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P-37: Just Noticeable Difference of Image Attributes for Natural Images

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Abstract
To model the relative importance of the image quality attributes white level, black level, color saturation and contour rendering, they need to be varied all to a perceptually equal extent. The just noticeable difference (JND) of each attribute can be used for this. These JNDs are well known for specific test patterns, but not for natural image content. In this paper, we describe several experiments to determine the relationship between the JNDs and the averaged image characteristics.

1. Introduction
To improve existing or develop new display systems, it would be very helpful to understand the relation between overall perceived image quality and its attributes. Some earlier qualitative research [1] in this area has revealed that, for non-expert viewers when assessing image quality of high-end TVs, the four most important attributes are brightness, contrast, color rendering and sharpness.

To determine the relative importance of these four attributes to the overall image quality, the attributes should be independently varied to a comparable extent. One main problem, however, is that these four most important attributes are not independent. As a consequence, for this research they are replaced by four more independent attributes, being black level (BL), white level (WL), chroma (CS) and contour rendering (CR), which largely cover the perception of the original attributes brightness, contrast, color rendering and sharpness. The second problem is to find a way to vary these attributes to a perceived equal extent. For this, the use of just noticeable differences (JNDs) was proposed in [2].

In literature [3, 4], the JND for luminance and chromaticity has been reported, but for specific test patterns and measured under critical viewing conditions. Also the visibility threshold for sharpness differences has been reported more specifically for text, being the most critical image material [5, 6]. This literature, however, does not indicate the visibility threshold for luminance, chromaticity and sharpness differences in case of natural image material viewed under standard ambient illumination (with e.g. the television application at home in mind). In our former study [2], the JND of chroma (CS), black level (BL), white level (WL) and contour rendering (CR) was measured for natural image material under 20 lux ambient illumination, using the paired comparison method. As a result, the JNDs were determined with a relatively low accuracy, and in some cases, the stimuli used were not homogeneously distributed around the threshold. In this paper, the JNDs are determined again, but now more accurately using the staircase method. Additionally, image content dependency is evaluated by using images with different luminance and chromaticity distributions.

2. Experimental setup
This research consisted of three experiments. In the first experiment, critical image material was selected for each attribute: i.e. an extremely dark image (“night”) to measure the JND for the BL, an extremely bright image (“polar bear”) for the WL and an extremely colorful image (“house”) for the CS. These images are shown in figure 1(a). In the second experiment, four images with intermediate gray levels and being less colorful were used. These images are shown in figure 1(b). These images were also used to evaluate whether our former results [5, 6] on the JND of CR for text were confirmed for natural image content. In the third experiment, six images with mainly a variation in their chroma were used. These images are shown in figure 1(c). The last two images of figure 1(c) (i.e. “toy” and “toy_half”) have the same content, but for “toy_half” the chroma of the whole image was...
halved in order to evaluate the effect of chroma on the JND for CS directly.

To change WL and BL, each pixel in the original image was processed in xyY space. BL was changed according to \( Y' = Y_{\text{max}} - \alpha_b(Y_{\text{max}} - Y) \), and WL according to \( Y' = \alpha_w Y \), where \( \alpha_b \) and \( \alpha_w \) determined the step size with which the luminance was varied. For CS, a variation in chromaticity was simulated changing the value of C (in the LCH color space) per pixel by subtracting the \( \Delta C \) corresponding to a fixed \( \Delta E_{94} \). For CR, the contour was blurred by using the same Gaussian convolution filter as in [5, 6].

In all three experiments the JND was measured with the staircase method [7]. Care was taken that the final step size was sufficiently small, such that the JNDs were determined with a high accuracy. For WL, \( \alpha_w \) was varied between 0.80 and 0.99, and for BL, \( \alpha_b \) was varied between 0.994 and 1, for both cases in 25 steps. For the CS the step size was 0.1 expressed in \( \Delta E_{94} \) with only a change in chroma. For CR, the step size was \( \sigma=0.4 \) expressed in terms of the width (in pixel units) of a Gaussian convolution filter. The procedure of the staircase method is shown in figure 2 as an illustration. All trials started at the maximum distortion level well above threshold, and the distortion was decreased with a step size of 4 units until the subject couldn’t perceive the distortion anymore. Then, the distortion level was increased until it became visible again. After that the level was decreased and the procedure was repeated, until after four reversals, the step size was halved. After another six reversals, the step size was halved once more, and the staircase stopped after six reversals with a step size of 1 unit. The reversal points were recorded automatically, and the JND was calculated as the average over the last 8 reversals (indicated as the stars in figure 2).

