Building Haptic Texture Perceptual Space from Real-Life Textured Surfaces Using Multidimensional Scaling

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Abstract

This paper presents an effort towards building a haptic texture perceptual space using multidimensional scaling. In order to build this perceptual space, a psychophysical experiment was carried out with real life surface textures. A large number (84) of textured surfaces were used in the experiment, to ensure that the whole range of daily life haptic interactions are covered. Additionally, a specific aspect of texture perception was not our target, instead the overall haptic perception was evaluated. After carrying out the experiment, multidimensional scaling was applied to the data from experiment. Thus, a three dimensional haptic perceptual space was built as a result. The resulting graph showed distinct groupings of perceptually similar surfaces.

I. INTRODUCTION

Due to the human tactile sensitivity to surface texture, we are able to distinguish wood from rubber, plastic from metal or even one metal from another one. Surface textures can vary between very fine, of the order of micrometers, or very rough, of the order of millimeters. When we touch the surface of an object, we receive information about the surface micro geometry. This information is termed as the perceived surface texture of the object. Perceived surface texture is the perception of the qualities and properties of material surfaces felt through touch.

Many researches have been carried out to build a unified structure where different textural properties are defined to represent various textured surfaces [1]. The aim of such researches is to establish some sort of a coordinate system where different textures can be readily differentiated from one another based on their textural differences. One of the common methods to achieve such a system is the multidimensional scaling [2], where surface textures are located in an n-dimensional space. The distances between different textures represent the differences between the perceived textures. Such a coordinate system is termed as a perceptual space.

There have been several problems in the researches carried out for establishing such a perceptual space. First is the nature of the surfaces being used. The surfaces used in these researches were artificially made, for example, dot surfaces or grating surfaces, etc. [3]. Second is the limited number of surfaces used in the study. Commonly, around 20 surfaces are being used in such studies. This low number was mostly due to the narrow scope of the research. For example, in [4] the authors focused on discrimination of paper and used only ten different surfaces. Similarly, in [5] only 24 car-seat textures were used. The fact. that most researches focused just on a single or a few types of materials, meant that a unified set of surfaces which covered all the daily life haptic interactions was still missing. There has been precious little research where a huge number of different textured surfaces have been used.

In this study, we address the above problems and try to establish a generic and wholesome perceptual space. A total of 84 different real-life textured surfaces are used. These surfaces were chosen in such a way that they cover most of the daily life haptic interactions. Additionally, this study does not look at any particular aspect of haptic interaction, for example, just friction or stiffness etc., instead our focus was to capture the overall haptic feel of the surfaces.

The rest of the paper is organized as follows. Section II provides details about the psychophysical experiment. In section III we analyze the data from the experiment and then explore the results of the experiment. Section IV examines the implications of the results. And finally, Section V concludes the manuscript.

II. PSYCHOPHYSICAL EXPERIMENT

In order to find out the dissimilarities between the real-life textures, a cluster sorting experiment task was performed. It has been proven in [6] that cluster sorting can accurately capture the dissimilarity data between different stimuli. The dissimilarity data obtained from the experiment was used to establish the haptic texture perceptual space.

1) Participants and Stimuli: Ten participants were included in the experiment. The ages of participants were from 23 to 29 years. They reported no disabilities. All participants had little or no expertise regarding the haptics or psychophysical experiments. All the participants were paid for their participation.

A total of 84 different real life textured surfaces were used in the experiment. These surfaces were selected in such a way that they captured the whole range of daily life haptic interactions that happen daily life. The textured surfaces were glued to acrylic plates of size 100*x*100*x*5 mm. The details of all the textured surfaces can be found in Figure 1.

The real life textured surfaces will be referred to as 'samples' from here on for convenience.

2) Procedure: A table was placed in front of the participants. Instructions to the participants were provided on a printed piece of paper. The participants wore a blindfold and earphones to restrict visual and auditory cues, respectively. The experimental setup can be seen in Figure 2.

The experiment was a cluster sorting task similar to the one carried out in [6,7]. The task was to classify all the samples into a predefined number of groups. Every participant conducted five trials. The total number of groups in the five trials were 3, 6, 9, 12, and, 15, respectively. The order of the total number of groups in a given trial was changed to remove ordering bias. The reason behind the variable number of total groups across trials was that lower number of groups per trial ensured a broader classification of the samples, while higher number of groups ensured precise classification. Samples were assigned to a group based on the similarities between their textures. Samples having similar perceived texture were assigned to the same group. The participants were free to use any strategy to explore the samples. After classifying all the samples, the participants were given another chance to check for any errors in classification. In case of an error, they were allowed to assign it to a new group.

Figure 1 Textured samples used in this study.

III. DATA ANALYSIS AND RESULTS

The dissimilarity scores between all the individual samples were used to form a dissimilarity matrix. Score to a pair of samples was assigned based on the total number of groups present in that particular trial.

Afterwards, the scores for all the trials for a given participant were added together. For example, if a pair of samples was grouped together in the trials with total number of groups at 3, 6, and, 9, then the total score for that particular pair would be 3 + 6 + 9 = 18. This

Figure 2 Experimental setup.

data was used to form a similarity matrix for all the participants. Afterwards, the similarity matrix was converted to a dissimilarity matrix and scaled from zero to 1000. Finally, the dissimilarity matrix was averaged across all participants.

Using the average dissimilarity matrix, MDS analysis was performed. In order to select total number of dimensions for perceptual space, Kruskal stress test was conducted. The stress value at dimension three is 0.05, which is considered as fair according to [2]. If we increase the dimensions further, the gain in terms of decrease in error is relatively small as compared to the complexity added due to the extra dimension. Kruskal stress for the first ten dimensions is shown in Figure 3. The three dimensional MDS scatter graph of the perceptual space is shown in Figure 4.

