0.0: Visual Preference for ClearType Technology

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Abstract

ClearType filtering is a sub-pixel rendering method that improves the perceived image quality of text. The method renders text at subpixel resolution and then applies a one-dimensional filter to reduce color artifacts. We performed behavioral and computational experiments to analyze the effect of varying the linear filter parameters. Specifically, we systematically varied the values of a symmetric, mean-preserving, five-tap filter; such filters are described by a two-dimensional parameterization. We generated ClearType versions of the same letter from a large set of these filters and asked subjects to select the version that they preferred. Subjects' preferred renderings from a compact region in the two-dimensional parameter space. Computational analyses show that the preference data are predicted by the SCIELAB metric, a spatio-chromatic metric of human visual sensitivity.

1. Introduction

In most color displays, each pixel is composed of three horizontally adjacent subpixels that emit the red, green, and blue (RGB) primary lights. Traditional display algorithms treat the subpixels as spatially coincident and forfeit the potential resolution enhancement in the horizontal dimension. ClearType uses the individual subpixel elements to increase the horizontal resolution of displayed text.

ClearType technology effectively triples the spatial resolution in the horizontal axis; but at the same time subpixel rendering introduces color artifacts. Platt [1] used the principles in the S-CIELAB [3] visible difference metric to quantify the perceptual tradeoff between spatial resolution and color errors and optimize the design of linear filters to minimize the metric. This was done by applying three color filters to each color channel of the full-color input image to produce values for each subpixel, i.e. the three filters applied to red color channel are denoted by R→R, G→R, and B→R. Subsequently, Betrisey et al. [2] found that the cross-channel filters (R→G, R→B, G→B, etc.) have relatively little power, and the three within-channel filters (R→R, G→G, and B→B) are nearly identical but centered at different subpixels. Hence, Betrisey et al replaced the nine filters with one box filter and referred this approximation as RGB decimation with displaced box filters. These simplifications are the basis of a real-time implementation of ClearType.

In this paper, we report the results of a series of visual psychophysical experiments that investigate the effect that display, font and ClearType filter properties have upon the perceived image quality of ClearType text.

2. Method

We conducted a series of visual psychophysical experiments in which 3 subjects chose a preferred rendering from a variety of different alternatives. The alternatives were generated by systematically varying the spatial filter used to smooth the ClearType letters. We used one-dimensional symmetric, mean-preserving, five-tap filters (a,b,c,b,a). The three filter parameters sum to one ($2a + 2b + c = 1$) and can thus be described by a two-dimensional parameterization.

We created the different versions by varying the two filter parameter values, *a* and *b*. We displayed these different ClearType versions of the same letter and asked people to select the letter that they preferred. We used the subjects' preference judgments to determine the filter parameters that optimize the perceived quality of ClearType fonts.

Even for a single display, and a letter with fixed font size and family, the number of different versions of the same letters (different parameter values) is quite large. We conducted several preliminary experiments to determine how best to search the space of possible parameter values. In the experiment we report here, letters were arranged in a line and subjects indicated which letter had the best perceived quality. Each trial sampled a line in the space of possible filter parameter values as shown in Figure 1.

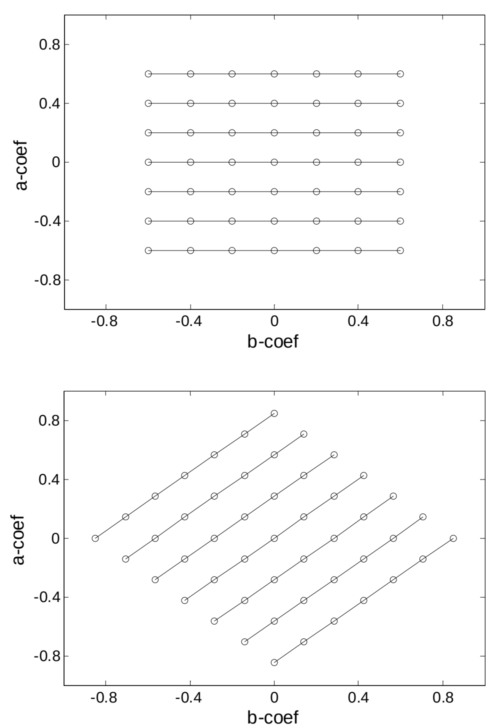

Figure 1. The space of possible filter parameter values. Each point represents the *a* and *b* filter coefficients for a particular letter. Lines connect the filter values of letters that were presented in a given trial.

In each block of trials, subjects saw the same letter in one typeface and size. The only differences between letters within a block of trials were the filter parameter values that were used to generate the ClearType letter. Each trial consisted of a row of letters that was sequentially ordered by parameter value. Each block of trials consisted of 140 randomly ordered presentations during which 14 different rows of letters were displayed 10 times each.

