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Effects of Roughness and Texture on Surface Material Perception in Virtual Environments: The Psychophysics Approach

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ABSTRACT

Introduction:

Through a series of psychophysical experiments, this paper investigates the perceptual difference of roughness and texture on surface materials in immersive Virtual Reality (VR) viewing mode and traditional 2D viewing mode. Visual perception is generally considered as the most reliable perceptual mechanism, which is often studied for exploring and revealing the relationship between cognitive processes and visual information transmission [1]. VR provides users with a strong sense of presence. Furthermore, it utilizes our stereoscopic vision to form a vivid impression of depth. This stereoscopic depth effect thus became a key factor differentiating the experiences in VR and traditional 2D viewing modes. VR technology has been applied to the stage of product design, development, and evaluation. Many studies have confirmed its applicability and effectiveness. Visual evaluation of virtual product models reduces the prototyping cost, which benefits from the versatility and user-friendliness of VR technology [2]. More specifically, the visual appearance of product materials has been proved to effectively affect the usability, satisfaction, and pleasure of product design [3]. In the design process, we rely on visual sensory stimuli to perceive and identify the material, surface quality, or internal state of an object. The outcome of material perception directly affects the results of design evaluation. Nishida [4] pointed out that human perception of materials seems to depend on the image features of materials, which are related to the material properties in the natural visual environment. We also can accurately estimate these material properties according to their visual appearances. Human perception is beyond the scope of strict physics. Psychophysical studies have shown that human material perception does respond to these material characteristics for optical reasons [5]. Realistic material representation is the result of the joint action of the visual system and perceptual process. One of the physical factors affecting the optical reflection characteristics is the roughness of the object's surface. In previous VR studies, the judgment of material properties focused more on estimating the related force feedback. The visual judgment of material properties is much less investigated. If VR ultimately aims to simulate and represent physical reality, the visual experience resulted from how we perceive the real world remain as a central agenda in its development.

The device gap caused by HMD reminds users of the boundary between reality and virtual reality [6]. As mentioned above, however, the material perception influenced by the binocular projection in VR display technology has not received much attention, which may be one of the key factors to developing VR as a design evaluation tool. Each material has specific optical properties, and the way light is reflected along the surface materials will change, and the mode of this change varies with the materials. Furthermore, many materials (such as fabrics, trees, and leather) have specific natural textures characterized by regular incompleteness and random fluctuations [7]. One can

also regard the surface roughness as a special type of textural features, which is highly homogeneous and scatters the incident light uniformly in different directions. Nowadays, visual texture is often used for adding expressive and functional features to a product or its packaging. The simulation of texture in rendering virtual product prototypes is thus important for a comprehensive design evaluation. Previous research on texture perception and material attributes focuses more on the induced tactile feedback but visual judgments, which usually drive design decisions. Psychophysical methods are usually used to evaluate the visual perception and provide practical design guidance, which is preferable to measuring the surface materials perception than subjective rating [8]. Our study utilizes the psychophysics approach and aims to respond to the following questions: (1) Whether users exhibit differences in perceiving the changes of material properties in the traditional 2D viewing mode and VR viewing mode? (2) Whether surface textures have an influence on the perceptual responses identified in those two viewing modes? Our research process thus involves establishing the perceptual scale of material attribute in VR viewing condition through psychophysical methods and analyze the impact of surface textures on material perception in such an immersive viewing environment.

Methods:

The experiment is to measure the difference threshold (Just-Noticeable Difference, JND) of subjects' visual perception on material appearance in traditional 2D and VR viewing modes. The experiment contains two parts to understand whether the surface texture will affect the perceived changes of material properties. The differences between the two viewing modes without texture and the performance results with texture are measured, respectively. In the selection of test materials, the five most common materials for product design evaluation were selected [9]. They include two non-textured material: metal and plastic, and three textured materials: fabric, leather, and wood. The participants were asked to view at the computer screen (2D) and the HMD (VR) to perform the experiment. A total of 100 rendered stimuli were tested with the systematic variations of the roughness parameter. In order to evaluate the ability of subjects to distinguish changes in material properties, the method of adjustment (MoA) were carried out as the psychophysical experiment procedures. During the trials, the participants observed the roughness changes of one selected material, and the same procedure was repeated for the other four materials. The experimenters recorded all JND values that the participants could perceive during the change of material properties. Three participants (2 males and 1 female) participated in the experiment. With a large number of repeated tests, each participant conducted 20 trials for each material respectively. The collected data were then analyzed with both descriptive and inferential statistical methods.

Summary of the Results:

The results show that the participants are more sensitive in visually detecting the change of material properties in VR. Specifically, when comparing the JND values resulted from viewing the same material, more JNDs are found in the VR viewing mode. As for the influence of surface textures, significant difference is found in the identified JNDs with and without textures. The textures also affects the participants' judgment on the changes of roughness. The finding indicates that VR viewing mode seems to provide more perceptibility of material property changes than the traditional viewing mode does. VR may help reveal more material details so as to facilitate design evaluation. In addition, textures, as a common feature for materials, does hinder a user's visual judgment in VR. These results give us and the relevant researchers deeper insights in presenting product materials in a virtual, immersive viewing environment.

KEYWORDS

Material perception; virtual reality; psychophysical study; visual performance

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