Size Matters: The Influence of Viewing Distance on Perceived Spatial Frequency and Contrast

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Abstract

The use of soft-copy displays to simulate printing devices is a common practice in the color imaging community. CRT and LCD displays can be used as a means of proofing hardcopy prints, and can also be used as tools for the development and evaluation of future imaging systems. Desktop display devices are typically of a much lower resolution than most printers, which can make it difficult to evaluate the spatial structure of prints such as the perceptibility of half-tone dots or graininess. To evaluate these spatial properties one common practice is to use a larger soft-copy display viewed further away. A psychophysical study was performed to determine the influence of this increase in viewing distance on perceived spatial frequency and contrast. Observers were asked to match the appearance of band-passed noise patterns between two displays viewed at different distances by adjusting spatial frequency and contrast. The results indicate that observers perceive a higher spatial frequency in the far image as a match the appearance of the closer image. Therefore, when a near and far object have identical spatial frequencies, the far image is perceived at a lower spatial frequency. This suggests that the overall visibility of spatial structure cannot be modeled by simple retinal frequencies.

Introduction

The spatial resolution of display technologies is ever increasing, now reaching up to 200 pixels-per-inch. Even with these impressive increases in resolution, displays lag far behind even the cheapest desktop printer. Despite this resolution gap it is very desirable to use soft-copy displays to simulate the color appearance and image quality of printers. Color appearance models have allowed for accurate cross-media color reproduction, though they do not take into account the inherent differences between a multiple bit-depth color display verses a binary printing system. It is often desirable to simulate and model spatial properties of these binary systems, such as the perceptibility of halftone dots with respect to uniformity or graininess or effect of ink-droplet size on image quality. To simulate such systems using a soft-copy display researchers often use lower resolution displays viewed further away. It has been observed that the spatial and color appearance of a near and far display do not match despite the best efforts to equate the retinal stimuli. It is unknown how exactly the spatial and color appearance of an image is affected by this size/distance question.

One potential influence of using this technique to increase the perceived spatial frequencies is the perceptual concept of size constancy. The human visual system is remarkably adept at distilling additional information from the viewing environment when determine the appearance of an object. The retinal size, and corresponding retinal spatial frequency, of an image should be enough to determine the spatial appearance of the image. The physiological behavior of eye can account for some changes in appearance based on viewing conditions, such as lens accommodation and differing spatial sensitivities outside the fovea. Size constancy, however, can be thought of as a cognitive addition to the physiological changes. Humans are typically able to correctly deduce the physical size of objects at a variety of viewing distances, and this perceived size remains constant despite the fact that the retinal sizes of the objects are vastly different. This behavior can be mitigated by removing the knowledge or ability to discern of the physical distance. An excellent overview of size constancy can be found in Palmer.[1]

So how how might size constancy influence the appearance of a soft-copy display when viewed at a variety of distances? If observers ignore size constancy then retinal size is all that matters and viewing distance should not drastically alter the spatial appearance of an image. If, however, observers recognize that the object displayed further away is a larger image this might influence the overall appearance of the image. This change in appearance may not be taken into account when analyzing experimental results or applying spatial image quality models or visual difference predictors.

Experimental

A psychophysical experiment was performed to determine the influence of the viewing distance on the perception of spatial frequency and contrast. The goal of the experiment was to measure this influence for a variety of viewing distances, spatial frequencies, colors, and contrasts.

The experimental setup consisted of two colorimetrically characterized Apple 23" LCD HD displays, each characterized to a mean CIEDE2000 of less than 0.5, with a maximum error of less than 1.0. The maximum luminances of the displays were matched to 160 cd/m^2 prior to characterization. One display was placed at a fixed viewing distance of 24 inches, which corresponds to a maximum spatial frequency of 42 cycle-per-degree of visual angle. The second display was placed at a distance of either 48 or 74 inches, corresponding to 84 and 126 cycles-per-degree. The observers were presented with an image on the close display and were told to adjust the spatial frequency and contrast of an image on the far display such that it appeared to match. Hard edges were used on all the image stimuli, rather than blurring with a Gaussian envelope, to better simulate viewing real images at different viewing distances. The images were displayed on a neutral D65 background.

