Improved Performance of Inverse Halftoning Algorithms via Coupled Dictionaries

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by

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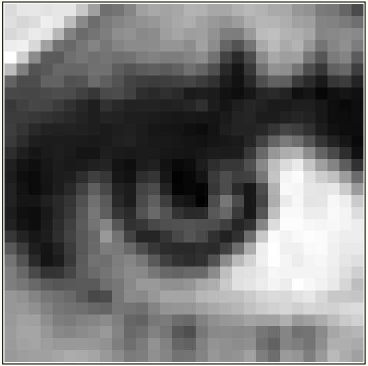
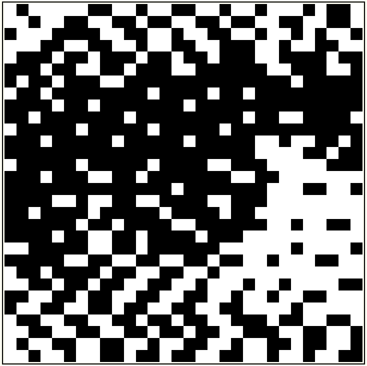
Motivation

Halftoning

Grayscale $\longrightarrow$ Binary image

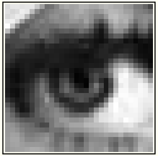




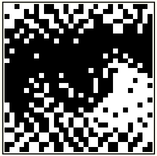
Halftoning Algorithms

- Ordered Dithering (OD)
  - Clustered-dots
  - Dispersed dots (Bayer)
  - Central white point
- Error Diffusion (ED)
  - White noise
  - Floyd-Steinberg
  - Jarvis
  - Stucki
- Dot Diffusion (DD)
  - Block truncation coding
  - Electrostatic halftoning
  - Neural-net based
- Direct Binary Search
  - Adaptive Search
  - Hard Circular Dots
  - Error minimization

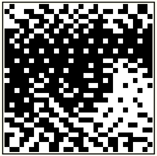
Examples of Halftones



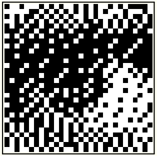
Grayscale



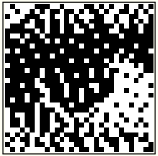
Atkinson



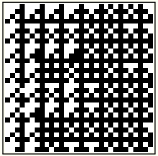
Burkes



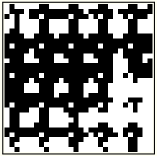
Floyd-Steinberg



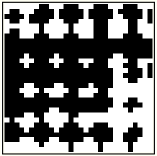
Jarvis



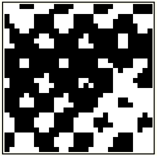
Bayer (OD)



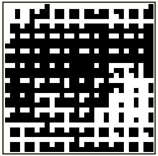
Centralized Point



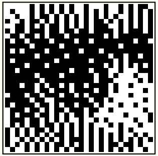
Clustered Dot



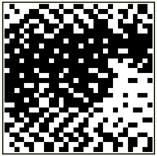
Diagonal Matrix



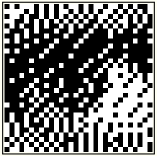
Dispersed Dots



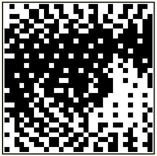
Shiufan



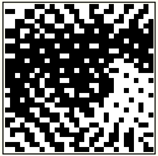
Stuki



Sierra (v1)



Sierra (v2)

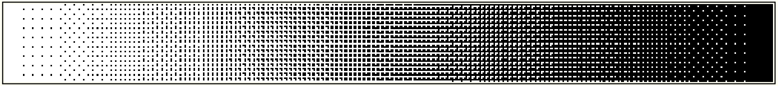


Sierra (v3)

Inverse Halftoning

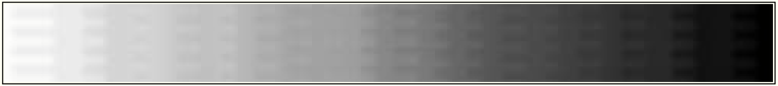
Grayscale (I_g)

$\downarrow$ Halftone $\qquad I_b = f(I_g)$



Binary (I_b)

$\downarrow$ Inverse Halftone $\qquad \hat{I}_g = f^{-1}(I_b) : I_g = \hat{I}_g + \epsilon$



Recovered Grayscale ($\hat{I}_g$)

Inverse Halftoning

- There is loss of information in halftoning;

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- The inverse problem:
  - $I_b = f(I_g) \quad \xrightarrow[?]{I_g \sim \hat{I}_g} \quad \hat{I}_g = f^{-1}(I_b)$
- The inverse problem is usually non-linear.
  - Find $\hat{I}_g$ such that

    $$\|I_g - \hat{I}_g\| \leq \epsilon$$

    ϵ is the distortion.

