https://doi.org/10.2352/EI.2026.38.10.HVEI-236

Method and findings for Determining the Just Noticeable Difference (JND) for an Image Sharpness Metric

Tero Vuori, Jukka-Pekka Raunio, and Ari Partinen
Microsoft, Finland

ABSTRACT

In camera product development, where the goal is to achieve the best possible image quality and user experience, it is necessary to use both objective and subjective test methods. Both methods have their own advantages and disadvantages. The goal of this study is to bring these methods closer together and help the user of objective tests understand the meaning of the test result for the end user. Objective image quality measures are fast and efficient. They form the basis for, for example, camera product comparisons daily basis. The comparison of two camera products is completed quickly and the result is reliable and repeatable. Based on the results provided by the measure, it is possible to rank any camera products easily. However, how big is the noticeable difference between two products for a user if such an objective measure is used? When is the difference significant? Or does the user notice the measured difference at all? In this study, we wanted to get answers to these questions for the acutance measure which is used daily basis. We conducted numerous subjective tests in a controlled lab with carefully chosen stimuli. To include the effect of image content in the study, we used both an image with a lot of detail and a test image with a lot of flat areas and little detail as test samples. Based on these subjective results, we calculated the corresponding Just Noticeable Difference (JND) values for our acutance measure. Results were slightly different to image content with flat areas versus image content with a lot of detail. This study presents methods and results for finding JND values for an objective acutance measure that can be more broadly generalized to all objective acutance measures and, in terms of the method, to all objective measures.

Keywords: Camera, image quality, objective image quality, subjective image quality, perception, just-noticeable-difference, JND, acutance, sharpness.

1. INTRODUCTION

1.1 Background

In any camera product development team or any team that compares imaging products, it is a typical scenario to use an objective acutance measure to get the idea of quality differences between measured products and put them to preference order or benchmark them. Devices under study can easily score based on acutance metric result. However, even if preference order is easy to get, there is a question of how this order appears in a real use case situation. It can be assumed that bigger differences are also perceived bigger, but are differences over all products visible at all or do they all appear similar to the end user?

There are some educated opinions in the image quality industry about the relationship between the acutance measurement and subjective perception and preference. For example, Imatest gives very good industrial information on acutance and refers to CPIQ as JND estimates that the JND of the acutance meter would be about 0.02 units [10]. However, there does not seem to be much empirical or methodological information available in the literature on the relationship between the acutance and subjective perception of sharpness or quality. In this study, we wanted to answer this question thoroughly and scientifically. We wanted to put our objective metric on a subjective scale so that we could always assess the significance of the acutance difference between two products, also from the observer's perspective in perceived sharpness. The appropriate concept and tool for this seemed to be the just-noticeable -difference so JND.

1.2 Just-Noticeable-Difference (JND)

Just-noticeable-difference (JND) is a statistical concept for defining observable differences, for example in psychology and other sciences that study human activity and behavior [1,2,3]. Being a statistical concept means that JND is not an absolute value but has variation in population and depends on perceptual factors but also motivation and situation. In our case, we understand that JND for acutance perception has variation and as in image quality perception usually has also acutance perception dependencies on image content, so whether image has high spatial frequency, so lot of details ("very busy image") versus an image with large smooth areas where perception of acutance is difficult or unnecessary for image evaluation.

The theory of JND is based on the Weber's - Fechner's law. Weber conducted experiments on tactile sensitivity [4, pp. 46-57], weight perception [4, pp. 82-85], and sound perception [4, pp. 41-43]. Weber's law states that the perception of differences in stimuli is proportional to the magnitude of the stimuli [4, pp. 143]. This means that for our study, the defined JND is only valid within the specified, experimentally validated range, not across the entire theoretical scale of acutance or sharpness. On the other hand, we also limit the study to the range within which normal consumer products under test operate, so we can assume that the JND is somewhat constant over this relatively small range of sharpness scale.