Across different blocks of trials, subjects saw the letters “v”, “g”, “s” and “E”, in Georgia and Times New Roman typefaces at 10 and 12 point size. Letters were presented on Dell display with vertical stripe pixel structure (Figure2a) and a Dell display with a chevron pixel structure (Figure 2b). Subjects used a chin rest to keep their viewing distance constant at 15 inches.

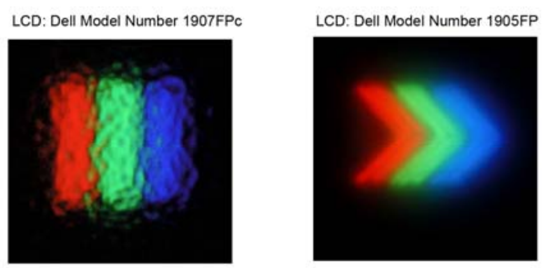

Figure 2. Camera images of a white pixel illuminated on a Dell LCD Display Model 1907FPc (left) and a Dell LCD Display Model 1905FP (right).

3. Results

We used the number of times subjects preferred a letter to calculate iso-preference contours spanning the entire range of *a* and *b* filter parameter values. Figure 3 shows typical iso-preference curves plotted as a function of the Cleartype filter parameters, *a* and *b*. Each contour falls off with the number of times the subject indicated a preference for that filtered version.

Analysis of the iso-preference curves for all 3 subjects reveal the following similarities. First, we found that subjects never preferred letters with no filtering (a=b=0). In other words, the filtering is important.

Second, we found that for all letters, typefaces, sizes, displays and subjects, there is a zone in the two-dimensional parameter space that produces the most preferred letters. In other words, there is a range of filter parameters *(a, b)* that yield equivalent preferences.

Third, we found that the zone of preferred ClearType filter parameters contains a three-tap filter (i.e., a=0). This three-tap filter is preferred about as often as the best five-tap filters. The three tap filter is defined by only one filter parameter, *b*. The other filter parameter, *c*, is equal to *1-2b*.

Figure 3 shows the results for one (“v”) of the 4 letters that were presented in the experiment. We found similar results for the other three letters (“g”, “s” and “E”). When *a=0*, all three subjects preferred *b* values that ranged between 0.2 and 0.4 for all stimulus conditions (i.e. display, typeface, point size and letters). Given the differences in the pixel structure for the two different displays (see Figure 2), it is surprising that these differences did not affect the preferred filter parameter values. But, as we show in the next section, the optical images that are projected onto the retina when the same letter is rendered on the two different displays are very similar.

