Roughness vs. Contrast in Natural Textures

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ABSTRACT

We investigate the effect of contrast enhancement on the subjective roughness of visual textures. Our analysis is based on subjective experiments with seventeen images from the CUReT database in three variants: original, synthesized textures, and contrast-enhanced synthesized textures. In Experiment 1, participants were asked to adjust the contrast of a synthesized image so that it became similar in roughness to the original image. A new adaptive procedure that extends the staircase paradigm was used for efficient placement of the stimuli. In Experiment 2, the subjective roughness and the subjective contrast of the original, synthesized, and contrast-enhanced synthesized images were determined using a pairwise comparison paradigm. The results of the two experiments show that although contrast enhancement of a synthesized image results in a similar subjective roughness as the original, the subjective contrast of that image is considerably higher than that of the original image. Future research should give more insights in the interaction between roughness and contrast.

Keywords: Roughness metrics, subjective evaluation, texture analysis/synthesis

1. INTRODUCTION

Visual texture provides valuable information about objects and events in the environment, and can be described along different perceptual dimensions, such as roughness, contrast, and glossiness. However, deriving objective metrics that quantify the perception of such attributes based on low-level image parameters is an open research problem. The focus of this paper is on the visual roughness of natural and synthetic textures and how it relates to the contrast of such textures.

In Ref. 1, van Egmond *et al.* conducted subjective experiments with 49 natural textures from the CUReT database[2,3] and found that humans provide systematic judgments of their visual roughness. Then, in Ref. 4, van Egmond *et al.* proposed an objective metric for visual texture roughness that is equal to the sum of the perceptually weighted variances (energy) of the coefficients of a subband decomposition of the texture image. They found that this simple metric is a good predictor of subjective roughness for a subset of the 49 CUReT textures that consists of mostly uniform non-directional textures. To test the hypothesis that textures with the same subband variances will be perceived as having the same roughness, they synthesized textures with the same subband variances but random distribution of subband coefficients. They then conducted subjective tests to compare the visual roughness of the real and synthesized textures. They found that, even though the appearance of the synthetic textures is not necessarily similar to that of the real textures, there was a high correlation between the subjective ratings and the metric predictions for the two types of textures. However, they also found a systematic deviation between the perceived roughness of the original and synthesized textures. The synthesized textures were systematically perceived as less rough than the corresponding real textures. A subsequent study indicated that enhancing the contrast of the synthesized images affected the subjective roughness.

In this paper we want to explore this relation between contrast variations and their influence on subjective roughness. Could a decrease in contrast explain the systematic deviation between the subjective roughness of original and synthesized images found in van Egmond *et al.*[4]? If so, the decrease in contrast could be compensated with an appropriate level of contrast enhancement, which should result in equal roughness between the original and contrast-enhanced synthesized images. To address this question we used a simple S-curve transformation to increase the contrast of the synthetic textures and conducted subjective tests using a new adaptive procedure for

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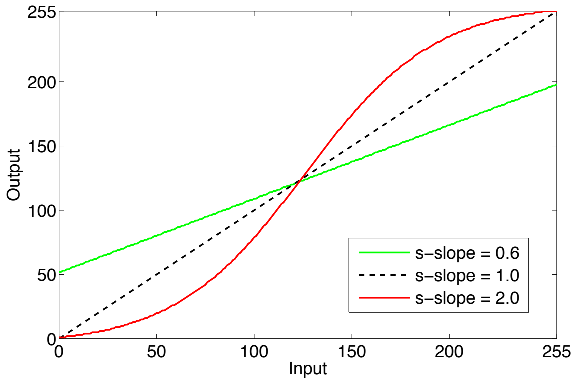

Figure 1. S-curve and linear transformations for generating contrast modified images for CUReT texture #10.