1.3 Measuring sharpness as an objective acutance measurement

Image sharpness is a fundamental attribute of visual quality. In a camera system, sharpness is primarily influenced by two factors: the sensor resolution and the optical quality of the lens. In optical engineering, sharpness is commonly evaluated using the Modulation Transfer Function (MTF) [5,6], which describes the ability of a lens to reproduce contrast at different spatial frequencies. The MTF curve represents values between 0 and 1, with a value of 1 indicating perfect contrast reproduction. In an ideal case, an optical system would maintain a value of 1 across all frequencies. However, in practice, performance is limited by diffraction, causing the MTF curve to decline at higher spatial frequencies, even for high-quality lenses. When considering the entire imaging system, including the finite pixel size of the image sensor, it is more appropriate to refer to the Spatial Frequency Response (SFR) rather than the optical MTF alone. The SFR accounts for both optical and sensor-related factors, providing a more comprehensive characterization of image sharpness.

In this study, we measured image sharpness objectively using acutance metric [7] in which the Spatial Frequency Response (SFR) curve [6] was applied. The calculation of the acutance metric is based on the ISO standard [7]. The acutance metric also incorporates viewing conditions, such as the viewing distance and the physical size of the display on which the image is observed. This makes acutance particularly valuable in studies that aim to understand the relationship between objective sharpness metrics and perceptual thresholds, such as the Just Noticeable Difference (JND). The parameters used in the acutance calculation were adjusted to the subjective test arrangements in this study (see chapter 2.3).

2. METHOD

2.1 Test people

A test group consisted of 30 people who were educated to understand the concept of sharpness, detail and acutance. Their age varied between 25 – 55, and they had normal or corrected to normal vision.

2.2 Test sample creation

The starting point is a very high-quality image taken in bright light of a typical image quality laboratory test target, which contains both objective test objects and subjective details. It is therefore a so-called multipurpose target. The image was taken with a high-quality system camera in such a way that it represents the sharpest possible image in original resolution 7286x5464 pixels. Even though the starting point is as sharp as possible, it is not zero point for blur or so called origin to the sharpness scale but our sharpness scale is still interval scale as usual in image quality and more common in psychometric studies [3]: sharpness scale does not have a specific zero, logical minimum or maximum points in measurable scale. The levels of blur were selected so that they start from as sharp image as possible and go with small steps through the meaningful sharpness scale. The original very sharp image was then processed to blur it in very small steps. The steps absolutely had to be much smaller than one JND, otherwise our test would not reach the level of the actual JND. These levels were measured using the acutance metric and we included in the study a slightly wider scale than is typically the case for products that are tested on that acutance scale, so that we could be sure to include the entire sharpness scale of the products being measured.

The images were blurred by convolving each image pixel with the two-dimensional gaussian kernel. This method is called gaussian blur and several image processing libraries are providing such functionality by default. The kernel standard deviation (= sigma) was varying between 0.33 and 4.15 pixels in this study. The gaussian blur was selected because it has nicely behaving frequency response and it does not cause any ringing artifacts to blurred image [8].

To avoid any scaling of the test images in the subjective test, we wanted to show images in their native resolution without any up- or downscaling. This means that we needed to select an area from the original multipurpose test chart image (7286x5464). By selecting smaller area of the image, we also wanted to guide test people to evaluate certain content at the time, so we wanted to limit the dispersion in the results due to the influence of image content and partly that we wanted the test subjects to focus on a point in the image for which sharpness is a very important variable. The test crops used in the subjective test of the original very sharp image are shown in Figure 2.1 for the first test image content (very detailed feathers content) and for the second test image content (smooth). The pair comparison test view to a test person is shown in Figure 2.2 for “smooth” image content and in Figure 2.3 for the “feathers” test image content.

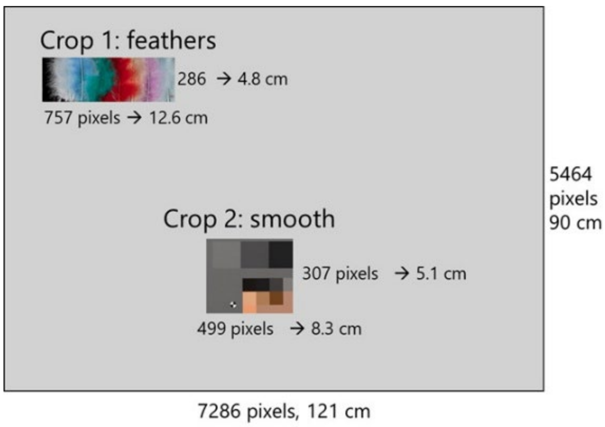

Figure 2.1. Test image contents as part of the original test target image (7286x5464): crop 1: “feathers” (757x286), and crop2: “smooth” (499x307). By cropping the original image, we guided test people to concentrate on specific content at the time, and we were able to show images in the Eizo display in original resolution without any up or downscaling. That means that with the Eizo resolution, our original theoretical image height (used in the objective acutance calculations) is 90 centimeters.