Inverse Halftoning

- There are different halftoning methods.
- Inverse halftoning methods are usually designed to restore the grayscale levels from specific halftoning algorithm.
- Different inverse halftoning algorithms may produce different visual artifacts (noise, blur, color bleeding, etc).

Original

WInHD (error diffusion)

FIHT (ordered dithering)

Proposed Method

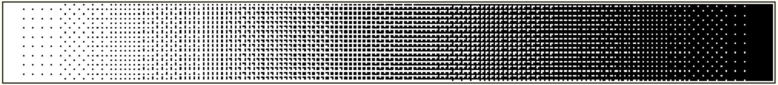
Research Question

Instead of developing a new inverse halftoning algorithm, can we use images generated with existent methods as an initial guess to generate a better reconstructed multi-level images?

Overview

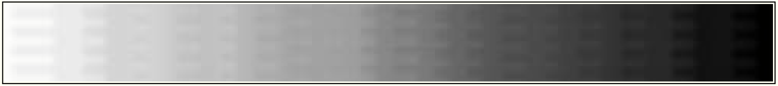
Grayscale (I_g)

↓ Halftone $$I_b = f(I_g)$$



Binary (I_b)

↓ Inverse Halftone $$I_g = \hat{I}_g + \epsilon$$



Recovered Grayscale ($\hat{I}_g$)

↓ Concealed Distortions $$I_g = \tilde{I}_g + \sigma : \sigma < \epsilon$$

Undistorted Grayscale ($\tilde{I}_g$)

Proposed Method

- Enhance the visual quality of images reconstructed using inverse halftoning techniques;
- Inverse halftoned images are the *distorted versions* of the original images.

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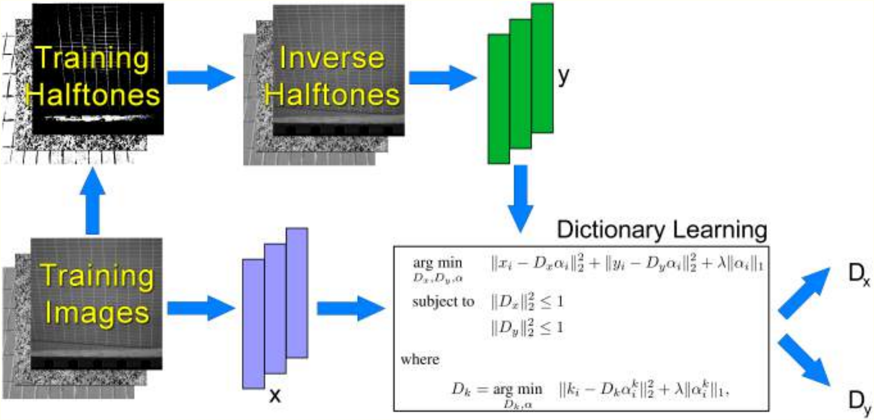
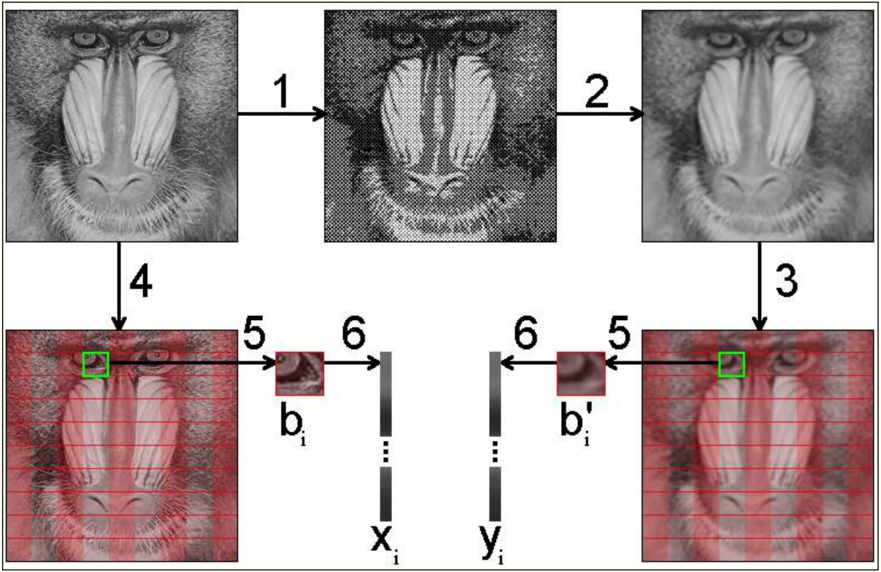
- Enhance the visual quality of images reconstructed using inverse halftoning techniques;
- Inverse halftoned images are the *distorted versions* of the original images.
- The sparse representation of signals shows there are linear relationships among non-distorted and distorted signals – it is possible to reconstruct an approximation of the original image from its distorted version;
- A dictionary learning method finds a dictionary that sparsely encodes the fitted data;