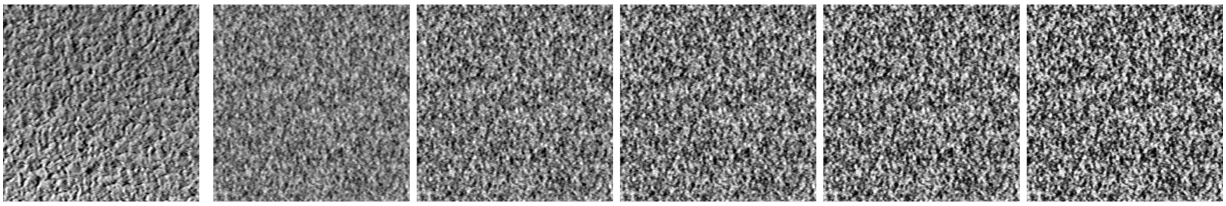

Figure 2. Contrast modifications for CUReT #10: Original, synthetic with $S = 0.8$, $S = 1.0$ (unmodified), $S = 1.2$, $S = 1.4$, and $S = 1.6$.

placing the stimuli in a two-alternative forced choice experiment, whereby the participants were asked to select the rougher of two textures, one original and one synthesized with various amounts of contrast enhancement.

In this paper, we first summarize the results of this experiment, which, along with the detailed description of the new procedure will be presented in a forthcoming paper.[5] Using this new procedure, we found that enhancing the contrast of a synthesized image will indeed result in a similar subjective roughness as for the original image. We then describe another set of subjective experiments, in which participants were asked to evaluate (separately) the roughness and the contrast of (a) the original texture, (b) the synthesized texture, and (c) the contrast-modified texture from the first experiment, that is, the slope value that produces equal roughness with the original texture. We found that equal roughness does not mean equal subjective contrast. In general, the original image has a much lower perceived contrast. Overall, our results indicate that contrast may be a factor in the determination of roughness, but other factors besides contrast affect perceived roughness, such as perceived glossiness,[6–8] relief, and naturalness.

2. ROUGHNESS MATCHING EXPERIMENT

In this section we discuss the first experiment, whereby the physical contrast of the synthesized textures was varied until the perceived roughness matched that of the original textures.

2.1 Method

To test our conjecture that a contrast increase can compensate for the reduced roughness, without changing any other aspects of the images, we used a simple S-curve transformation in the image domain. Figure 1 shows an example of an S-curve for contrast increase, as well as a linear curve for decreasing the contrast. The slope s of the S-curve was the only control parameter for the contrast modification experiment. For compactness and clarity, in the following, we will also refer to s as the *s-slope*. When $s > 1$, the contrast increases, and when $s < 1$ the contrast decreases. When $s = 1$ the texture is unmodified. Figure 2 shows an example of an original texture, and synthesized textures with various degrees of contrast modification.

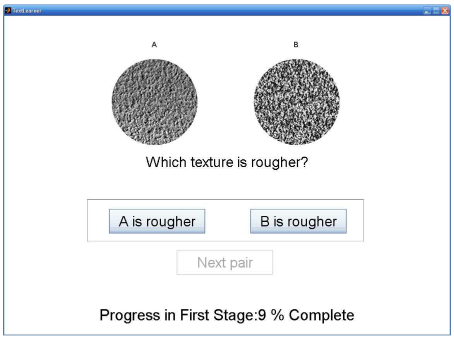

Figure 3. The graphical user interface utilized in conducting the experiment

The goal of the subjective experiment was to find the s-slope value for which the original and the contrast modified synthesized texture have the same perceived roughness. For this, we conducted a two-alternative forced choice experiment, where one of the stimuli was always the original texture and the other was the contrast modified synthesized texture. The subject was asked to pick the rougher texture.

2.2 Apparatus

To be consistent with the experiments of Ref. 1,4, the textures were shown to the participants as circles with 224 pixel diameter, as shown in Figure 3. The participants were seated in front of a computer monitor at a distance of approximately two feet. The participants were asked to click the button under the image that is rougher. The experiment was conducted under typical office lighting conditions using a 20.1 inch Dell 2007WFP Flat Panel Monitor with 1680×1050 resolution and 60 Hz refresh rate. We did not perform any display calibration, but the luminance scale of the display was fairly linear.

