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Research paper

Psychophysics Behavior of Human Tactile Mechanism to Discriminate Extremely Thin Copper Foils.

Mohammad Azzeim Bin Mat Jusoh[1]*, Masahiro Ohka[2], Tetsu Miyaoka[3], Sukarnur Bin Che Abdullah[4], Hafizan Bin Hashim[5],

[1 4 5] Fakulti Kejuruteraan Mekanikal (FKM), UiTM Shah Alam, Selangor, MALAYSIA
[2]Graduate School of Information Science, Nagoya University, Furo-cho, Chikusa-ku, Nagoya, 464-8601, JPN
[3]Shizuoka Institute of Science and Technology, 2200-2 Toyosawa, Fukuroi-shi, Shizuoka 437-8555, JPN
**Corresponding author E-mail: m_azzeim@yahoo.com*

Abstract

In this study, our objective is to analyze human tactile mechanism behavior in recognizing extremely thin foils using the psychophysics method. Seven pairs of copper foils ranging in thickness from 20 ~ 150 μm were used in the experiment. We applied the method of constant stimuli to define the difference threshold between the materials. In order to increase the detection rate, contact between human tactile function and the metal foils was maintained. As a result, the Weber fraction c consistently reduces as thickness increases. However, the slope decrement is steep compared to previous experimentation (using stainless steel as base). We also validated the behavior of the undetected regions up to 150-μm thicknesses. This achievement was quite significant considering the higher thickness test ratio. In future, further comparison shall be made using different material type.

Keywords: *Human tactile mechanism; Cutaneous function; Mechanoreceptor; Psychophysics; Weber fraction; Difference Threshold (DL).*

1. Introduction

The ability of human tactile sensations to distinguish foil thickness until several 10 μm of thicknesses; when such ultra-thin thickness cannot be monitored through joint sensory organs, is a tremendous skill. Since tactile sensations play a major role in this thickness discrimination process of ultra-thin foils, elucidating this mechanism is the main focus of our study.

Previous psychophysics studies by Miyaoka and Ohka have shown the existence of an undetected region when analyzing materials of 70 to 350 μm in thickness [1, 2]. This hypothesis can be summarized from Fig.1, where the accuracy in detecting material thickness is shown. For humans, the process of thickness discrimination is influenced by two major sensing systems: the cutaneous function (related to delicate contact or touch) and the kinesthetic function (influenced by muscle joint motion) [3, 4].

In previous simulation work, we have discussed on the application of finite element analysis (FEA) towards the study of human tactile sensation [5]. Using human finger model, we have showed the capability of human in defining specific properties of material, such as the stainless steel and copper type material. At first, contact is made between human tactile function (index finger and thumb) and the foil. Next, the skin deforms and adapts to the foils' shape. The mechanoreceptor senses and perceives change, and transforms information into electrical signals (neural pulses). The stimulus is then carried via an extensive nerve network to the Central Nervous System (specifically towards the somatosensory cortex region) for the next processing phase.

One hypothesis is that both systems are functioning simultaneously and the transition state occurs somewhere within this region. As mentioned previously, the activation of such critical skill could come from mechanoreceptors that are sensitive to constant pressure, constant velocity, or acceleration-type information, such as SA-I, SA-II, FA-I, and FA-II. It could be possible that plastic deformation also influence the judging process, especially when discriminating extremely thin materials [1]. From Just Noticeable Difference (JND) evaluation, it is concluded that when the plate was thinner than critical thickness, the curvature became large enough to provide cue through tactile function. Whereas, when the plate was effectively unbendable, the kinesthetic function was the only cue for discriminating thickness.

