Robust reversible watermarking via histogram folding and flexible quantized shifting

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Summary

- This work addresses the key challenge in Robust Reversible Watermarking (RRW): achieving a better trade-off between imperceptibility and robustness.
- We propose a novel, two-stage RRW framework founded on two key innovations:
  - A Histogram Folding technique reshapes the sparse feature distribution into a dense, regular form, creating an efficient embedding domain.
  - A Flexible Quantized Shifting mechanism enables arbitrary-distance shifting of histogram bins while minimizing image distortion.
- Experimental results show a PSNR improvement of up to 3 dB compared to the baseline method under JPEG compression, while ensuring perfect reversibility.

Introduction

- An effective Robust Reversible Watermarking (RRW) technique must satisfy a dual objective:
  - Reversibility: Lossless recovery of the original image from an *unaltered* watermarked version.
  - Robustness: Accurate watermark extraction from a *distorted* (e.g., JPEG compressed) version.
- Existing methods, such as Multi-Layer Watermarking (MLW) and Redundant Histogram Shifting (RHS), face limitations in balancing visual quality and robustness.
- This work aims to overcome this limitation by introducing a novel histogram manipulation strategy.

Proposed Method

- Our RRW scheme is a two-stage process: 1) Robust watermark embedding powered by two novel techniques, and 2) Reversible embedding of auxiliary data for lossless recovery.
- 1. Flexible Quantized Shifting Mechanism
  - Overcomes the limitation of prior work where shifts were restricted to fixed step-sizes.
  - Our mechanism enables arbitrary integer shifts of feature values by uniformly distributing pixel modifications.
  - This provides a fundamental tool for histogram manipulation with minimal distortion.
- 2. Histogram Folding
  - Instead of using the sparse, native histogram (H_orig), we propose a folding technique to create a compact and regularized histogram (H_f).
  - Blocks with feature values (α) in the outer tails are shifted towards the center, effectively "folding" the histogram.
  - This process allows for a significantly larger guard interval (G) between bit zones, which is crucial for enhancing robustness against JPEG compression.

