Reading Between the Pixels: Photographic Steganography for Camera Display Messaging

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Abstract

- Challenge: Light-modulated messages less visible to the human eye, but recoverable by cameras.
- Goal: Maximize bit throughput, minimize error, and reduce the visible effect to humans.
- Approach: Find the color gradient that maximizes camera response, while minimizing human response.
- Key innovation: Exploit the mismatch between human and camera spectral sensitivity.
- Does **not** require prior knowledge of these sensitivity curves.
- Data-driven approach: Learn a differential metamer pair for each input color.
- Learn ellipsoidal partitionings of the six-dimensional space of base colors and color gradients.
- Our color modulation methods beat traditional, intensity-based approaches.

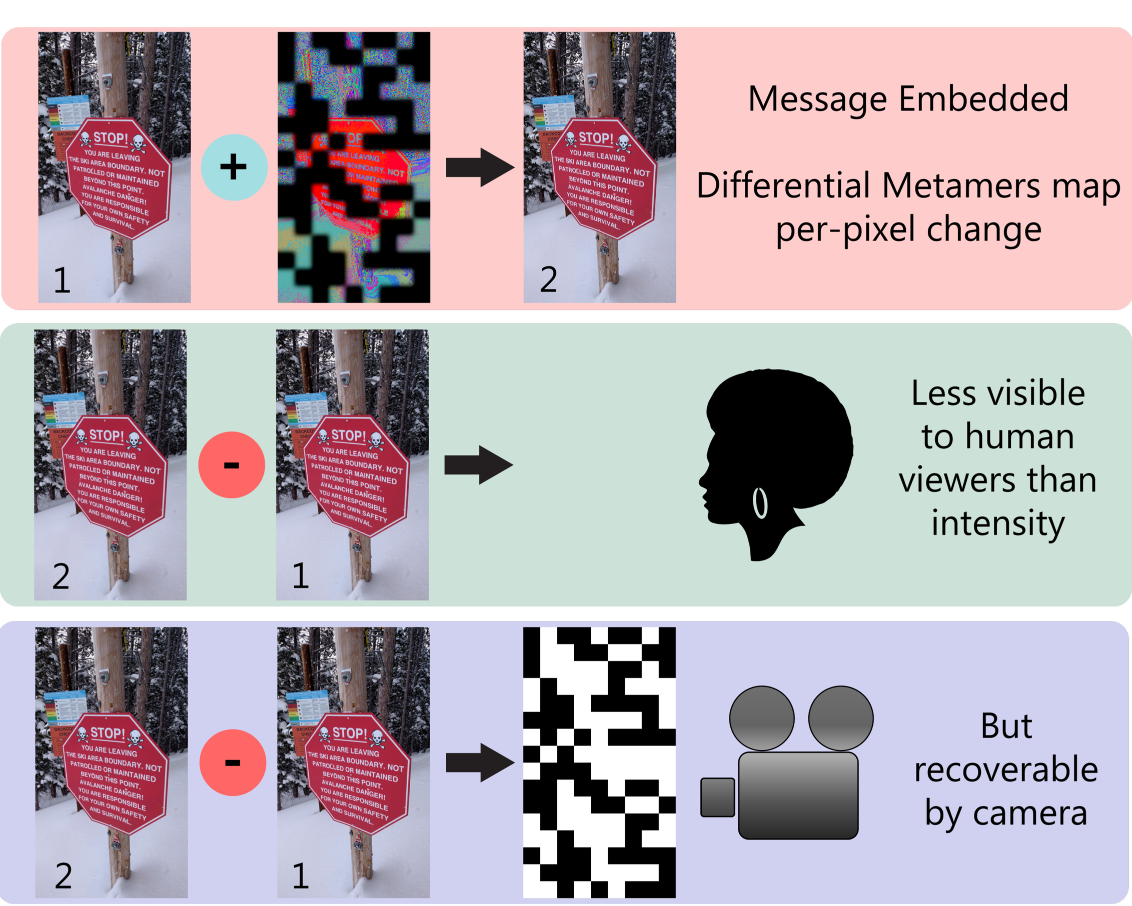
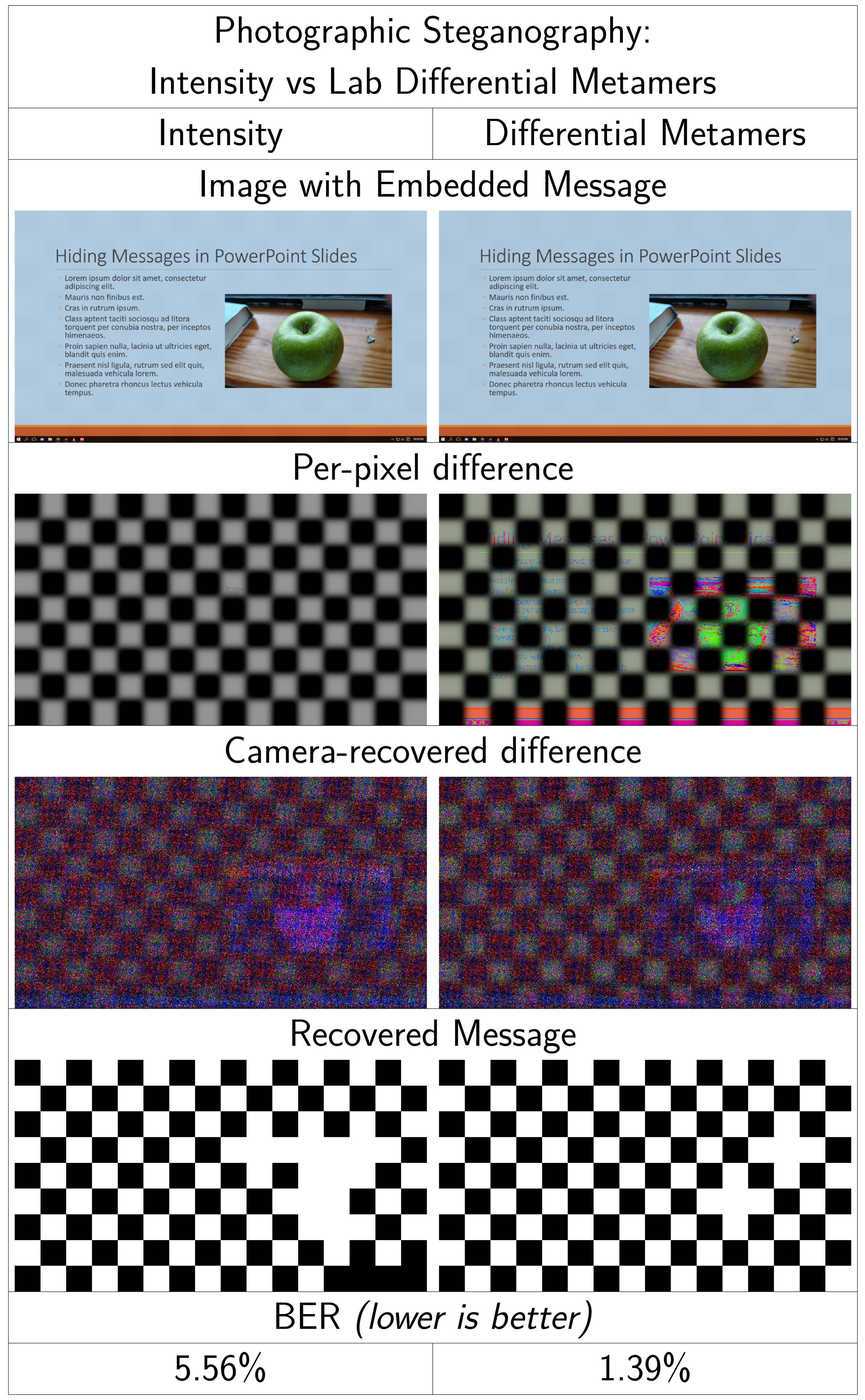
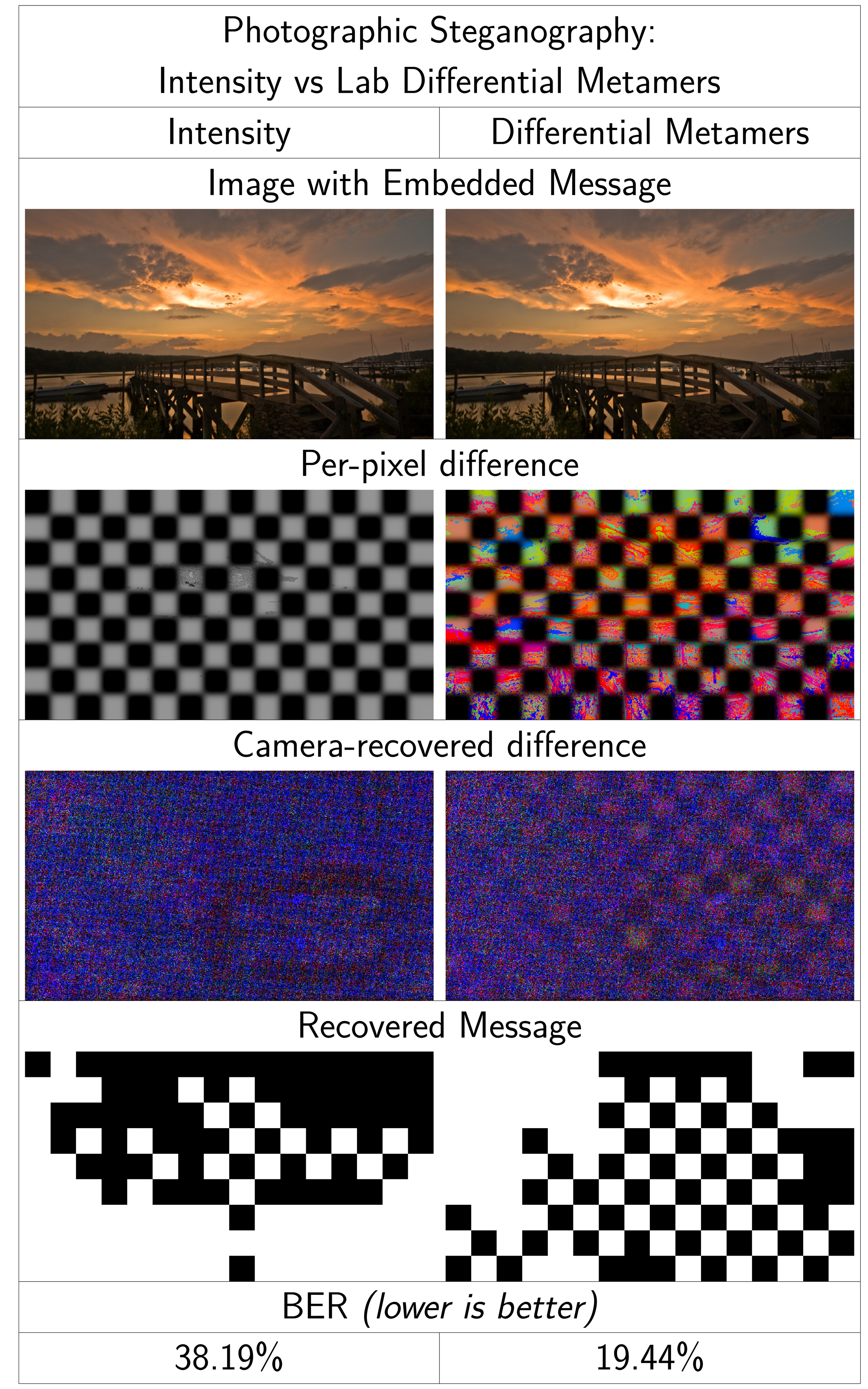


