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Naturalness perception of 2.5D prints: elevation and size of prints relation

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Abstract

Naturalness is a complex concept and a number of parameters might impact naturalness perception. In this work, we addressed how the combination of different elevation levels and size of prints impacts naturalness perception of 2.5D prints. The results of a subjective ranking experiment showed that observers perceived 2.5D prints as more natural at higher elevation with larger size of print. Moreover, we observed that elevation seems to be a more dominant parameter than size of the print for observers when evaluating naturalness.

Introduction

Reproduction of material appearance is a very challenging task. To date, there are no tools that can fully reproduce the appearance of complex surfaces [1] and objects [2]. Some of the features of material appearance can be reproduced via 2.5D printing. 2.5D printing builds a surface relief by using multiple layers of inks [3]. In other words, reproductions (i.e., 2.5D prints) will be printed with specific surface elevations. It is important to note that 2.5D prints might not fully represent their original materials in terms of some appearance aspects. One of these aspects can be the naturalness of the 2.5D prints. To reproduce materials with a natural look, the impact of different parameters on the naturalness perception of 2.5D prints needs to be addressed.

The aim of this work was to study how the combination of two parameters (i.e., elevation levels and size of prints) affects the perception of naturalness of 2.5D prints. Elevation was selected because it can be considered as the key attribute that describes the perception of naturalness of 2.5D prints [4]. The size of the print was selected because, for some content, it is assumed that a larger or smaller size can be appropriate to give a natural look. Overall, it is now generally accepted that prints or objects that look natural can be more demanded by customers and therefore, they can be considered of high quality.

This article is organised as follows: we start with reporting existing works on naturalness perception of 2.5D prints; then, we provide a methodology description before presenting results and discussion; last, conclusions and future perspectives are given.

Related works

This section aims to provide relevant information regarding the perception of naturalness of 2.5D prints. In other words, this section is not intended to be a comprehensive review on naturalness perception.

Depending on the application, naturalness can have a specific definition. Binninger [5] mentioned that there is no standard definition of a natural product. As a result, one needs to select the naturalness definition in advance depending on the usage field.

Naturalness has been studied in a variety of fields. As an example, it has been investigated with regard to textile [6], food [7, 8], water [9], wood [10, 11], and 2.5D prints [12, 4, 13], to name a few.

2.5D printing is an important area of enquiry; nonetheless, relatively little is known about naturalness perception of 2.5D prints.

Several recent studies [12, 4, 13] have investigated naturalness perception of 2.5D prints by considering the effects of different parameters such as multiple ink types [13], elevation [4], and the combination of elevation and surface roughness [12]. Observers perceived 2.5D prints of wood images as natural when they were fabricated with matt inks [13]. The results on naturalness perception of various material (wood, glass, metal, and stone) images fabricated in 2.5D showed that elevation affected perception of naturalness and its effect was content specific [12]. Kadyrova et al. [4] suggested optimal elevation to use for 2.5D prints of wood images so that they can be perceived as natural looking. They mentioned that their results were content specific.

The above-described studies, however, had one

fixed size for prints and the size was quite small (i.e., 6.62 × 6.62 cm). Thus, they did not consider the effect of print's size on naturalness perception. We assume that size of the print can impact naturalness perception to some degree. To the best of our knowledge, variation of 2.5D print's size has not been explored before. As a result, investigations on the impact of size of the print alone or in combination with other parameters for naturalness perception of 2.5D prints are needed.

Methodology

We use the definition by Drago et al. [14] for naturalness: degree of similarity between an image and a realistic scene. Thus, the term realistic was used to refer to naturalness. Also, naturalness can be associated with the word - real [15] and some words such as real, unreal, natural, and unnatural were grouped under naturalness [16, 17].

