Research on Copyright Protection Strategies for Library, Museum and Archive Video Resources Based on Quantization Modulation Watermarking: Postprint

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Abstract

【Objective】To design a video watermarking algorithm with better transparency and real-time performance in network environments, protecting the copyright of video resources in libraries, museums, and archives (LMAs). 【Application Background】To ensure the visual quality of video resources and meet the real-time requirements for copyright protection of LMA video resources. 【Method】The pixel values of the 8-bit watermark image are defined as index information, with index information and watermark information embedded alternately. The watermark image undergoes Arnold scrambling, and the scrambled watermark information is embedded into video regions randomly selected by a key using a quantization modulation method. 【Results】The quantization modulation-based video watermarking algorithm can effectively verify and identify the copyright of video resources, demonstrating good transparency and strong robustness against video operations, with correlation coefficients maintained above 0.8. The watermark extraction time is approximately 3 seconds, exhibiting excellent real-time performance. 【Conclusion】This research contributes to the copyright protection of LMA video resources and promotes the sharing and service integration of LMA information resources in big data environments.

Full Text

A New Video Watermarking Technology for Copyright Protection

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Abstract: This paper proposes a novel video watermarking algorithm designed to protect the copyright of video resources from libraries, museums, and archives (LAM) in network environments, offering improved transparency and real-time performance. The method defines pixel values of 8-bit watermark images as index information, which is embedded alternately with the actual watermark data. The watermark undergoes Arnold scrambling before being embedded into randomly selected video regions via quantization modulation. Experimental results demonstrate that the algorithm effectively verifies copyright ownership while maintaining good transparency and robustness against video operations, with correlation coefficients remaining above 0.8. With watermark extraction time of approximately three seconds, the algorithm exhibits excellent real-time performance. This research contributes to copyright protection for LAM video resources and promotes information resource sharing and service integration in big data environments.

Keywords: Libraries, Museums and Archives; Video Resources; Copyright Protection; Watermarking; Quantization Modulation; Real-time Performance
Classification: G250.76

1. Introduction

With the advent of the big data era, collaborative construction and sharing of digital information resources in network environments has become a central focus for literature preservation and information service institutions [**?**]. Libraries, museums, and archives have been digitizing their collections and disseminating them through online platforms, significantly improving information service quality and user access capabilities. Benefiting from advances in digital information technology and the proliferation of high-speed networks, vivid digital video has gradually become the mainstream type of information resource. However, as digital video resource sharing deepens, copyright protection faces unprecedented challenges. In big data sharing environments, unauthorized groups and individuals can edit, copy, and distribute video resources without restriction, causing substantial infringement upon the intellectual property rights of original creators and suppliers. Effectively protecting the legitimate copyright of digital video resources has become an urgent problem requiring solution.

This paper applies digital watermarking technology to copyright protection of digital video resources from libraries, museums, and archives. Considering the characteristics of LAM video resources and the real-time requirements for copyright protection in network environments, we propose a video watermarking algorithm based on quantization modulation of Discrete Cosine Transform (DCT) coefficients. This approach effectively addresses the shortcomings of existing video watermarking technologies in terms of execution efficiency and real-time performance, providing new technical insights and solutions for digital video resource copyright protection.

Digital watermarking has emerged in recent years as an information security and copyright protection technology that embeds copyright identifiers (digital watermarks) into specific regions of digital carriers through spatial or temporal transformations. During copyright verification, the extracted watermark information serves as evidence to safeguard the legitimate rights of copyright owners [?]. Current research on digital watermarking technology primarily focuses on image watermarking [?]. Since digital video comprises consecutive frame images along the time axis, video watermarking shares many commonalities with image watermarking in terms of performance requirements and design patterns. However, while image watermarking only needs to consider requirements for static images, video watermarking must additionally account for temporal domain factors. Consequently, beyond maintaining robustness against conventional image attacks, video watermarking algorithms must also resist video-specific attacks such as frame insertion, frame deletion, and frame reordering.