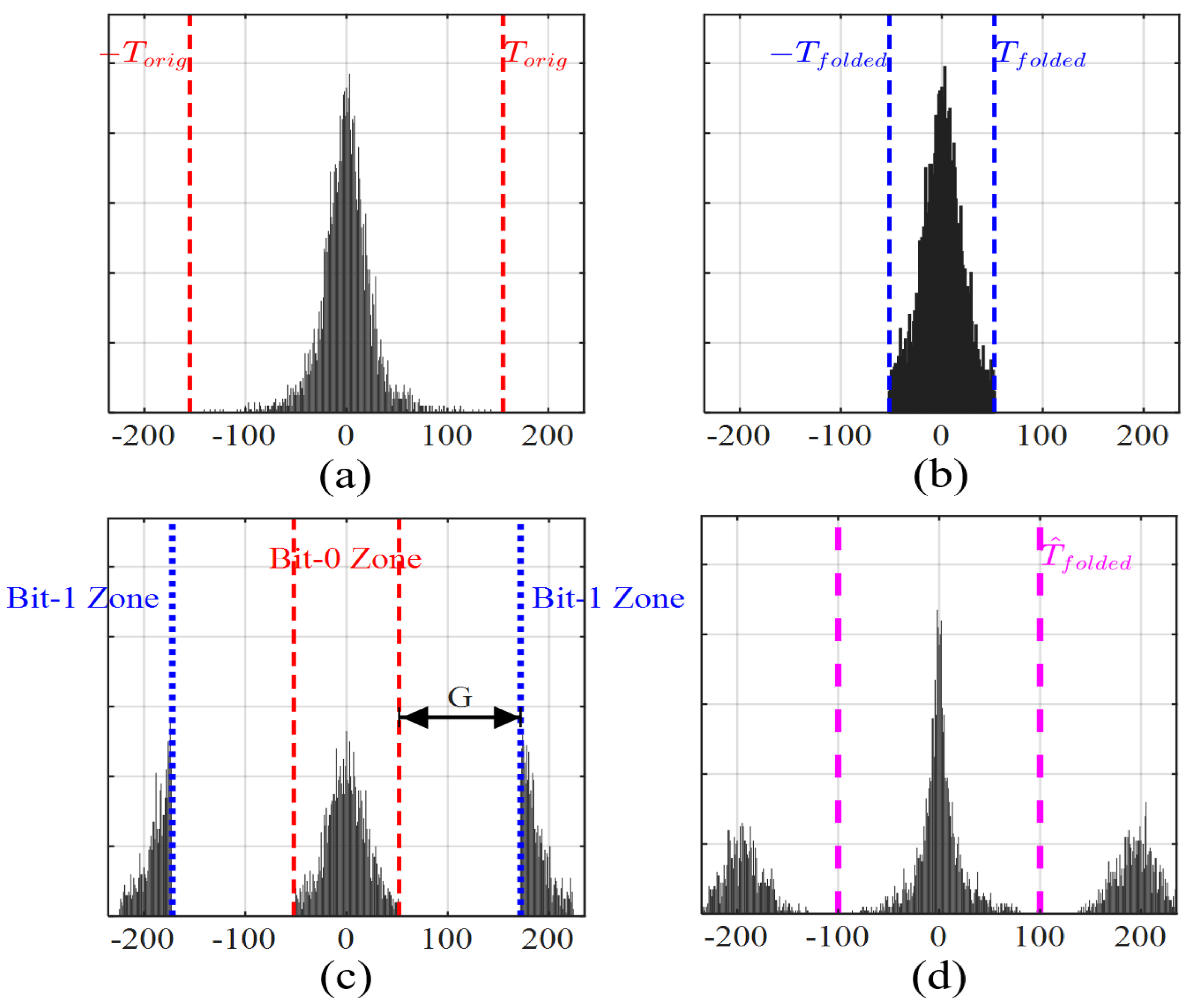

Figure 1. Evolution of the feature histogram. (a) The original sparse distribution is reshaped by (b) our histogram folding technique into a compact domain. (c) This allows for clear separation between the '0' and '1' bit zones after embedding. (d) Crucially, this separation is maintained even after JPEG compression, demonstrating the method's robustness.

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Experimental Results

- Visual Quality Comparison:
  - Under a fair condition (BER ≈ 0.09% at QF=95), our method introduces markedly fainter modifications compared to the baseline method.
  - The residual maps below show our method's distortion (f) is significantly closer to the ideal (all black) than the baseline's (e).