2.3 Participants

A total of 12 participants, ten male and two female, took part in the experiment. There was no financial compensation for participation in the experiments. At the beginning of the experiments, participants were asked to sign a consent form and to provide demographical information. The age of the participants ranged from 22 to 57 years old (average 32.5). All participants reported normal or corrected to normal vision.

2.4 Stimuli

We used the 17 original textures from the CUReT database[2,3] that were used in Ref. 4. They correspond to lighting and viewing condition 122, for which the polar angle of the viewing direction was 0.88 radians, the azimuthal angle of the viewing direction was -2.38 radians, the polar angle of the illumination direction was 0.88 radians, and the azimuthal angle of the illumination direction was -0.76 radians. These images were selected to span the first dimension of the multidimensional scale analysis that can be associated with roughness.[4] A 224×224 pixel section of the images was extracted and converted to grayscale. We then used an 8×8 generalized quadrature mirror filter (GQMF) bank[9] to obtain a subband decomposition, and synthesized the textures using white noise in each subband with variance equal to that of the original texture. The original and synthesized texture images are shown in Figure 4.

2.5 Procedure

To familiarize themselves with the experimental setup and the range of stimuli used in the experiment, the participants were given a training session prior to the start of the experiment.

The location of the original and the contrast modified synthesized images was random, and the contrast modifications were presented in random order. In addition, the trials for different original textures were randomly interleaved, so that participants could not guess the pattern of presentation. There was no time limit for the trials, but the participants were encouraged to move at a fast pace.