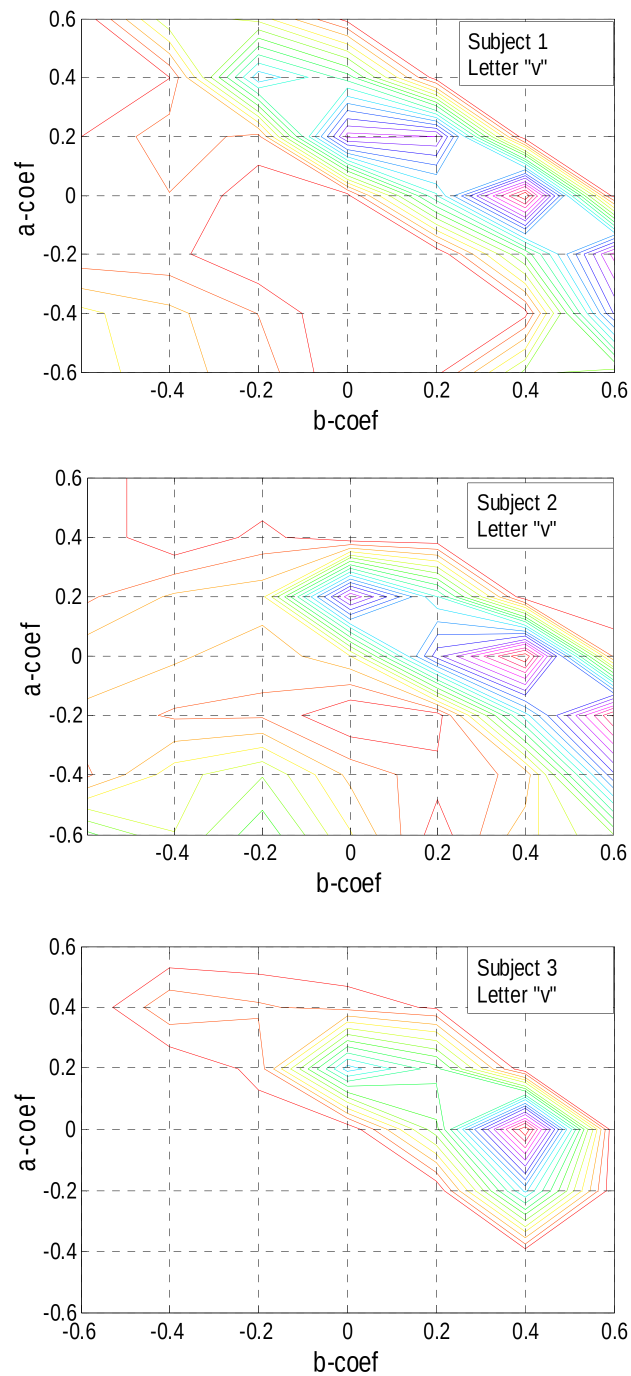

Figure 3. Iso-preference curves for three subjects. The results shown here represent the data collected in the condition in which the Georgia 10 point letter “v” was presented on the Dell 1905FP display.

4. S-CIELAB Predictions

In a previous paper, we described a Display Simulation Toolbox that was developed to predict the displayed radiance of stimuli rendered on a calibrated display [3]. Given an accurate representation of the stimulus, we can calculate the optical image of the stimulus as it is projected onto the retina.

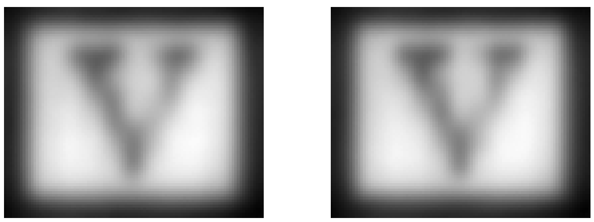

Figure 4. Predicted retinal images for the Georgia 10 point letter "v" rendered on the Dell LCD Display Model 1907FPc (left), a Dell LCD Display Model 1905FP (right).

Figure 4 compares the predicted retinal images of the same letter rendered on the two different displays (Dell LCD Display Model 1907FPc and Dell LCD Display Model 1905FP). The retinal images were calculated by convolving the physical stimulus (displayed radiance images) with wavelength-dependent pointspread functions for a 3 mm pupil [4]. The energy in the retinal image was summed over all wavelengths to produce the grayscale images shown in Figure 4. This figure illustrates that after taking into account the optical blur, there is very little difference between the retinal images of the same letter rendered on the two different displays. This explains why the display pixel structure did not have a significant effect on the linear filter parameters for the preferred rendering.

We used the Display Simulation Toolbox to calculate the displayed radiance of each of the ClearType versions of the same letter as measured on the display [5]. Then, we used the S-CIELAB ΔE metric [6] to compare the radiance images of different ClearType letters rendered on a color display with the same letters rendered on a monochrome display matched in resolution. The font outline on the matched monochrome display is identical to the outline used in the ClearType rendering and the differences between displays are all due to contrast and color. Hence, we used S-CIELAB to predict the visibility of the difference between the ClearType rendering on a color display and the rendering on a matched monochrome display. (Alternatively, we could have compared the radiance difference between ClearType letters and an ideal high-resolution letter. However this exaggerates the error because typefaces are programmed to adjust letter shape given the available resolution.)

Figure 5 illustrates the S-CIELAB calculation. We begin by calculating the displayed radiance of a letter rendered on a color display and the displayed radiance of the same letter rendered on a monochrome display matched in resolution. We then calculate the S-CIELAB difference (ΔE) between the two radiance images to produce an error (ΔE) map. We use the mean S-CIELAB difference (ΔE) (averaged across the error map) as a measure of the visibility of the difference between the ClearType rendering and the rendering on the matched monochrome display. As the ClearType filter parameter values (*a* and *b*) change, the ΔE map and mean ΔE value change significantly. These errors capture changes in the rendered font colorfulness and contrast.

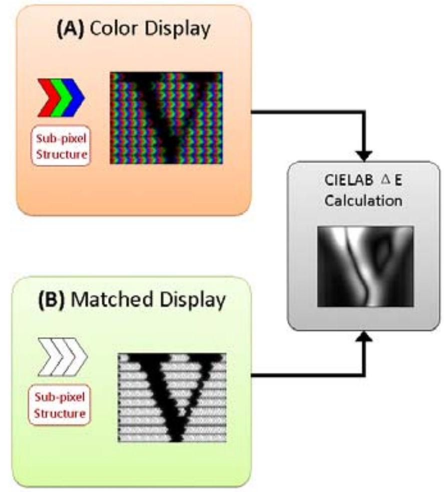

Figure 5. Calculation of the S-CIELAB difference between the displayed radiance of a letter rendered on a color display (A) and the displayed radiance of the same letter rendered on a monochrome display matched in resolution (B). The error map is the S-CIELAB difference (ΔE) between the two radiance images.