Fifteen wood images (containing content such as wooden floor, wooden wall, wooden wicker, and wooden roof) were used in our work (Figure 1). Colour images and their height maps were reproduced from 3D textures (copyright-free website) [18]. A Gaussian filter (with σ = 4, standard deviation of the Gaussian distribution) was applied to reduce black edges while an intensity adjustment was performed to reach the intended maximum elevation on the height maps. The images (both colour and height maps) had a dimension of 782 × 782 pixels for the print size of 6.62 × 6.62 cm and 1136 × 1136 pixels for the print size of 9.62 × 9.62 cm before being printed. The 2.5D prints were fabricated on a Forex substrate (with 3 mm thickness) with a Canon Arizona flatbed printer (modified Arizona 480 model) using Canon IJC 255 ink.

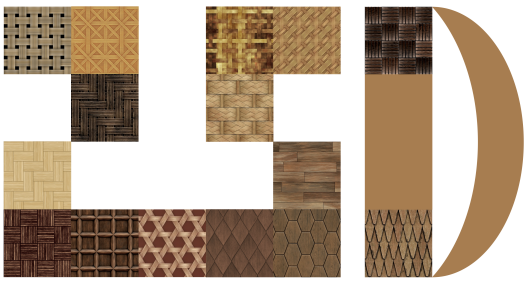

Figure 1: The fifteen images used in our work. They were placed randomly in space to display '2.5D' and thus, two brown shapes in letter 'D' were added for creativity sake.

We had four reproductions per image: two different print sizes at two elevation (i.e., height) levels. The print size of 6.62 × 6.62 cm is further referred to as the smaller size while the print size of 9.62 × 9.62 cm is further referred to as the larger size. Likewise, 0.5 mm is further referred to as lower elevation while 1.0 mm is further referred to as higher elevation. Each print had an additional 0.3 cm on each side of the substrate. It was done for the purpose of observers being able to hold the prints without touching the surface.

The reason for including 0.5 mm elevation was based on the results of Kadyrova et al.[4] where they found that this elevation level is the optimal elevation for naturalness perception of 2.5D prints of wood images. Then, 1.0 mm elevation was included to see the effect of different elevation levels on naturalness perception. We started with a print size of 6.62 × 6.62 cm and then increased size to 9.62 × 9.62 cm so that the prints would fit inside the light booth cabinet. Four reproductions for fifteen images gave sixty 2.5D prints for the visual experiment.

To assess naturalness perception of 2.5D prints, a subjective ranking experiment was conducted in Japan in English. Before starting the experiment, consent was obtained from the observers. Afterwards, the observers had an adaptation period to illumination while reading the instruction. The 2.5D prints were given in a random order inside a light booth cabinet (Macbeth, The Judge II, illumination was around 1294 lux) with simulated daylight (D65). The observers' task was to rank the 2.5D prints from the most to the least realistic representation of wooden wicker/wooden floor/wooden roof/wooden wall and explain why. Therefore, we provided a keyword as a reference (e.g., wooden floor). It was permissible for observers to tilt and move the prints with provided gloves without touching surface of the prints. The distance between the observer's eyes and the prints was around 50 cm. There was no time restriction for the observers to do the experiment. The average duration per observer was about approximately 29 minutes.

Twenty observers (sixteen males and four females) with an average age of around twenty-three years and a standard deviation of around two years were recruited for the experiment. The observers had normal colour vision. A Snellen chart was used to check their visual acuity whereas their colour vision was checked by Ishihara plates. The recruited observers were Japanese except for five observers (one from Georgia, two from China, one from Finland, and one from Germany). Most observers appeared to have experience with material appearance and visual perception.