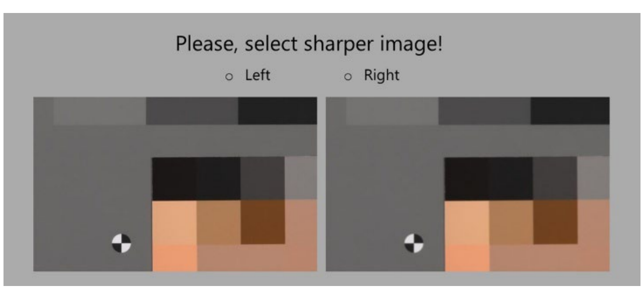

Figure 2.2. The display view to a test person in the pair comparison study with the “smooth” test image content.

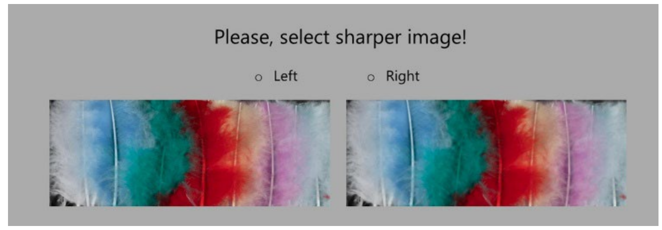

Figure 2.3. The display view to a test person in the pair comparison study with the “feathers” test image content.

2.3 Subjective test arrangements

Testing was conducted in a laboratory environment where interior was middle gray, illumination about 100 lux, and test display was adjusted to the illumination. The test display used was the Eizo ColorEdge CG319X 31.1" with resolution 4096 x 2160 (4K). The test display background during the test was middle gray and images were shown in the middle of the display. As images were crops of a larger multipurpose test chart, their resolution was relatively small (757x286 and 499x307), so they used display only partly. Images were shown in their full resolution, so no scaling was done. Viewing this way, so no downscaling at all, means that these results are best applicable to large display size viewing conditions. Theoretical original image height applied to the objective acutance calculation is 90 cm, which comes from the pixel size of the Eizo display and the original test image height (5464 pixels). That image height and the viewing distance 50 cm were applied as parameters to the acutance calculation algorithm.

People were shown to the test room at the beginning of the test. Their viewing distance was guided around 50 cm, no head rest or similar was used, so the viewing distance varied naturally a bit. 50 cm was also the estimated distance used in the objective acutance calculation. All the pairs in the test were compared in a random order; all the images were randomized inside the contents but all images in the same content were shown consecutively. Also, the order of image contents shown was randomized. The test question for each pair was “Which image appears sharper?”. The answers were collected automatically to a result file which was then combined with other result files in the result analysis.

2.4 JND calculations

In this study, we apply so called 50%-JNDs which are sometimes also called 75%-JNDs in literature (Keelan 2002, pp. 40). This means that any difference between two samples is exactly one JND when 75% of the test people report the difference to one direction. When difference is two JNDs, it is reported by 93% of the population (Keelan 2002, pp. 40). JND is statistical by nature, so JND is a point in a typical psychometric cumulative distribution function.

2.5 Objective measurements calculations

In this study we are using acutance for objective sharpness metric. Acutance is defined as the integrated product of the camera system SFR curve and a CSF-weighting function that models human sensitivity to different spatial frequencies.

$$\text{Acutance} = \int_0^{f_{max}} SFR(f)CSF(f)df$$

Where SFR(f) is the camera's spectral response function (= SFR calculated from the image), and CSF(f) is a contrast sensitivity function. Unit of frequency is typically cycles per degree (cpd), related to image size, viewing distance, and resolution. The acutance metric fits well with our study because the viewing conditions - screen resolution, screen size, and viewing distance - were well defined in subjective test arrangements.