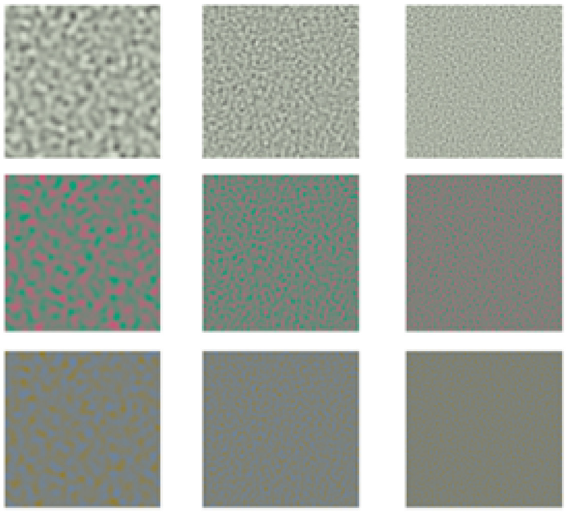

Figure 1. Example of Stimuli Used in Experiment

The stimuli consisted of octave band-passed noise images created in the $Y'C_1C_2$ color space. This space was designed to be a linear opponent space that is isoluminant and mathematically orthogonal[2]. Band-passed noise was chosen instead of simple sinusoidal or square-wave gratings to prevent observers from simply counting the number of cycles when making a match. Three initial spatial frequencies were chosen for the near stimuli: corresponding to 3.5 cycles-per-degree (cpd), 6 cpd, and 10 cpd. The noise was generated in the three color channels, roughly equivalent to luminance, red-green, and yellow-blue. Two levels of contrast were used, where "contrast" in the chromatic channels can be thought of as chromatic contrast or linear distance from the white-point in a chromaticity diagram. The stimuli presented on the near display spanned 256 pixels, or approximately 3 degrees of visual angle. Two sets of stimuli were presented on the further display that differed in their overall size: one set matching the retinal size of 3 degree, and the other 100 pixels smaller. The smaller images were used to determine if the physical image size has an effect on size constance or perceived spatial frequencies. There were a total of 36 trials at each viewing distance. The order of the images were randomly presented, as was the vertical placement of the images on the displays. Observers were able to adjust the spatial frequency of the band-pass filter in 0.1 cpd increments as well as the contrast of the far image in real-time using a shuttle dial. A chin rest was utilized to assure that the spatial frequencies and retinal image sizes were accurately maintained. A total of 16 observer participated in the experiment, which took approximately 45 minutes for both viewing distances.

After performing the experiment the observers were presented with a casual exit interview. Most observers felt that the task was easy and expressed confidence in their results. In addition most observers agreed that the image on the far display always appeared to be larger than the image on the near display. When shown that the images spanned the same visual angle many observers actually expressed surprise. Another interesting note was that the majority of observers did not realize that there were two different image sizes displayed on the far screen. This was facilitated by the random placement of the images on the screen, as observers could not see the image change size.

Analysis of Results

The results of the experiments were averaged across observers for each viewing condition. The inter-observer variation was very small for both spatial frequency matches and contrast matching. A four-way ANOVA was performed on the spatial frequency matches and contrast matches (spatial frequency, contrast, color, image size). For the spatial frequency matches the initial frequency and image size were statistically significant. This suggests that neither the color nor contrast influenced the chosen frequency match. It should be noted that all the noise stimuli and matches were chosen to be well above threshold visibility. Figure 2 shows the relationship between the spatial frequency of the near stimuli and the spatial frequencies matches for the far stimuli averaged across all colors, contrast, and sizes.