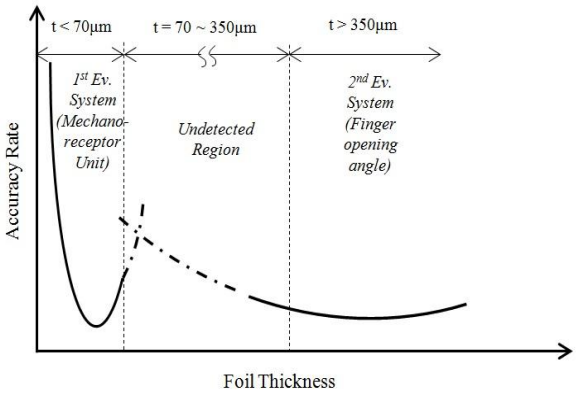

Fig. 1: Hypothesis for the material thickness detecting rate

The human mechanoreceptor consist of four main components which is the Meissner's Corpuscles (FA-I), the Pacinian Corpuscles (FA-II), the Merkel's Discs (SA-I) and the Ruffini's End organs (SA-II). The FA-I is sensitive towards skin indentation, capable of detecting changes in terms of normal vibration (around 50 Hz) and adapts rapidly regardless the stimulus size. The FA-II

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detects rapid vibrations (around 200~300 Hz) according to stimulus size. As for SA-I, it detects sustained touch and pressure, and having high-sustained sensitivity especially to static force. Finally, the SA-II is sensitive to low dynamic sensation and able to detect tension deep within the skin regardless the stimulus size [6~9]. The main focus in this research is towards the SA-I mechanoreceptor unit, which plays the role of defining sensitive sensation from the skin (Refer Fig. 2)

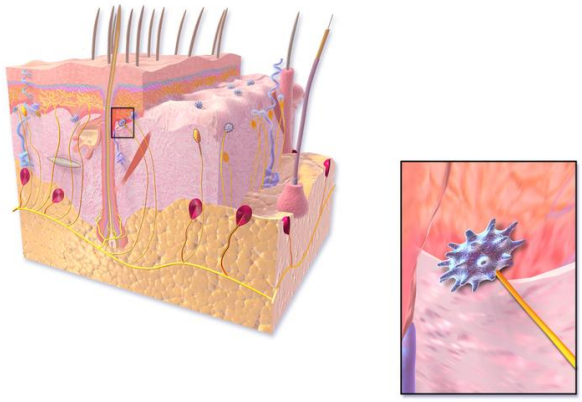

Fig. 2: The Merkel's discs (Slowly Adaptive Mechanoreceptive Type I unit or SA-I) in the skin (Adapted from Blausen gallery) [10]

In this paper, we shall discuss on the basic function of psychophysics, and the possibility to use it to explain on human's tactile behavior using copper material as base. Application wise, during the development of a dexterous mechanical hand capable of handling delicate functions is needed, especially for daily use. To create a device able to perform such critical tasks, the best option is to study the complexity of the human tactile mechanism. Through such study, we will be able to improve and optimize the performance of tactile sensors, especially in robotics.

2. Literature Review

At first, we shall discuss regarding fundamental psychophysics application. Psychophysics can be defined as the study of the relationship between the physical properties of a stimulus and perception ability. In theory, the Weber fraction shows the ability of a subject to detect distortion of stimuli and discriminate stimuli thicknesses from the amount of distortion [11~13]. The ratio between the change of stimulus intensity that is just noticeable ($\Delta\varnothing$) and the actual value of stimulus $\varnothing$ could be described using the constant value c, resulting in Eq. (1) below.

$$c=(\Delta\varnothing)/\varnothing \quad (1)$$

Fechner further expanded this law, resulting in Fechner's Law. The main difference is that Weber defines the psychophysics relation using a linear function, whereas Fechner's Law postulated the relation using a logarithmic function, which fits most psychophysics experimentation phenomena. This results in Eq. (2), where S and k represent the sensation magnitude and a constant value, respectively [12].

$$S=k\log(\varnothing) \quad (2)$$

Next, we discuss regarding related psychophysics studies. The research done by John et al. [14] in discriminating the thickness of thin copper plates shows that the test subjects were capable of discriminating thicknesses from t = 200 ~ 500 μm (within a 75-μm range). John et al. also discussed the influence of the gripping angle between the fingers, as there were no differences when discriminating between the foil's edge and the surface.

