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Adaptive inverse halftoning for scanned document images through multiresolution and multiscale analysis

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Abstract

This paper describes an efficient algorithm for inverse halftoning of scanned document images to resolve problems with interference patterns such as moiré and graininess when the images are displayed or printed out. The algorithm is suitable for software implementation and useful for high quality printing or display of scanned document images delivered via networks from unknown scanners. A multi-resolution approach is used to achieve practical processing speed under software implementation. Through data-driven, adaptive, multi-scale processing, the algorithm can cope with a variety of input devices and requires no information on the halftoning method or properties (such as coefficients in dither matrices, filter coefficients of error diffusion kernels, screen angles, or dot frequencies). Effectiveness of the new algorithm is demonstrated through real examples of scanned document images, as well as quantitative evaluations with synthetic data.

Keywords: Document image processing; Network imaging; Color; Image quality; Moiré; Graininess; Inverse halftoning

1. Introduction

When we display or print out scanned document images (obtained through image input devices) without applying any image processing operations to them or after scaling or rotating them, we often observe image distortions or degradations such as moiré phenomena and graininess. Halftone areas on printed document images consist of dot patterns generated by screening methods or error-diffusion algorithms. Such dot patterns often interact with image processing operations (halftoning, scaling, etc.) performed by output devices such as printers or displays. This problem of image degradation can be resolved if halftone areas composed of dot patterns are transformed to ideal continuous-tone representations. Such an operation of restoring ideal continuous-tone representations from halftone dot patterns is usually referred to as *inverse halftoning*. In designing inverse halftoning algorithms for scanned document images, we require that characters, graphics such as line drawings, and significant edges be preserved without being blurred.

Such processing for improving image quality has been embedded into imaging devices such as copiers. In particular, there have been a number of methods for inverse halftoning. Methods applicable to halftone patterns generated by screening methods and error-diffusion algorithms are nonlinear permutation filters [1], a combination of Gaussian filters, median filters, and edge enhancement [2], and a wavelet-based method [3]. Statistical approaches include a convex-projection method using knowledge on error-diffusion kernels and nonlinear optimization [4], MAP projection and estimation of error-diffusion kernels using a modified LMS method [5], Bayesian estimation with nonlinear optimization [6], and MAP projection using wavelet [7]. However, they require expensive computation

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because iterative computations are involved. Kite et al. [8], Roetling [9,10], Miceli and Parker [11], and Chen and Hang [12] employ space-variant linear filters along with multi-scale gradient information. A hybrid LMS-MMSE method [13] and an LUT-based method [14] are computationally inexpensive.

In network and Internet environments, digital image data acquired with any input device can be transmitted to remote sites over networks, and the recipient can display or print out the image data delivered via networks from unknown input devices. Under these conditions, image data must be processed with software on individual PCs so that images can be printed or displayed in adequate quality without annoying distortions or degradations. Now, new technical requirements have emerged as follows:

(1) Practical processing speed must be achieved under software implementation.

Under network environments, image data delivered via network from remotely located input devices are often processed on individual PCs for improving image quality when the data are displayed or printed out. Practical processing speed must be achieved under software implementation on PCs. If space-variant linear filters or wavelet-based inverse halftoning algorithms are implemented with software, computation time is not acceptable when they are applied to scanned color document images of A4 or letter size.

(2) Image processing systems and algorithms must easily adapt to a variety of input devices.

In image processing systems embedded into stand-alone imaging devices where input and output media are integrated into single devices, algorithms and parameters are designed so that they fit the color characteristics, resolution, and frequency characteristics (MTF) of particular devices. However, image-processing systems optimal for a particular imaging device are not necessarily effective for other devices with different characteristics. Under network environments, there are large variations in characteristics of imaging devices, and the characteristics are even unknown when image data are transmitted from a remote site. Therefore, image-processing systems and algorithms must easily adapt to a variety of input devices. For instance, satisfactory image quality should be achieved for image data obtained through an unknown scanner just by setting a few, simple parameters.

(3) Information on the halftoning methods or properties is not required.

Specific methods for inverse halftoning can be employed if information is available on the halftoning method or properties (such as coefficients in dither matrices, filter coefficients of error diffusion kernels, screen angles, and dot frequencies). However, our targets are scanned images of books, magazines, journals, and newspapers that have been printed through unknown printing processes. Furthermore, characteristics of halftone dot patterns cannot be extracted when the input device has a poor response to high frequencies or the image resolution is inadequate. Therefore, blind methods are required without depending on the type or properties of halftoning processes.

In this paper, we describe an efficient algorithm for inverse halftoning of scanned document images to resolve problems of interference patterns such as moiré and graininess when the images are displayed or printed out. The algorithm is suitable for software implementation and useful for high quality printing or display of scanned document images delivered via networks from unknown scanners. A multi-resolution approach is used to achieve practical processing speed under software implementation. Through data-driven, adaptive, multi-scale processing, the algorithm can cope with a variety of input devices and requires no information on the halftoning method or properties (such as coefficients in dither matrices, filter coefficients of error diffusion kernels, screen angles, or dot frequencies). Effectiveness of the new algorithm is demonstrated through real examples of scanned document images, as well as quantitative evaluations with synthetic data.

This paper is organized as follows: An overview of the proposed algorithm is given in Section 2. The details of the algorithm are presented in Section 3. Examples and experimental results are shown in Section 4. Section 5 is the conclusion.

2. Outline

We outline the approach to resolving the three problems mentioned in Section 1. The overall architecture is shown in Fig. 1. A multi-resolution approach is used to achieve practical processing speed under software implementation. In each resolution, through data-driven, adaptive, multi-scale processing, the algorithm can cope with a variety of input devices and requires no information on the halftoning method or properties.

2.1. Multi-resolution analysis

According to the mixed raster content (MRC) imaging model, a document image is composed of the following two components:

- Foreground: texts, graphics (line drawings, in particular), and significant edges
- Background: other areas (continuous tone areas).

There are few significant edges in the background, which can be compressed to low resolution such as 100 dpi with-