Embedding Color Watermarks into Halftoning Images using Minimum-Distance Binary Patterns

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by

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Overview

Motivation

Proposed Method

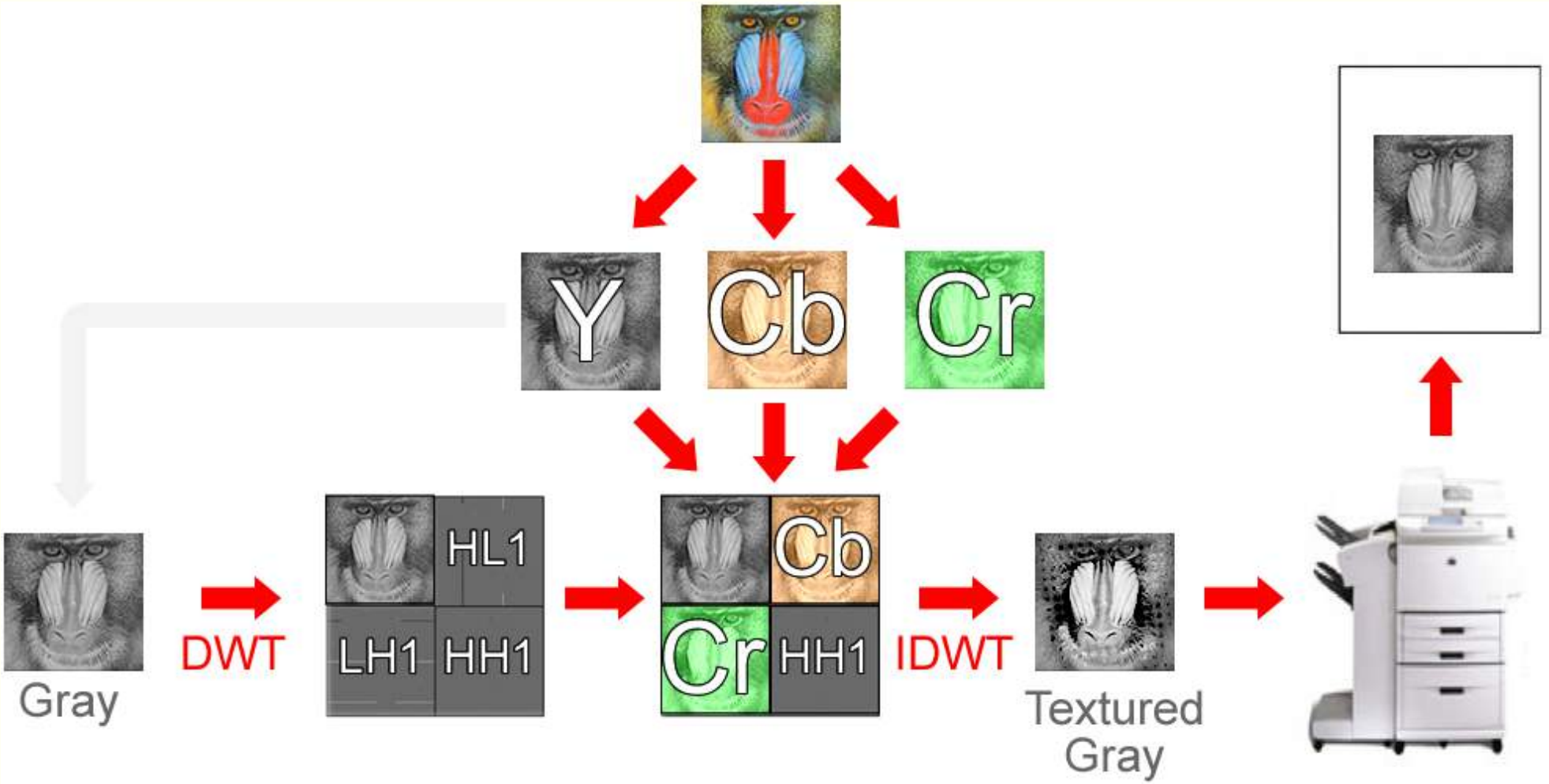
Results

Conclusions

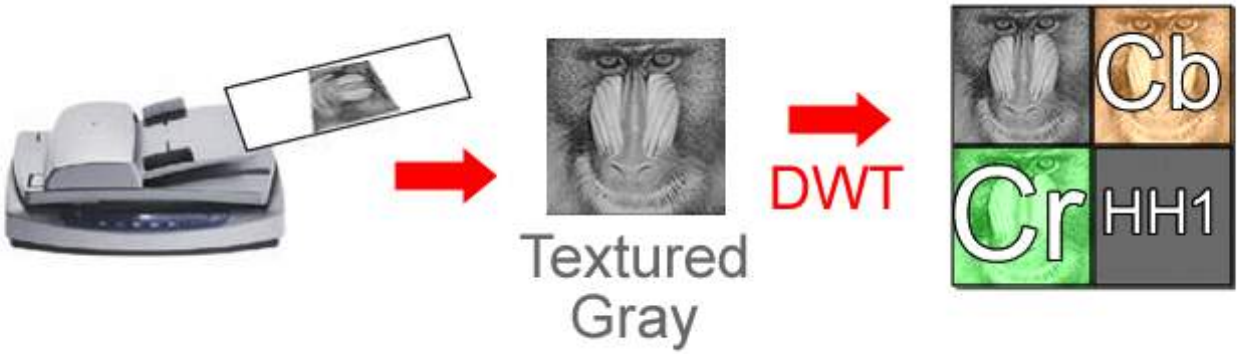
Motivation

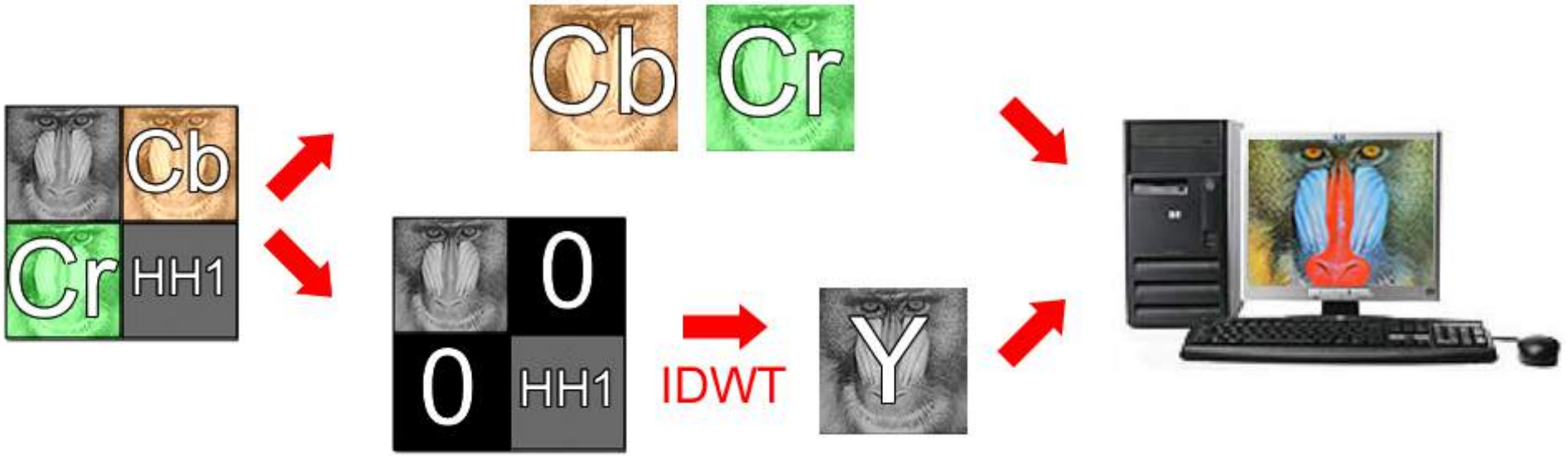
Colors in Hardcopy

Naive Watermarking



Naive Restoration





Background

- Published studies based on this type approach
  - DE QUEIROZ, Ricardo L.; BRAUN, Karen M. **Color embedding into gray images**. In: Image Processing, 2005. ICIP 2005. IEEE International Conference on. IEEE, 2005. p. III-944-7.
  - DE QUEIROZ, Ricardo L.; BRAUN, Karen M. **Color to gray and back: color embedding into textured gray images**. Image Processing, IEEE transactions on, v. 15, n. 6, p. 1464-1470, 2006.
  - DE QUEIROZ, Ricardo L. **Improved Reversible Mapping from Color to Gray**. In: SIBGRAPI. 2007. p. 113-120.