Miyaoka and Ohka also performed similar experimentation, but with thinner SUS and Cu foils, proposing that humans are capable of discriminating until t = 8 ~ 50-µm thickness (which normally cannot be detected by the angular sensory organs of the human finger) [1, 2]. Their hypothesis is that evaluations of material of less than 70-µm thickness must be performed using the cutaneous function (of SA-I mechanoreceptor units) and, for thicknesses above 350 µm, the kinesthetic function. There is an undetected region between 70- and 350-μm thicknesses that marks the transition state from one system to another, suggesting the inter-function state between both systems that we described in the earlier section.

The previous simulation work demonstrates the importance of finite element analysis towards indirect monitoring of human tactile behaviour [5]. We also highlighted the impact of angular load on the result and the need to maintain contact between human tactile function and the metal foils to improve the detection rate.

Whereas, the previous psychophysics experiment shows that the test subject is capable of detecting the thickness of stimuli through this gripping method using stainless material as base [15]. We employed a specific procedure to maintain contact between the human finger and SUS foils throughout the experiment. The test subject was required to grip the material between the index finger and thumb without releasing contact with the foils in order to ensure that the only mechanism that activates during contact is the cutaneous stimuli (or mechanoreceptor), especially in detecting distortion. Finally, comparison between the behavior of human tactile mechanism versus a robotic hand equipped with 3-axis tactile sensors, in recognizing extremely thin sheets (or foils) and plates was also performed [16]. Hypothetically, when comparing extremely thin material, human shall judge the thickness based from the spring constant of the material instead of physical (geometrical) thickness. This hypothesis also applies to robot hand during similar evaluation process.

The clarification between psychophysics test and FE simulation result was made by referring to the Weber Fraction. The method of constant stimuli was used for this experiment by adapting the concept of difference threshold, where comparison and judgement must be made by the test subject between standard stimulus and comparison stimulus. It is considered as one of the most accurate method in psychophysics, yet also the most time consuming compared to others. Until today, the application of psychophysics is still relevant in describing the relationship between a person's sensations versus psychological judgement; as supported by Gescheider [11] and Read [17].

3. Methodology

The main purpose of the experimentation procedure is to measure the thickness difference thresholds using a pair of copper foils. Six males aged in their twenties participated in this experiment as our test subjects, all with zero experience in psychophysics experiments, particularly in regard to the thickness differentiating process. Based on a simple interview, all test subjects were determined to be right handed.

Seven pairs of copper foils were used as stimuli with thicknesses of 20, 40, 60, 80, 100, 120, and 150 μm. Each foil was clamped between aluminum jigs with a 60-mm diameter exposed opening. The temperature of the jig was controlled using two hot plates (AS ONE, EHP-250N), each positioned beside the test subject's hand (Refer Fig. 3 & 4).

First, each test subject was seated and required to wear an eye mask to prevent viewing any of the test materials. They were also required to wear earphones inputting white noise sounds to neutralize any external noise that could influence their judgement. Next, the tester randomly selected a pair of foils from each comparison stimulus and standard stimulus group, and placed the pair near the test subject's hands. After receiving a tap signal from the tester, the test subject gripped each foil simultaneously using the

index fingers and thumbs of both hands. This was to determine which foil was perceived to be thicker using the two-alternative, forced-choice technique.

The test subject was allowed to move their fingers with five times gripping motion only, maintaining contact with the metal foil throughout the whole process. Finally, each test subject signalled which material was perceived to be thicker by raising the hand which perceived the thicker feeling.

