New Halftoning Method Combining the Best of Masking and Error Diffusion Algorithms

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Abstract

- **Two halftoning method**
  - **Masking**
    - Not producing worms
    - Limited spatial bandwidth
  - **Error diffusion**
    - Good rendition of very thin lines and patterns according to very broad bandwidth
    - Unpleasant worms

- **Proposed method**
  - Combining the advantage of both masking and error diffusion algorithm
Introduction

◆ Halftoning techniques
  – Point operation
    • Halftoning through usage of mask
    • Low computation consuming
    • Limitation of high frequencies
    • Ordered dither
  – Neighborhood operation
    • Using threshold and dispersed error to neighbor pixels
    • High computation consumption and better render in the high frequency
    • Unpleasant artifacts

◆ Proposal
  – New algorithm combining the benefits of ordered dither and error diffusion
Test image

◆ Aim
  – Discrimination of the quality of rendition

◆ Focusing field
  – Graininess and pattering
    • Using uniform gray patches and a grayscale
  – Spatial bandwidth
    • Thin lines on a grayscale background
  – Global quality
    • Photographic image
Error diffusion and ordered dither algorithms

Error diffusion

- **Benefit**: broad spatial bandwidth
  - Well defined thin lines and not blurred contour
  - Homogeneous dot placement and visually pleasant

- **Disadvantage**
  - Wavy lines called worms
  - Unwanted texture – coarse noise pattern in the midtones
Ordered dither (masking)

- Employing output is function of the entry image pixel value and the pre-calculated matrix
- Two different masks
  - Hierarchical set of masks (dither matrix)
    - If in the gray level $n$ a dot is “on”, this dot will be “on” for all levels higher than $n$
  - Non hierarchical masks
    - Free of this constraint
Selecting one specific bitmaps, halftoning each gray level (not comparing)

Hierarchical and non hierarchical mask as well

Correlation between the masks for hierarchical mask

Uncorrelated mask for non hierarchical mask

If the pixel value is greater than the dither mask value, the output pixel is set to on

Conversely, the output pixel is set to off

Fig 2. Flow diagram for hierarchical ordered-dither algorithm.

Fig 3. Flow diagram for generic ordered-dither implementation.
- **Advantages and drawbacks**
  - **Correlated mask**
    - Narrow spatial bandwidth
      - Not well defined very thin lines
    - Not producing worms defect but having graininess
  - **Uncorrelated mask**
    - Optimized to have the best dot placement for each bitmap
    - Very pleasant in large uniform areas
    - Contouring effect pattern in continuously varying images
Discussion

- Error diffusion
  - Broad spatial bandwidth and a pleasant dot placement, but having the worms defect (fig. 8b, 9b and 10b)
  - Very pleasant for dot distribution, not appearing worms and coarse noise pattern (fig. 8b-2)
  - Unpleasant worms defect (fig. 8b-1)
  - Coarse noise patterns (fig. 8b-3 and 8b-4)
  - Unpleasant patterns in the gray scale (fig. 9b)
  - Well defined thin lines (fig. 10b)
  - Good thin details and coarse noise pattern (fig. 11b)
– Ordered dither (hierarchical masks)
  • More uniform dot placement and a limited spatial bandwidth (fig. 8c, 9c, and 10c)
  • Uniform dot placement without worms defects or coarse noise pattern (fig. 8c-1, 8c-3, and 8c-4)
  • Grainer than error diffusion (fig. 8c-2)
  • Blurred lines because of the limited bandwidth (fig. 10c)
  • Lack of thin details, not well defined contour, and not unpleasant patterns (fig. 11c)

– Improvement
  • Dot arrangement (detailed thin lines) with a broad bandwidth
  • Uniform (not grainy and worms free) dot distribution
Threshold modulation literature

◆ Former study
  – Output dependent threshold modulation
    • Using output function through output
    • Changing threshold to inhibit unwanted patterns

Fig 4. Error diffusion with threshold modulation output dependent.
Input dependent threshold modulation

- Employing the input function through input
- Modifying the threshold to enhance edges

Fig 5. Error diffusion with threshold modulation input dependent.
- **Image independent threshold modulation**
  - Not using a function of pixel value but function of pixel address
  - More edges enhancement
  - Similar to the result of threshold modulation by a random signal generator (high pass filter)

![Diagram](image.png)

**Fig 6.** Error diffusion with threshold modulation image independent.
Error diffusion combined with ordered dithering through threshold modulation

◆ Target
  – Placing one dot
    • Without disturbing the error diffusion in transition areas
    • Placing one dot made through masking

◆ Method
  – Using the output of ordered dithering as input of threshold modulation function
Fig 7. Proposed error diffusion algorithm with threshold modulation ordered dither dependent.

\[ F_k(Y_m) = T_0 - \frac{2 \cdot Y_m - 1}{k} \]

**where** \( T_0 \) is 0.5

\( k = \infty \) the behavior is identical to the error diffusion

\( k \leq 1 \) the behavior is identical to the masking

\( k = 3 \) is a good compromise
Results

**Proposed method**

- Broad spatial bandwidth and a pleasant dot placement (fig. 8d, 9d, and 10d)
- Less worms in a very light area (fig. 8d-1)
- Disappeared coarse noise pattern and smaller graininess (fig. 8d-2, 8d-3, 8d-4)
- Disappeared coarse noise pattern and reduced graininess (fig. 9d)
- More contrasted in the lines and similar as error diffusion (fig. 10d)
- Not spoilt by noise coarse patterns in the surface of rose and sharp all details (fig. 11d)
a) Uniform patches and continuous tone image.

b) Uniform patches halftoned by Floyd-Steinberg error diffusion.

c) Uniform patches halftoned by hierarchical ordered dither.

d) Uniform patches halftoned by proposed algorithm.

Fig 8. Uniform patches, respectively 2%, 12%, 25% and 50% coverage.
Fig 9. Gray scale.

a) Grayscale contone image.

b) Grayscale halftoned by Floyd-Steinberg error diffusion.

c) Grayscale halftoned by hierarchical ordered dither.

d) Grayscale halftoned by proposed algorithm.
Fig 10. Thin lines on grayscale background.

a) Grayscale contone image.

b) Grayscale halftoned by Floyd-Steinberg error diffusion.

c) Grayscale halftoned by hierarchical ordered dither.

d) Grayscale halftoned by proposed algorithm.
a) Photographic image, original version.

b) Photographic image halftoned by Floyd-Steinberg error diffusion.

c) Photographic image halftoned by hierarchical ordered dither.

d) Photographic image halftoned by proposed algorithm.
Conclusion

◆ Propose method
  – Combining the advantages of both error diffusion and masking

◆ Effect
  – Broad bandwidth
  – Pleasant dot placement
  – Reduced worms defect