Proposed Method



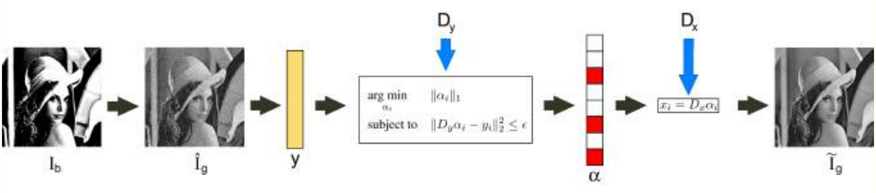
Texture set of USC-SIPI Image Database

Proposed Method



Restoration Stage

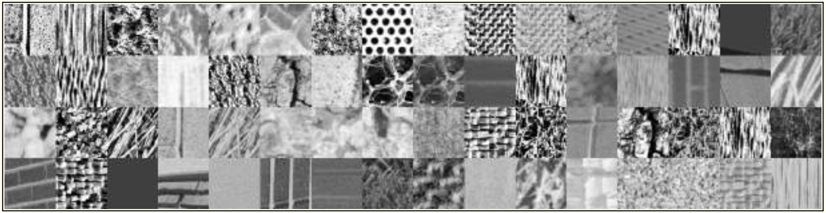
1. Extract the distorted patches y_i from $\hat{I}_g$
2. For each i-th distorted path, find the sparse representation corresponding to D_y (using a linear regression statistical technique with ℓ_1-norm)
3. Obtain the corresponding non-distorted patch x_i;
4. Generate the reconstructed image $\tilde{I}_g$ by substituting each non-distorted patch $\{x_i\}$ in the corresponding position of the binary image.



Results

Training Set

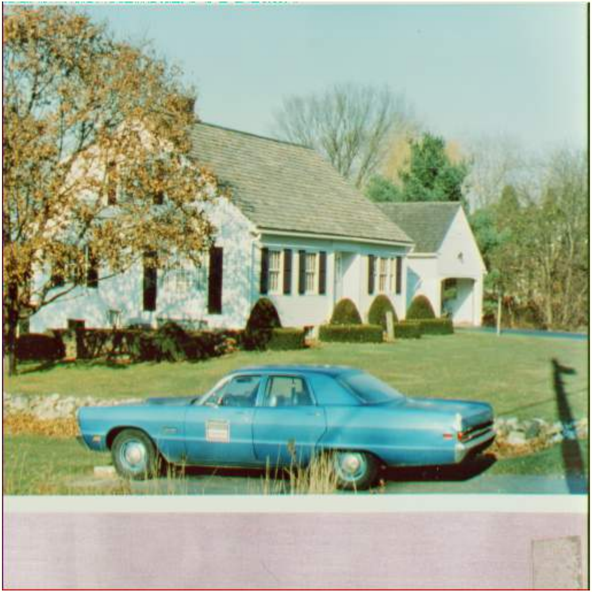
- 64 training images from USC-SIPI image database (Texture set).
- Textures: from coarse to fine and from smooth to busy.
- Patches are sampled randomly from these images.



Test Set

- 8 test images from USC-SIPI image database (Miscellaneous set).
- Tested inverse halftoning techniques:
  - Wavelet-based Inverse Halftoning via Deconvolution (WInHD)
  - Fast Inverse Halftoning Algorithm for Ordered Dithered Images (FIHT)

Subjective results



Original

Subjective results

Subjective results

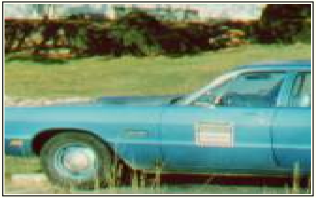
Subjective results


Original


WInHD


WInHD+CD

Subjective results



Original

WInHD

WInHD+CD

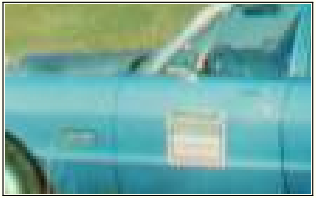
Subjective results

Original

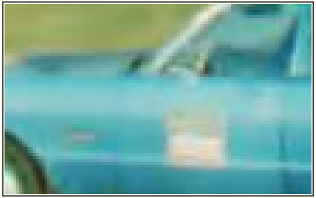
WInHD

WInHD+CD

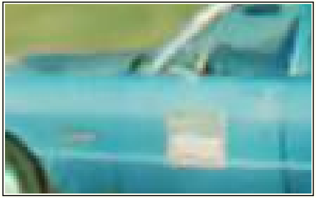
Subjective results



Original



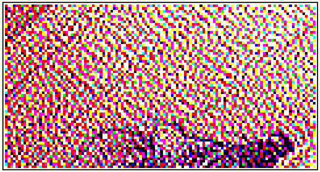
WInHD



WInHD+CD

Subjective results

(a) original image



(b) Halftoned (Jarvis)