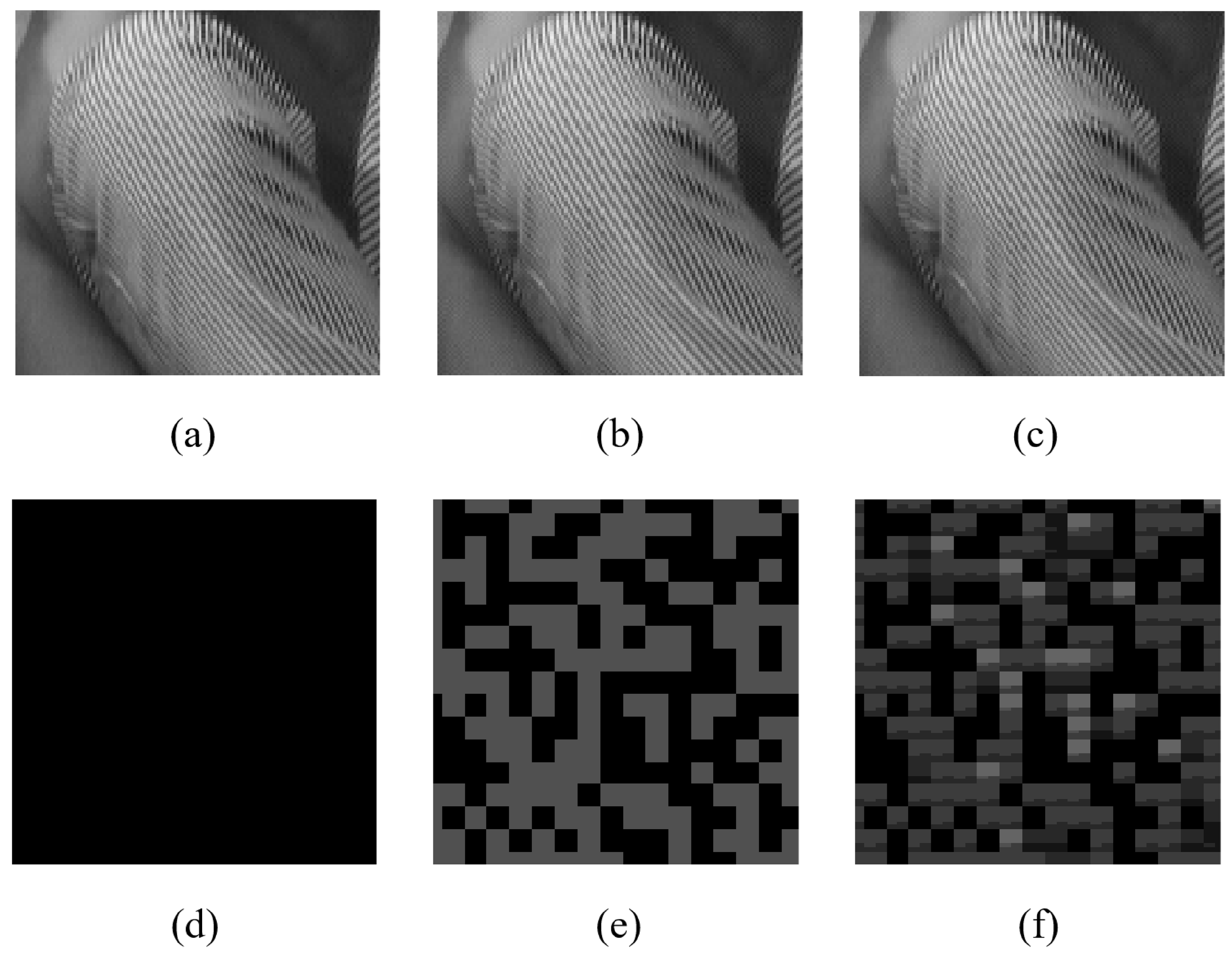

Figure 2. Visual quality comparison on a cropped region of the Barbara image (8x8 blocks, BER≈0.09% at QF=95). Our proposed method (c) results in a significantly fainter residual map (f) compared to the baseline method (e), indicating lower distortion and superior visual quality.

- Performance Comparison (PSNR):
  - With the constraint that Bit Error Rate (BER) does not exceed 0.15%, our method achieves superior PSNR results across all tested conditions.
  - The average PSNR gain is as high as 2.13 dB for 8x8 blocks and 2.51 dB for 16x16 blocks, demonstrating consistent and significant improvement.

