Digital multitoning with overmodulation for smooth texture transition

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Abstract. *Multilevel halftoning (multitoning) is an extension of bitonal halftoning, in which the appearance of intermediate tones is created by the spatial modulation of more than two tones, i.e., black, white, and one or more shades of gray. In this paper, the conventional multitoning approach and a previously proposed approach, both using stochastic screen dithering, are investigated. A human visual model is employed to measure the perceived halftone error for both algorithms. The performance of each algorithm at gray levels near the printer's intermediate output levels is compared. Based*

screen dithering, are investigated regarding texture variation across the tone scale. A human visual model is employed to measure the perceived halftone error for both algorithms. The performance of each algorithm at gray levels near the printer's intermediate output levels is compared. Based on this study, a new overmodulation algorithm is proposed that consists of a preprocessing stage where the pixels in the input image are modi®ed, followed by conventional multitoning with specially design stochasdifferent conditions, as well as the extension of $H(f_{ij})$ to a two-dimensional function $H(f_i, f_j)$ that is required in Eq. ~3!.

A plot of this visual model is shown in Fig. 5, which

is called, which requires as inputs the pixel value I, the speci®c level X, and corresponding screen value S for that pixel location. The modi®ed input pixel value (I') is then used as the input for the conventional multitoning scheme to get the ®nal output value O. The modulation process is nonlinear, and could be best described with the following pseudo computer code:

```
D5 I2 X;
A5 MAP(D);
if (D.5   0)
        if (S.5   128)
                I′5 X2 A;
        else
                I′5 I1 A;
else
        if (S.5   128)
                I′5 I2 A;
        else
                I′5 X1 A;
```

where MAP~! is a mapping function determining which pixels are to be modi®ed during the preprocessing stage and also how much those pixels are modi®ed. The MAP function should peak when the input pixel is right at the output level so as to reduce the difference of texture appearance between this typical level and rest of the tone scale; on the other hand, the MAP function should gradually decrease as input pixel values deviate from the output level to avoid adding additional texture to the adjacent gray levels gray

This overmodulation multitone approach is a meaning-preserving process, and an example is given in the Appendix for demonstration.

A gray ramp ~around output level 170! multitoned using a regular stochastic screen with the overmodulation scheme is shown in Fig. 11~b!. For visual comparison, the multiscreen. It can be seen that the texture transition in the sky region is smoother for the binar image.

4.3 *De®ciency of FWMSE and Introducing a New Halftone/Multitone Texture Visibility Metric*

Figure 14 shows the curves of FWMSE versus gray level for multitoning outputs from the three different screens ¬regular, maximally dispersed, and binar. One observation is that, if FWMSE is used as the texture visibility metric, then the output from the ``maximally dispersed''

5.2 *Inkjet Multilevel Printing Simulation*

To this point, all the simulations have been done on a thermal continuous tone printer; however, the overmodulation scheme is initially intended for a wide range of printers. Therefore, experiments with different printing engines are worthwhile. The one with the inkjet is reported as follows.

Inkjet output devices have traditionally been binary engines that rely on halftone techniques to render continuous tone input images. Recent technological advances in the design and manufacture of inkjet printheads have paved the way for the development of multilevel inkjet devices. The appearance of multiple output density levels is achieved by modulating the volume of ink that leaves the nozzle, which

On the other hand, if S, 128, then $I' 5$ 2L1 A; thus, the expected value $E_2$$O%$ for O is given by

E