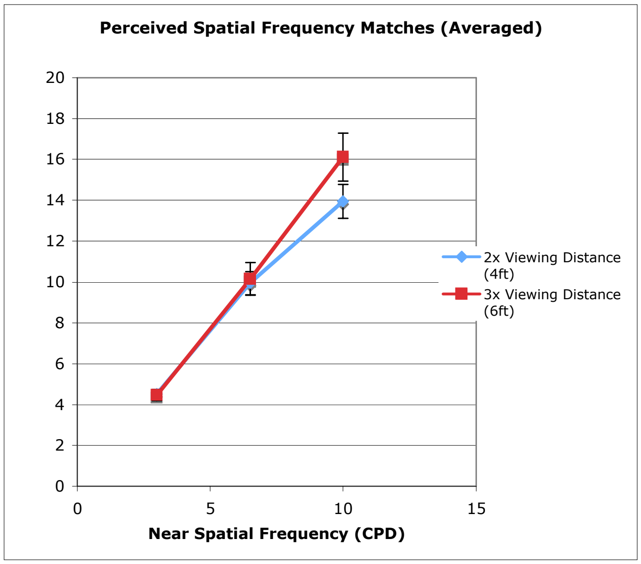

Figure 2. Spatial frequency matches between near and far noise stimuli

From Figure 2 it is clear that higher spatial frequencies were needed for the far stimuli to match those of the near stimuli. This trend appears very linear in nature. Observers matched the 3.5 cpd stimulus with approximately 5 cpd, the 6 cpd with approximately 10 cpd, and the 10 cpd with approximately 15 cpd. What is interesting to note is that this behavior was relatively constant for both viewing distances, with only the matches at 10 cpd statistically different between them. Another interesting note is the relatively small standard errors, represented by the error bars in Figure 2. The standard error was always less than 1 cpd across all observers, and often much smaller.

The ANOVA analysis suggested that the size of image on the far display also played a role on the spatial frequency matches. This is illustrated in Figure 3 for the two viewing distances.

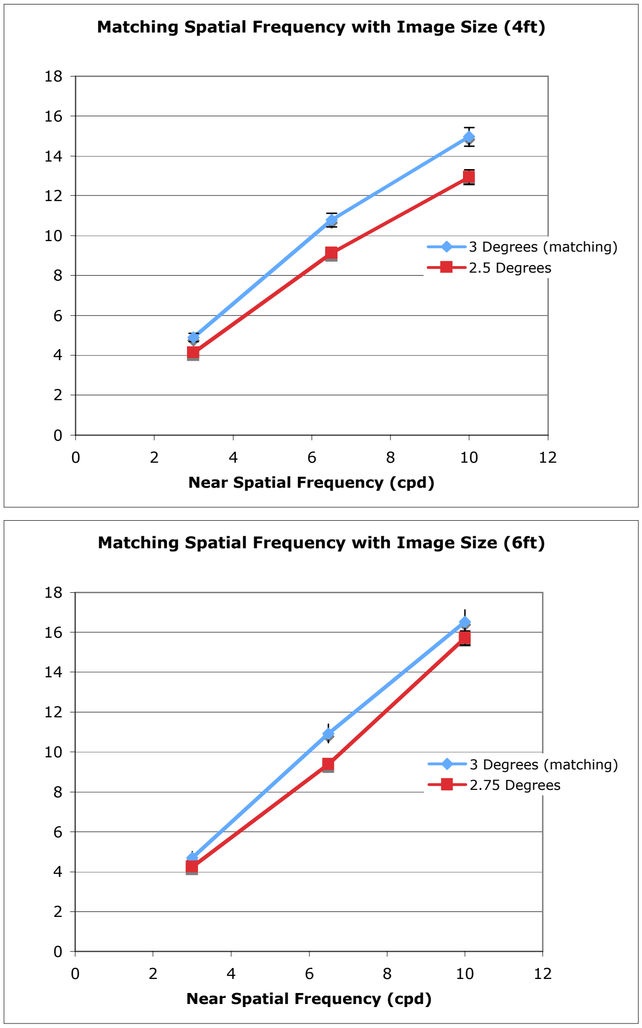

Figure 3. Effect of images size of spatial frequency matches

From the top plot in Figure 3 we can see that the size of the far image does change the spatial frequency match. This occurred despite the fact that most observers did not even recognize that there were two distinct image sizes. The image size was more influential at the viewing distance of 48 inches than 72, but that is most likely because the 100 pixel change represented a drop in retinal size from 3 cpd to 2.5 for the closer viewing distance and a drop to 2.75 for the far.

Another ANOVA was performed on the contrast matches, which suggested that only the effect of the initial contrast and color were significant factors in contrast matches. These data are shown for the three color channels in Figure 4.