The JNDs were determined against the original image, always shown as a reference. Both images, i.e. the distorted and original one, were displayed simultaneously on a 19-inch Philips LCD monitor with a resolution of 1280*1024. The maximum and minimum luminance of the LCD monitor was 238 cd/m² and 0.33 cd/m², respectively. The user interface is shown in figure 3. The original image was shown on the left side of the panel, and the distorted image on the right side. Luminance asymmetry between the left and right half of the display was compensated for with software. The influence of a remaining slight asymmetry in color was avoided by horizontally flipping the distorted image with respect to the original image. The ambient illumination was about 20 lux measured on the screen in the direction perpendicular to the viewer, and about 18 lux measured on the background. The viewing distance was 4 times the height of the screen, viz. about 1.2m.

3. Results
From the perception experiments, the JNDs of BL, WL, CS and CR were calculated as the mean over all subjects. It should be noted that the JNDs of BL and WL are expressed in luminance.

3.1 Black level & White level
The JNDs of BL and WL measured in experiments 1 and 2 are summarized in table 1. It indicates that for the images used in experiment 1, the JND of BL is 0.19 cd/m² and that of WL 16.8 cd/m². These values are larger than the ones obtained with the paired comparison method, as reported in [2]. In that paper, the JND of BL was 0.1 cd/m² and that of WL was around 10 cd/m². For the images with intermediate gray levels used in experiment 2, both the JND of BL and WL become substantially larger: the JND of BL is in the order of 1.2 cd/m², and the JND of WL around 57 cd/m².
To explore the effect of image content on the JNDs of BL and WL, the averaged output luminance on the screen for each image was calculated, and these values are added to table 1. The relation between the JND of BL per image and the averaged image luminance is plotted in figure 4. As expected, images with a higher averaged luminance have a larger JND value for the BL. Similarly, the JND of WL per image is plotted as a function of the averaged image luminance in figure 5. Here, one would expect that images with a lower averaged luminance exhibit a higher JND of WL. This roughly seems to be the case in figure 5: the image with the largest averaged luminance clearly has a lower JND threshold than the four images with more intermediate gray levels. Among the latter four images, however, the tendency is rather opposite: a higher JND for a higher averaged image luminance.

![Figure 5 Relation between JND of WL and averaged luminance of the displayed image](image)

3.2 Contour rendering
The JND of CR is determined for the four natural images used in experiment 2 (see figure 1(b)). As shown in table 1, the JND only slightly depends on image content and varies between 0.50 and 0.57. These data are consistent with the results reported in [2], but are slightly higher than those reported in [6] for text. It should, however, be noted that the results obtained in [6] were measured on a CRT, whereas the results here were measured on a LCD. Taking into account the difference in pixel size between both monitors explains the difference in JND. The visual angle corresponding to $\sigma = 0.4$ (expressed in pixel units) on the CRT is 1.33', which is close to the visual angle of 1.28' corresponding to $\sigma = 0.5$ on the LCD.

3.3 Chroma
In literature [2], a JND of 0.50 in terms of $\Delta E_{94}$ for CS is reported. As shown in table 1, the JND for CS obtained in experiment 1 for a more colorful image is 0.85 in terms of $\Delta E_{94}$. For the less colorful images in experiment 2 the JND for CS is equal to or lower than this value, which is against our expectations. To study the effect of image content on the JND of CS further, experiment 3 was performed with another 6 images, which were again more colorful and showed prominent differences in their chroma histogram. The resulting JND values are given in table 2. In this table, roughly two groups of images can be distinguished: one group with a JND of about 0.7 and one group with a JND around 1 (both expressed in $\Delta E_{94}$). The main difference between these two groups of images is their degree of details in the colored information. The first three images with a JND of around 1 exhibit a high level of detail, whereas the last three images with a JND of around 0.7 have larger homogeneously colored areas, which we will call homochromatic areas. Hence, table 2 indicates that the size of the homochromatic area affects the JND for CS. Within each group of images, there still is a slight tendency of a larger JND for a higher averaged chroma, which contradicts our expectations. This becomes especially clear in the comparison between the images “toy” and “half toy”. In the latter case, the chroma of the whole image is halved, and with that the JND becomes smaller instead of larger.