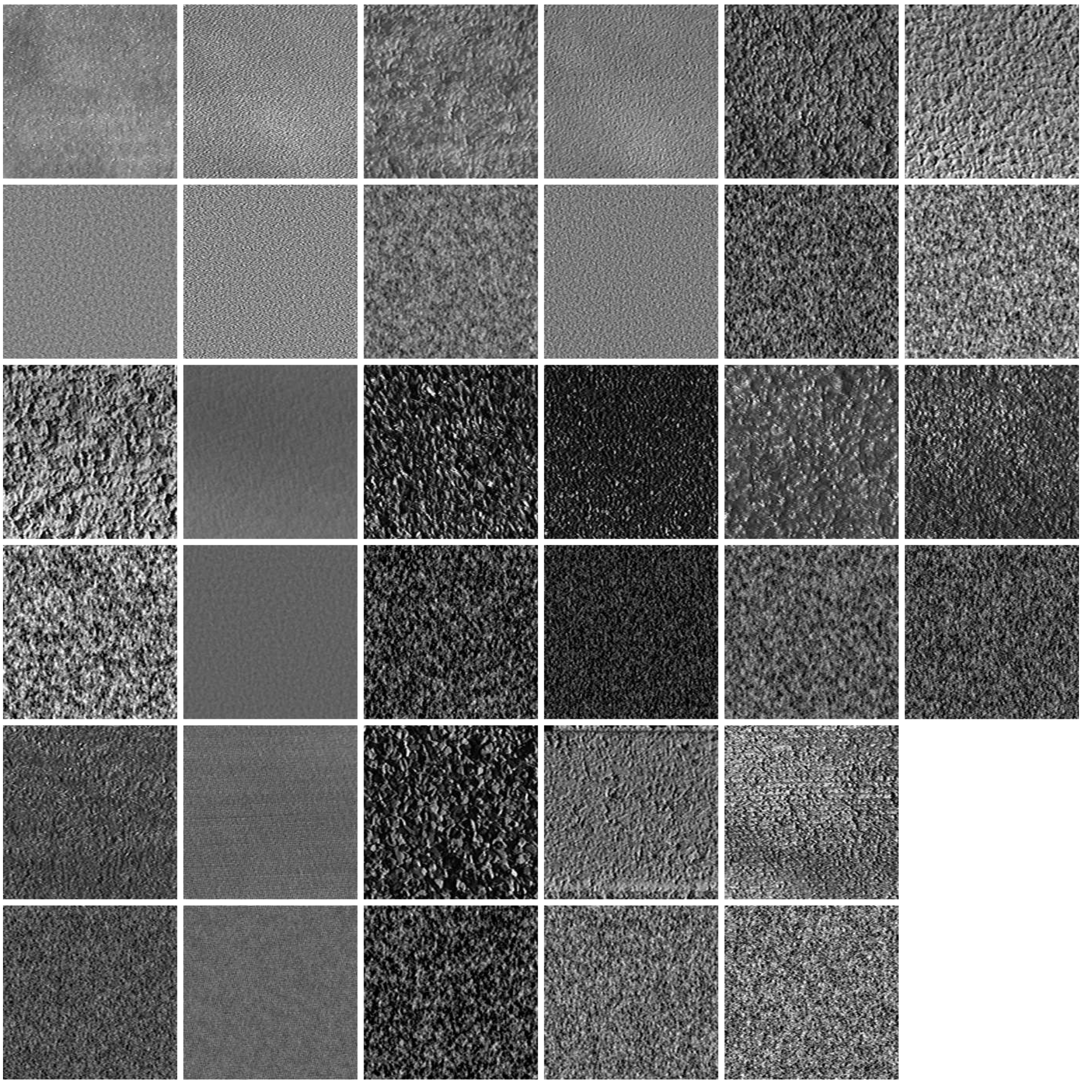

Figure 4. Original and synthesized CUReT textures. First row: original textures 1, 2, 3, 6, 8, 10. Second row: corresponding synthesized textures. Third row: original textures 11, 12, 13, 14, 18, 19. Fourth row: corresponding synthesized textures. Fifth row: original textures 26, 46, 47, 49, 54. Sixth row: corresponding synthesized textures.

To control the number of trials for determining the degree of contrast increase (s-slope) needed to equalize the perceived roughness of the real and synthetic textures, we used a new adaptive procedure for placing the stimuli in the two-alternative forced choice experiment. The adaptive procedure, a detailed description of which will be described in Ref. 5, consists of two stages. The first stage is a single staircase for the initial placement of the stimuli near the 50% point of the psychometric function.[10] The goal of the second stage is to acquire additional points of the psychometric function in the 25% to 75% range, so that a more reliable estimate of the 50% point can be obtained. Figure 5 shows the histograms at the end of the two stages.

2.6 Results

Figure 6 shows the contrast modification (s-slope) of the synthesized image as a function of subjective roughness. It can be seen that the contrast modification increases with an increase of subjective roughness of the

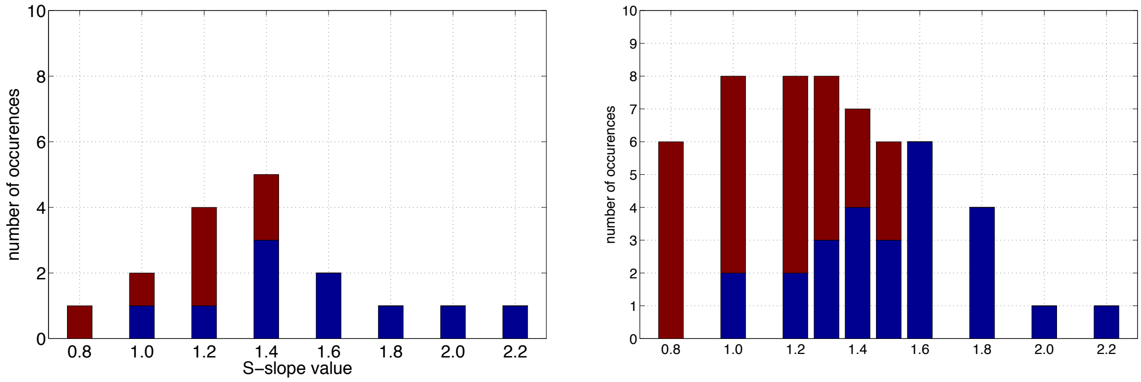

Figure 5. Histogram at the end of the first stage (single staircase) and the second stage of the adaptive procedure for Subject #4, CUReT #3; positive responses shown in blue, negative in red.

