Study on Human Fingers Perception over Textured Surfaces for the Textural Applications in Haptics Technology

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Abstract. Haptics technology uses skin as a source for feedback and helps in the perception of the stimulus. There are various types of actuators or displays used in haptics perception, like electro-tactile, vibrotactile, thermal coil and physical pins. These actuators require larger neural density for being used as an application. Hairy and Non-Hairy skin, its neural density pattern must be observed for perception memory applications. The textural applications in haptics technology are one of the kinds which use skin and its perception levels. The paper discusses the behaviour of fingertips and fingertip’s skin behaviour pattern towards textural applications in tactile feedback. The experiment in the paper uses psychophysical assumptions and single-blinded method of perception over six human participants under three environmental condition, and 10 stimuli which are used in everyday activity. The experimental result focuses on the perception time and perception memory of human fingertips, which will a comparative data with real-time haptic feedback. The experimental methods discussed in the paper addresses low-cost perception experiment for a preliminary study of haptics textural applications.

Keywords: Haptics, Psychophysics, Textural Applications, Human Perception.

1. Introduction

Haptics is the study of science and behaviour of skin, and the applications which use skin and its property with mechanical constrains through embedded protocols is termed as Haptics Technology [9]. The concepts like virtual reality, mixed reality, teleoperated and sections of human-machine interfacing has a shadow of human perception, and haptic interaction. The most common haptic feedback is perceived using vibrotactile displays/actuators [4]. The other unexplored devices are electro-tactile displays, physical pins, thermal displays, and mixed displays [5][6]. The human body is covered with 98.6% with skin and it is the most effective sensing part compared to other human sensors due to its perception memory. The skin is classified dermis and epidermis and holds millions of mechanoreceptors. Mechanoreceptors are cells which are responsible for differential human skin sensation, like pressure, pain, stiffness, and force [2]. The receptors are classified based on the depth of penetration from the outer surface of human skin, as rapid responsive and slow responsive [8].
The use of haptic devices and actuators are widely used in engineering applications like entertainment, automobile safety systems, avionics, rehabilitation and specially challenged human physical interaction, without perceiving skin behaviour. The behaviour of human skin changes from hairy skin to non-hairy skin. Non-hairy skin is very less responsive towards physical stimulus than hairy skin.

![Figure 1](image1.png)

Figure 1: The classification of skin and its receptors representation [1].

Places like palm, feet, forehead, tongue, and parts of the face are very active towards a mild change in external stimuli. The external stimuli responses may change with the noise and noise in the skin is generated through sweat, humidity, physical work or occupation, and temperature. In haptics technology, the majority of the applications use human hand for physical interaction with machines or virtual reality applications. The property of skin or any human sensor is judge using psychophysical experiments. The psychophysical experiments discuss the responsive time of skin towards any stimuli and give the behaviour of in terms of just noticeable difference (JND). The ratio of sensory responses to its upper and lower limits is given as JND. There are many methods to calculate JND, but the best method was coined by Weber–Fechner law. The paper discusses the responses of human fingers towards possible external stimulus in three different environmental conditions to check the response time to check the psychophysics of skin and its sensitivity [3]. The experimental results are validated with the data taken from 1080 samples using descriptive statistics.

