CONTRIBUTION TO T1 STANDARDS PROJECT

STANDARDS PROJECT: Analog Interface Performance Specifications for Digital Video Teleconferencing/Video Telephony Service (T1Q1-12) and Advanced Television (T1A1-07)

TITLE: Detection and Discrimination of Blur in Edges and Lines

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SOURCE: AT&T

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DATE: October 27, 1997

DISTRIBUTION: Working Group T1A1.5

ABSTRACT:
Several recent contributions to T1A1.5 describe objective video quality assessment methods that model properties of the human visual system (HVS). The results of psychophysical experiments are one key source of knowledge about HVS properties.
This accompanying paper by Hamerly and Dvorak describes one such experiment to determine observer sensitivity to blur in edges and lines. It finds that human discrimination between different levels of blur is more acute than between blurred and non-blurred features. This raises several points that are pertinent to video quality assessment system specification, including:

1. Different methods or models may be necessary for quantification of perceptible blur levels and sub-detection levels. In either case, the blur detection threshold must be known.
2. This result helps explain why different video digital sampling format densities (e.g. ITU-R Rec 601, CIF, QCIF) with their inherent ability to render edges and lines may be easily distinguished at usual viewing distances.
3. Other spatial impairments may exhibit different detection and discrimination HVS sensitivities, and this would influence the specification of performance assessment methods.

The acute HVS sensitivity to different levels of blur should be directly accounted for in any measurement method adopted under this project.

Detection and discrimination of blur in edges and lines

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Received July 28, 1980; revised manuscript received October 28, 1980

Observer-sensitivity to edge and line blur was examined by measuring just-noticeable differences of blur as a function of contrast, edge-profile shape, line width, and for white lines on black and black lines on white. At high luminance ratios, observers can discriminate a blurred image from an unblurred image when the edge-transition width (10-90% luminance points) is of the order of 25 sec of arc. However, when both images are blurred, they can be discriminated when they differ by as little as 5-10 sec of arc.

INTRODUCTION

The sharpness of images has been the subject of considerable research[1-12] culminating in a number of algorithms[3,8-11] that attempt to relate observers' ratings of sharpness to physical properties of the image. For images containing large numbers of edges, the general inference is that an increase in sharpness occurs for an increase in contrast, a decrease in the transition width of the edge, or both. However, there is little indication about what is required to ensure that the image is not unsharp. Further, there has been little distinction made between the terms unsharp and blurred.

The purpose of the work reported herein is to determine whether the image appears blurred and under what conditions blur can be discriminated between two images. For example, if two images are identical in every other respect, by how much must the edge-transition width of one of the images increase before that image can be correctly identified as more blurred? Or, having the same edge transitions, by what amount can the contrast of one be reduced before it appears as more blurred? The practical significance of studying blur is in establishing performance specifications for imaging systems operating under fixed constraints: For example, given a maximum contrast achievable by a system, the blur threshold indicates the lower limit of edge-transition width required for a nonblurred image at that contrast.

DEFINITIONS

Figure 1 shows a sectioned three-dimensional view of an edge image. The maximum luminance is assumed to have a normalized value of 1.0; the lower luminance[13] value is I_r. Hereafter, I_r, will be referred to as the luminance ratio of the image. This is one of the ways of defining luminance ratios, all definitions of which are arbitrary. Note that high-luminance-ratio images are low contrast; low-luminance-ratio images are high contrast. For the types of edges considered, the luminance of the normal edge profile decreases monotonically according to one of the following functional forms:

Gaussian $\quad I(x) = I_r + (1 - I_r)e^{-(x/w)^2}$

Exponential $\quad I(x) = I_r + (1 - I_r)e^{-(x/w)}$

Linear
$$I(x) = \begin{cases} 1 & x < 0 \\ 1 - (1 - I_r)(x/w) & 0 \le x \le w \\ I_r & x > w \end{cases}$$

The edge-transition width w is defined to be the spatial distance over which the edge luminance goes from 10% to 90% of its range. For the Gaussian, exponential, and linear profiles the transition widths are 1.36, 2.19, and 0.8 w, respectively. This is an arbitrary way of defining transition width that is applicable to each of the cases considered.