3. RESULTS

3.1 Sharpness and Acutance JND

Figure 3.1 presents the cumulative JND values as a function of Gaussian blur (σ in pixels). The x-axis shows the applied blur level, while the y-axis indicates the cumulative JNDs. The curves demonstrate a nearly linear increase of JND with blur, reflecting good consistency between subjective and objective sharpness metrics. As expected, the perceived differences in sharpness (cumulative JNDs) are larger for feathers content compared to smooth content. This suggests that detecting sharpness changes is more challenging in smooth images lacking fine details, whereas in textured content, such as feathers, differences between blur levels are more perceptible.

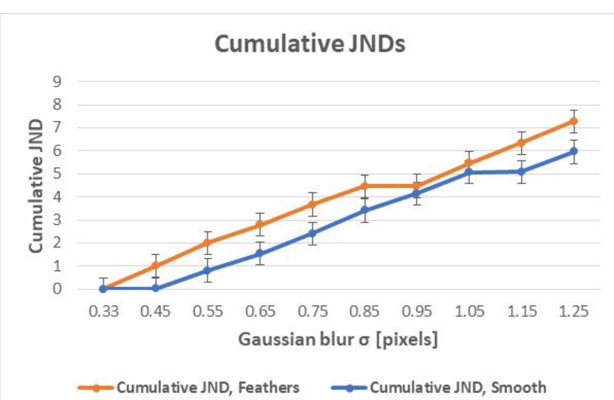

Figure 3.1. The cumulative JNDs for Feathers and Smooth contents.

Figure 3.2 shows the acutance values corresponding to a single JND (JND = 1) across different Gaussian blur levels. The x-axis represents the applied blur strength (σ in pixels), while the y-axis shows the acutance change per JND. The results indicate that one JND corresponds to approximately 0.02 acutance units, with this value remaining relatively stable across blur levels. Both feathers and smooth content exhibit similar trends, although small variations are visible. These findings suggest that the perceptual threshold for sharpness differences is consistent across image types and largely independent of the applied blur.

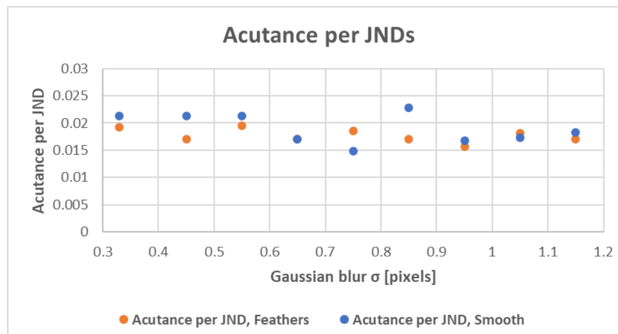

Figure 3.2. The acutance value for one JND for Feathers and Smooth contents. The results show that one JND corresponds to approximately 0.02 acutance units.

4. CONCLUSION

This study investigated the relationship between subjective sharpness perception and objective acutance measure, with the goal of linking objective test results more directly to end-user experience. By conducting controlled subjective experiments and calculating Just Noticeable Differences (JNDs) for acutance, we established that one JND corresponds to about 0.02 acutance units. Considering that acutance values lie within the range [0,1], this corresponds to a perceptual difference of approximately 2% in acutance units. This result is in congruence with the previous industrial understanding [10] but now also empirically tested methodologically reported. The results further revealed that image content has an effect on perception: sharpness differences were more easily detected in detailed textures compared to smooth regions, so JND being slightly bigger when test image content is less detailed but can still be rounded to about 2 percent. These findings provide a practical interpretation of objective acutance measurements and clarify when differences reported by such metrics are likely to be noticeable to users. The presented methodology can be extended to other objective image quality measures, helping to strengthen the connection between technical test results and human perception in camera product evaluation.

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Author Biography

Tero Vuori holds a master's degree in psychology from the University of Helsinki, Finland. He has also studied computer science, linguistics and statistics. Tero has worked on subjective image quality in camera technology at, among others, Nokia, Intel and Microsoft for 20+ years. Tero has been involved in developing many image quality testing standards and camera industry processes.

Jukka-Pekka Raunio earned a PhD in 2015, focusing on the use of computer vision systems in industrial factory environments. After academia, he transitioned to the mobile camera industry (AAC and Microsoft), where he has built strong expertise in image quality evaluation and AI-based imaging algorithms.

Ari Partinen holds a master's degree in engineering from Aalto University, Finland. Ari has worked for leading camera companies such as Apple and Microsoft in several leadership positions in camera development. Ari is a passionate photographer and a camera technology professional.