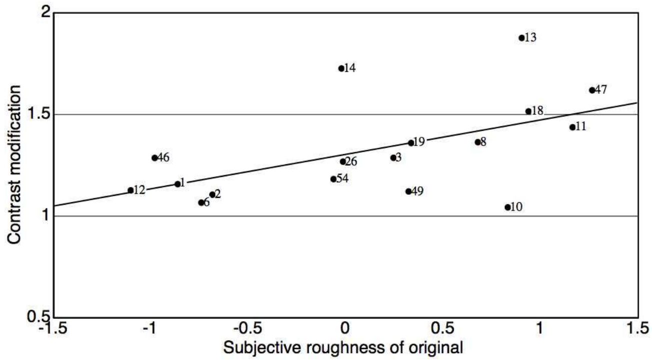

Figure 6. Contrast modification as a function of the roughness of the original (based on the results of Ref. 4. Numbers indicate the CUReT identification.

original image. Note that synthesized images 13 and 14 need a higher contrast modification than the general trend (represented by the images along the regression line), while synthesized texture 10 needs a lower contrast modification than the general trend.

2.7 Discussion

Our results show that by increasing the contrast of a synthesized image, which has been resynthesized based on the subband variance of the original CUReT textures, the subjective roughness increases. In Ref. 4, van Egmond *et al.* showed that the subjective roughness of the original image was systematically higher than that of the synthesized images. In Figure 7, the dashed lines visualize this earlier finding. The upper dashed line represents the original images and the lower dashed line represents the synthesized images. In our first experiment, participants had to judge images in which the contrast was modified such that the participants said the subjective roughness of one image (original) was similar to the other (enhanced contrast image). This general finding is illustrated in Figure 7. The three circles represent the original CUReT image (O), the image synthesized in Ref. 4 without modification (S), and the modified contrast image (C). It can be seen that for the general trend the subjective roughness of the synthesized image with enhanced contrast has become similar to that of the original image.

Although the subjective roughness of the original and synthesized images has become similar, it needs to be determined if the contrast enhancement affected the subjective contrast of the synthesized image and how this relates to the subjective contrast of the original image and the (non-enhanced) synthesized image. Therefore, in the next experiment we will investigate the subjective contrast of the original, synthesized, and contrast enhanced images for the 17 CUReT textures. In addition, we will determine the subjective roughness of these images so as to verify the results of the first experiment.

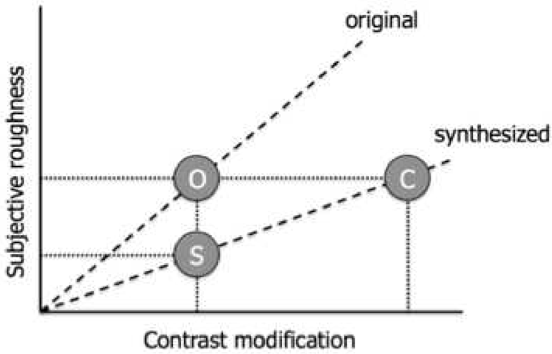

Figure 7. Schematic representation of the overall results. Subjective roughness as a function of contrast modification (s-slope). Circles indicate Original (O), Synthesized (S), Contrast Enhanced (C) images. The dashed lines indicate the findings of Ref. 4.

3. SUBJECTIVE CONTRAST AND ROUGHNESS EXPERIMENT

3.1 Method

In this experiment, we determined subjective judgments of contrast and roughness of the 17 textures from the CUReT database of three variants (original, synthesized, and synthesized with enhanced contrast).

3.2 Participants

Five participants (male; median age 45 years) volunteered for these experiments. The participants were employees and students of the Faculty of Industrial Design Engineering of the Delft University of Technology.

3.3 Stimuli

We used the 17 original images from the CUReT database, the synthesized textures with white noise in each subband with variance equal to that of the original texture (as in Ref. 4 and the first experiment), and the contrast-enhanced synthesized textures (to match the roughness of the original textures, as described in the first experiment). This yielded a total of 51 stimuli.

3.4 Apparatus

The stimuli were presented on an iMac with 20 inch screen, using a special written program in MAX.