The maximum time to give their feedback was 20 sec (including 15 sec of the gripping process) for each combination of stimulus. The inter-stimulus interval is important for the tester to record data and to exchange material for the next combination of stimulus. Basically, pair-wise combinations of seven distinct stimuli (plus self-combinations) produces 28 steps, with comparison between same thicknesses done twice. As it was necessary to counterbalance the right and left positions of stimuli, the total number of combinations doubles up to 56 steps. Overall, each subject performed around ten trials for each combination of stimuli, resulting in a total of 560 steps each. The total simulation time per trial was about 30 minutes (including 10 minutes resting time during each interval). In order to maintain the decision-making quality, the maximum experiment time was kept below two hours, which limits the number of trials to a maximum of four per day.



(a) (b)

Fig. 3: Humidity chamber to preserve material sample (a) and various thickness of copper material arranged on hot plate (b).

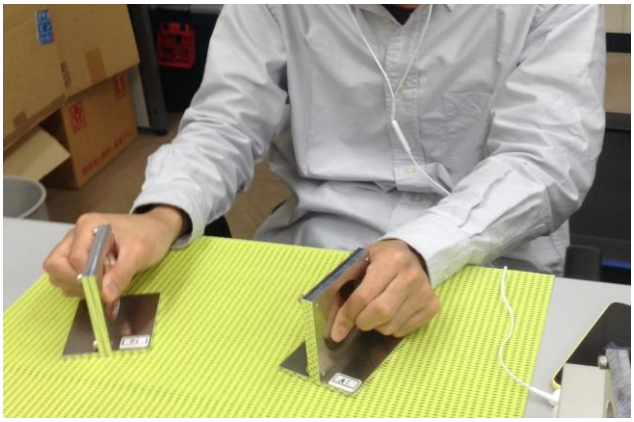

Fig. 4: Experimental setup where the test subject is comparing the stimulus between two copper samples with specified thickness.

In order to estimate the gripping force of previous psychophysics experimentation, at first the anthropometric data from FAA William J Hughes Technical Center has been referred to; resulting in gripping force of 48 N (momentary) and 28 N (sustained hold) between thumb and index finger during handling. Due to such excessive figure compared with actual physical confirmation, the resultant force has been reduced with average of 1.0 N for both index finger and thumb.

As for current setting, we have decided the temperature to set the room temperature to 25°C. As for humidity, it should be controlled within 60% range (Currently the average is about 50%, as the optimum indoor setting for either heating or cooling climate is around this value). The temperature of the hot plate shall be kept around 35 ± 1 °C, and the temperature of the foil is targeted around 32± 4 °C, which is set as close as possible to normal body temperature. Even though the heat dispersion factor might effect the temperature of the foils (due to varieties of thickness, material type and others), as long as the temperature is kept within this range, the test subject could not differentiate the temperature differences between the foils.

4. Result

In this section, we shall discuss the psychophysics experimental result, using copper as the base material. The psychometrics function using *p* values can be referred from Fig. 5. The vertical axis shows the probability for the comparison stimuli to be judged thicker than standard stimuli, while the horizontal axis shows the thickness of the comparison stimuli. Each of the lines represents the probability trend of base material. For example, referring to the data on the upper left corner, which represents the trend line for copper comparison stimulus material (with t=40 μm) with probability of 0.98 to be judge thicker when compared with 20 μm base or standard material. Overall, when p=0.5, it marks the threshold point where the probability of judging both type of material's thicknesses as similar.

By referring to this data, we could see the relation between each plot, which reflects the accumulated result for each standard stimuli. From here, we could verify that the psychometric function increases as the thickness of comparison stimuli increases. This shows the ability of the tactile function (of test subject) to discriminate the thickness of the stimuli, which increases as the thickness of comparison stimulus material increases.

As for the z-score function (Fig. 6), basically it produces similar result because initially the data of psychometric functions were normalized and normal distribution curves were fitted using the least square method for the main purpose of difference threshold calculation. Compared to the previous result using stainless steel material [15], the probability of detection for copper material shows a rapid increase especially for t = 20~40 μm thickness. This also could be seen during experimentation where the usage of 20 μm as comparison or base resulting in almost 100% detection compared to other thicknesses. The probability function and z-score function also shows an increase.

