Error Diffusion with Homogeneous Highlight and Shadow Response

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Abstract

This talk* describes a modification to the standard error diffusion algorithm that results in a more homogenous response in the dark and light image regions. This is achieved using a dynamic threshold imprint function that depends on the input image and the binarized output pixel.

1 Introduction

Error diffusion (ED) is a common technique for binarizing continuous tone image data for printing. The algorithm is simple and fast, and can take advantage of the properties of devices that are capable of printing individual dots, like ink-jet printers. A large variety of modifications to the original algorithm by Floyd and Steinberg[1] have been proposed over the years,[2] attempting to improve some of the drawbacks or artifacts of error diffusion.[3]

This paper proposes a modification to the error diffusion algorithm that generates a more homogeneous response in the highlight and shadow regions of images. In order to achieve this, a threshold imprint is introduced that is a function of both, the original input and the binary output. The effect of this imprint is to space the pulses in a more evenly manner than in the original algorithm. The modification is described in the context of the original error diffusion algorithm, but it can be combined with other error diffusion modifications that have been suggested in the past.

2. Error Diffusion

In ED, the input value i is modified using past errors to give a "modified input" value i_{mod}, which is compared to a threshold t. If the modified input value exceeds the threshold, a '1' is set as binary output, otherwise a '0' is set. The operation of thresholding the input has produced

Figure 1. Result of the standard error diffusion algorithm on an image with large shadow areas.

Figure 2. Applying the proposed algorithm to the same input image as used in Figure 1.

an error e which is defined as $e = i_{mod} - b$. This error is used in creating the modified input value for future pixels in order to minimize the overall error of the binarization. The error is spread over a neighbohood of unprocessed pixels, by means of a weighting matrix.

Figure 1 shows the result of processing an image with the original error diffusion algorithm. It should be noted that this image was selected to show some of the deficiencies of the algorithm and is not representative for its performance on the majority of images.

The picture used as input for the binarization has large shadow areas that result in an error diffusion reproduction with a very non-homogeneous pulse distribution. This paper will refer to the artifacts seen in Figure 1 as “worms”. Figure 1 is an extreme exqample, but large dark or light areas are often encountered in documents containing graphics, and the same artifacts appear in graphics.

The following section describes a method to create a more homogeneous pulse distribution in the shadow areas (and due to symmetry also in the highlight areas) of an image. This is achieved by replacing the constant threshold in error diffusion with a dynamic threshold.

3 Threshold Imprints

In order to create a more homogeneous pulse distribution in the shadow and highlight areas, the threshold modulation has to discourage “black” pixels in the neighborhood of other “black” pixels in the highlight area, and discourage “white” pixels in the neighborhood of other “white” pixels in the shadow area. This is achieved by raising the threshold (assuming “white” = “1”) in the shadow region as soon as a “white” pixel is set, and thereby reducing the likelihood of another “white” pixel nearby, and by lowering the threshold in the highlight region as soon as a “black” pixel is set (this increases the likelihood of a “white” pixel, and consequently reduces the likelihood of a “black” pixel). Figure 2 shows the result of using such an algorithm on the same input image as used in Figure 1. The change in the homogeneity of the pulse distribution in the shadow areas is clearly visible.

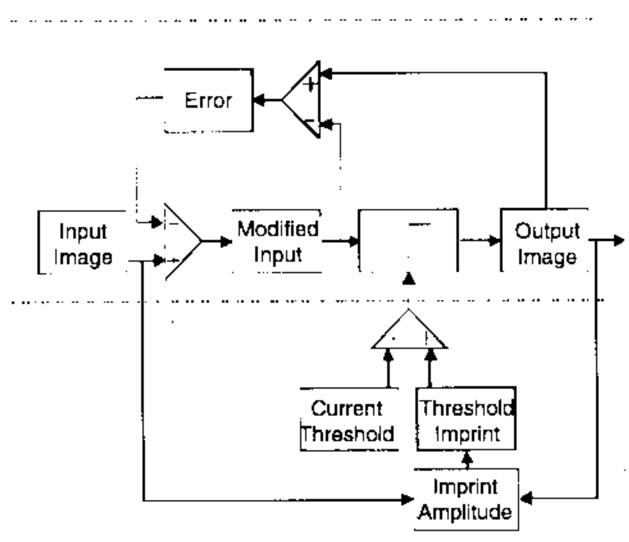

Figure 3. Flowchart of the proposed algorithm.

The change in the pulse distribution was obtained by generating a threshold imprint that lowered the threshold each time a black pixel is set and raised the threshold each tima a white pixel is set. The amplitude of the imprints was balanced in a way that the amplitude of the threshold imprint for a black pixel in a region of 1/5 intensity was 1/4 of the amplitude for the imprint of a white pixel at the same intensity. in this way, 4 black plus 1 white imprint cancel each other out (this is only approximately true, since the imprints are executed at different locations).

Figure 3 shows a flowchart of the proposed algorithm, where the original error diffusion algorithm is contained in the dotted line.

4. Conclusion

Threshold modulation can be a powerful tool to influence the distribution of output pulses in error diffusion. This talk described the use of an input and output dependent threshold imprint to reduce the common shadow and highlight artifacts of error diffusion. The modifications are straightforward and do not change the general scope of the algorithm. The improved shadow and highlight behaviour of the algorithm enhances the image quality for a large number of images, and—maybe more importantly—generates pleasing outputs for documents containing business graphics, such as bar-charts, pie-charts, etc.

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[1] A full paper describing the work has been submitted to the *IS&T/SPIE Journal of Electronic Imaging*

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