3.5 Procedure

A pairwise comparison paradigm was employed. All combinations within one texture (three images, original, synthesized, synthesized contrast-enhanced) were generated. This yields six pairs. A total of 102 pairs resulted for the 17 textures. The order over these 102 pairs was randomized. A participant had to indicate the preferred image before he could proceed to the next pair. Two sessions were used. In the first session a participant had to choose which texture within one pair had the highest contrast. In the second session, a couple of days later, the participant had to choose which texture within one pair was higher in roughness.

3.6 Results

The choices were analyzed using the logit model for paired comparison of Ref. 11, henceforth the BTL-model. This model yielded three scale values for the variants of each texture. Thus, the judgments on the six pairs were reduced to three values (per definition one of the scale values is set to 0).

The scale values for the textures are presented in Table 1. The leftmost column of the table contains the identification numbers for the CUReT textures. Scale values for the Original (O), Synthesized (S), and Contrast-Enhanced (C) for both the subjective contrast and the subjective roughness are presented. In addition,

	Contrast				Roughness			
Texture	O	S	C	Prob O-C	O	S	C	Prob O-C
1	0.00	0	0.41	0.40	1.55	0	1.24	0.58
2	-0.3	0	1.24	0.18	-0.3	0	1.24	0.18
3	0.99	0	3.54	0.07	3.40	0	2.86	0.63
6	0.58	0	1.15	0.36	0.99	0	0.71	0.57
8	0.49	0	2.00	0.18	3.04	0	2.86	0.54
10	-0.5	0	1.51	0.12	0.13	0	-0.13	0.56
11	-0.2	0	1.66	0.13	2.88	0	1.12	0.85
12	0.15	0	1.17	0.27	0.58	0	1.15	0.36
13	2.56	0	3.54	0.27	0.58	0	1.15	0.36
14	3.26	0	2.70	0.64	3.04	0	2.86	0.54
18	17.7	0	19.06	0.20	1.82	0	1.66	0.54
19	2.43	0	3.94	0.18	1.89	0	2.60	0.33
26	17.8	0	18.69	0.29	3.26	0	2.70	0.64
46	-0.2	0	1.66	0.13	1.10	0	1.73	0.35
47	3.26	0	2.70	0.64	3.54	0	2.56	0.73
49	0.00	0	2.20	0.10	1.33	0	0.89	0.61
54	-0.3	0	0.71	0.27	3.54	0	2.56	0.73

NOTE: Prob O-C is the probability that the original image was preferred in contrast or roughness over the synthesized contrast-enhanced image.

Table 1. Subjective contrast and roughness scale values for original (O) CUReT textures, synthesized (S), and synthesized with enhanced contrast (C)

the probability that O has been chosen over C (Prob O-C) is presented in the last column of each subjective measure. The BTL-model is a chance model. Using the obtained scale values, the probability that one stimulus would be chosen over another can be calculated using the following formula:

$$\text{prob}_{O-C} = \frac{\exp^{(S_O - S_C)}}{1 + \exp^{(S_O - S_C)}} \tag{1}$$

It can be readily seen that, for contrast, 80% of the probabilities are smaller than .40. This means that C is mostly chosen over O. For example, for Texture 3, the chance that O will be chosen is 0.07. The Textures 14 and 17 have probabilities higher than 0.50, indicating that only in two cases O is chosen more over C. For subjective roughness, five textures have probabilities below 0.40, six textures have probabilities of approximately 0.50, and six textures have probabilities above 0.60. The latter probability indicates that O is clearly chosen over C. Thus, this means that for the majority of textures the subjective roughness for contrast-enhanced textures is lower or almost similar to the original one.

In order to determine the general trend in these data, scale values were calculated over textures for each subjective measure. Three scale values resulted for the subjective measures of contrast and roughness. In Figure 8 the subjective contrast (left panel) and roughness (right panel) scale values are presented. It can be seen that subjective contrast increases in the following way: synthesized, original, contrast-enhanced. In addition, the values are clearly separated from each other. For the subjective roughness, it appears that the original and contrast-enhanced are rather similar, whereas there is a clear distinction between synthesized images and original/contrast-enhanced images.