  - KO, Kyung-Woo et al. **Color embedding and recovery based on wavelet packet transform**. Journal of Imaging Science and Technology, v. 52, n. 1, p. 10501-1-10501-10, 2008.
  - DE QUEIROZ, Ricardo L. **Reversible color-to-gray mapping using subband domain texturization**. Pattern Recognition Letters, v. 31, n. 4, p. 269-276, 2010.
  - KO, Kyung-Woo et al. **Color embedding and recovery using wavelet packet transform with pseudorandomized saturation code**. Journal of Imaging Science and Technology, v. 55, n. 3, p. 30501-1-30501-10, 2011.
  - MIYASHITA, Yuito et al. **Adaptive color-to-gray image mapping using directional transform**. In: Image Processing (ICIP), 2012 19th IEEE International Conference on. IEEE, 2012. p. 809-812.
  - ...

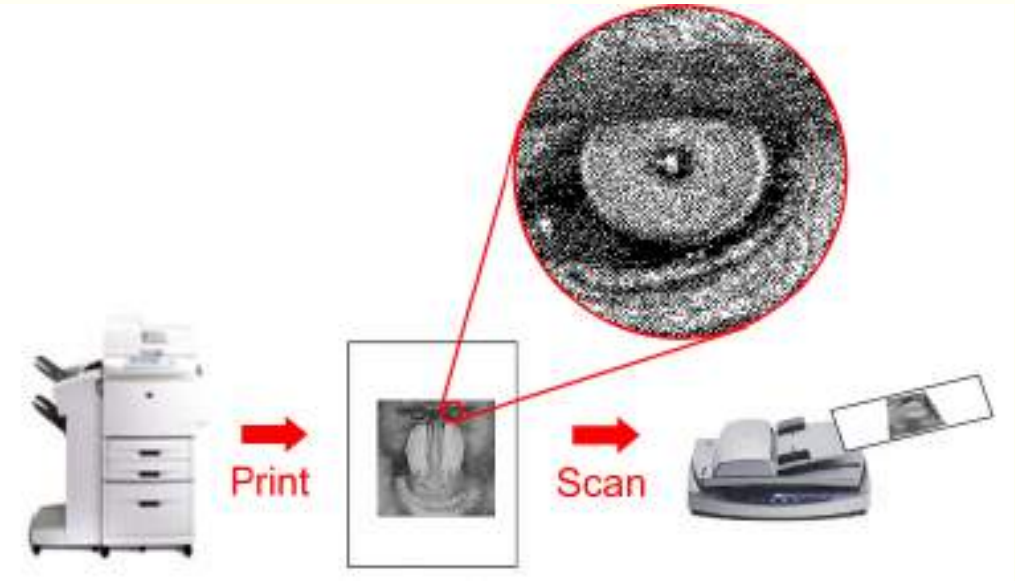
- KEKRE, H. B.; THEPADE, Sudeep D.; CHATURVEDI, Ratnesh N. **"Color to Gray and Back" Using DST-DCT, Haar-DCT, Walsh-DCT, Hartley-DCT, Slant-DCT, Kekre-DCT Hybrid Wavelet Transforms**. In: Proceedings of the Third International Conference on Soft Computing for Problem Solving. Springer India, 2014. p. 613-623.