2. Experimentation

In this paper, the psychophysical experiment was carried out over six human male subjects and ten material subjects with single-blinded technique over three different environmental conditions. The conditions were taken to check the response time irrespective of correctness. The selection of participants was done using the finger scales measurement. Six participants with age less than 30 years old and not more than 25 years old were subjected for the experiment, assuming the range as an average [7]. The ink impressions of each participant were taken and using digital imaging microscope the selection criteria were taken into account. The figure (2) shows the best outer cutaneous surface and distorted cutaneous surface. The method is a very basic understanding of human skin sensitivity and skin thickness based on the physical work engaged in everyday activity. Six participants were selected out of thirty-two participants in random profession.
The experimental setup for surface roughness recognition was done using a test bench setup. Two models were identified to perform the experiment, circular and rectangular. A trial run was performed for recognition. The circular setup had better reachability and was selected for the experiment, shown in figure (3). The experiment used ten stimuli for the experiment. Metal, Brick, Cardboard, Cloth, Glass, Paper, Rough Paper, Rough Plastic, Rubber and Wood are the most common stimuli that have a reference in perceptual memory and are quite commonly used in everyday life. Each stimulus was 4 cm X 4 cm in surface dimension with variable thickness. The categorization of stimuli was noted using roughness values. The roughness value can be found from contact and non-contact type metrology setup. In the experiment, the roughness was noted using the non-contact type roughness measuring setup. The stimulus was placed in equal distance from each other and 50 cm away from participant, shown in figure (4).

Six participants were subjected to the ten stimuli and recognition test was conducted using the single-blinded experimental method. Ten stimuli were subjected over six fingers (5 fingers + Index finger repeated the second time) over three environmental conditions. Air-conditioned environment (20°C to 24°C), room temperature and open environment were the three environmental conditions.
The conditions are not controlled environments and are subject to fluctuations. The three conditions were taken to make sure maximum samples of data are available to see the behavior of the fingers towards textural perception. Each participant is given 10 stimuli one after another over left hand and asked to identify over test bench using the right hand. The time taken for perception is noted irrespective of appropriateness. The process is repeated over three environmental conditions generating 1080 samples (Six Participants, Six Fingers, Three environmental conditions and Ten stimuli) over each participant.

3. Results

The results are explained taking descriptive statistics as a key root and understanding the best suitable conditions. The results are discussed individually for each environmental condition.

1. 20 °C -24°C temperature condition:

In this condition, all the finger did detect the stimuli and has very less point of error in identifying the stimuli. The maximum time taken to detect a particular stimulus was 8.375 seconds, whereas the minimum time of detecting was 0.546, with a standard deviation from 1.351 to 2.087. The statistical observation is shown in table (1). For the first trail thumb was used and it took total time for perseverance as 53.568 seconds (which is the cumulative addition of the average values of each finger). This time is the sum of the entire stimulus over a single finger for all the participants. With the increase in the number of trails, the standard deviation and total time for perseverance tend to decrease due to the perceptual memory and repeatability. The total correct detected stimulus was close to 93%.

| Fingers | MEAN | Standard Deviation (σ) | Total Time | Minimum Detected time | Median | Maximum Detected time |
|---------|------|------------------------|------------|-----------------------|--------|-----------------------|
| Thumb   | 5.356| 2.087                  | 53.568     | 1.850                 | 5.475  | 8.375                 |
| Index   | 4.026| 2.059                  | 40.261     | 1.210                 | 4.090  | 7.261                 |
| Middle  | 3.406| 1.871                  | 34.061     | 0.715                 | 3.665  | 5.931                 |
| Ring    | 2.911| 1.690                  | 29.115     | 0.558                 | 3.167  | 5.413                 |
| Little  | 2.834| 1.836                  | 28.341     | 0.576                 | 2.982  | 6.053                 |
| Index Re| 2.285| 1.351                  | 22.855     | 0.546                 | 2.497  | 4.433                 |

2. Room temperature condition:

In this condition, total time duration taken to detect was 108.306 seconds (Which is the cumulative addition of the average values of each finger) which had a maximum duration of 29.206 seconds. The minimum time taken to detect one particular stimulus is 0.323 seconds. Just like the previous condition, the time duration reduced with a particular rate under multiple iterations which are represented in table (2). The correct detected stimulus was 68% which is 1.36 times lesser than 20-24°C temperature condition.
Table 2: Descriptive Statistics of room temperature condition (Average values of each finger over 10 materials).

