別紙４－１（課程博士（英文））

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Department of Computer Science and Engineering	Student ID Number	D123352		Supervisors	Shigeki Nakauchi Michiteru Kitazaki
Applicant's name	Hideki Tamura				

Abstract (Doctor)

Title of Thesis	Distinguishing mirror from glass by the human visual system and its modelling (ヒト視覚系による鏡・ガラス材質の識別とそのモデリング)

Approx. 800 words

The human visual system effortlessly recognizes various objects made from many kinds of materials, such as steel, wood, and plastic. It is easy to infer their physical, functional, and multisensory properties at a glance. This ability, which we use involuntarily, is called "material perception," and is broadly studied in various research fields to understand an important aspect of the visual system. One challenging case is to distinguish a mirror (a perfect specular surface such as polished metal) from glass (a transparent and refractive medium) because their appearances are totally derived from their surroundings. Just changing the surroundings or the object shape dramatically alters the image. Thus, discrimination is hard and complex, and remains poorly understood. In this thesis, we investigated how the visual system distinguishes mirrors from glass materials, and clarified what visual cues contribute to this task.

First, we developed various models (classifiers), which were designed to mimic the visual system and trained to distinguish mirror from glass using over 750,000 images rendered by computer graphics. Then, we compared the performance of humans and the models, including thousands of feedforward neural networks and other models based on "hand-engineered" image features. For randomly selected images, humans and all models performed with high accuracy, and therefore correlated highly with one another. To tease the models apart, a series of human psychophysics defined "diagnostic" images were used to decouple the true material class and the class perceived by humans. We used these images for a large-scale and organized optimization to find a neural network that behaves like humans do. The best network was relatively shallow, and none of the models correlated better than 0.6 with human responses despite an extensive and systematic search. These findings imply the existence of three important gaps between humans and the networks, such as the feedback architecture, training objective, and task generality.

Next, we clarified visual static and dynamic cues that contribute to distinguishing mirror from glass as image and video stimuli, respectively. A new image editing method that we proposed modulates the luminance and color saturation profiles along the trajectory from the object contour to its center. These two kinds of pixel information altered material appearances between the mirror and glass in each other, suggesting that they contributed as static cues. Additionally, as dynamic cues, we found that the motion ratio between the direction of object rotation and its opposite direction determined the extent of material appearance between transparent and specular reflective objects. Our model based on dynamic cues sufficiently identified the different materials.

Moreover, we tested two optical illusions involved in mirror and glass to understand material perception in the aspect of a bridge between a physical property and our perception. We focused on the glare illusion to test the relationship between brightness enhancement and self-luminosity related to specular highlights of the materials. This was robust across stimulus intensities ranging from dark to light with subjective gray, white, and luminous appearances. We also discovered a new illusion in which a rotating glass prism was perceived as being made of a mirror, and simultaneously, its direction of rotation was also misperceived. This finding suggests that the interaction between shape, surface properties, and illumination strongly affects our material and motion judgements.

Even though we only focused on two specific materials that are common and basic, they have entirely different physical properties and enrich our lives. Our approach can expand the possibilities for other materials or optical properties to help us understand the visual system more deeply. Thus, this thesis clarified various aspects of distinguishing mirror from glass and provided further related challenges.