Figure 1: Differential Metamers are color pairs that are optimized to be hidden from human vision, but sensitive to a camera. By modulating small, per-pixel changes in an image, differential metamers can be used to embed hidden messages.



(a) Low Texture Image



(b) Highly Textured Image

- First row: Modulated image with steganographic message.
- Second row: Ground-truth of Per-pixel difference. For illustrative purposes of this figure, the pixel difference values have been multiplied by 50 to increase visibility.
- Third row: Camera-recovered difference after the image sequence has been displayed electronically, and captured by a camera. Notice that the differences between ground truth and camera-captured are large. Again for illustrative purposes of this figure, the pixel difference values have been multiplied by 50.
- Fourth row: Recovered, machine-readable message.
- Intensity embedding fails in dark and highly textured areas of the image.
- Lab differential metamers are significantly more effective for steganographic embedding and robust message and recovery.
- In both (a) and (b), the δ step-size is 5/255 across all algorithms.

Bit Recovery Error (BER)

	Embedding Algorithms			
$\lvert\delta\rvert_2$	Intensity	Random	*RGB* Differential Metamers	*Lab* Differential Metamers
1	50.69%	50.99%	50.45%	49.85%
2	47.92%	48.81%	42.06%	42.06%
3	43.85%	46.97%	36.11%	37.25%
4	37.00%	44.59%	29.02%	27.83%
5	34.52%	42.41%	22.42%	21.73%
6	23.41%	41.22%	19.84%	17.61%
7	18.70%	38.10%	15.53%	15.08%
8	13.49%	35.57%	13.84%	12.80%
9	09.97%	34.72%	12.50%	12.00%
10	09.13%	32.89%	11.01%	10.91%

Table 1: BER for various embedding schemes (*lower is better*) across 14 images. The red-shaded cells indicate step-sizes where an embedded, blended checkerboard-pattern is easily visible.

Conclusion

- Our color modulation methods beat traditional, intensity-based approaches.
- Reduce BER (bit error rate)
- Reduce human-observable flicker
- Applications: highly-directional networks; interactive television, projectors, and museum exhibits; and indoor localization.

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