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ScienceDirect

Procedia CIRP 50 (2016) 577 – 582

www.elsevier.com/locate/procedia

26th CIRP Design Conference

Experimental Study on Haptic Perception of Rough Surfaces Using MDS

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Abstract

The knowledge of the customer's perception of a product is a precondition to reduce efforts in product development. This paper presents the results of a study in which stochastic, e.g. leather-like, surfaces have been analyzed in terms of their perceived roughness using Multi-Dimensional-Scaling (MDS). 100 naive, male and female subjects, aged 16-72 were asked to evaluate the roughness of 24 different surfaces. Focus of this study was to analyze the effect of demographic factors such as age and gender on the haptic perception of surface roughness. The correlation between haptic perception and physical parameters (e.g. *Rsm*) is used to predict the haptic perception for rough surfaces for different customer groups.

Peer-review under responsibility of the organizing committee of the 26th CIRP Design Conference

Keywords: Perceived Quality; Roughness; Multidimensional scaling; objectifying subjectiv perception; Haptic;

1. Introduction

Today, consumer products in mature markets (e.g. automobiles, electronics, etc.) often share similar functionalities. Thus, for products to stand out from their respective markets, differentiation via non-functional, product attributes is vital. For this purpose designers focus on a products visual design. At the same time, haptic product attributes are essential for a product’s perception by the customer [1, 2]. To describe the perceived characteristics of a product, the term perceived quality is used. Garvin [3] described the Perceived Quality as a very ambiguous construct, which is influenced by e.g. the image of a company [4], the experiences of the user [5] and the sensory perception of a product before, during and after purchase [6]. Human perception differs from subject to subject, e.g. it is known that the visual perception decreases with age, but it is not yet known if the haptic perception does so as well. [7–9] Therefore, in order to develop customer oriented products, the target group and their ability of haptic perception is of interest for a company.

An approach has been developed by Schmitt et al. [10], which enables manufacturers to break down the holistic impression of a product into descriptors and technical parameters. According to Schmitt et al. a human is able to characterize a product by using descriptors. This is the most detailed level of sensory impression a human is able to describe while evaluating a product. For example the perceived roughness of a surface is a descriptor. To objectify descriptors for the purpose of having a common understanding of the perception, correlations with measurable technical parameters of a product need to be identified.

In order to acquire knowledge about the customers haptic perception and their preferences, a methodology to objectify specific haptic quality characteristics has been developed and applied by the authors Neumann et al. und Frank et al.[11, 12]. This work presents further results of a study in which stochastic, e.g. leather-like, surfaces have been analyzed in terms of their perceived roughness using Multi-Dimensional-Scaling (MDS). Focus of this study was to analyze the effect of demographic factors such as age and gender on the haptic perception of surface roughness.

2. State of Research

A number of papers have discussed the correlation between subjective haptic perception and technical measurements of surfaces in the past. Lederman and Taylor (1972) have conducted several studies on perceived roughness. In one, subjects rated 8 surfaces with different groove widths

Peer-review under responsibility of the organizing committee of the 26th CIRP Design Conference
doi:10.1016/j.procir.2016.05.087

regarding the perception of roughness. Result of the study show that the groove width has an influence on the perception of roughness.[13]

The correlation between measureable surface characteristics and roughness perception has been reviewed by Hollins and Bensmaia (2005, 2007). The result of their studies is, that for relatively coarse surfaces (spatial period >0.2mm), the spatial period is a good predictor for perceived roughness. For finer surfaces (spatial period <0.2mm), they found out that the spatial period is not an optimal predictor. They attribute this difference to the fact, that Pacinian corpuscles of the human skin are responsible for the characterization of these finer surfaces, through the vibration between the surface and the skin. [14, 15]

Several studies on perceived roughness have been conducted by Bergman and Tiest (2007). In one, 96 surfaces were rated by 12 subjects. The correlation coefficient between the evaluation and the physical measurements (e.g. *Ra*, *Rz*) was between 0.4 and 0.8 varying between the subjects. A major result of the study was the observed deviation of the physical roughness from perceived roughness. [16]