In the S-CIELAB ΔE calculations we report here, we used a viewing distance of 15 inches, just as it was in the subjective preference experiments. To compare the S-CIELAB predictions to the data we collected on subjective preferences, we plot the mean ΔE values as a contour plot in the filter parameter space. We can then superimpose the S-CIELAB predictions on iso-preference contours for the same letter. Figure 6 compares the S-CIELAB predictions for the Georgia 10 point letter "v" displayed on the Dell 1905FP monitor to the subjects' iso-preference contours for that same stimulus.

For this and all other stimuli, the contour plots for the preference data and the S-CIELAB predictions share important similarities. Letters that are not filtered using ClearType technology (a=b=0) produce very large S-CIELAB values. There is a systematic zone in the two-dimensional parameter space that produces the minimum mean SCIELAB values. And three-tap filters are always within this zone.

The peak-signal-to-noise (PSNR) metric is used widely in the engineering literature. Hence, we performed the same analysis using PSNR for comparison with S-CIELAB. For all letters, typefaces, sizes and displays, the smallest PSNR error occurs with no filtering at the parameter values (a=b=0). The PSNR metric does not predict the preference data we collected in this experiment. Nor can it predict the effects of viewing distance on the visibility of imaging artifacts in any visual psychophysical experiment.

Hence, to predict user preferences we find it is important to use a visibility metric that incorporates essential features of human color-pattern visibility: an opponent-colors representation and differential spatial sensitivity in the luminance and opponent-colors channels. The use of these two principles was originally noted in the paper that introduced the ClearType technology [1], and we confirm the value of these principles here.

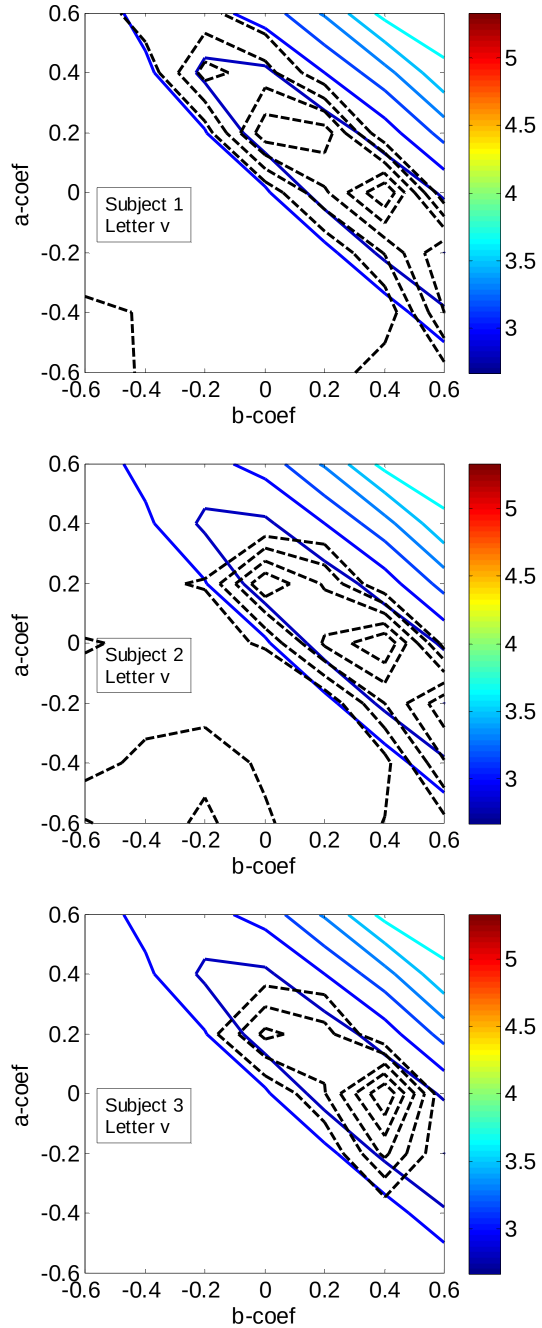

Figure 6. Contour plots showing the S-CIELAB predictions (color lines) as a function of *a* and *b* filter coefficients, superimposed on subjects' iso-preference curves (dotted black lines) for the same stimulus.

5. Summary

We systematically varied the parameters of a five-tap filter to generate different ClearType versions of the same letter and asked subjects to select the version that they preferred. Our experiments are based on symmetric, mean-preserving five-tap filters that can be described by a two-dimensional parameterization. We found that there is a systematic zone in this two-dimensional parameter space that produces the most preferred letters and a range of filter parameter values that are preferred the most. This range includes values when a=0, and thus the five-tap filter becomes a three-tap filter.

Finally, we compared the results of our visual psychophysical experiments with predictions based on the S-CIELAB ΔE metric. The contour plots for the preference data and the S-CIELAB predictions are similar.

6. Acknowledgements

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7. References

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