3.7 Discussion

Figure 9 provides a schematic summary of our findings. The left panel shows the findings of van Egmond *et al.*[4] in which the subjective roughness of images from the CUReT database was determined. The images were resynthesized on the basis of the subband variance. Although the subjective roughness of the original and

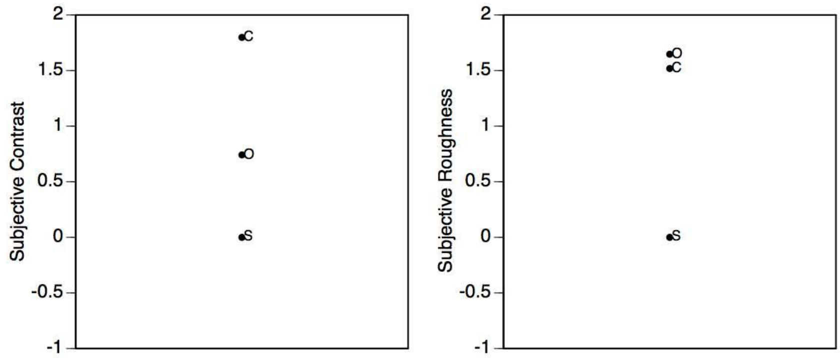

Figure 8. The subjective contrast (left panel) and subjective roughness (right panel) values over all textures. O is original image, S synthesized image, and C enhanced contrast image.

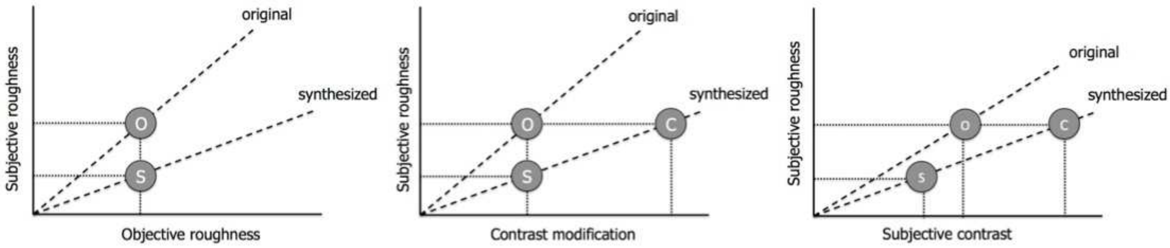

Figure 9. Schematic representations of the three experiments in this. Left panel: Systematic difference in subjective roughness between original and synthesized images according to Ref. 4. Middle panel: Enhanced contrast modification results in a similar subjective roughness. Right panel: Enhanced contrast results in a higher subjective contrast than original but similar roughness.

synthesized images was highly correlated, the synthesized images were rated systematically lower in roughness. The middle panel reflects the findings of Experiment 1 of this paper. Using a modified staircase paradigm, the enhancement of contrast of the synthesized images resulted in a similar subjective roughness. The right panel reflects the findings of Experiment 2. The subjective roughness of the synthesized images with enhanced contrast from Experiment 1 was very similar to that of the original image. However, the subjective contrast of the synthesized images with enhanced contrast was higher than that of the subjective contrast of the original image. Thus, although contrast influences the subjective roughness the relationship is not linear. Future research will try to disentangle subjective roughness and subjective contrast.

Our main finding is that enhancing contrast of a synthesized image will result in a similar subjective roughness as for the original image. This means that contrast may be a factor in our determination of roughness. The other finding is that the contrast needs to be adjusted such that the subjective contrast of the enhanced contrast image is much higher than that of the original image. This means that one has to overcompensate contrast when adjusting it for subjective roughness, which is an indication that other factors besides contrast affect perceived roughness, such as perceived glossiness,[6–8] relief, and naturalness. In fact, there are strong indications that there are close links between all these perceptual attributes, and there is a need for a better understanding of these connections.

4. ACKNOWLEDGMENTS

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