We classify video watermarking algorithms into three categories based on the video encoding format into which watermark information is embedded [?], as illustrated in [Figure 1: see original paper].

[Figure 1: see original paper]

Figure 1. Classification of video watermarking algorithms

(1) Raw video stream-based algorithms: These embed watermarks into raw video resources before compression encoding. Li et al. [?] proposed a reversible video watermarking algorithm based on intra-frame prediction that embeds video features as watermarks into selected coefficients using difference expansion, achieving good robustness. Xu et al. [?] proposed a ring-embedding video watermarking algorithm that employs histogram shifting to embed motion vector information as watermarks into quantized cosine coefficients, enhancing algorithm concealment and security. However, such algorithms significantly increase video data capacity and cause certain quality degradation during watermark embedding and extraction.

(2) Video encoding-based algorithms: These embed and extract watermarks during video encoding and decoding without increasing data capacity, effectively preserving visual quality. A representative work is Xu et al.'s [?] adaptive video watermarking algorithm based on LDPC codes. However, these algorithms require complete encoding and decoding processes, resulting in poor real-time performance.

(3) Compressed domain algorithms: These have become a research hotspot in recent years. They first compress raw video (e.g., MPEG) before embedding watermarks into the compressed stream. Jiang et al. [?] proposed a compressed-domain video watermarking algorithm without error drift that embeds watermarks into sub-block coefficients by modulating the positive/negative correlation between residual coefficients and watermark templates, satisfying transparency and robustness requirements. Tanima et al. [?] proposed a blind video watermarking algorithm for High Efficiency Video Coding that effectively resists filtering, compression, and noise attacks while ensuring security through random keys. Pejman et al. [?] developed an adaptive video watermarking algorithm using quantization decomposition and entropy models, employing entropy models to calculate motion information and quantization decomposition to obtain human visual masking thresholds as maximum watermark embedding strength, maintaining high robustness against frame operations, noise addition, and compression attacks. These algorithms no longer require encoding/decoding for watermark embedding and extraction, thus better preserving video quality, though algorithm complexity increases and execution efficiency decreases.

In summary, existing video watermarking algorithms suffer from high computational complexity that fails to meet real-time copyright verification requirements in network environments, hindering promotion and application in information service institutions such as libraries, museums, and archives. Meanwhile, most algorithms do not consider the characteristics of LAM video resources—namely low resolution, uniform format, and small capacity—and lack application specificity. Therefore, building upon relevant research and focusing on algorithm effectiveness and real-time performance, this paper designs a spread-spectrum watermarking algorithm based on raw video frames. The approach first scans binary watermark images into one-dimensional sequences, converts them into matrices matching original video frame size using spread-spectrum coefficients, and then embeds watermark information through amplitude modulation. The algorithm achieves high execution efficiency and strong robustness against common video attacks while ensuring video quality.

2. Proposed Methodology

The proposed video watermarking algorithm can extract watermark information from any video frame while simultaneously resisting malicious attacks such as frame insertion and removal. This requires synchronous embedding of index information within video resources, with index and watermark information embedded alternately, as shown in [Figure 2: see original paper].

[Figure 2: see original paper]

Figure 2. Alternating embedding of index and watermark information

2.1 Watermark Embedding

We employ DCT coefficient modulation for watermark embedding. By calculating distortion rates for different coefficients in 4×4 DCT blocks, we select coefficients with minimum distortion as embedding locations [?]. The embedding process is illustrated in [Figure 3: see original paper].

[Figure 3: see original paper]

Figure 3. Watermark information embedding process

Define the binary watermark image as $K \times L$, video frame size as $M \times N$, and spread-spectrum embedding coefficient as c_r. The watermark information capacity embeddable in each video frame is $M \times N/c_r = \text{Num}$. We define pixel values of the 8-bit watermark image as index information, requiring $(K \times L)/(\text{Num} - 8)$ video frames to embed complete watermark information. The specific embedding steps are as follows:

(1) Perform Arnold scrambling (with key K_1) on binary watermark image $w(i,j)$ to ensure security [?], then map the scrambled image to binary watermark sequence $w(i)$ where $w(i) \in \{0,1\}$ for $i \in [1, K \times L]$. Embed corresponding index information every $(\text{Num} - 8)$ $w(i)$ elements.