The study of Chen et al. (2009) focused on the link between perception and physical characteristics of packaging materials. During one study different packaging materials were rated on different scales, like warm/cold and smooth/rough. The subjects had to give a statement on their hedonic impression (like, do not like, unsure). The result of the study was a determination coefficient of $R^2 \sim 0.6$ between the roughness perception and the physical characteristics (Ra). [17]

First evaluations with MDS were already conducted in the ‘60s. MDS is a method of visualizing similarities and dissimilarities of individual cases of a dataset. MDS evaluates datasets in such a way that objects become spatially arranged so that the distances between the respective objects relate to the imposed similarities/dissimilarities. The greater the distance between objects, the more dissimilar they are. In accordance with the minimum condition the dimension of the representation space should remain as small as possible. The S-Stress is a normalized measure of variance. It is calculated by taking the square root of the normalized squared discrepancies between interpoint distances in the MDS plot and the smoothed distances predicted from the dissimilarities collected through the pairwise comparisons. Yoshida (1968) used MDS for evaluating the similarity of eight objects. He came to the conclusion that the rating of similarity potentially correlates with haptic perception. [18, 19] Hollins et al. (1993) [20] conducted a study with 20 subjects and 17 tactile stimuli using MDS with the result of three dimensions. The first two dimensions are roughness-smoothness and hardness-softness which were found to be robust for the differentiation of surface texture, the third dimension has not been clearly defined by the authors. Bergmann Tiest et al. 2005 [18] evaluated more than 124 different surfaces and identified that haptic perception can be described on a 4 dimensional scale. Two dimensions are identified as roughness and compressibility, the other two dimension are not clearly defined by the authors. For the past few years MDS became more and more important for multivariate and explorative data analysis, to identify scales for the perception. [21]

None of the mentioned studies was able to predict human perception of roughness using physical material parameters to a sufficient degree. In the industry different samples sets (e.g.Rupert Company or Sensotact) for haptic comparison are available but not further evaluated have been done. Furthermore, the influence of the demographic data of the subjects has not been evaluated.

In order to achieve a proper method to connect the technical parameters and the perception of roughness, MDS will be used to identify the scales in this study. Frank et al. (2015) [11] presented the first results of the study, the correlation of vibration signals with the perceived roughness of different surfaces, and compared those with the results of the correlation between the standard roughness values and the perceived roughness. The paper at hands will present an approach to identify the influence of the demographic data of the subjects of the perception of roughness using the dataset from Frank et al. [11] One hypothesis is, e.g. that older subjects perceive different than younger subjects.

3. Methodology

In order to identify the influence of demographic variables on the haptic perception of roughness, four steps are necessary:

1. A set of different materials needs to be identified.
2. The materials need to be analyzed technically in order to receive objective and comparable results.
3. A sensory study needs to be executed including the collection of different demographic information, a pairwise comparison to create the MDS and an evaluation using a ordinal scale.
4. The statistic analysis of the collected data is necessary to correlate the technical data and the haptic perception to identify differences in haptic perception between the demographic groups.

3.1. Selection of materials (Step 1)

The haptic perception depends on the surface structure of a material. [22] Groove- and ridge width as well as the spatial period are distinctive parameters for roughness [13, 23]. Neumann et al. (2015) [12] showed that the surface structure is not relevant, but the *Rsm* value has an impact on the roughness perception of geometrical surfaces. Therefore, 24 samples from natural materials (e.g. leather, wood, paper, sand paper) with different technical parameters were chosen in this study to evaluate transferability of results from the geometrical surfaces (e.g. *Ssk, Sa, Sv, Sku*).

According to Yoshioka et al. (2001) [24] the spatial period (*RSm)* value is one of the most important factors for the perception of roughness. Regarding the *RSm* value, surfaces with smoother and rougher surface structures vary in their haptic perception. In total 24 surfaces (two sets with 12 surfaces) with common materials have been selected as natural surfaces. Further technical parameters (*Ssk, Sa, Sv, Sku*) were evaluated which showed the best correlation with the haptic perception of the geometrical surfaces in former