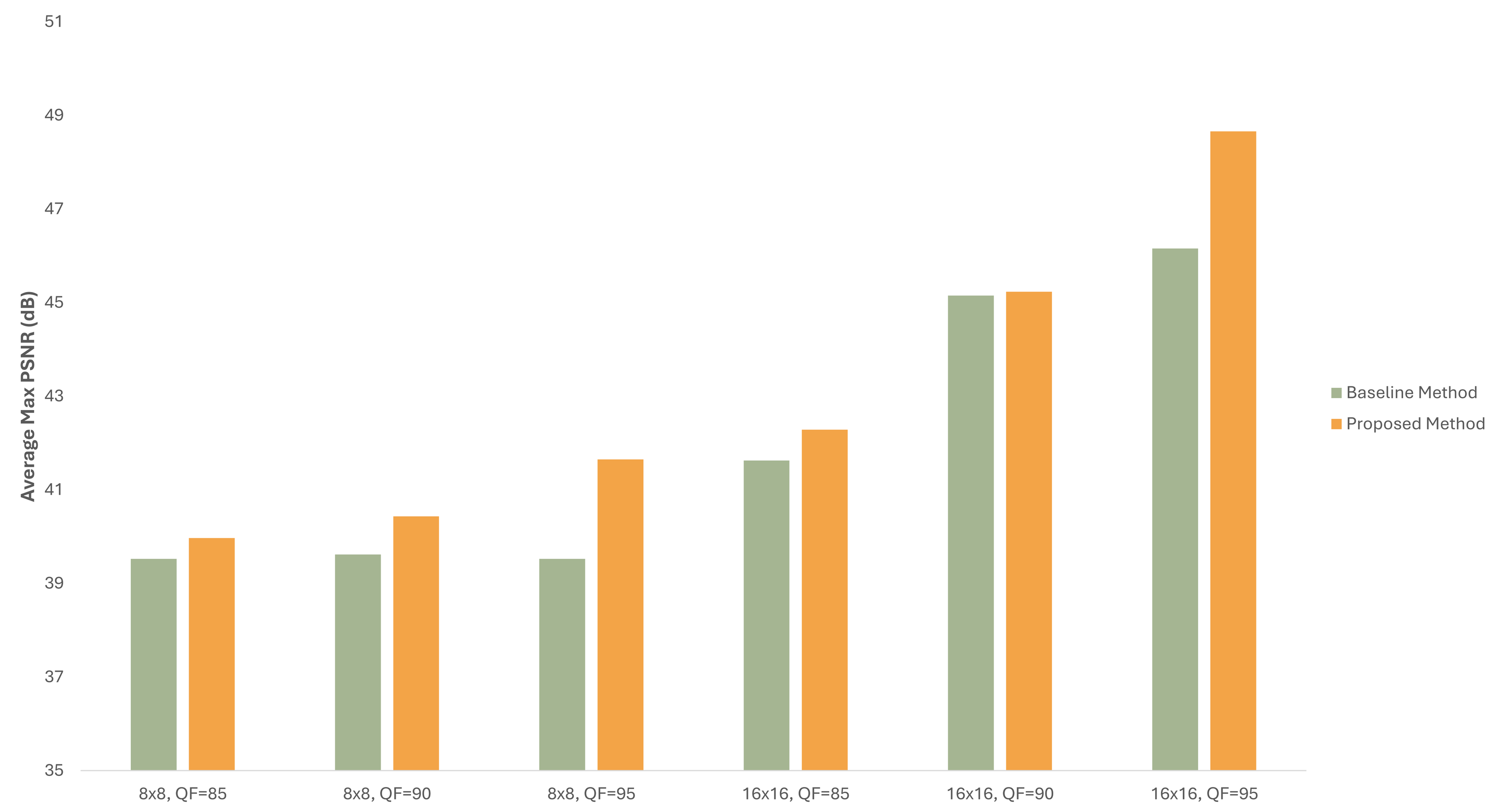

Figure 3. Average PSNR comparison under different JPEG quality factors (BER ≤ 0.15%).

Conclusions & Future Work

- We successfully designed a novel two-stage RRW framework that more effectively balances visual quality and robustness.
- Our method achieves significant PSNR improvements of up to 3 dB over the baseline under various JPEG compression attacks, while ensuring perfect reversibility.
- The key innovations—Histogram Folding and Flexible Quantized Shifting—allow for larger guard intervals, leading to significantly enhanced robustness.
- Future Work: To further optimize performance by developing adaptive pixel modification strategies based on local image features.

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