Analysis Of A Threshold Modulation Dither Using Space Curve Point Movement, Forward Propagation And Noise Removal

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ABSTRACT

Space-filling curves are regularly proposed as methods of traversing an image plane. Such methods, though more complicated than point movement by rows, have the advantage of moving the point within an area before moving to another area. Point movement is inherently within tiles and within areas of similar frequencies.

Isis Imaging's Standard threshold-modulation screen, first commercially released in March 1994, is a device-independent screening method available in software residing on the host computer. It is widely used for print and photography applications. The algorithm is described, its properties examined and its output evaluated.

Key Words: threshold modulation, Hilbert, error propagation, FM screen, halftone, space-filling curve, stochastic screening

INTRODUCTION

Isis Imaging's Standard dither algorithm performs scalar, point-specific movement through the image plane. Errors are forward propagated within the space curve. In practice the algorithm is used for 8-bit to 1-bit conversion of pre-separated planes of cyan, magenta, yellow and black. The color vector pattern is a dot-on-dot and a dot-off-dot pattern. The result is optical and physical mixing of primary inks.

While there are descriptions of error diffusion[2,3] along space-filling curves, this algorithm uses a weighted five-cell diffusion matrix, and a selected range of random noise removes pattern artifacts caused by the space-filling curve.

There are several advantages to the algorithm:

- Bit-depth can be any practical depth. (8-bit, 12-bit and 16-bit is common.)
- Performance is excellence.
- The filter neither sharpens nor blurs.
- Gradients display no pattern jumps or worms.
- There are no repeating patterns.
- Cluster building and perimeter gain is linear.
- It has been effectively used at resolutions of 2400 dpi to 400 dpi.
- Data handling may be by tiles, bands or rows.
- There are no tiling edge artifacts.
- Ease of parallel programming[7].

Disadvantages include:

- Slight noise content in the highlights.
- At low resolutions, blue-noise content is observable.
- Multiplicative or vector clusters occur.

1.0 BACKGROUND

Spatial threshold screening methods based on space-filling curves display dot-pattern characteristics intrinsic to the space-filling curve. Low-pass filter dispersion through a matrix results in undesirable blurring, highpass dispersion results in unwanted sharpening, and dot cluster building adds other pattern noise. The algorithm described eliminates such additive noise.

1.1 Description of software implementation

The supporting application is programmed in C++ for the Apple Macintosh computer. ColorSync and QuickTime 4 system extensions for Apple OS 8.6 are used for color management, color-space transformations and file format support. The application is modular allowing multiple image processing operations and any number of halftoning algorithms.

The image path is: RGB (to image filtering) to CMYK to device-C'M'Y'K' to 1-bit interleaved or planer CMYK raster. Image filtering is applied to the incoming RGB. No image processing of the original CMYK data is permitted. Grayscale data is also image processed, and converted to raster. The conversion from CMYK to 1-bit raster is described in this paper.

A CMYK to device-C'M'Y'K' conversion is performed to compensate for output device dot-gain. Density compensation for dot-gain is attained through a transfer or gamma curve (TRC) correction of the original image data. The curves are user controlled through the normal linearization, trial-and-error, procedure for correcting output devices' densities.

2.0 THE ALGORITHM CONSISTS OF FIVE COMPONENTS

- Point movement through the image data by the Hilbert space-filling curve.
- Threshold conversion from bit-depth to 1-bit depth.
- Five-position error propagation ahead of the current point.
- Each error-position is weighted for optimal error dispersion and minimum noise.
- Pseudo random noise of a selected range is used to compensate for the error propagation noise. The result is a blue-noise effect.

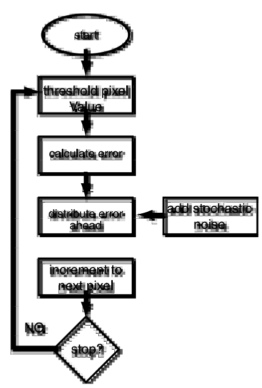

Figure 1. Flow chart of the dither process

2.1 Properties of the Hilbert space filling curve

The Hilbert space-filling curve or fractal was selected for its ease of implementation in C++ and its high-speed performance. The point moves recursively through the bit plane in the following procedure.

begin
    positive angle movement
        increment one pixel
//the Initiator or connection between the first two pixels
    positive angle movement
        increment one pixel
    negative angle movement
        increment one pixel
//The Generator or 'U"-shaped connection of the first four pixels.