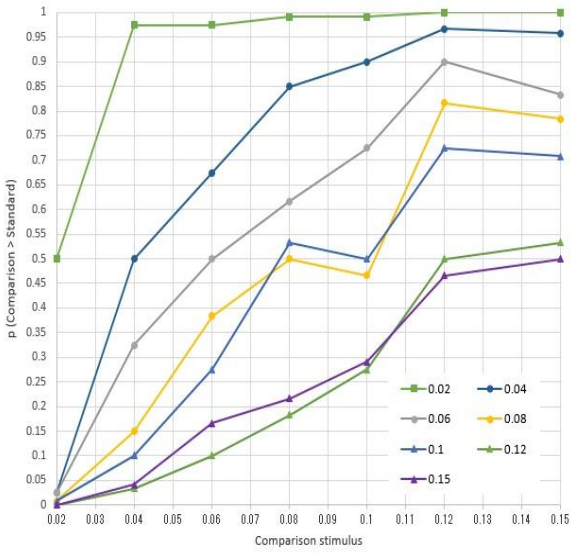

Fig. 5: Psychometric function using *p* values for Cu vs Cu

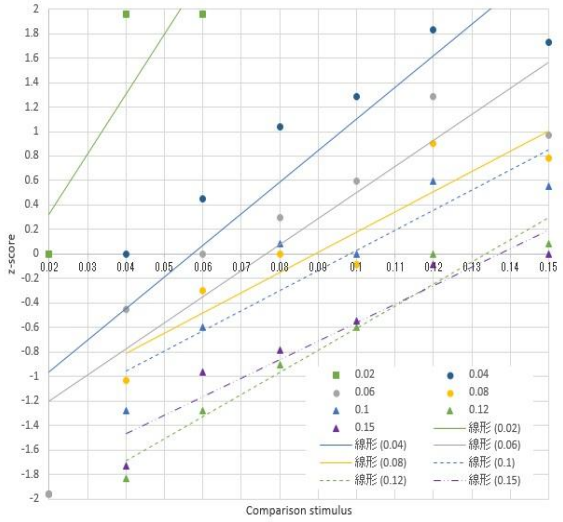

Fig. 6: Psychometric function using Z-Score for Cu vs Cu

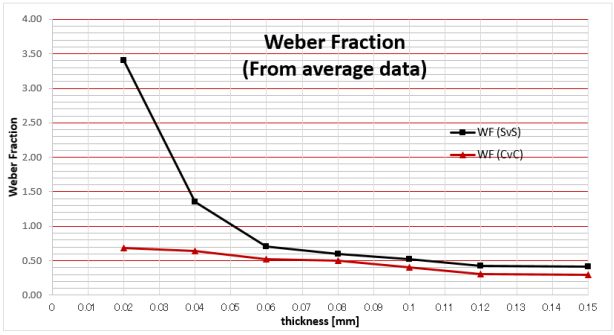

Fig. 7: Comparison of Weber Fraction (SUS vs SUS and Cu vs Cu)

Next is to refer to the Weber fraction result for copper material in Fig. 7, beginning from 0.68 when t=20 μm and further reduced to 0.28 when the thickness decreased to t=150 μm thickness. As informed previously, the Weber Fraction shows the ability of a subject to detect distortion of stimuli and discriminate between the thicknesses of stimuli from the amount of distortion. The Weber fraction for copper (Cu) reduces almost consistently with linear trends compared to the result from stainless steel (SUS) material, which have extremely high Weber fraction value at the beginning (around 3.5). This shows that the test subject is still capable of differentiating the thickness for within this range of data when using copper material. The evidence could been seen from the accuracy level graph, where the average accuracy level increases to almost 87% compared when using stainless steel material as base. Also, the slope of stimuli for stainless steel material is high during low thickness showing signs of limitation when evaluating extremely thin material and further reduces to normal, when the Weber fraction becomes more consistent.