METHODS

Apparatus

Edge and line images were displayed on a well-regulated, high-resolution cathode-ray tube (CRT) (P45 blue-white phosphor), which subtended a viewing angle of approximately 2° at a viewing distance of 2.6 m (5.0 m was used for the linewidth study). Maximum luminance was 25.5 fl. Surrounding the CRT was a 10° × 13° surround illuminated to obtain 25.5 fl and that had approximately the same color. The subjects viewed the images binocularly with natural pupils.

The CRT was driven in a noninterlaced mode with a frame rate of 60 Hz. The display consisted of 512 × 512 pixels with the luminance value of each pixel quantized to eight bits; the interpixel spacing was approximately three times the spot width resulting in a modulation transfer function of nearly 1.0 at the spatial-frequency limit of 130 cycles/degree. The CRT video source was a 262-kbyte memory that stored one full

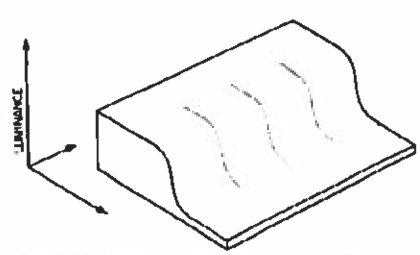

Fig. 1. Sectioned view of an edge image.

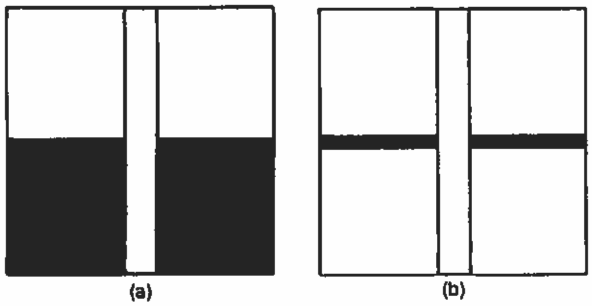

Fig. 2. (a) Stimulus configuration for edge experiments, (b) Stimulus configuration for line experiments.

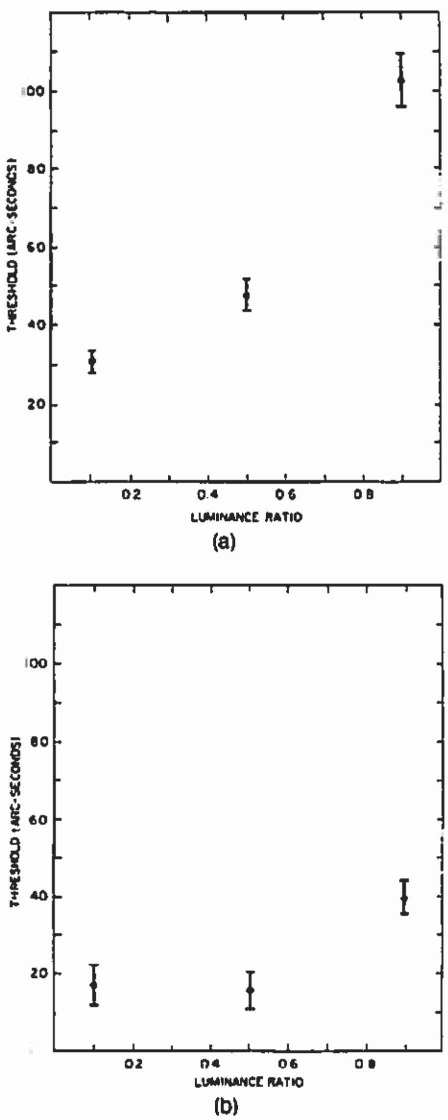

Fig. 3. (a) Blur thresholds for Gaussian edges as a function of luminance ratio. Observer JH. Maximum luminance, 25.5 fl. (b) Blur thresholds for Gaussian edges as a function of luminance ratio. Observer CD. Maximum luminance, 25.5 fl.

frame of an image; an addressable video look-up table allowed pointwise luminance transformations to permit phosphor gamma correction. The host processor and peripherals were used to generate, process, and store images and to control the psychophysical experiment.