Results and discussion

The ranked data were converted into Z-scores which are visualised by an error bar plot (Figure 2). A

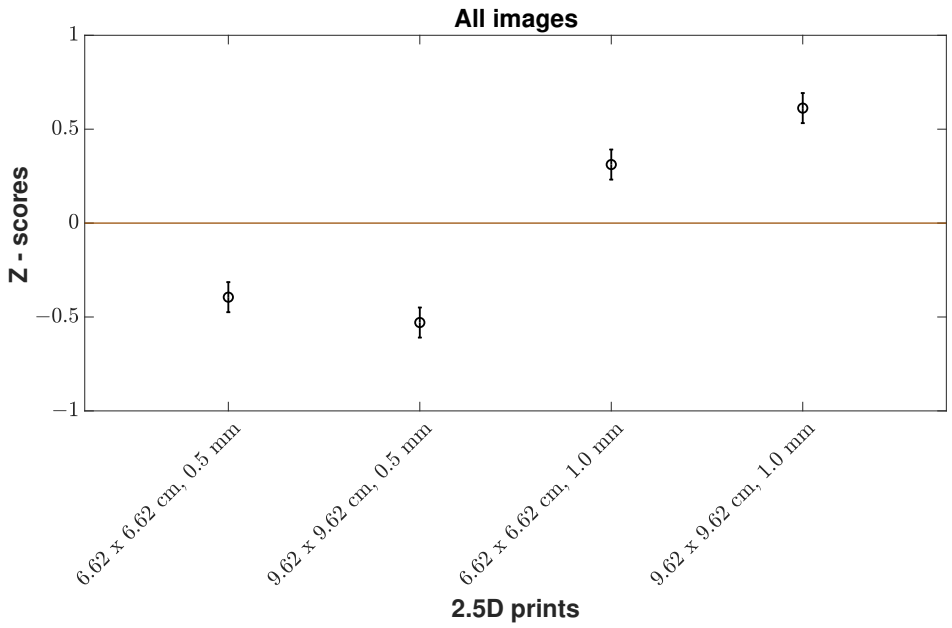

Figure 2: Z-scores of all images by all observers. The mean Z-score values are given with 95% CIs for four reproductions (x-axis).

circle in the centre of the vertical line shows the mean Z-score value. Confidence Intervals (CI) were computed using Equation (1) [19].

$$CI = 1.96 \cdot \frac{\sigma}{\sqrt{N}}, \tag{1}$$

where σ is the standard deviation (in the case of Z-score can be calculated as $1/\sqrt{2}$ [20]) and N is the number of observations. The mean Z-scores $\pm$ CI give a 95% CI.

In Figure 2, we can see that 2.5D prints at 1.0 mm elevation with a size of 9.62 $\times$ 9.62 cm were found as the most natural. Furthermore, we can note that 2.5D prints of both sizes at higher elevation were perceived as more natural than at lower elevation. This can mean that elevation could have primary importance while size of the print could have secondary importance for naturalness perception. However, this assumption needs to be verified in further work.

We can further observe that 2.5D prints at lower elevation were perceived as less natural regardless of size of prints as CIs slightly overlap. Thus, it seems that size of print plays a role at higher elevation in perception of naturalness of 2.5D prints.

To compare, 2.5D prints of wood images were perceived as more natural at 0.5 mm in an experiment conducted by Kadyrova et al. [4] where their prints' size was 6.62 $\times$ 6.62 cm for all the prints. Our results differ from theirs because of the following reasons: first, we had two varying parameters (i.e., elevation and size of print) whereas they varied only elevation; second, our majority of observers were Japanese whereas they had around equal number of Asian and European observers; third, we had more male observers whereas they had more female observers; fourth, average ages of our and their observers were around twenty-three and thirty-five years, respectively; fifth, we had four reproductions per image whereas they had six reproductions per image; and finally, we had minor differences in number of observers and number of images from each other.

Heatmap illustrated in Figure 3 shows how many times each reproduction was selected by all observers as the most, second most, second least, and the least realistic representation of wooden wicker/wooden floor/wooden roof/wooden wall through all individual images' Z-scores. When analysing Z-scores of individual images, we found that 2.5D prints with larger size at higher elevation were selected as the most realistic by the observers in eleven out of fifteen images and they were not selected as the least realistic in any of the images. 2.5D prints at lower elevation with both sizes were not chosen as the most realistic in any of the images. In eight out of fifteen images, 2.5D prints at lower elevation with larger size were chosen as the least realistic by the observers.

