy of 83.24±13.95% was achieved using round configuration. This result is better than vertical configuration due to more suitable location of stimulator. Subjects were easy to locate the vibrator either it is from upper or lower part of human upper arm. Finally, U-shape configuration deliver the highest accuracy which is 86.86±12.34% compared to others. This is due to its arrangement of stimulator. The arrangement covers all part of upper arm. This make the subject were easier to locate the stimulator.

Subjective evaluation

All subjects were in complete agreement that the vertical configuration is the hardest configuration in order to distinguish accurately and clearly perceive where the feedback stimulus is originating form. They preferred the u-shape configuration as five vibrotactile cover all parts of upper arm which increases empty space between coin motor. In addition, U-shape configurations is better compared to rounded configuration because the subjects feel it is easy to distinguish where the feedback stimulus coming from. During the experiment, some of the subjects also mention that they need more focus while conducting the experiment. For future work, the experiment will be conducted in a quiet room in order to make the subject more focus during the experiment.

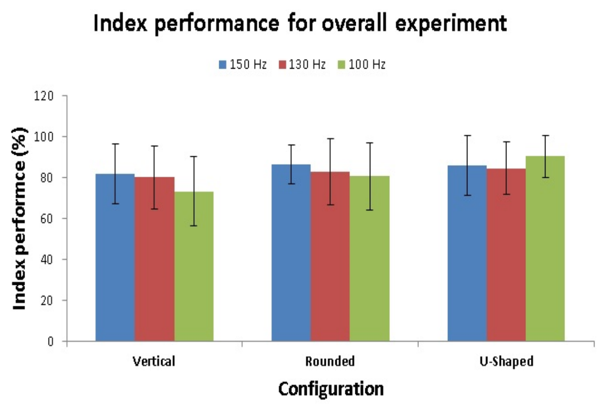


Figure-4. Result for overall experiment.

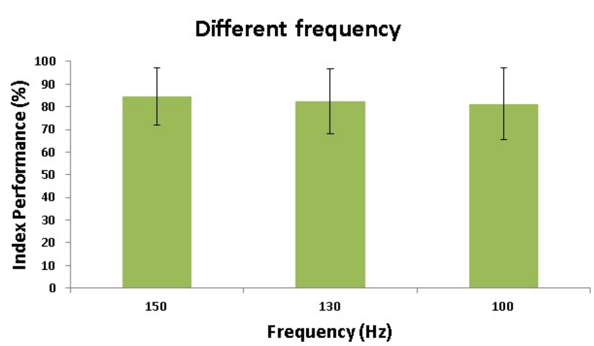


Figure-5. Result for different frequency.

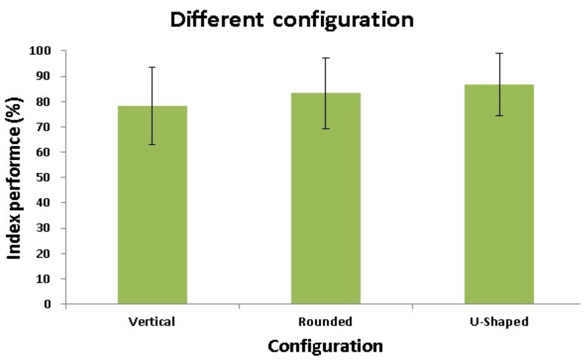


Figure-6. Result for different configuration.

CONCLUSIONS

In conclusions, subjects were able to distinguish the stimulator coming from. It is proven that different type stimulator configurations gives different result in term of accuracy. The U-shaped configuration has more superior result compare to vertical and rounded configurations. Higher vibratory frequency resulted better performance. Future work will try other type of stimulator with higher frequency by using U-shaped configuration.

ACKNOWLEDGEMENTS

This work was supported in part by the Centre for Research and Innovation Management (CRIM) of Universiti Teknikal Malaysia Melaka (UTeM) which was funded by the Malaysian government under the Fundamental Research Grant Scheme (FRGS/2/2013/TK02/FKEKK/02/1/F00170).

REFERENCES

[1] K. a. Kaczmarek, J. G. Webster, P. Bach-y-Rita, and W. J. Tompkins. 1991. Electrotactile and vibrotactile displays for sensory substitution systems. IEEE Trans. Biomed. Eng. vol. 38, no. 1, pp. 1-16.

[2] H. J. B. Witteveen, F. Luft, J. S. Rietman, and P. H. Veltink. 2014. Stiffness feedback for myoelectric forearm prostheses using vibrotactile stimulation. IEEE Trans. Neural Syst. Rehabil. Eng. vol. 22, no. 1, pp. 53-61.

[3] H. J. B. Witteveen, J. S. Rietman, and P. H. Veltink, 2012. Grasping force and slip feedback through vibrotactile stimulation to be used in myoelectric forearm prostheses. Proc. Annu. Int. Conf. IEEE Eng. Med. Biol. Soc. EMBS, pp. 2969-2972.

[4] J. M. Walker, A. a. Blank, P. a. Shewokis, and M. K. O'Malley. 2014. "Tactile feedback of object slip improves performance in a grasp and hold task," IEEE Haptics Symp. HAPTICS, pp. 461-466,

[5] E. Rombokas, C. E. Stepp, C. Chang, M. Malhotra, and Y. Matsuoka. 2013. Vibrotactile sensory substitution for electromyographic control of object manipulation, IEEE Trans. Biomed. Eng. vol. 60, no. 8, pp. 2226-2232.

[6] C. Tejeiro, C. E. Stepp, M. Malhotra, E. Rombokas, and Y. Matsuoka. 2012. Comparison of remote pressure and vibrotactile feedback for prosthetic hand control," Proc. IEEE RAS EMBS Int. Conf. Biomed. Robot. Biomechatronics, pp. 521-525.

[7] J. Tapson, J. Diaz, D. Sander, N. Gurari, E. Chicca, P. Pouliquen, and R. Etienne-Cummings, 2008. The feeling of color: A haptic feedback device for the visually disabled. 2008 IEEE-BIOCAS Biomed. Circuits Syst. Conf. BIOCAS. pp. 381-384,

[8] C. Cipriani, M. Dalonzo, and M. C. Carrozza. 2012. A miniature vibrotactile sensory substitution device for multifingered hand prosthetics. IEEE Trans. Biomed. Eng. vol. 59, no. 2, pp. 400-408,

[9] C. E. Stepp, C. Chang, M. Malhotra, and Y. Matsuoka. 2011. Vibrotactile feedback aids EMG control of object manipulation. Proc. Annu. Int. Conf. IEEE Eng. Med. Biol. Soc. EMBS, no. 1, pp. 1061-1064.

[10] C. Pylatiuk, A. Kargov, and S. Schulz. 2006. Design and Evaluation of a Low-Cost Force Feedback System for Myoelectric Prosthetic Hands," JPO J. Prosthetics Orthot. vol. 18, no. 2, pp. 57–61.

[11] L. a. Jones, J. Kunkel, and E. Piateski. 2009. Vibrotactile pattern recognition on the arm and back. Perception, vol. 38, no. 1, pp. 52-68.