Four iterations in the same angle movement of the generator produces the basic fractal unit. The fractal unit is then repeatedly moved throughout the data plane following the same angle directions.

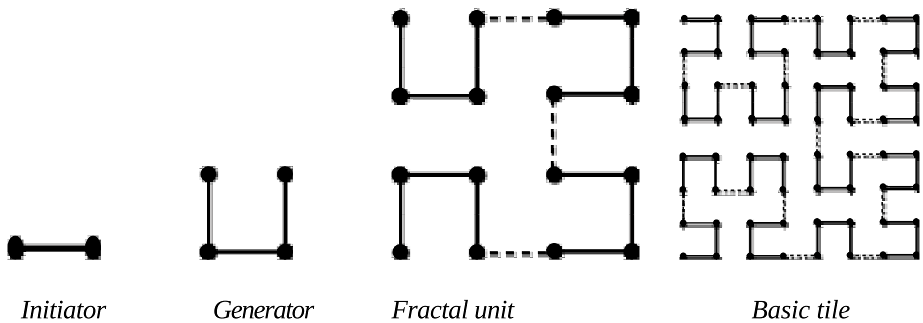

Figure 2. The Hilbert space-filling curve

The fractal unit moves the point through every pixel in a minimum 8 pixel by 8 pixel tile.

2.2 Threshold modulation

The threshold pixel value is the value used to make a decision to write a pixel. In an 8-bit image plane the mid-point or 127th grayscale is used. Other grayscale values were considered, but no observable pattern differences were observed when using other threshold levels.

Current pixel >=127 write pixel
    error = current pixel - 127
        //cascade error through the five-cell matrix.

2.3 Five-cell error distribution

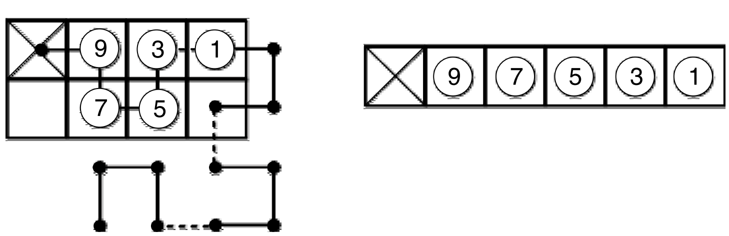

Figure 3. The filter neighborhood

The pattern of point movement regularly changes the neighborhood pattern. As illustrated above, the pattern at one position may be similar to the Floyd-Steinberg pattern. The Cartesian neighborhood pattern may at other times be the inverse with three cells below two cells or may be vertical. The space-filling view of the neighborhood is always linear.

2.4 Weights for accumulating errors

The matrix consists of six cells—the cell under threshold consideration and five neighboring cells. The error propagation diminishes according to the distance from the point of consideration. Odd number weights are used to evenly distribute errors over five cells.

Cascade error forward through the neighborhood:

current pixel + [(error * 9/25)+random]
current pixel + [(error * 7/25)- random]
current pixel + [(error * 5/25)+ random]
current pixel + [(error * 3/25)- random]
current pixel + [(error * 1/25)]

The sum of the weights is 25. The effect of the weights times errors is balanced by dividing the product by the sum of the weights.

2.5 Stochastic process to control dimensional relationship noise

Signal to noise ratio is diminished by adding noise that is the inverse of the noise signal.

The noise inherent in the fractal pattern is canceled by adding noise in the form of random numbers to the weights that position the dots. The noise signal to be diminished is the output of the weights and their spatial relationship. A range of numbers added to the error results in positioning pixels in a blue noise pattern.