From the duplex theory [1], one of the conclusions is that the thickness discrimination was possible only when the stimuli were either extremely thin, from 20~70 μm thickness, or from 350~1000 μm thickness. The discrimination of thickness was considered difficult by the test subjects when the thickness of the stimuli were between 70~350 μm, marking the possibility of a changing points from one discriminating system to another. The previous hypothesis also discussed on the possibilities of intersection between two discriminating system processes. However, based from current experimentation, it is quite hard to judge the discriminating system by just looking at the probability or *z*-score function result.

One of the limitations is due to the nature of our experimentation. We need to control the testing environment so that the test subject could produce good judgement within specified timeline. At the same time, this also means that we need to break the material into certain thickness categories. Our judgement also needs to be based from observing the Weber fraction graph.

5. Discussion & Conclusion

Miyaoka and Ohka [1] shows that the test subjects were able to detect distortion of stimuli and discriminate between the thicknesses of stimuli from the amount of distortion. When the amount of distortion is small, the material thickness shall be defined as thick and vice versa. This concept could also be monitored through the behavior of human during contact with soft object, as mentioned by Fujita and Ohmori [18]. One of the conclusions is the mechanoreceptor responding to velocity or acceleration information has been used in detecting such distortion as mentioned by Johansson and Vallbo [6~7].

From this experiment result, it could be possible that SA-I or FA-I is responsible in detecting the distortion during extremely thin thickness (Based from this experiment result is around t=20~50 μm). Burgess et al. [19] also states that compression signalled by cutaneous mechanoreceptor particularly the slow adapting class. However, Srinivasan and La Motte [20] states that the softness perception rely primaly on cutaneous and kinestatic have no effect in discriminating softness. Goodwin [21] also reports that SA-I responds the best to static stimuli when encoding object with curvature, while only 50% of FA-I responds and none for FA-II. This could mean that SA-I is the primary source for tactile discrimination.

For current experiment, although majority of the effort is focused towards controlling the detection feeling through static load, it is quite impossible for the test subject to perform and response throughout the whole experiment without involving dynamic motion. As the thickness increases from around 50~90 μm, the detection could have been made by another mechanoreceptor unit such as the FA-II. The basis on such hypothesis was made referring to the findings by Bolanowski et al. [22].

As highlighted during the beginning of the experiment, the test subject are required to grip the material between index finger and also thumb without releasing contact with the foil. Thus, the only mechanism that should work during this motion is the stimuli in detecting distortion, which is available at the mechanoreceptor within our skin. This shows that the test subject is capable of detecting the thickness of stimuli even by gripping the sample and by moving their thumb and index finger only.

From the latest psychophysics experiment, we have further verified the tactile ratio during detection of extremely thin object. Due to further specification of material handling, basically we achieved similar trend. The only difference is the value of tactile ratio is more focused. Unfortunately, we are unable to monitor the changes of accuracy rate. The reason is because there is no major changes detected on the Weber function for t > 70 μm onwards. Eventhough some of the individual result shows such progress especially from 120 μm onwards, in average the increase is minimum and barely noticeable. Also, the duplex theory is not verified in this experiment. But the fact that it exists cannot be denied based from previous experimentation result, where the threshold exists when thickness is more than 100 μm. This is due to the nature of our experiment, where we specifically instruct the test subject to analyse differences of thickness using each hand simultaneously, and not the combination of two index finger as performed during duplex theory.

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References

[1] Miyaoka, T. and Ohka, M. 2001. Tactile Information Processing Mechanisms to Discriminate Foil Thickness. Proceedings of the Seventeenth Annual Meeting of the International Society for Psychophysics, Vol. 17.

[2] Miyaoka, T. and Ohka, M. 2002. The Duplex Theory of Thickness Discriminations by Touch. JSME Annual Meeting 2002(1), 231-232.

[3] Jones, L. A. and Lederman, S. J. 2006. Human Hand Function, Oxford University Press.