Drawback 01

Textured grayscale (watermarked) presents aliasing effects.

Drawback 02

No robustness to print-scan process.



Print-scan channel

Original | Queiroz

Ko | Proposed

Proposed Method

Research Questions

1. Instead of improve the watermarking on grayscale domain, can we embed the color channels in halftone (binary) domain? (Improves robustness to print-scan channel)
2. Can we add more than two color channels? (Improves restoration color fidelity and expands watermarking applications)

Overview

Previous approaches:	Proposed approach:
Create watermark	Create watermark
↓	↓
Embed	Generate Halftones
↓	↓
Generate Halftone	Embed
↓	↓
Print	Print
↓	↓
Scan	Scan
↓	↓
Inverse Halftone	Restore Watermark
↓	↓
Restore Watermark	Inverse Halftones

Proposed Method

1. Generate a common representation for embedding and restoration steps (Mask generation).
2. Watermark Embedding (Encoding)
3. Watermark Extraction and Restoration (Decoding)

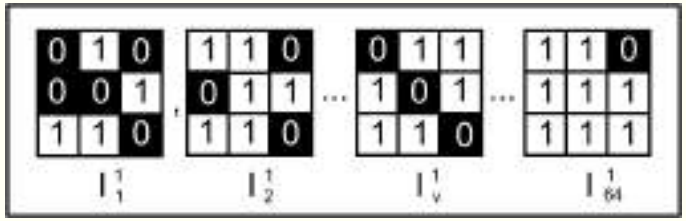
Mask Generation

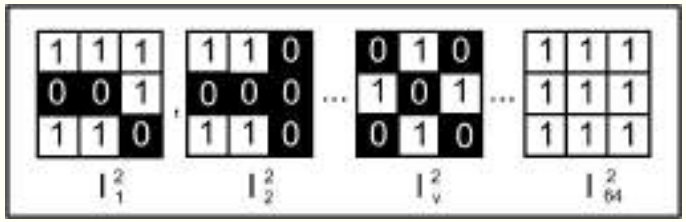
1. The encoding masks are generated by computing the finite n-ary Cartesian Product of the set $X = \{0, 1\}$

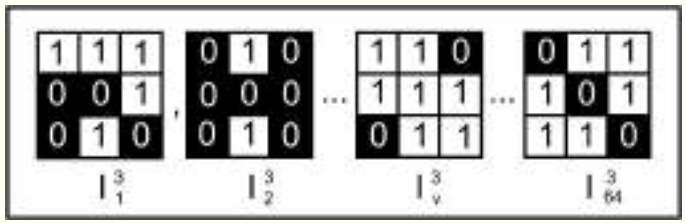
$$X^n = \prod_{k=1}^{n} X = \{(x_1, \ldots, x_n) : \forall k \in \mathbb{N}_n^* : x_k \in X\}$$

2. Use $n = 3$ to generate 2^3 combinations (keys).
3. Use $n = 9$ to generate 2^9 combinations (masks).
4. Distribute the masks in 2^3 distinct groups.