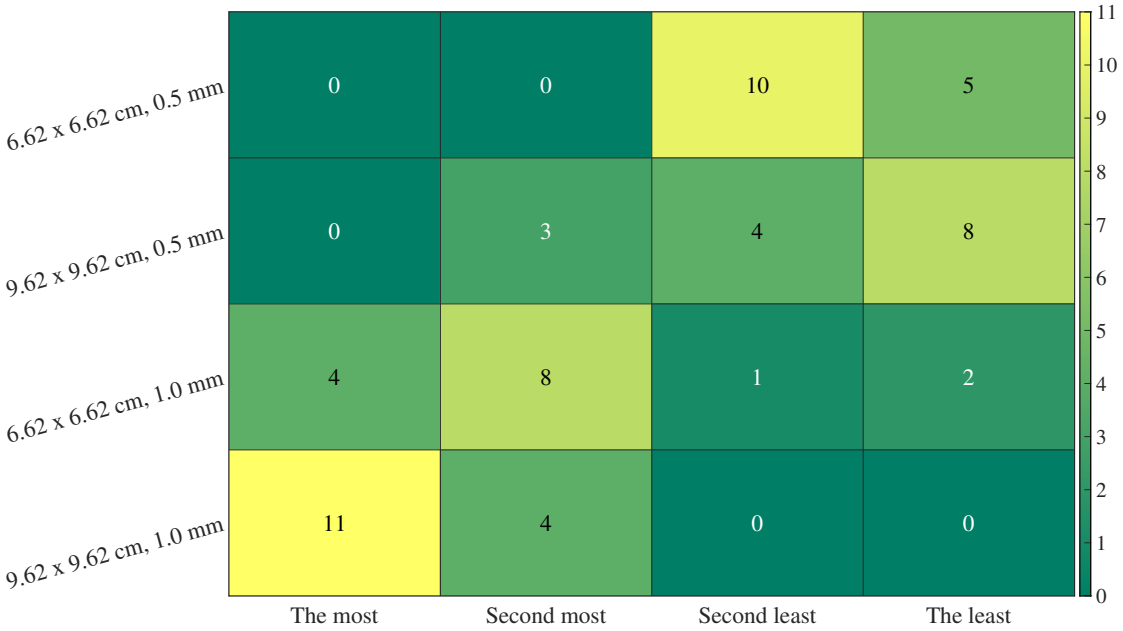

Figure 3: Heatmap of ranks (x-axis) and reproductions (y-axis) based on Z-scores of fifteen individual images.

This again supports that 2.5D prints at higher elevation were perceived as more natural and, in particular, 2.5D prints with larger size at higher elevation were perceived as the most natural in most of the images. We assume that the observers, for some content of images, found 2.5D prints with smaller size as more towards being natural but still at higher elevation. In other words, content of images seems to be affecting on perception of naturalness of 2.5D prints fabricated with different sizes of prints at higher elevation.

Conclusions and future perspectives

We found that observers perceived larger size 2.5D prints at higher elevation as naturally looking. Moreover, elevation seems to be of primary importance compared to the size of the print during naturalness assessment of 2.5D prints.

We assume that our results depend on the specific cultural background, gender, and age of observers. The limitations of this work are as follows: focus was on one content (i.e., wood images), the observers were not native English speakers, there were less female observers, and number of varying parameters was low (i.e., two - elevation and size of print).

These limitations make it difficult to generalise the findings. Therefore, they need to be taken into account in future works. Furthermore, future research will have to look at ways on how collected subjective data (i.e., responses of observers) can be used to work on creating a metric along with other subjective data on 2.5D prints' naturalness perception. This is needed to do an objective assessment of 2.5D prints because it allows to acquire consistent results and it is less resourceful.

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