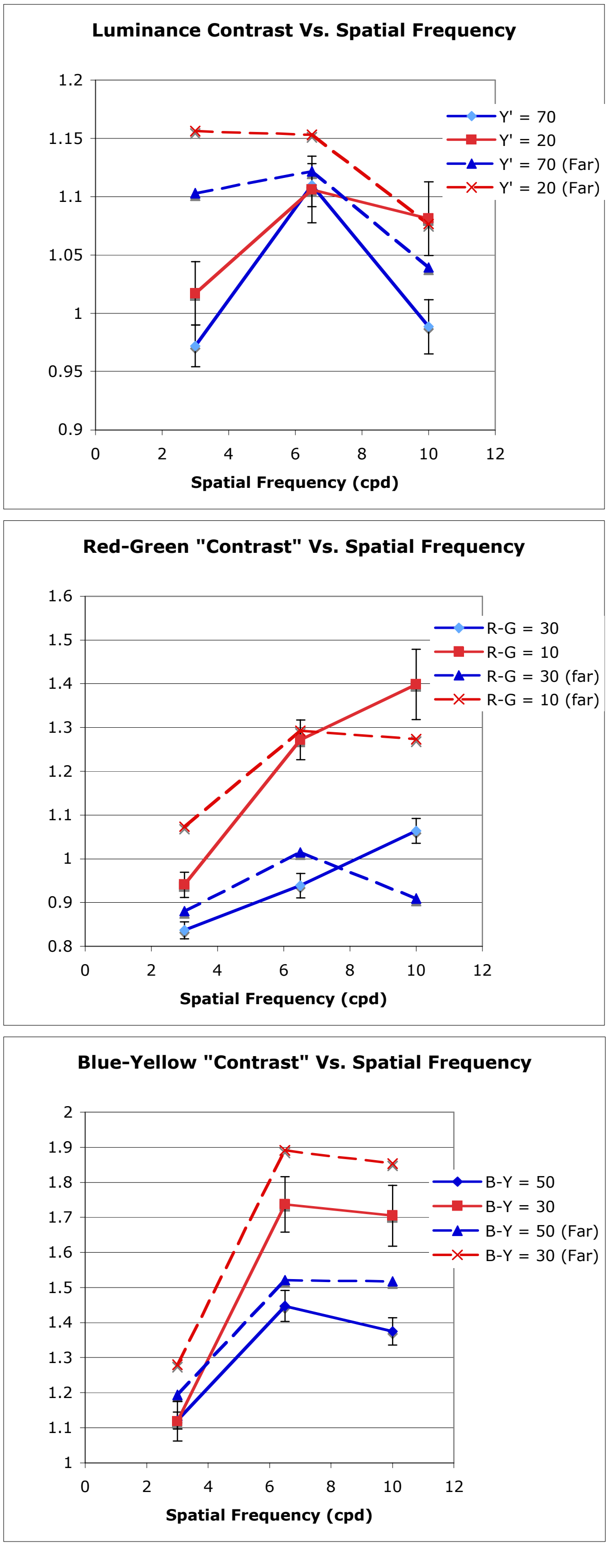

Figure 4. “Contrast” matches for three color channels

Figure 4 shows the contrast matches for the four color channels, as a function of spatial frequency. The contrast matches are represented as ratios of adjusted contrast to original contrast, so that anything above 1.0 is an increase in adjusted contrast while anything below is a decrease. It should also be noted that the spatial frequency shown on the abscissa is that of the original (near) image, rather than the perceived frequency match. Clearly from the plots in Figure 4 it can be seen that spatial frequency does influence the amount of contrast necessary to get a match, but it does so differently for the three color channels. Because the observers do not match the spatial frequency based on their retinal subtense, there will be differences in the perceived contrast based on the contrast sensitivity of the eye. Therefor although the higher spatial frequency may appear to be lower, the contrast necessary to make a match still must be higher.

For the luminance channel the contrast ratio follows a band-pass trend, which may be expected do to the band-pass nature of the human visual system with regards to luminance contrast sensitivity. At higher spatial frequencies the chromatic channels show a general increase in the amount of contrast necessary to match the original. This is more so for the blue-yellow channel than the red-green. This also follows the intuitive behavior of a low-pass chromatic contrast sensitivity function. For all the channels a larger contrast increase was necessary for the lower initial contrast values, and there does seem to be an effect of further increasing viewing distance.

Discussion

The results of this experiment clearly indicate that image size and viewing distance can greatly influence the appearance of the image. When asked to match spatial frequencies of an image viewed at close distance to an image viewed at a further distance that spanned the same retinal size observers always selected higher frequencies. This suggests that the identical spatial frequencies actually appeared too low, or too large. This follows the concept of size constancy as observers were acutely aware that the far image was actually a larger image at a greater distance. As such observer might assume that the low frequencies were also larger and further away.

That the size of the far image itself also greatly influences the spatial frequency match further complicates the matter. This may be an example of relative size constancy, whereas observers were matching internal spatial frequencies relative to the border size of the image itself. This is also despite the fact that many observers did not realize this size was changing.