(2) Map the one-dimensional watermark sequence to a spread-spectrum watermark matrix matching video frame size using spread-spectrum coefficient c_r. Divide the spread-spectrum matrix into 4×4 blocks and perform DCT transform on each sub-block.

(3) Segment the original video resource into frame images and perform DCT transform on each frame. Use key K_2 to select 4×4 DCT sub-blocks for watermark embedding and calculate the DCT coefficient r with minimum distortion rate.

(4) For robust watermarking, embed watermark information using quantization modulation [?]:

If $w(i) = 1$:

$$r' = \begin{cases} r - \text{mod}(r,Q) + Q/4 & \text{if mod}(r,Q) \geq Q/4 \\ r - \text{mod}(r,Q) + 5Q/4 & \text{if mod}(r,Q) < Q/4 \end{cases}$$

If $w(i) = 0$:

$$r' = \begin{cases} r - \text{mod}(r,Q) + 3Q/4 & \text{if mod}(r,Q) \geq 3Q/4 \\ r - \text{mod}(r,Q) + 7Q/4 & \text{if mod}(r,Q) < 3Q/4 \end{cases}$$

where mod denotes modulo operation, Q is quantization step size, r is the DCT coefficient, and $w(i)$ is binary watermark information.

(5) Perform correlation calculation on adjacent video frames. If the correlation coefficient exceeds threshold T, embed the same watermark information in the next frame. If below threshold T, embed the next group of watermark information in the subsequent video frame.

2.2 Watermark Extraction

The proposed algorithm is a blind watermarking scheme that does not require original video resources for watermark extraction. The specific steps are:

(1) To remove inherent correlation of video signals, first apply Butterworth filtering to watermarked video V_i to obtain filtered video sequence $\hat{V}_i$ [?].

(2) Use key K_2 to identify video regions (4×4 sub-blocks) containing embedded watermark information.

(3) Perform DCT transform on watermark embedding regions and calculate the DCT coefficient r' with minimum distortion rate. The watermark extraction rule is:

$$\begin{cases} W(i,j) = 1 & \text{if } \mathrm{mod}(r,Q) \geq Q/2 \\ W(i,j) = 0 & \text{if } \mathrm{mod}(r,Q) < Q/2 \end{cases}$$

(4) Rearrange watermark information according to index coefficients of 8-bit image pixel values and perform inverse Arnold scrambling using key K_1 to obtain the final watermark image.

3. Experimental Results and Analysis

Using Matlab 2010 as the simulation platform, we validated the proposed watermarking algorithm on multiple video resources. We selected ten representative test videos from the Nanjing Library video repository (Peking Opera videos: "Qianlong's Trial," "Mulan," "Lü Bu Tests His Horse," "Hongniang"), Nanjing Museum video exhibitions ("Jiangsu Ancient Civilization Exhibition," "Treasure Gallery," "Ceramics Gallery"), and Nantong Museum collections ("Peacock Mingwang Statue," "Peony Pattern Vase," "Yuhuchun Vase"). All videos are in WMV format, with frame screenshots shown in [Figure 4: see original paper].

[Figure 4: see original paper]

Figure 4. Test videos

3.1 Security Analysis

Watermark algorithm security should depend on keys rather than algorithm secrecy. Our algorithm employs key K_1 for Arnold scrambling—without knowledge of K_1, correct copyright information cannot be generated. Key K_2 selects watermark embedding regions, preventing malicious attacks by adversaries unaware of K_2. Therefore, the security of our video watermarking algorithm relies entirely on keys K_1 and K_2, while the algorithm process can be fully public.