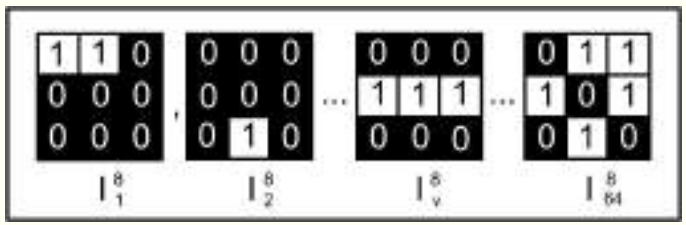
Mask Generation

$\tau_1 \mapsto$ 

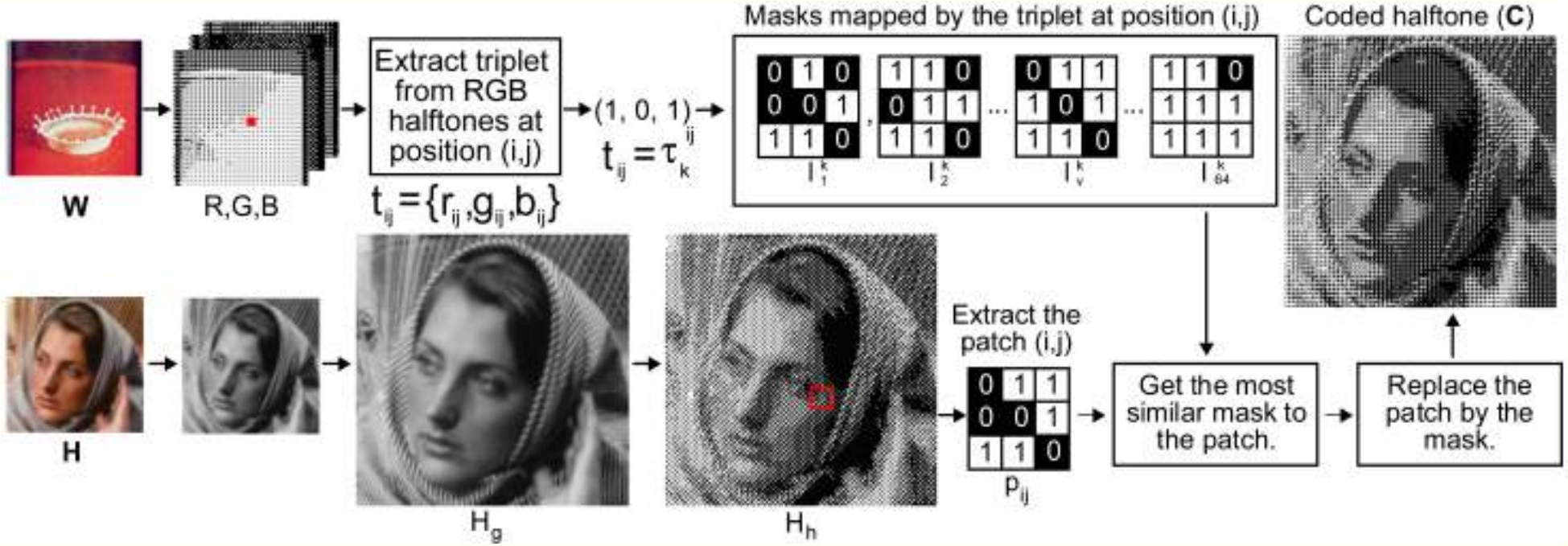
$\tau_2 \mapsto$ 

$\tau_3 \mapsto$ 

$\vdots \qquad \vdots$

$\tau_8 \mapsto$ 

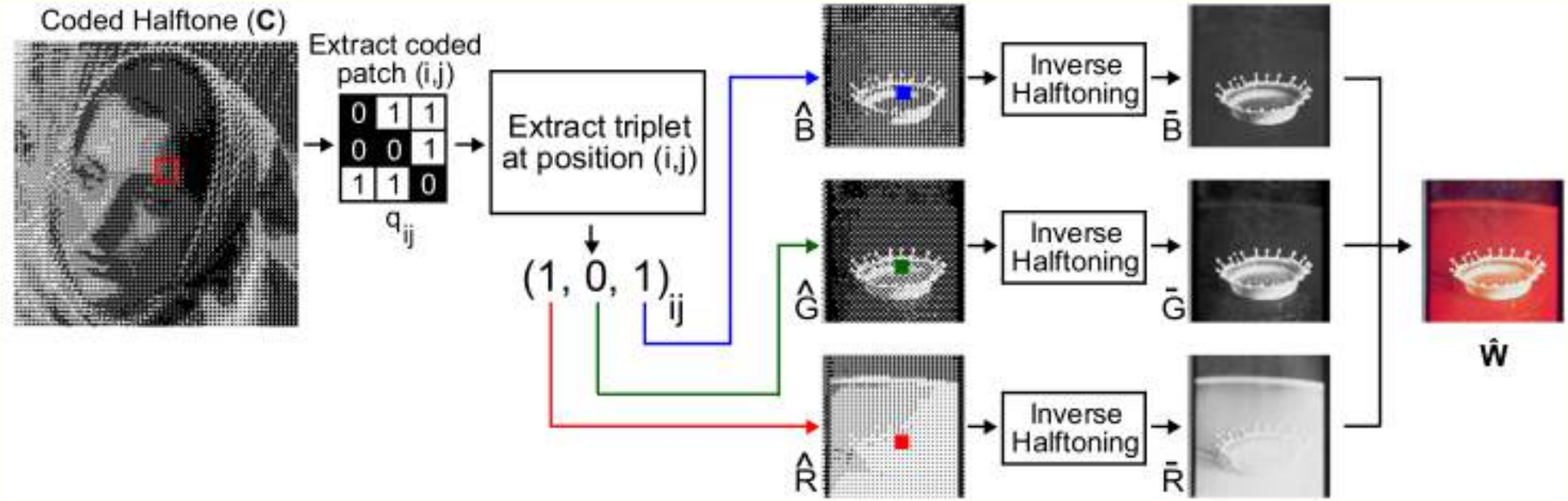
Watermark Embedding



The most similar mask is selected by minimizing the binary distance D (Dice, Jaccard, Sokal-Sneath, Russell, etc).

$$\begin{aligned} \arg\min_{Y} \quad & D(X, Y) \\ \text{subject to} \quad & X = p_{ij} \\ & Y \in L_k, \end{aligned}$$

Watermark Extraction (Decoding)



Results

Test Set

- 8 test images from USC-SIPI image database (Miscellaneous set).