Images

The luminance ratio of the edge image was 0.1, 0.5, or 0.9. For the line images, two cases were presented, white lines on a gray-black background or gray-black lines on a white background. The luminance ratios of the lines were 0.01, 0.03, 0.1, 0.5, or 0.9. Figures 2(a) and 2(b) show the experimental field as viewed by the subject. In all cases, an unblurred or blurred horizontal edge or line was presented in the center of one half of the field, with a more blurred but otherwise identical image in the other half field. The transitions in luminance of the edge profiles were Gaussian, exponential, or linear; the lines had symmetric edge profiles that were Gaussian. The two half fields were separated by a vertical strip 0.2° wide.

Subjects

Both authors served as subjects and had normal or corrected vision. Both had considerable experience making psychophysical judgments.

Experimental Procedure

The experimental method used to determine just-noticeable differences consisted of a two-alternative forced-choice staircase procedure. The subject viewed one image randomly presented in one of the two half fields and a second image in the other half field; both fields were presented simultaneously. The observer was instructed to select the field with the lesser amount of blur. If the observer correctly identified the less blurred image on more than 75% of a series of trials (typically four), the transition width was reduced; if the response was correct in fewer than 75% of the trials, the transition width was increased; if the response was correct on exactly 75% of the trials, the width was not changed. The amount of increase or decrease was halved after a given nurhber of reversals of increase or decrease (typically one). When the amount of increase or decrease was less than a prescribed criterion level, a fixed number of trials (40-60) was then presented and the just-noticeable difference threshold calculated from this fixed set of trials. In the context of these experiments, the just noticeable difference (JND), is the edge-transition width for

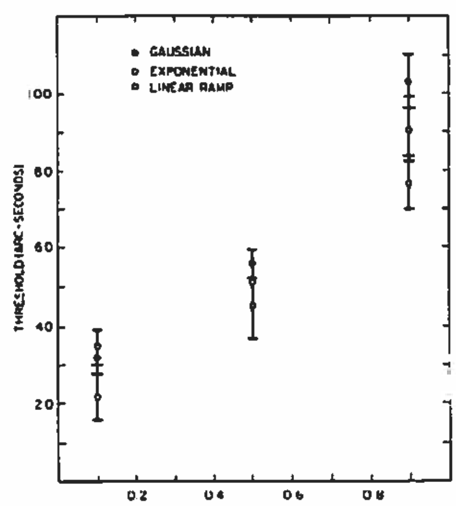

Fig. 4. Blur thresholds for different edge profiles as a function of luminance ratio. Observer JH. Filled circles are for Gaussian, open circles for exponential, and squares for linear ramp-profile data. Maximum luminance, 25.5 fl.

