Comparative Analysis of Inverse Halftoning Techniques

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Motivation

- **Halftoning** (or **dithering**): image compression technique which reproduces tone with a limited colour palette (e.g. black and white) using distribution of halftone dots.
- **Inverse halftoning**: retrieval of continuous-tone images from halftoned images.
- **Applications:**
  - recovery and preservation of printed media [3]
  - image editing [3]
  - use of dithered images for lower bandwidth websites [1]
- **Problem: i**nverse processes can be energy intensive.
- **Goal**: evaluate techniques for inverse halftoning based on a standard of quality that considers both **reconstructed image quality** and **computational efficiency**.

Related Work

Many methods for inverse halftoning [3, 4, 6]:

- **Low-pass filter**: simplest, but causes edge information to be lost [3].
- **Look-up-table (LUT):** improved both reconstruction accuracy and efficiency in comparison to previous implementations [3].
- **Neural networks and deep learning:** Xia et al. [6] achieved state-of-the-art performance using progressive residual learning.
- Edge-preserving denoising techniques (e.g. bilateral).

References

[1] De Decker, K., & Grosjean, V. (2007). Low-Tech Magazine. *LOW← TECH MAGAZINE https://solar.lowtechmagazine.com/about. html.*

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[3] Mese, M., & Vaidyanathan, P. P. (2001). Look-up table (LUT) method for inverse halftoning. *IEEE Transactions on Image Processing*, *10*(10), 1566-1578.

[4] Mese, M., & Vaidyanathan, P. P. (2002). Recent advances in digital halftoning and inverse halftoning methods. *IEEE Transactions on Circuits and Systems I: Fundamental Theory and Applications*, *49*(6), 790-805.

[5] Ulichney, R. A. (1988). Dithering with blue noise. *Proceedings of the IEEE*, *76*(1), 56-79.

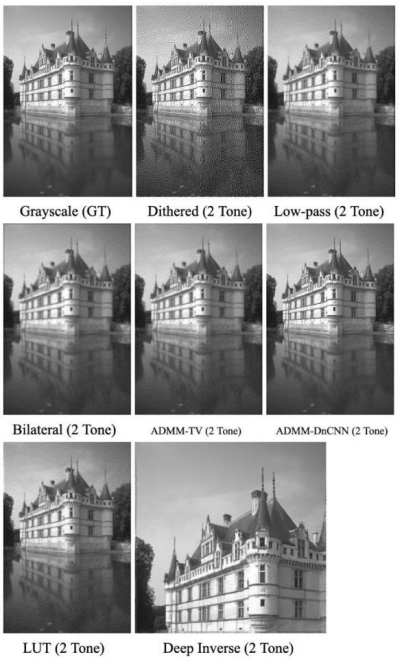
[6] Xia, M., Hu, W., Liu, X., & Wong, T. T. (2021). Deep halftoning with reversible binary pattern. In *Proceedings of the IEEE/CVF International Conference on Computer Vision* (pp. 14000-14009).

Methods

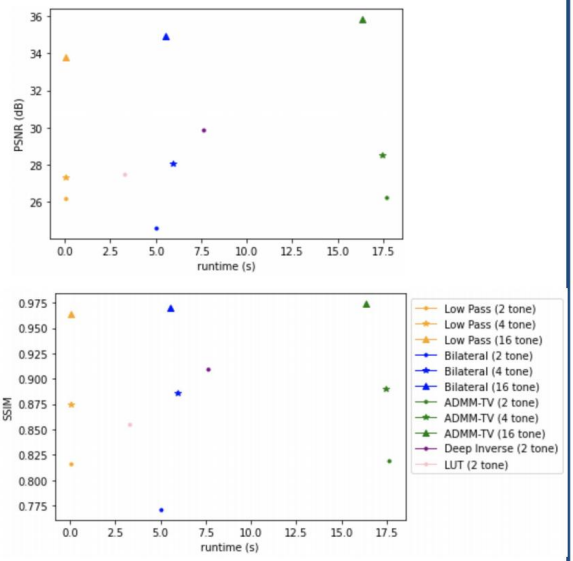
- We used Floyd-Steinberg dithering to generate image sets with (i) 2 tone, (ii) 4 tone, and (iii) 16 tone colour palettes [5, 6].
  - 200 training images, 100 test images from BSDS300 dataset [2].
- Implemented 6 inverse halftoning techniques:
  - (1) a **low-pass filter***
  - (2) **bilateral filter***
  - (3) **Alternating Direction Method of Multipliers (ADMM)** with **Total Variation (TV)***
  - (4) **ADMM** with a **denoising convolutional neural network (DnCNN)***
  - (5) Mese and Vaidyanathan's **LUT** [3]
  - (6) Xia et al.'s **deep learning** technique [6].
- Evaluated techniques based on average peak signal-to-noise ratio (PSNR), Structural Similarity Index (SSIM), and runtime per image.

* For techniques 1, 2, 3, 4, we conducted a hyperparameter search, and used the parameters which gave the highest average PSNR / SSIM

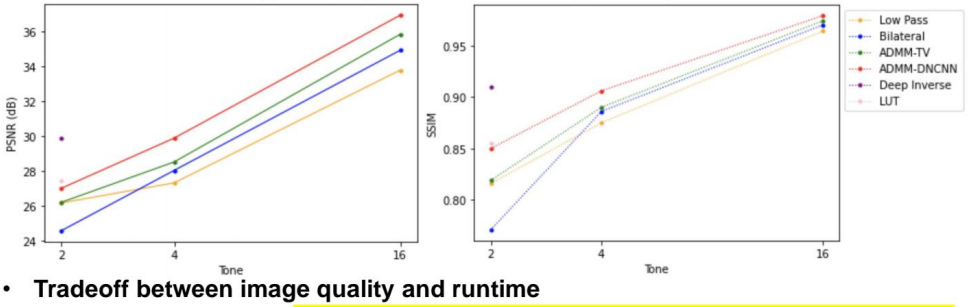
Experimental Results



Reconstructed Image Quality vs. Runtime



Reconstructed Image Quality vs. Dithered Image Compression Level



- **Tradeoff between image quality and runtime**
  - For 2 tone images, **deep inverse, LUT, and low pass have best image quality-to-runtime ratio**
    - Deep inverse and LUT give highest quality results, low pass is fastest
- For higher tone images (less compressed), low pass and general denoising approaches become more interesting
  - Do not require re-training for different compression levels
  - LUT would not perform as well on higher tone images
- **These plots can guide algorithm choice** depending on desired image quality, number of images to be converted
  - Training time for deep inverse and LUT should also be taken into consideration