Test Set

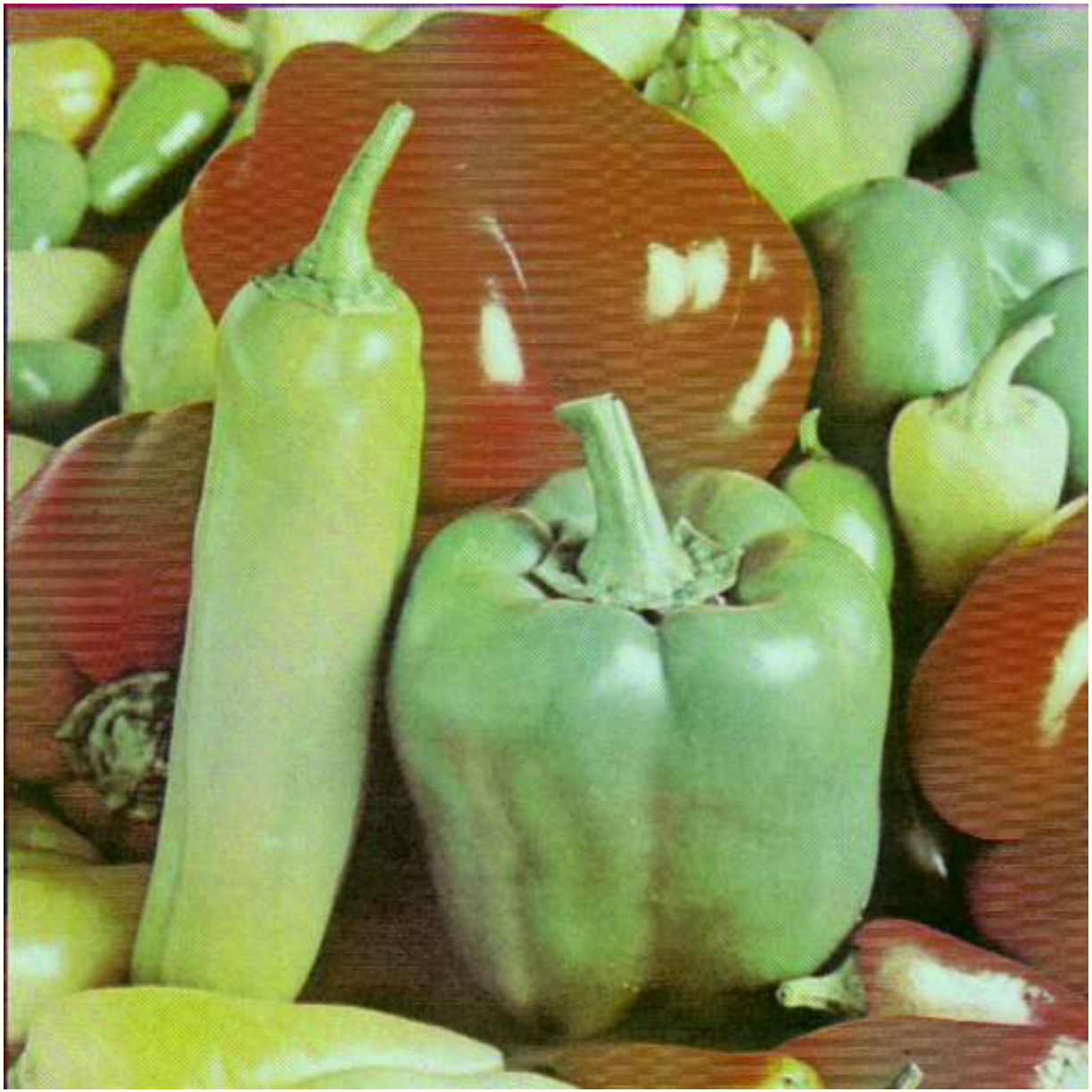
- Compared with two other 'color-to-gray-and-back' algorithms:
  - Queiroz: DE QUEIROZ, Ricardo L. **Reversible color-to-gray mapping using subband domain texturization**. Pattern Recognition Letters, v. 31, n. 4, p. 269-276, 2010.
  - Ko: KO, Kyung-Woo et al. **Color embedding and recovery based on wavelet packet transform**. Journal of Imaging Science and Technology, v. 52, n. 1, p. 10501-1-10501-10, 2008.