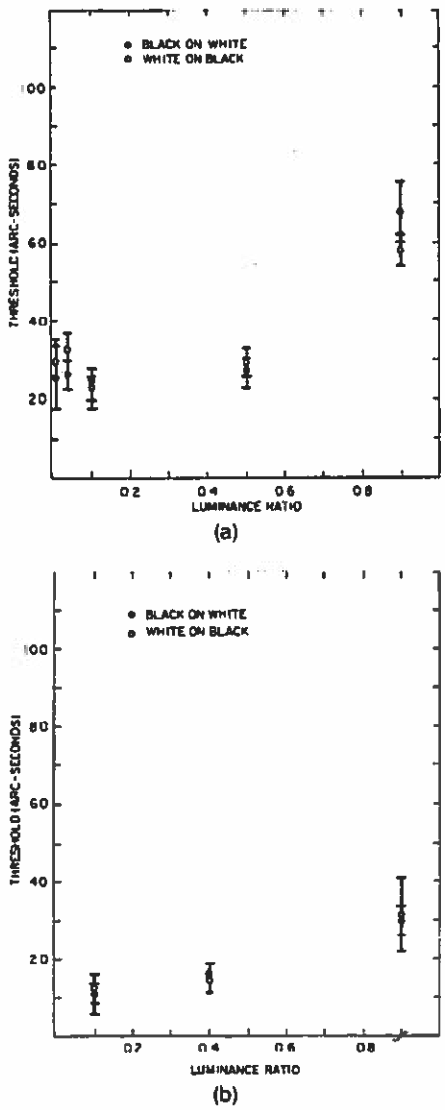

Fig. 5. (a) Blur thresholds for 150-arc-sec width lines as a function of luminance ratio. Observer JH. Open circles represent whitelines-on-black, filled circles black-lines-on-white data. Maximum luminance, 25.5 fl. (b) Blur thresholds for 150-arc-sec-width lines as a function of luminance ratio. Observer CD. Open circles represent white-lines-on-black, filled circles black-lines-on-white data. Maximum luminance, 25.5 fl.

which an observer, on 75% of a series of trials, correctly identified the less blurred of two images. The first JND, or threshold, is the edge-transition width for which an observer correctly identified the image on 75% of the trials when the companion image had an edge-transition width of zero (i.e., the edge was unblurred).

RESULTS

Figures 3(a) and 3(b) are plots of the just-detectable Gaussian edge blur as a function of the luminance ratio of the edge for the two subjects. All thresholds are expressed as the width of the 10-90% transition of the edge profile. Note that the threshold is of the order of 25 sec of arc at luminance ratios near zero and increases at higher luminance ratios.

Plotted in Fig. 4 are threshold data for Gaussian, exponential, and linear ramp edges as a function of luminance ratio for one subject; vertical bars indicate plus or minus one standard deviation. As in Fig. 3, there is an increase in threshold for increasing luminance ratio (i.e., decreasing contrast). There does not appear to be any difference in the thresholds for the different profiles; for the data shown, the hypothesis that the thresholds are the same is supported.

The data in Figs. 5(a) and 5(b) are just-detectable values of blur for lines whose width is 150 sec of arc; the edge profiles of both sides of the line are Gaussian. Open circles represent white lines on black thresholds; filled circles represent black lines on white. The hypothesis that the thresholds are the same is supported. Note that the thresholds for luminance ratios near zero (i.e., those with high-contrast images) are approximately 25 arc sec, similar to those obtained for edges.

Figure 6 is a plot of the blur thresholds for a 0.1 luminance ratio line as a function of linewidth for one observer. Note that the threshold does not change by a large amount with linewidth, even down to linewidths approaching 25 arc sec. At very narrow linewidths, approximately 50 arc sec and less, the observer reported detecting a change in contrast, rather than apparent blur; for this reason, most of these data are not included here.

Figures 7 and 8 are plots of the just-noticeable differences of edge and line blur, respectively, for the two subjects at two luminance ratios. For both edge and lines, the JND's are largest for unblurred images and decrease rapidly once the image is blurred.

DISCUSSION

The data indicate that the observers can discriminate a blurred from an unblurred high-contrast image when the edge-transition width is of the order of 25 sec of arc; at lower contrasts, the threshold for detection increased. A low- or high-contrast image at or below its respective blur threshold does not appear blurred, nor does one appear more blurred than the other. However, the higher-contrast image usually appears sharper in a direct comparison, as predicted by the

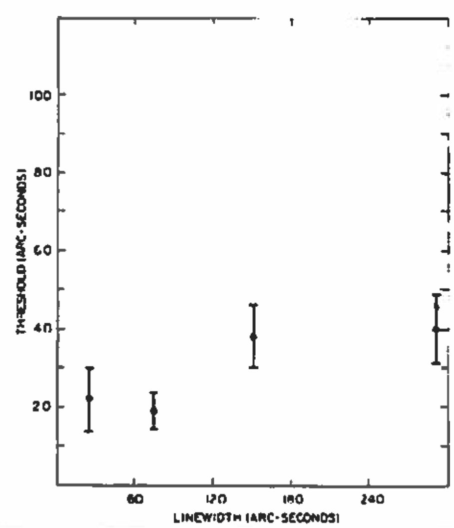

Fig. 6. Blur threshold for lines as a function of linewidth. Observer JH. Lines have Gaussian edge profiles and a luminance ratio of 0.1. Maximum luminance, 25.5 fl.