(c) Halftoned (OD)

(d) CD from Jarvis

(e) WInHD

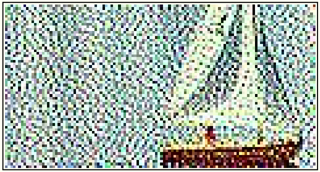
(f) WInHD+CD

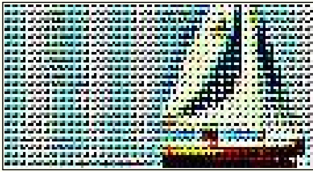
(g) FIHT

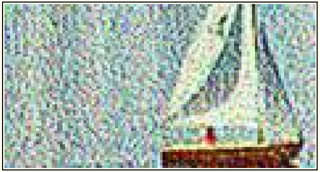
(h) FIHT+CD

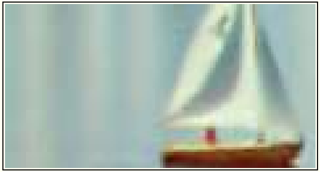
Subjective results


(a) original image

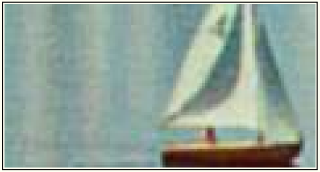

(b) Halftoned (Jarvis)

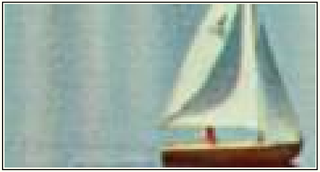

(c) Halftoned (OD)


(d) CD from Jarvis

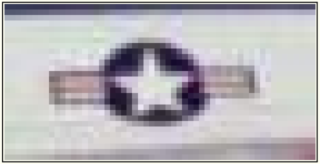

(e) WInHD

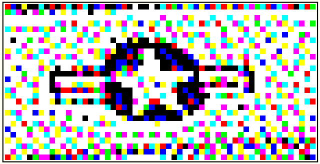

(f) WInHD+CD

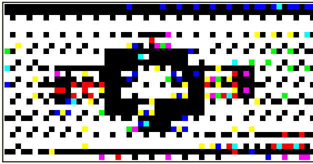

(g) FIHT

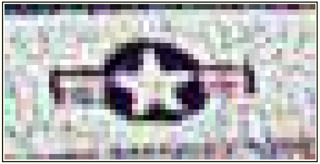

(h) FIHT+CD

Subjective results

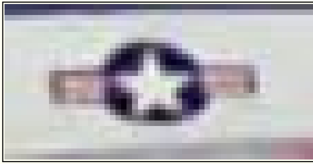

(a) original image


(b) Halftoned (Jarvis)


(c) Halftoned (OD)


(d) CD from Jarvis


(e) WInHD


(f) WInHD+CD


(g) FIHT


(h) FIHT+CD

Objective results

SSIM Image	WInHD	WInHD+CD	FIHT	FIHT+CD	CD
Airplane	0.91833	0.92137	0.88987	0.91487	0.51259
Baboon	0.76191	0.76934	0.83559	0.85362	0.57378
Girl	0.82917	0.83345	0.88337	0.90417	0.59847
House	0.88919	0.89611	0.89713	0.92071	0.50451
Lena	0.88623	0.89091	0.86406	0.88107	0.41437
Peppers	0.85510	0.85742	0.84406	0.86044	0.47974
Sailboat	0.84204	0.84621	0.83499	0.85400	0.55574
Splash	0.89055	0.89378	0.85100	0.86376	0.48803
Average	0.85906	**0.86355**	0.862509	**0.88158**	0.51590

Conclusions

Conclusions

- We presented an approach to improve the quality of images reconstructed using inverse halftoning algorithms.
- Framework is based on coupled dictionaries, trained using original images and images reconstructed using inverse halftoning algorithms.
- Experimental results show that it is able to conceal distortions caused by inverse halftoning techniques.
- Future works:
  - A study to find an optimal parameter for model to improve the results.
  - Investigation of the effect of the training image database on quality of the restored images.

Conclusions

Thank you.

Questions?

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