The viewing distance also greatly influenced the contrast perception resulting in the need to increase contrast in the far image to match the appearance of the near image. This result is confounded by the change in spatial frequency. The increase in contrast necessary may be a result of the increase in spatial frequency and the physiological decrease in sensitivity to those higher frequencies. That this effect is most noticeable for the blue-yellow channels, followed by the red-green and then the luminance channel lends some credence to this hypothesis. Further studies should be conducted to measure perceived contrast at fixed retinal spatial frequencies.

Doubling the viewing distance from 24 to 48 inches resulted in a large change in the spatial frequency matches, following a linear gain of almost 1.45. This large change was not as apparent when increasing further to 72 inches, as only the highest spatial frequency match was significantly different and the overall gain was approximately 1.6. Why was this further increase in viewing distance not accompanied by as large a change in spatial frequency perception? Size constancy is known to break-down at large distances. It could be that for these display devices the 72 inch viewing distance starts to diminish the influence of size constancy.

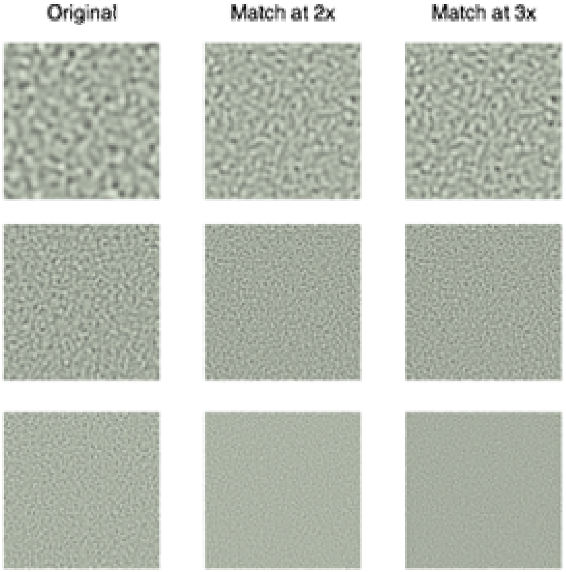

Figure 5. Original images and the adjusted matches for the two further viewing distances. The changes in contrast and frequency size should be evident

So how do the results apply in real world situations? Often increased viewing distances are used to simulate higher resolution imaging devices. Images that contain a large spatial variation such as halftones may be greatly influenced by the viewing distance. Figure 5 shows the three original luminance images, and the resulting matches for the two viewing conditions. The images viewed further show a noticeable increase in spatial frequency. This suggests the inverse may also be true. A image with spatial content, such as a halftone pattern or graininess at a particular frequency may appear to have this pattern at a lower frequency. This may result in an increase in perceptibility of the pattern which may not be apparent in the actual device. Such an effect has been observed in the case of color assimilation where the apparent size, rather than the retinal size, influences the degree of color blending in a chromatic grating.[3] Simulations and evaluations using this increased viewing distance technique may not accurate match evaluations of the higher resolution device viewed at a normal distance.

Certain image quality or visual difference models that rely on the spatial behavior of the human visual system may need to take viewing distance into account as well. Several models, such as the Daly VDP[4] and Barten SQRI[5] take viewing distance into account when calculating the contrast sensitivity function (CSF). These models, however, are typically concerned with the physiological change in the CSF with regards to accommodation. Other models that rely on the CSF to predict image differences and quality, such as S-CIELAB[6] and iCAM[7] may need to account for viewing distance when calculating the perceptibility of spatial structures in images.

Conclusions and Future Directions

A psychophysical experiment was performed to measure the influence of viewing distance on perceived spatial frequency and contrast. Octave band-limited noise images were matched in both spatial frequency and contrast between a near display and a display further away. In general a much higher spatial frequency and contrast was needed in the far image to match the near image indicating that observers were incapable of matching retinal size. This follows the concept of size "overconstancy," as the far image always appeared to be larger than the near image.[8] The change in frequency was not dependent on the color or contrast of the noise, but it was dependent on the image size. The change in contrast was influenced by the color, frequency, initial contrast, and viewing distance.

In order to be generally understood and practically applied more research should be performed. This might includes contrast matching at specific retinal frequencies, haploscopic and successive binocular matching, as well as using additional images sizes and viewing conditions.

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