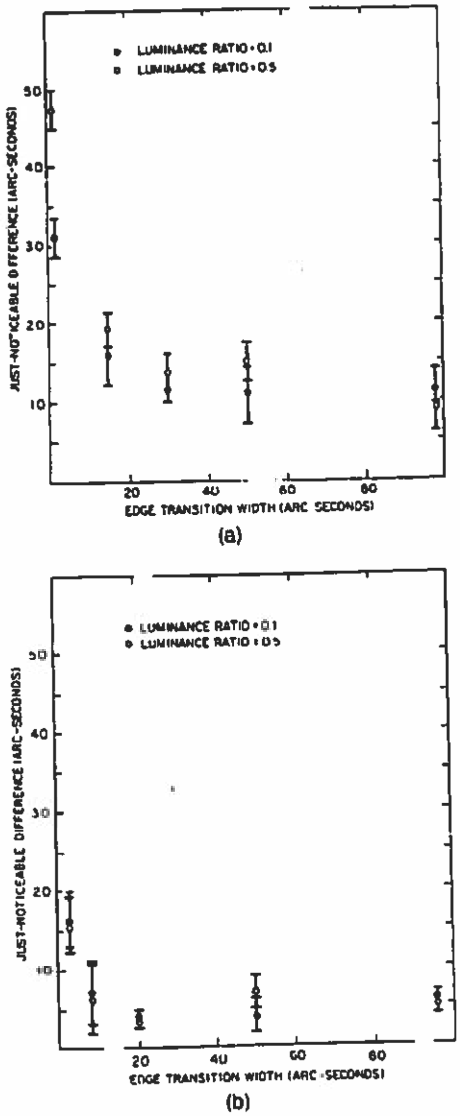

Fig. 7. (a) Edge-blur just-noticeable differences as a function of edge-transition width. Observer JH. Open circles represent luminance ratio of 0.5, filled circles a luminance ratio of 0.1. Maximum luminance, 25.5 fl. (b) Edge-blur just noticeable differences as a function of edge-transition width. Observer CD. Open circles represent luminance ratio of 0.5, filled circles a luminance ratio of 0.1. Maximum luminance, 25.5 fl.

sharpness algorithms, such as acutance[3] system modulation transfer[9] and cascaded modulation transferal acutance, and the subjective quality factor.[10] These algorithms derate the lower contrast image not only for its lower contrast but also for its greater transition width. However, by failing to incorporate a sharpness or blur threshold, algorithm predictions would lead to the possibly false conclusion that the lowercontrast image could be made to appear sharper by reducing edge-transition widths well below threshold. Hence it is suggested that algorithmic models of sharpness incorporate observer thresholds to indicate more accurately psychophysical response to near-threshold images.

Observers were found to be more sensitive to a difference in blur when each of the images was above blur threshold; discrimination thresholds were approximately 5-10 sec of arc. This increase in discrimination performance with blur is in