Since the effect of image chroma on JND of CS is not fully understood yet, we first limited ourselves to model the relationship between the level of detail in an image and the JND of CS. To do so, we calculated for each image the local difference in normalized gray level (0–1) of a pixel with all its neighbors in a 3x3 pixel surrounding, averaged over all pixels in the image. It should be clear that a higher value for this metric corresponds to a more detailed image. The relation between this metric and the JND of CS is shown in figure 6. It shows that more detailed images have a higher JND than the more homogeneous ones, which indicates that it is easier to use uniform areas to assess the JND of CS.

![Figure 6 Relation between JND of CS and mean gray difference](image)

4. Discussions and conclusions
In order to be able to model the relative importance of various image quality attributes at a later stage, their JNDs for natural image content were first studied in this paper. Compared to the paired comparison method used in our former study [2], we here used the staircase method, applying smaller steps of distortion, and as such determining the JNDs with a higher accuracy. The influence of image content was studied by selecting images with various gray level and chromaticity distributions.

The JNDs of BL and WL are significantly affected by the averaged luminance of the image content. The JND of BL steadily increases with the averaged image luminance. The JND of WL is also substantially lower for a mainly white image than for images with a more intermediate luminance, but in general this trend is less obvious.

The JND of CR is found to correspond to a visual angle of 1.3’ (half width of a Gaussian filter) for text as well as for natural
image content. Within – of course – certain ranges, the image content dependency seems to be small for this JND.

The JND of CS seems to be more affected by the degree of detail in the image than by its averaged chroma. A preliminary model shows an increase in the JND of CS for more detailed images. The additional expected effect of the image chroma is not understood yet.

In general, these results provide some first insights in the image characteristics affecting the JNDs. But, clearly more experimental evidence with a larger variation in image content is needed to develop a general model on the effect of image content on JND.

5. Acknowledgements
The project is supported by Philips Research Laboratories. The authors would also like to express their thanks to the volunteers who participated in the subjective evaluation.

6. References

Table 1 Average value and (standard deviation) of JND for all attributes in experiments 1 & 2

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Image</th>
<th>Averaged luminance (cd/m²)</th>
<th>JND of BL (cd/m²)</th>
<th>JND of WL (cd/m²)</th>
<th>JND of CR (σ)</th>
<th>JND of CS (ΔE94)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>6.72</td>
<td>0.19 (0.14)*</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td></td>
<td>159.22</td>
<td>--</td>
<td>1.08 (1.28)</td>
<td>30.8 (21.6)</td>
<td>0.85 (0.48)*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>51.96</td>
<td>1.52 (1.60)</td>
<td>38.1 (21.5)</td>
<td>0.52 (0.17)</td>
<td>0.84 (0.56)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>59.76</td>
<td>1.29 (1.33)</td>
<td>41.9 (23.0)</td>
<td>0.50 (0.17)</td>
<td>0.60 (0.43)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>70.69</td>
<td>34.4 (26.3)</td>
<td>41.5 (21.5)</td>
<td>0.53 (0.19)</td>
<td>0.62 (0.47)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>60.02</td>
<td>0.57 (0.21)</td>
<td>41.9 (23.0)</td>
<td>0.57 (0.21)</td>
<td>0.70 (0.47)</td>
</tr>
</tbody>
</table>

The number of participants was 11 for the left three images indicated with a (*), and 20 for the other images.

Table 2 Average value and (standard deviation) of JND for CS in experiment 3

<table>
<thead>
<tr>
<th>Image</th>
<th>Chroma histogram</th>
<th>JND of CS (ΔE94)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>x 10¹⁰</td>
<td>1.17 (0.67)</td>
</tr>
<tr>
<td></td>
<td>2 x 10⁶</td>
<td>2.00 (0.65)</td>
</tr>
<tr>
<td></td>
<td>2 x 10⁷</td>
<td>1.17 (0.61)</td>
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<tr>
<td></td>
<td>2 x 10⁸</td>
<td>0.79 (0.56)</td>
</tr>
<tr>
<td></td>
<td>2 x 10⁹</td>
<td>0.77 (0.45)</td>
</tr>
<tr>
<td></td>
<td>2 x 10¹⁰</td>
<td>0.64 (0.49)</td>
</tr>
</tbody>
</table>

The number of participants was 20 for all images.