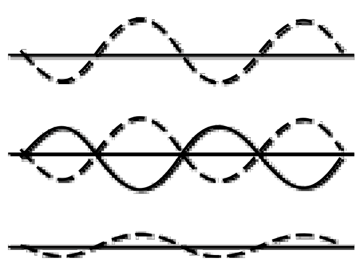

Figure 4. Noise removal

Signal noise in a space-filling fractal pattern may be charted as a modulating sine wave. That wave pattern can be neutralized by adding a wave pattern in phase but inverted to the wave pattern. The introduction of carefully selected noise diminishes the fractal noise. Unfortunately, the fractal noise cannot be practically calculated for every cell. The introduction of random numbers is within a pre-determined range. The range is clustered around the mean value of spatial movement errors. This stochastic process does not completely eliminate spatial noise. Regularity of dot formation occurs infrequently, if at all, within the gradient. The remaining noise results in varying pixel spatial relationships. The varying pixel distances provide excellent multiplicative relationships for the reproduction of neutral grays. (A neutral gray formed of process colors of the same density level would result in dot-on-dot reproduction if the dot pattern was always the same. The remaining noise in the spatial relationship causes each process color to have its own pattern. The result is the preferred dot-off-dot vector pattern.)

3.0 ANALYSIS OF RESULTS

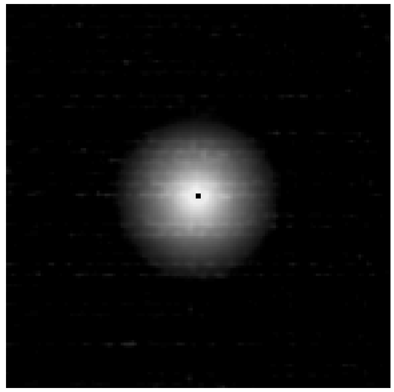

Figure 5. Fourier amplitude pattern

3.1 The Fourier amplitude spectra

A dot pattern at 50% gray level displays radical symmetry or dot positions with some linear noise resulting from regularities in the pattern.

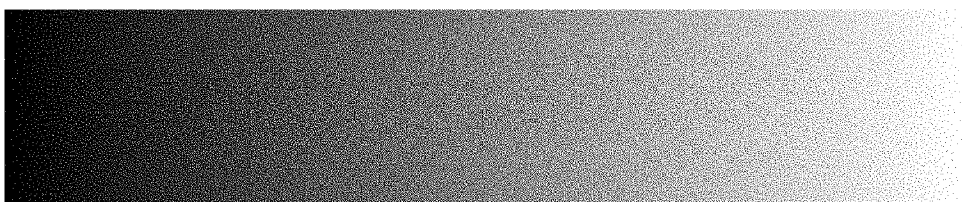

Figure 6. Grayscale sweep at 300 dpi.

3.2 Visual inspection of a sweep

The sweep displays uniform dot-touch growth without banding in the midtone area and few worms in the highlight and shadow area. There is only one unwanted texture -- a regularity of dots at about the 20% level.

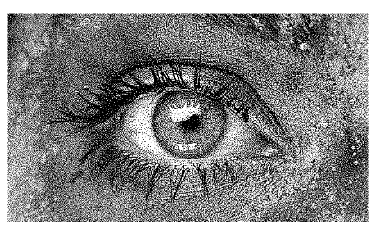

Figure 7. Pictorial image at 300 dpi.

3.3 Visual examination of reproduction

A comparison with a source image consisting of high-spatial frequencies reveals no measurable difference in sharpness of detail. Images with predominantly high-frequency content, such the photo in Figure 7, are reproduced without additional sharpening. The lack of inherent edge enhancement is the result of the linear and relatively short diffusion filter.

3.4 The addition of noise for phase neutralizing

The noise disrupts the fractal pattern and results in a regular pattern of dots at the 51st gray level (out of 255 gray levels).

3.5 The accuracy of bit depth to spatial domain conversion

Accuracy is an average of .02. The error is the result of quantization errors in the C++ implementation.

4. CONCLUSION

The dither pattern produced by the algorithm controls ink on paper well. The linear cluster growth allows preprocessing density compensation with the use of a gamma curve density decrease. The lack of bands, patterns and repeating cells allows for accurate low-frequency reproduction. The low populated neighborhood filter results in accurate reproduction of high spatial frequencies.

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