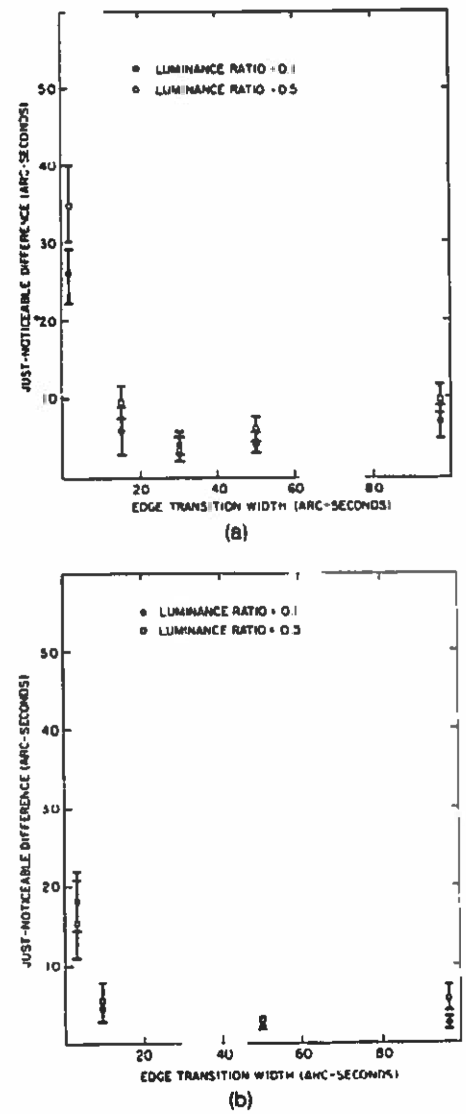

Fig. 8. (a) Line-blur just-noticeable differences as a function of edge-transition width. Observer JH. Open circles represent a luminance ratio of 0.5, filled circles a luminance ratio of 0.1. Maximum luminance, 25.5 fl. (b) Line-blur just-noticeable differences as a function of edge transition width. Observer CD. Open circles represent a luminance ratio of 0.5, filled circles a luminance ratio of 0.1. Maximum luminance, 25.5 fl.

qualitative agreement with previously published studies [1,5,12] which examined sharpness dependence on the video bandwidth of television systems. These studies concluded that a discriminable difference in sharpness requires substantially larger bandwidth increases for high-bandwidth (low-blur) systems than for low-bandwidth (high-blur) systems. Transforming the bandwidth-JND data of one of the studies[12] to edge-transition-JND data results in curves much like those found in Fig. 7. The increase in discrimination performance with increasing blur is also in accordance with predictions based on sharpness algorithms, which, to meet a criterion change in sharpness, require substantially greater gains in system performance at higher levels of sharpness.

One unexpected result is the similarity of blur thresholds for black-white and white-black lines. It has been our experience that, under certain conditions, black lines on white appear sharper than white lines on black given the same luminance ratio; hence it was expected that there would be significant differences in their blur thresholds. This simply points-out that blur and sharpness are not antonymous. As is pointed out above, images that appear equally blurred (or unblurred) can, under some conditions, be made to differ in sharpness. Similarly, an image that might be subjectively rated as sharp could possibly be discriminated as being more blurred than another.

REFERENCES

1. M. W. Baldwin, "The subjective sharpness of simulated television images," Bell Syst. Tech. J. 19, 563-586 (1940).
2. 0. H. Schade, Jr., "Image gradation, graininess and sharpness in television and motion picture systems," J. Soc. Motion Pict. Telev. Eng. 56,137-177 (1951).
3. G. C. Higgins and L. A. Jones, "The nature and evaluation of the sharpness of photographic images," J. Soc. Motion Pict. Telev. Eng. 58, 277-290 (1952).
4. G. C. Higgins and R. N. Wolfe, "The relation of definition to sharpness and resolving power in a photographic system," J. Opt. Soc. Am. 45, 121-129 (1955).
5. M. A. Sproson, "Subjective sharpness of television pictures," Radio Eng. 35,124-132 (1958).
6. N. W. Lewis and T. V. Hauser, "Microcontrast and blur in imaging systems," J. Photogr. Sci. Eng. 10, 288-301 (1962).
7. 0. H. Schade, Jr., "An evaluation of photographic image quality and resolving power," J. Soc. Motion Pict. Telev. Eng. 73, 81-119 (1964).
8. E. H. Linfoot, *Fourier Methods in Optical Image Evaluation* (Focal, New York, 1964).
9. E. M. Crane, "An objective method for rating picture sharpness: SMT acutance," J. Soc. Motion Pict. Telev. Eng. 73, 643-647 (1964).
10. E. M. Granger and K. N. Cupery, "An optical merit function (SQF), which correlates with subjective image judgments," Photogr. Sci. Eng. 16, 221-230 (1972).
11. R. G. Gendron, "An improved objective measure for rating picture . sharpness: CMT acutance," J. Soc. Motion Pict. Telev. Eng. 82, 1009-1012 (1973).
12. C. R. Carlson, "Thresholds for image sharpness," J. Photog. Sci. Eng. 22,69-71 (1978).
13. In active media, such as CRT displays, the parameter of interest is normalized luminance; in most cases involving passive media, such as paper, the luminance values may be taken as representing reflectance.