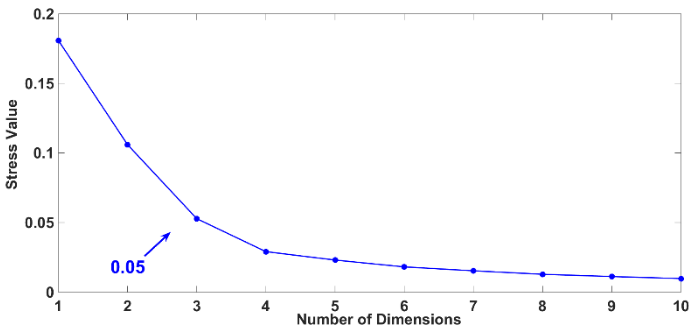

Figure 3 Kruskal stress for the first ten dimensions.

V. DISCUSSION

The MDS scatter graph of the perceptual space, in Figure 4, shows distinctive trends and groupings. It can be seen that perceptually similar samples are clustered together and a very peculiar trend is followed. The overall shape of the graph is in the form of a horse shoe. On the right side of the graph lie the roughest samples and the roughness of the samples gradually decreases as we move along the length of the horse shoe curve. Additionally, the width of the horse shoe curve also follows a trend. The samples located towards the inner side of the horse shoe curve tend to be softer samples as compared to the samples located on the outer side of the horse shoe curve at the same location.

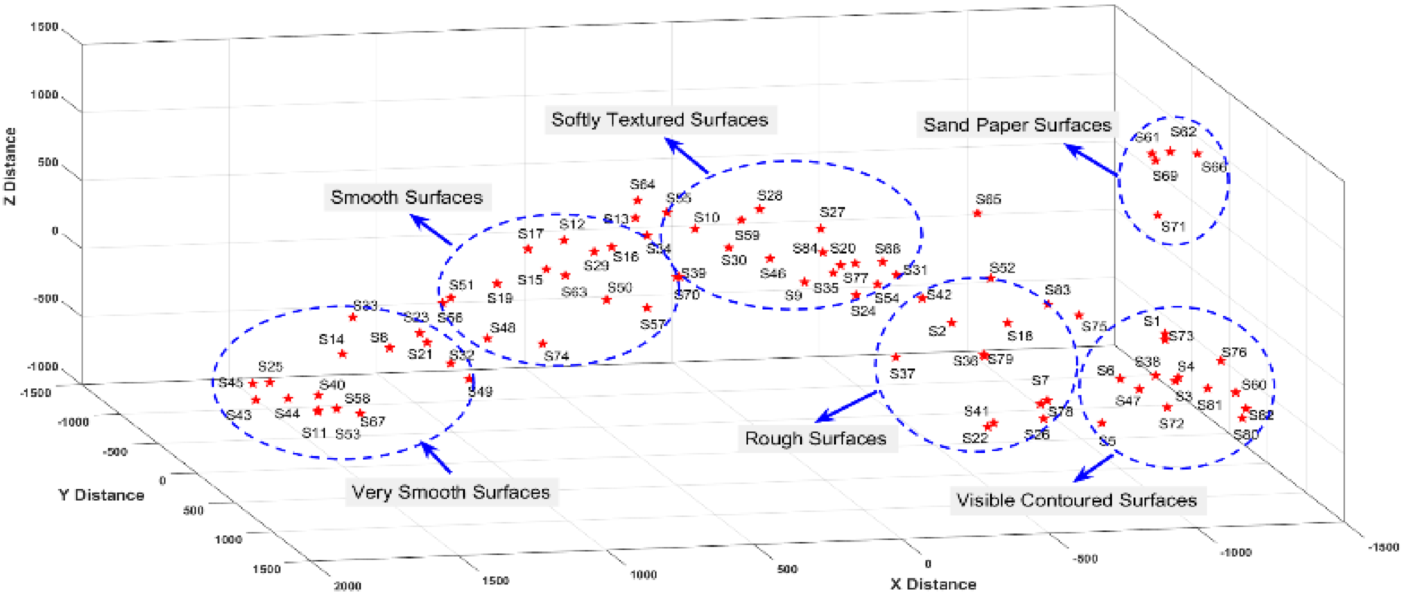

Figure 4 Three dimensional MDS of perceptual space.

Upon a closer inspection it can be seen that the sandpaper samples, which are distinctly different from all other surfaces, are located in a separate group nearby the other rough samples. Apart from this group, the other samples are located along a continuity. On one end, the horse shoe curve starts with the surfaces having visible contours, e.g., model tile, steel and plastic meshes, lined wood etc. These were deemed as the roughest samples by the participants. The rough samples follow the contoured samples along the horse shoe curve. These are the samples which have a rough surface e.g., towel, carpet, highly textured rubber etc. The middle of the horse shoe curve is occupied by the mildly textured surfaces, most of them being fabrics. These samples include, cloth-hard-cover, jeans, fine sand paper etc. The other end of the horse shoe contains the smooth and very smooth surfaces. Smooth surfaces are plain shoe padding, rough paper, hard board etc., while very smooth surfaces are aluminum, acrylic, glossy paper etc.

V. CONCLUSION

In this paper we established a haptic texture perceptual space from real life textured surfaces. A total of 84 surfaces, which are commonly found in daily life, were used to establish the perceptual space. A psychophysical experiment was carried out with these 84 samples using a cluster sorting task. Afterwards, multidimensional scaling was applied and a three dimensional perceptual space was built. All the samples in the perceptual space follow peculiar and distinctive trends.

VI. ACKNOWLEDGEMENT

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