| Fingers   | MEAN (Seconds) | Standard Deviation (σ) | Total Time | Minimum Detected time | Median Detected time | Maximum Detected time |
|-----------|----------------|------------------------|------------|-----------------------|----------------------|------------------------|
| Thumb     | 10.830         | 8.653                  | 108.306    | 1.791                 | 9.375                | 29.206                 |
| Index     | 6.850          | 5.410                  | 68.504     | 0.94                  | 5.867                | 18.076                 |
| Middle    | 5.398          | 4.366                  | 53.981     | 0.84                  | 4.582                | 13.958                 |
| Ring      | 4.876          | 4.428                  | 48.764     | 0.351                 | 3.511                | 13.796                 |
| Little    | 3.935          | 3.188                  | 39.352     | 0.573                 | 3.045                | 10.623                 |
| Index Re  | 3.420          | 3.406                  | 34.206     | 0.323                 | 2.648                | 11.068                 |

3. Open environmental condition:

Unlike the above two conditions, here the trend did change, and an uneven pattern was found in detecting the entire stimulus. The total average time taken was 323.524 seconds, which is three times more than room temperature first iteration and six times more than 20-24ºC temperature condition, Table (3). There was a reduction in minimum detected time under multiple iterations which were observed in higher roughness values like cloth and brick. The standard deviation that explains the change of duration occurring between iterations remains irregular and thus bringing out the correct detected stimulus to 11% which is far lesser than the above conditions.

Table 3: Descriptive Statistics of open environmental condition (Average values of each finger over 10 materials).

| Fingers   | MEAN (Seconds) | Standard Deviation (σ) | Total Time | Minimum Detected time | Median Detected time | Maximum Detected time |
|-----------|----------------|------------------------|------------|-----------------------|----------------------|------------------------|
| Thumb     | 32.361         | 11.503                 | 323.524    | 15.276                | 31.968               | 49.201                 |
| Index     | 30.840         | 10.155                 | 308.405    | 13.523                | 31.788               | 46.255                 |
| Middle    | 28.735         | 8.552                  | 287.356    | 13.272                | 29.112               | 41.855                 |
| Ring      | 27.709         | 11.145                 | 277.093    | 9.783                 | 27.494               | 44.516                 |
| Little    | 29.651         | 12.421                 | 296.956    | 8.487                 | 29.569               | 50.058                 |
| Index Re  | 25.088         | 9.225                  | 251.793    | 8.581                 | 25.305               | 39.334                 |

4. Discussion

The air-conditioned condition had rapid response compared to room temperature. The maximum time duration in both the conditions has shown a decrease in response repeatability as shown in figure (5). The response time in perception in controlled conditions shows very less time compared to room temperature and perception memory is quick in controlled condition.
Figure 5: The responsive graph of human fingers towards the stimulus. (a) left: 20°C-24°C temperature condition and (b) right: Room temperature condition.
Figure 6: The response graph of the human fingertip in an open environment.

While comparing the results with open environment condition the perception duration was very high, stating the noise insertion in the perception, figure (6). Comparing the total time duration, over repetitive experiments on fingertips the perception time has reduced drastically proving the concept of perception memory. The use of index finger in haptics textural applications can be very useful for rapid recognition. The index finger and 20-24°C temperature condition were identified as an ideal combination for haptics textural applications for preliminary study. A similar experiment can be conducted over any haptic display to identify the best-fit frequencies and intensities for textural applications.

5. Conclusion
The psychophysics experiments have less explored to confirm the use of skin in Haptic applications. The experimental setup discussed comprises of limited stimuli in application but can give required assessment and perception point for haptic application. The use human fingertips due to its dexterity creates or generates multiple applications like gaming, self-driving safety system, user feedback in medical teleoperation and other elite stages of engineering. Performing psychophysics experiments. The psychophysics experiment can vary the perception data and parameters based on
source. The source can be fingertips like the work discussed in the paper or can be with respect to stimuli. A researcher can select any parameter for designing application but for rendering haptics model, the stimulus individual response is required. The proposed work is time saving and can be used as a data set for deep learning algorithm and generate more data value to see the optimum frequency vs intensity for the roughness.

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