Subjective Results

Original

Subjective Results

Subjective Results

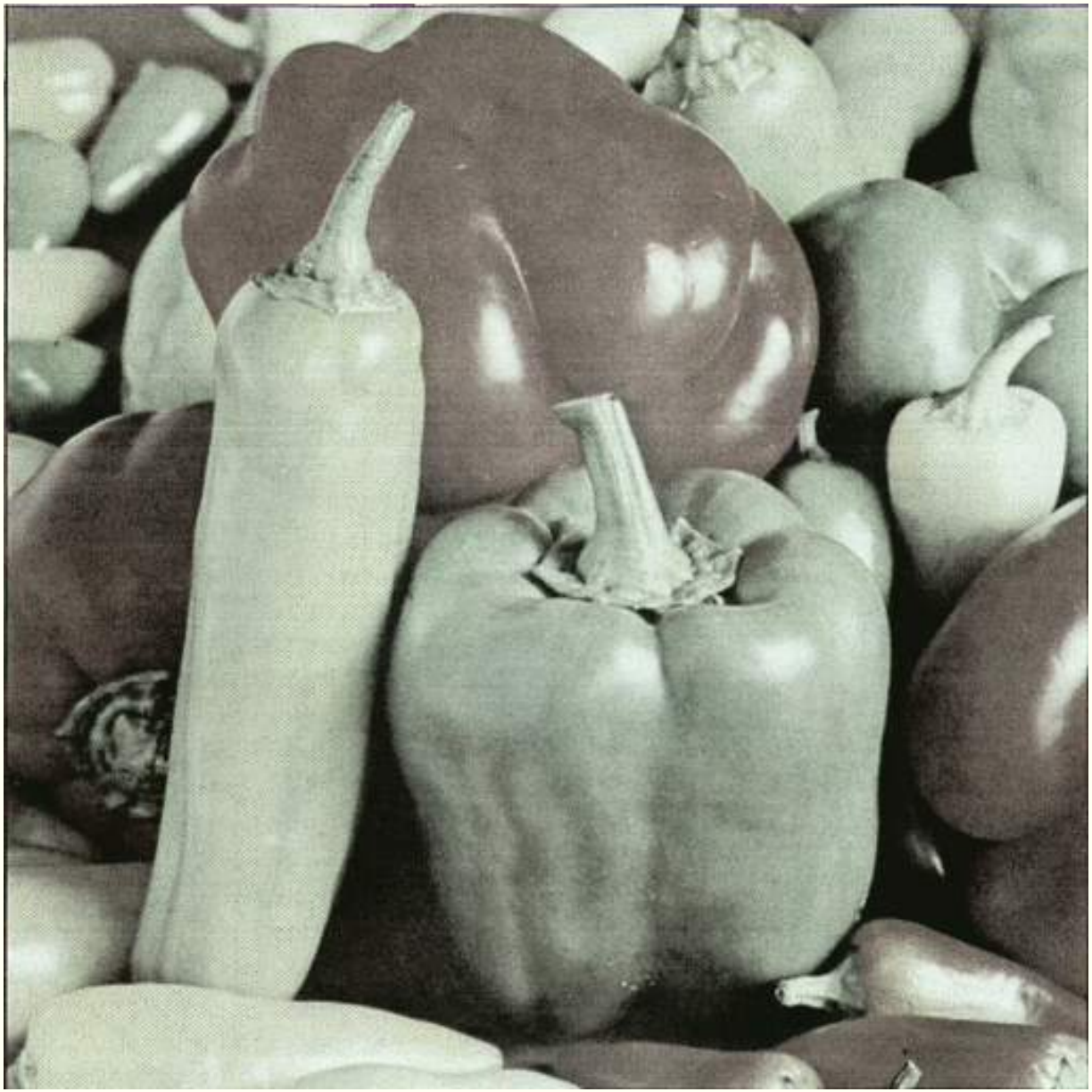


Queiroz with color enhancement

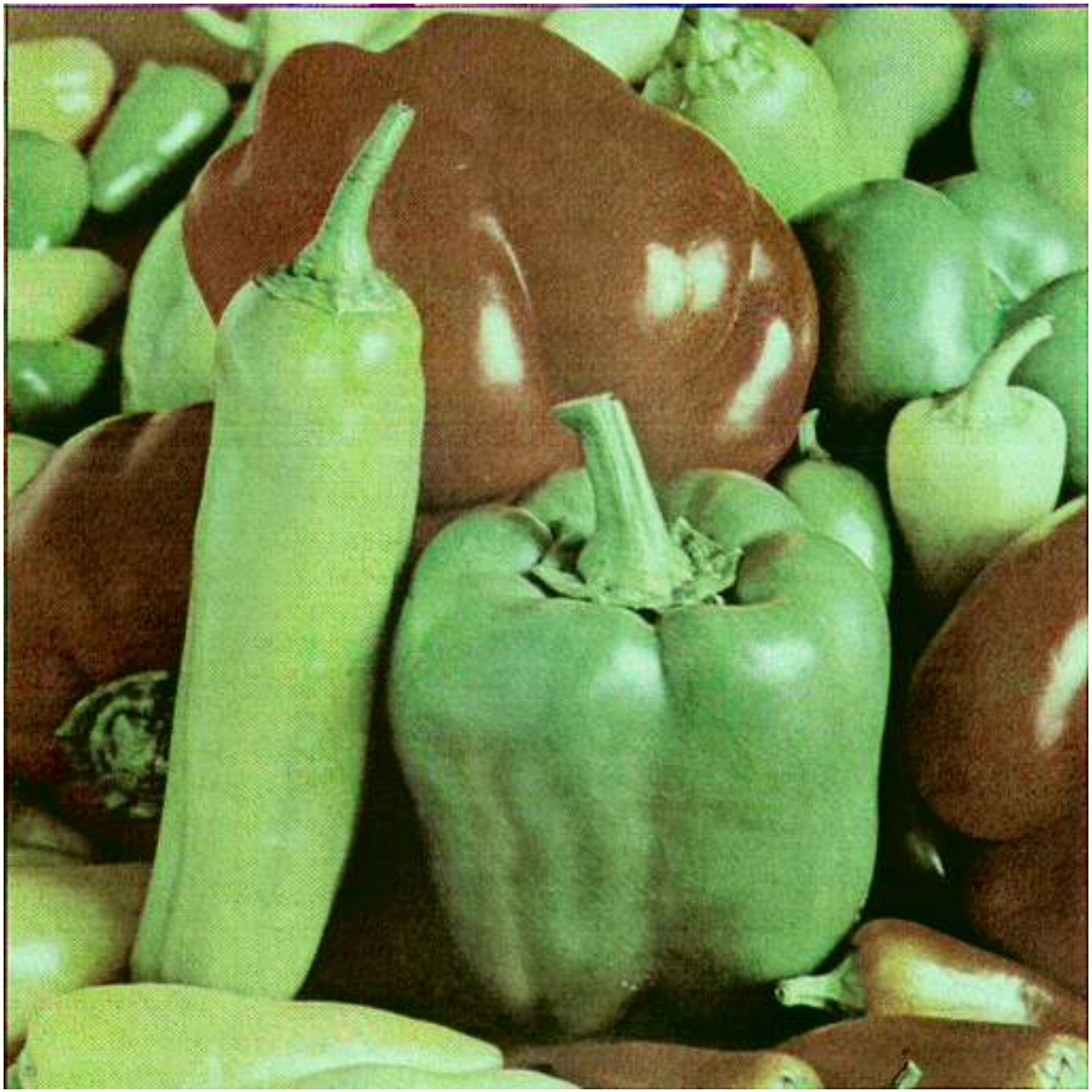
Subjective Results

Queiroz without print-scan process

Subjective Results



Subjective Results



Ko with color enhancement

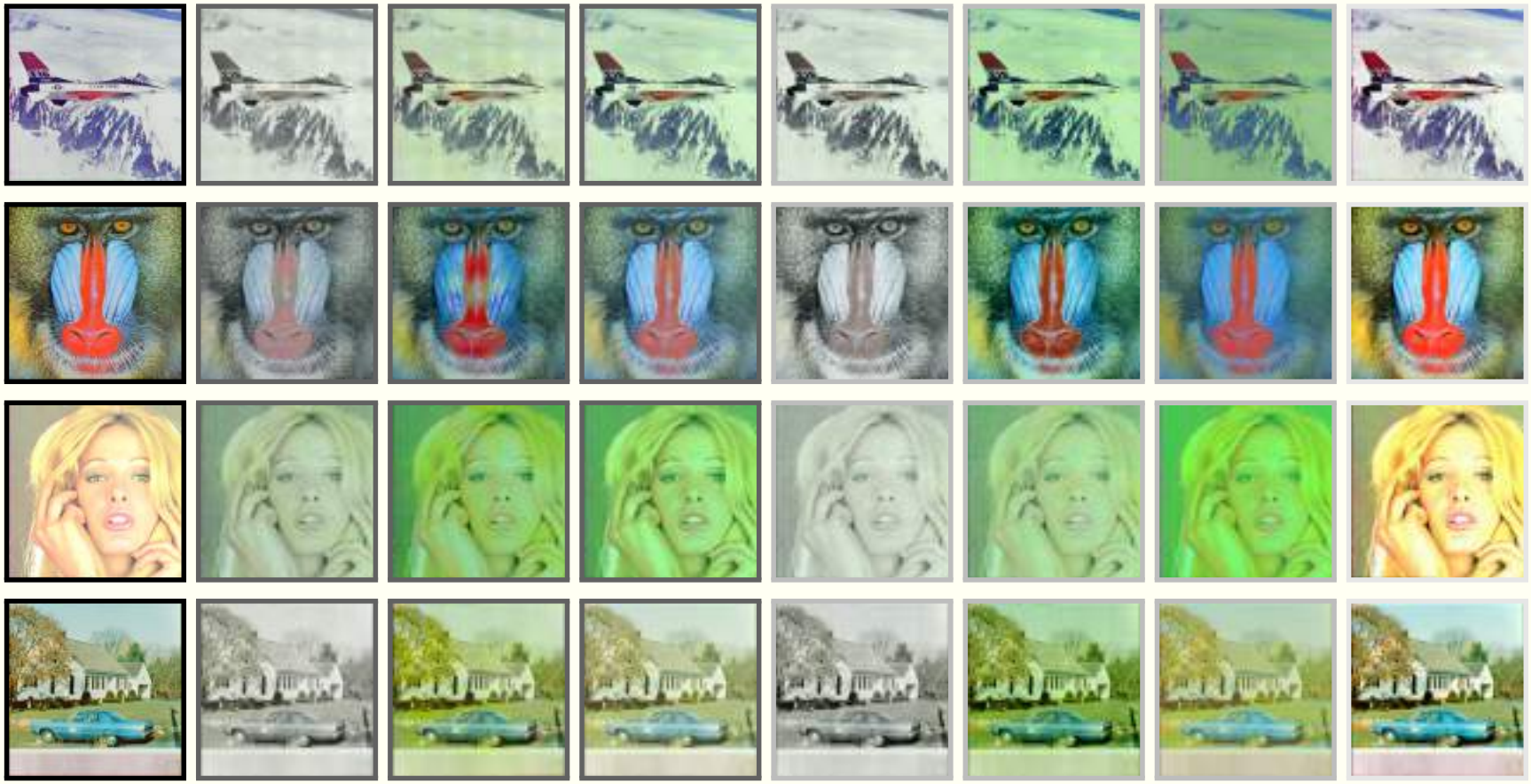
Subjective Results

Ko without print-scan process

Subjective Results

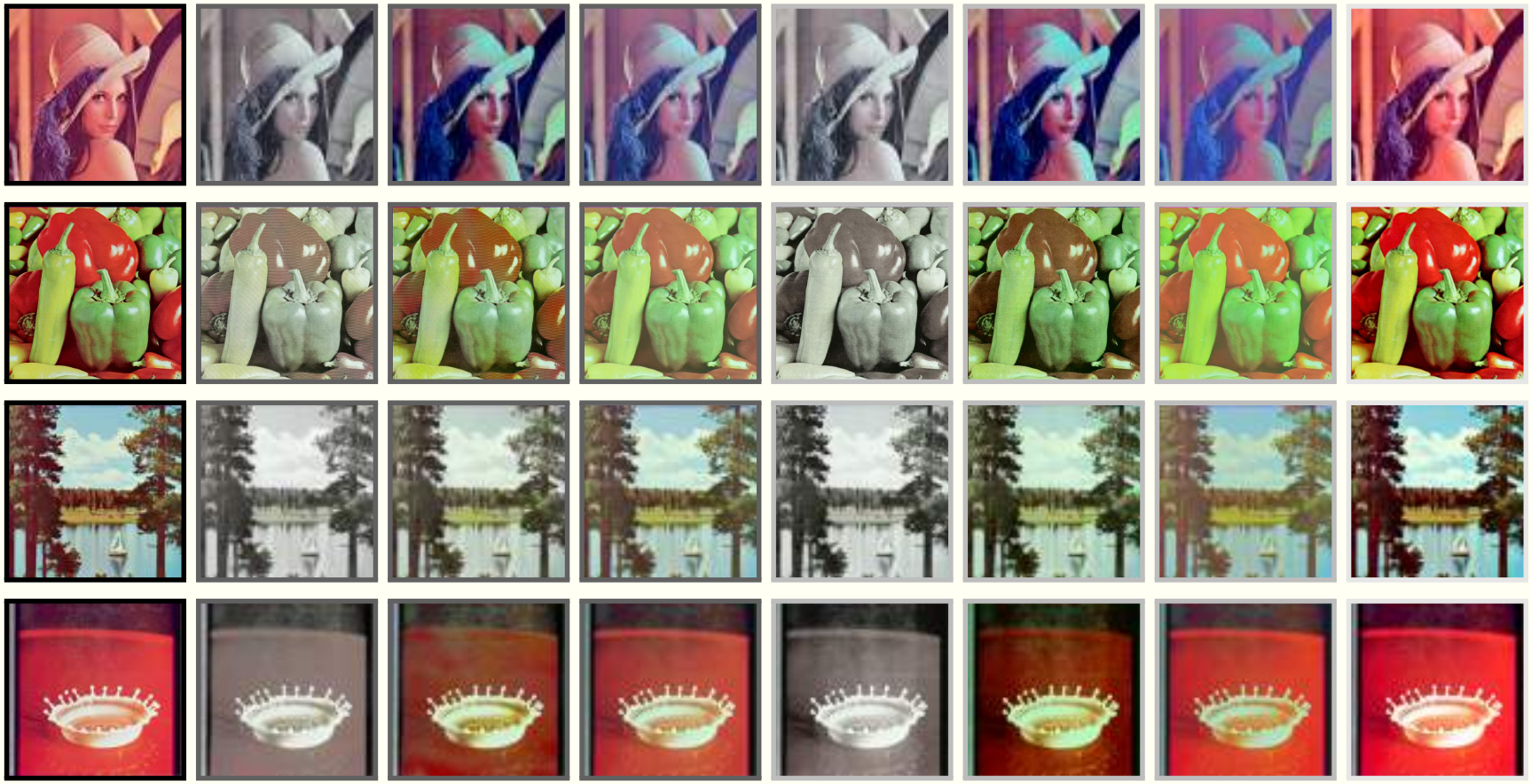
Proposed

Subjective Results



Original | Queiroz | Queiroz+CE | Queiroz-PS | Ko | Ko+CE | Ko-PS | Proposed

Subjective Results



Original | Queiroz | Queiroz+CE | Queiroz-PS | Ko | Ko+CE | Ko-PS | Proposed

Objective Results

Structural Similarity for Color Images (CMSSIM)

Image	Queiroz			Ko			Proposed
	PS	PS+CE	NoPS	PS	PS+CE	NoPS	
Airplane	0.561	0.315	0.456	0.600	0.323	0.336	0.734
Baboon	0.343	0.442	0.525	0.432	0.525	0.456	0.751
Girl	0.287	0.394	0.432	0.285	0.397	0.357	0.855
House	0.533	0.578	0.758	0.539	0.606	0.727	0.876