[4] Bossomaier, T. R. 2012. Introduction to the Senses: From Biology to Computer Science, Cambridge University Press.

[5] Mohammad Azzeim bin Mat Jusoh, M., Ohka, M., and Miyaoka, T. 2015. Finite Element Analysis of Human Tactile Sensing to Differentiate Thin Foils through Comparison Between Vertical & Angled Loads. Procedia Computer Science, Vol. 76: 40-46.

[6] Johansson, R.S. and Vallbo, A.B., 1979. Tactile Sensibility in the human hand: Relative and Absolute densities of four types of Mechanoreceptive Units in Glabrous Skin. J. Physiol., Vol. 286, 283-300.

[7] Johansson, R.S. and Flanagan, J.R., 2009. Coding and use of tactile signals from the fingertips in object manipulation tasks. Nature Reviews Neuroscience, 10(5), pp.345-359.

[8] Kandel, E.R., Schwartz, J.H., & Jessell, T.M. (Eds), 2000. Principles of Neural Science (Fifth Edition, pp. 500). New York: McGraw-Hill.

[9] Johanness, Z. 2010. Sensation, Perception and Action. An Evolutionary Perspective. Palgrave Macmillian.

[10] Blausen.com staff. Blausen Gallery 2014. Wikiversity Journal of Medicine. DOI:10.15347/wjm/2014.010.ISSN 20018762

[11] Gescheider G. A. 1997. Psychophysics: The Fundamentals, Third ed., Lawrence Erlbaum Associates.

[12] Manning, S. A. and Rosenstock, E. H. 1968. Classical Psychophysics and Scaling, McGraw-Hill Book Company.

[13] Stevens, S. S. 1975. Psychophysics: Introduction to Its Perceptual, Neural and Social Prospects, John Wiley & Sons, Inc.

[14] John, K. T., Goodwin, A. W., and Darian-Smith, I. 1989. Tactile Discrimination of Thickness. Experimental Brain Research, Vol. 78, No. 1: 62-68.

[15] Jusoh, Mohammad Azzeim Mat, Masahiro Ohka, and Tetsu Miyaoka. "Comparison of Tactile Discriminations to Verify the Undetectable Region of SUS Foil Thickness." Journal of Telecommunication, Electronic and Computer Engineering (JTEC) 8, no. 7 (2016): 83-86.

[16] Sugiman, Kenji, Masahiro Ohka, and Mohammad Azzeim bin Mat Jusoh. "A Basic Paper Handling Task Experiment Using Tri-axial Tactile Data." Procedia Computer Science 105 (2017): 270-275.

[17] Read, J.C.A. 2015. The place of Human Psychophysics in modern Neuroscience. Neuroscience, 296, pp. 116-129.

[18] Fujita, K. and Ohmori, H. 2001. A New Softness Display Interface by Dynamic Fingertip Contact Area Control. In 5th World Multiconference on Systemics, Cybernetics and Informatics, pp. 78-82.

[19] Burgess, P.R. and Perl, E.R., 1973. Cutaneous Mechanoreceptors and Nocireceptors. Somatosensory System, Springer.

[20] Srinivasan, M.A. and LaMotte, R.H. 1987. Tactile Discrimination of Shape: Response of Slowly and Rapidly Adapting Mechanoreceptive Afferrents to a step indented into the monkey fingerpad. The Journal of Neuroscience, 7(6), 1682-1697.

[21] Goodwin, A.W., Macefield, V.G., & Bisley, J.W. 1997. Encoding of Object Curviture by Tactile Afferrents from Human Fingers. Journal of Neurophysiology, 78(6), 2881-2888.

[22] Bolanowski, S.J. Jr., Gescheider, G.A., Verrillo, R.T. and Checkosky, C.M. 1988. Four Channels Mediate the Mechanical Aspects of Touch. Journal of the Acoustical Society of America, 84, 1680-1694.