3.2 Feasibility Analysis

Using "Peacock Mingwang Statue" as the original video, we conducted watermark embedding and extraction experiments using our algorithm, as shown in [Figure 5: see original paper]. Experimental results demonstrate the practical feasibility of the proposed video watermarking algorithm, enabling clear watermark extraction for copyright verification with high implementation efficiency.

[Figure 5: see original paper]

Figure 5. Feasibility analysis

3.3 Transparency Analysis

To further validate the effectiveness of our watermarking scheme in copyright protection applications, we conducted comparative analyses of transparency, robustness, and real-time performance. Transparency requires that visual quality not degrade significantly before and after watermark embedding. The objective evaluation metric is Peak Signal-to-Noise Ratio (PSNR), where higher values indicate better transparency. Defining $I(i,j)$ as a video frame and $I'(i,j)$ as the watermarked frame, PSNR is calculated as [**?**]:

$$\mathrm{PSNR} = 10\log_{10}\frac{MN\cdot\max[I(i,j)]^2}{\sum[I(i,j)-I'(i,j)]^2}$$

[Figure 6: see original paper] shows the 4th frame before and after watermark embedding, demonstrating no significant quality degradation, with watermark presence imperceptible to human vision.

[Figure 6: see original paper]

Figure 6. Transparency analysis

Comparison results with other algorithms regarding transparency are shown in [Figure 7: see original paper], demonstrating certain advantages of our algorithm.

[Figure 7: see original paper]

Figure 7. Transparency comparison

3.4 Robustness Analysis

Robustness refers to the ability to extract watermark identification information after various video operations and attacks to verify copyright ownership [**?**]. The evaluation metric is Normalized Correlation (NC), measuring similarity between original and extracted watermark images. Defining $W(i,j)$ as the original watermark and $W'(i,j)$ as the extracted watermark, NC is calculated as:

$$\mathrm{NC} = \frac{\sum W(i,j)W'(i,j)}{\sum[W(i,j)]^2}$$

We selected eight common video attacks to validate algorithm robustness, with attack types listed in and correlation coefficients for ten test videos under different attacks shown in . Using "Qianlong's Trial" as an example, relatively clear watermark images could still be extracted after video attacks, as shown in [Figure 8: see original paper]. Experimental results demonstrate strong robustness of our video watermarking algorithm against common attacks including MPEG compression, filtering, noise addition, and frame operations.

Table 1. Attack types

Table 2. Correlation coefficients of test videos under attacks

[Figure 8: see original paper]

Figure 8. Extracted watermark images after video attacks

Using "Qianlong's Trial" as a test case, we compared robustness with algorithms from references [**?**], as shown in [Figure 9: see original paper]. Results indicate that while the algorithm in [**?**] exhibits better robustness, its computational complexity is higher, with inferior transparency and real-time performance compared to our approach.

[Figure 9: see original paper]

Figure 9. Robustness comparison

Analyzing watermark extraction time across ten test videos and comparing with [**?**], experimental results in [Figure 10: see original paper] demonstrate that our algorithm offers superior real-time performance, making it more suitable for network environment implementation.

[Figure 10: see original paper]

Figure 10. Real-time performance comparison

4. Conclusion

Addressing copyright protection needs for LAM video resources in big data sharing environments, this paper designs a quantization modulation-based video watermarking algorithm that alternately embeds index and watermark information. The watermark undergoes Arnold scrambling and is embedded into randomly selected video regions via amplitude modulation. Simulation results demonstrate that the algorithm's security depends on keys, enabling effective copyright protection and verification without degrading video quality, while maintaining strong robustness against common video attacks. Meanwhile, low algorithmic complexity ensures real-time copyright verification in network environments. Future research will focus on designing watermarking algorithms for multiple video formats, further improving robustness, and establishing API interfaces for watermarking technology applications using Web Service and Mashup architectures.

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[1] Zhu Guang. Video watermarking.txt. Watermarking algorithm related code.
[2] Zhu Guang, Feng Mining. Transparency experimental data.doc. Transparency experimental data.
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