4-ROW SERPENTINE TONE-DEPENDENT FAST ERROR DIFFUSION*

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Motivation

Since conventional error diffusion is computed in raster, it produces worm artifacts in the highlights and shadows. In addition, as a serial algorithm, it limits the efficiency and flexibility of hardware implementations.

Goal: to optimize efficiency and locality of some hardware implementations while maintaining good image quality.

Background

Tone-dependent fast error diffusion (TDFED) is a neighborhood operation that moves through the input image in a designated order, quantizing each pixel and feeding the error back to the neighboring pixels with the tone-dependent weights and thresholds.

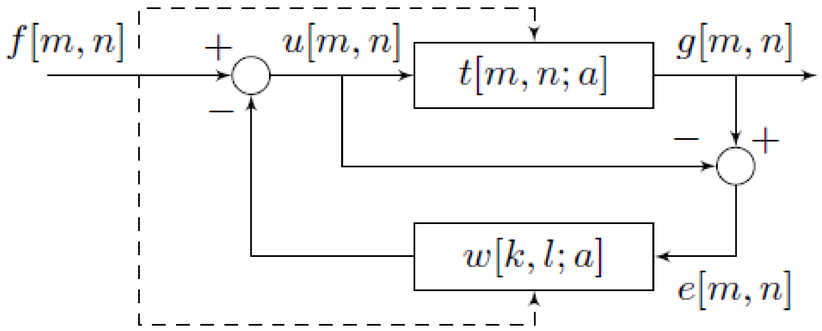

Figure 1. Tone-dependent fast error diffusion system.

Scan Path

In 4-row serpentine TDFED, every 4 rows of an input image are grouped as a swath. As depicted by the arrows in Fig. 2, inside each swath, error diffusion starts from the first pixel of the first row, and then it advances rightward along the first row in raster scan order until the next row is activated.

The activation condition is that the binarization of d pixels in the preceding row has been finished, where d is defined as the delay between the processing of sequential lines in the 4-row swath.

1	2	3	4	6	8	10	13	16	19	23	27
5	7	9	11	14	17	20	24	28	31	34	37
12	15	18	21	25	29	32	35	38	40	42	44
22	26	30	33	36	39	41	43	45	46	47	48
75	71	67	64	61	58	56	54	52	51	50	49
85	82	79	76	72	68	65	62	59	57	55	53
92	90	88	86	83	80	77	73	69	66	63	60
96	95	94	93	91	89	87	84	81	78	74	70
...	...	...	...	...	...	...	...	...	...	...	...

Figure 2. Scan path of 4-row serpentine scan with 3 pixel delay.

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Error Weight Location Matrix

Spreading the quantization error over a wider region can effectively disperse the worms. In 4-row serpentine TDFED, diffusing the errors to a further location requires an increase in the delay. We explored delays of 2, 3, and 6 pixels, which allow an increasingly larger spatial spread in the tone-dependent weight location matrix.

			$*$	w_1
w_4		w_3	w_2	

$\frac{1}{255} \le a \le \frac{63}{255}, \frac{192}{255} \le a \le \frac{254}{255}$

	$*$	w_1
w_4	w_3	w_2

$\frac{64}{255} \le a \le \frac{191}{255}$

	$*$	
	w_2	

$a = 0, a = 1$

Figure 3. Expanded error weight location matrices designed for 3 pixel delay.

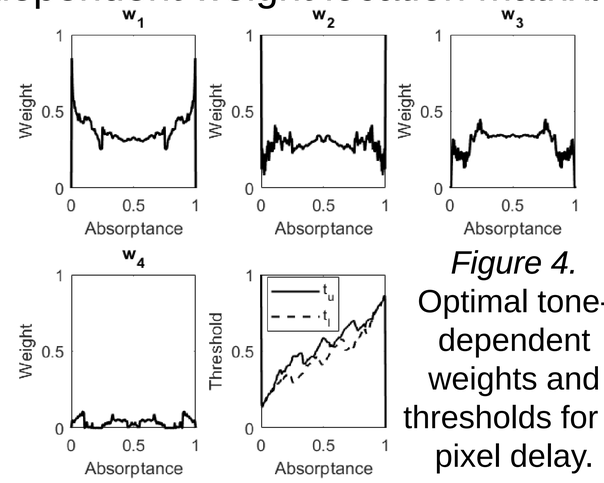
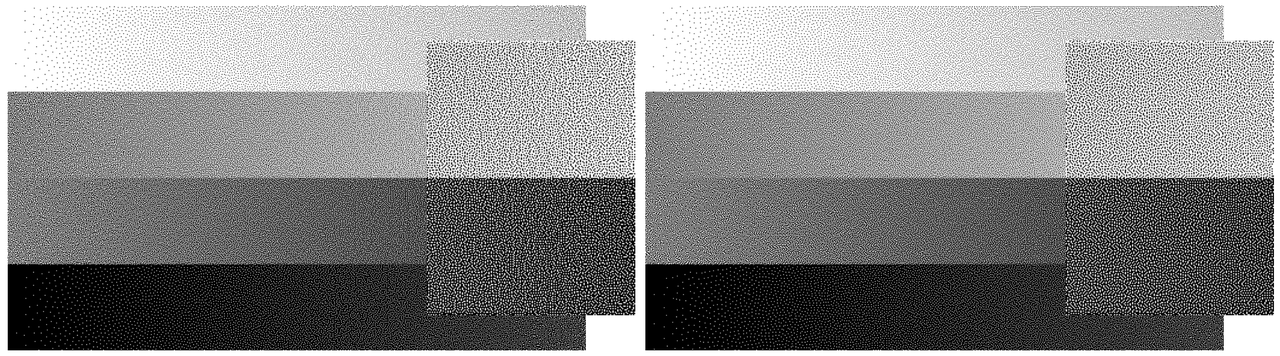


Figure 4. Optimal tone-dependent weights and thresholds for 3 pixel delay.

Results

- In the highlights and shadows, 3-pixel delay 4-row serpentine TDFED is comparable to 1 row serpentine TDFED.
- Fig. 5 (a) contains some vertical veining patterns in the zoomed in region. However, 4-row halftones are very smooth and homogeneous in that area.

Figure 5. Halftones of a folded ramp image generated by:



(a). The original 1-row serpentine TDFED *(b).* 4-row serpentine TDFED with 3 pixel delay

Conclusion

With a modest delay value, 4-row serpentine TDFED can achieve essentially the same or better image quality than that provided by the original 1-row serpentine TDFED, except perhaps in the extreme gray levels. Besides, it will also boost efficiency in some hardware implementations.