Lena	0.138	0.243	0.238	0.148	0.232	0.243	0.948
Peppers	0.340	0.625	0.782	0.339	0.683	0.794	0.933
Sailboat	0.390	0.529	0.803	0.490	0.594	0.782	0.825
Splash	0.334	0.628	0.830	0.256	0.479	0.854	0.901
Average	0.366	0.469	0.603	0.386	0.480	0.569	0.853

Objective Results

Perceived color difference (CIELab ΔE^*)

Image	Queiroz			Ko			Proposed
	PS	PS+CE	NoPS	PS	PS+CE	NoPS	
Airplane	09.95	17.29	17.02	12.02	21.67	21.35	07.52
Baboon	17.30	18.00	14.09	17.15	18.92	16.55	10.20
Girl	18.65	22.22	24.65	17.35	21.64	27.39	10.37
House	12.98	14.41	10.49	12.19	14.93	11.95	06.24
Lena	22.31	24.63	20.75	22.48	24.31	22.82	05.40
Peppers	22.01	18.22	15.63	21.05	16.42	17.15	05.54
Sailboat	17.52	16.59	11.54	16.97	17.47	13.37	08.58
Splash	20.62	18.66	9.52	22.23	23.37	09.27	06.47
Average	17.67	18.75	15.46	17.68	19.84	17.48	07.53

Objective Results

HPSNR values comparing marked halftone and original grayscale image.

Image	Dice, Jaccard, Sokal-Sneath	Matching, Rogers, Sokal-Michener	Russell	Yule
Airplane	43.74401	39.35379	39.83867	11.10960
Baboon	43.36772	35.89738	38.78762	14.51172
Girl	40.99878	42.46510	38.45246	10.41496
House	42.37456	39.30285	37.68586	12.28634
Lena	40.31220	40.98477	35.94697	16.46699
Peppers	42.80871	36.12626	40.95991	14.55234
Sailboat	42.63261	38.18374	39.35358	13.98017
Splash	43.88915	38.05749	41.10926	17.71411
Average	42.51597	38.79642	39.01679	13.87953

Conclusions

Conclusions

- We have presented a method for directly embedding and recovering a color image watermark into a halftone image.
- The proposed method is not limited to color reconstruction of coded luminance.
- Experimental results show that it is superior to other techniques and can be further improved.
- Future works:
  - A study to find an optimal distribution for the mask groups using machine learning technique.
  - To reduce the computation time, the proposed method can be parallelized in order to be used in real-time applications.

Conclusions

Thank you.

Questions?

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