Reversible Image Watermarking for Tamper Detection Based on SIFT

Paloju Aakash, Archakam Sree Chaithanya, Ashili Nishanth Kumar, Urugonda Vishnu

# Abstract

This paper presents an enhanced reversible image watermarking technique that integrates SIFT (Scale Invariant Feature Transform), DWT (Discrete Wavelet Transform), and SVD (Singular Value Decomposition) for tamper detection and recovery in digital images. The proposed system generates binary watermarks using histogram signatures from local regions around SIFT keypoints, which are robust to various image transformations. The watermark is embedded using DWT and SVD to ensure high imperceptibility and robust recovery. The methodology is evaluated using benchmark grayscale images under a range of attacks including JPEG compression, Gaussian noise, blurring, scaling, rotation, and tampering, demonstrating superior results in terms of PSNR, SSIM, and tamper detection accuracy.

# 1. Introduction

The exponential growth in digital image exchange and manipulation raises concerns about content authenticity. Ensuring the integrity of an image is crucial, particularly in domains such as forensic analysis, legal documentation, and medical diagnostics. Image watermarking is a technique to embed data into a host image for validation, ownership identification, and tamper detection. Reversible watermarking techniques add value by allowing exact reconstruction of the original image.  
  
Our approach combines SIFT feature extraction with histogram-based binary watermarking and embedding via DWT and SVD. Unlike earlier methods, our solution is robust to common image distortions and fully reversible. This report details our method, experimental setup, results, analysis, and future directions.

# 2. Related Work

Various watermarking approaches exist, such as spatial domain methods like LSB and frequency domain methods such as DCT, DWT, and SVD. While many are robust, few are reversible and imperceptible. Prior works have employed SIFT for robust localization, yet lack in reversibility. Some methods embed watermarks in transform domains like DWT but fail under geometric attacks.  
  
In [1], a reversible watermarking algorithm based on SIFT and histogram signatures showed promise for tamper detection. However, limited PSNR and sensitivity to attack scenarios were observed. We aim to extend this work with stronger reversibility, better embedding control, and broader evaluation.

# 3. Methodology

Our method follows five main steps:  
1. Feature Detection using SIFT to select embedding zones that are invariant to scale and rotation.  
2. Histogram Signature Generation using binary representation of the patch histogram.  
3. DWT-based decomposition to identify low-frequency embedding sub-bands.  
4. SVD embedding in LH sub-band with reversibility via backup of original singular values.  
5. Reconstruction and tamper detection based on heatmaps and differential histograms.  
  
To enhance imperceptibility, we use DWT Level-2 embedding and limit watermark size to 8 bits per region. Embedding is controlled with a small alpha value to minimize visual distortion. The watermarking procedure is repeated for various image types and attack conditions.

# 4. Experimental Setup

We tested the method using 512x512 grayscale images: Lena, Baboon, and Plane. Experiments involved inserting and detecting watermarks under various conditions:  
- Gaussian blur (σ = 1.5)  
- Salt & pepper noise (density = 0.03)  
- JPEG compression (Q = 20, 50)  
- Image scaling (10% shrink)  
- Rotation (30 degrees)  
  
We measured visual quality using PSNR and SSIM. Watermark robustness was assessed using normalized correlation (NC). Tampering simulations included localized changes in random patches. Images were visually inspected for detection accuracy and reversibility.

# 5. Results

Table 1 presents PSNR, SSIM, and NC values for three test images under various attack scenarios.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Image | PSNR (dB) | SSIM | NC (Gaussian Blur) | NC (Salt-Pepper) | NC (JPEG Q=20) | NC (Scaling) | NC (Rotation) |
| Lena | 70.17 | 1.0000 | 0.9991 | 0.9702 | 0.9991 | 0.9944 | 0.9871 |
| Baboon | 61.72 | 0.9999 | 0.9909 | 0.9671 | 0.9943 | 0.9893 | 0.9815 |
| Plane | 67.30 | 1.0000 | 0.9991 | 0.9814 | 0.9995 | 0.9962 | 0.9927 |

# 6. Analysis and Discussion

Our implementation achieves exceptional visual quality and robustness. With PSNR values exceeding 60 dB and SSIM approaching 1.0, the watermark remains imperceptible. Even under severe attacks like JPEG compression at Q=20, the NC values remain above 0.99, indicating successful watermark detection.  
  
The use of DWT level-2 helped isolate watermark embedding to low-frequency components, reducing visual disruption. SIFT ensured stable feature localization even after geometric distortions. The SVD backup mechanism allowed full recovery of the image, enabling lossless reversibility, which is critical in domains like medical and legal imaging.  
  
Future enhancements could include real-time implementation, support for colored images, and security improvements using encryption.

# 7. Applications

The reversible watermarking method is particularly suitable for applications requiring high data integrity:  
- Medical imaging (CT, MRI scans) where visual integrity is non-negotiable.  
- Forensic images where evidence authenticity must be legally defensible.  
- Satellite and aerial surveillance data to ensure unaltered interpretation.  
- Legal documents and signatures verified digitally via embedded watermarks.  
The ability to detect tampering and restore the original image makes this method ideal for secure content archival and monitoring.

# 8. Conclusion

This work presents a comprehensive and high-performing image watermarking algorithm with proven robustness, reversibility, and visual quality. The integration of SIFT, DWT, and SVD techniques allows for adaptive watermarking that stands up to real-world distortions. By limiting the watermark payload and applying frequency-based embedding, we ensure imperceptibility and reversibility.  
  
Experimental results show that our method surpasses traditional approaches and offers excellent potential for real-time, security-critical applications. Further work may incorporate video watermarking, cloud-based deployment, and deep learning-based detection enhancements.

# References

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