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REVIEW

The Robust Digital Video Watermarking Methods: A Comparative Study

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ABSTRACT

Digital data such as images, audio, and video have become widely available since the invention of the Internet. Due to the ease of access to this multimedia, challenges such as content authentication, security, copyright protection, and ownership determination arose. In this paper, an explanation of watermark techniques, embedding, and extraction methods are provided. It further discusses the utilization of artificial intelligence methods and conversion of host media from the spatial domain to the frequency domain; these methods aim to improve the quality of watermarks. This paper also included a classification of the basic characteristics of the digital watermark and the most recent areas in which the watermark was used. A comparative analysis of watermarking technologies has been conducted over the past few years (from 2018 to date), and a set of challenges are discussed, such as domain, robustness, security, and visual imperceptibility, as well as methods to address them. The findings of this paper demonstrate that employing intelligent methods can enhance the robustness of the watermark by making it undetectable and challenging to manipulate the host media.

Keywords: Digital watermarking, Peak signal-to-noise ratio, Swarm optimization algorithms, Wavelet transform

1. Introduction

The ability to collect information is the key to the success of an organization in the modern era. The extent to which it can prevent others from accessing the information produced by its processes and operations is also a cause for concern [1]. The ease of access to digital storage devices and the Internet's widespread use have made it simple to produce and distribute digital material. This has made it imperative to create strategies

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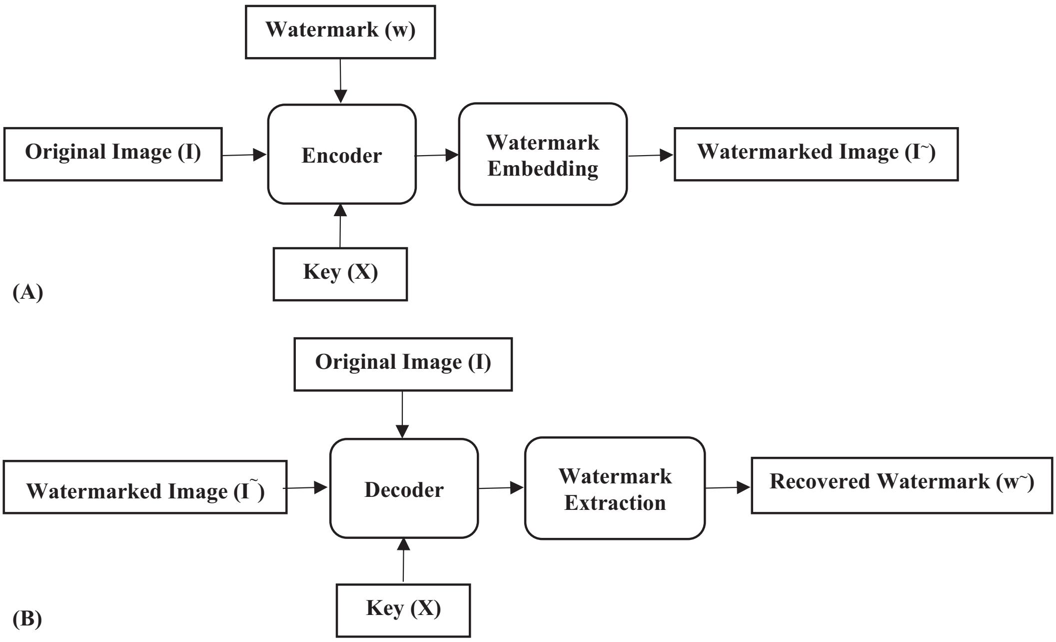

Fig. 1. Digital watermarking block diagram, (A): Watermark embedding, (B): Watermark extraction.

for combating copyright violations [2]. Digital watermarking is a widely used approach in cases where an organization needs to prevent data from leaking into the public domain [3].

Digital watermarking is a technique for offering security against any modification or tampering [4]. It protects digital content and authenticates users. Signal information is inserted into the original media content as part of the digital watermarking process. To identify the true owner of the digital media, the implanted information is then discovered and removed. Watermarking entails incorporating watermarks, digital signatures, or label data into the digital medium. This watermark can be removed to show the media object's validity [5]. The digital watermarking algorithm consists of three fundamental elements: watermarking, encoding, and decoding algorithms [2, 6].

Fig. 1 shows a block diagram illustrating the idea of digital watermarking. This technique can be applied for confidential communication, copyright protection, data integrity checks, and authentication [2]. Data can be further tracked to prevent violations of copyright. This unauthorized dissemination of digital content requires the implementation of rigorous restrictions [7].

The main contribution of this paper is to produce a comprehensive explanation of watermarking techniques, embedding, and extraction methods. Another contribution is to provide a discussion on how to use artificial intelligence methods and methods of converting host media from the spatial domain to the frequency domain for the purpose of enhancing the quality of the watermark. The last contribution of this paper is to provide a classification of the basic characteristics of digital watermarking and the most recent areas in which watermarking has been employed.

The rest of this paper is organized as follows: Section 2 explains the characteristics of digital watermarking. The classification of digital watermarking based on different properties is presented in Section 3. After that, the recent applications of digital watermarking

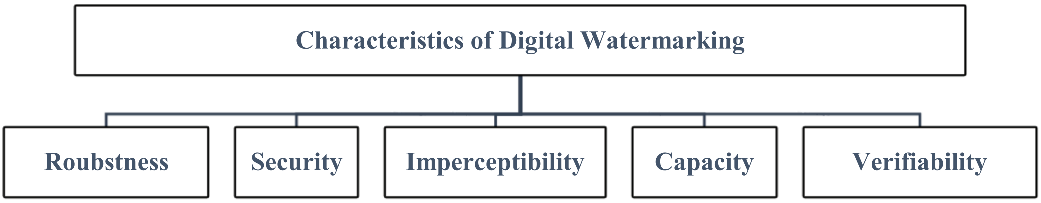

Fig. 2. Characteristics of digital watermarking.

are described in Section 4. Some research results are analyzed, and the most important recommendations are explained in Sections 5 and 6, respectively. Finally, the comparative concludes with limitations, and suggestions for future work are presented in Section 7.

2. Characteristics of digital watermarking

There are several desirable characteristics that a watermark ought to have. These requirements include being hard to detect, resistant to typical signal distortions, impervious to malicious attempts to remove the watermark, supporting a sufficient data rate appropriate for the application, allowing the addition of numerous watermarks, and having a scalable decoder. The following section goes into further detail about these characteristics, as depicted in Fig. 2.

- **Robustness:** According to the robustness characteristic, the digital watermark can withstand various processing activities and attacks [1].
- **Security:** The security feature states that the embedded digital watermark cannot be deleted, even in the event of targeted attacks. According to watermark security, it should be difficult to change or remove a watermark without harming the host signal [2]. It is possible to explain watermarking security as a technique to guarantee data ownership, secrecy, and protection [8, 9].
- **Imperceptibility:** According to the imperceptibility feature, a digital watermark should not be visible to the naked eye; only specialist procedures can detect it. The procedure of embedding a watermark should be designed to preserve the content's quality, while ensuring that the watermark remains unnoticed to viewers [4].
- **Capacity:** Data payload is another name for the quantity of information in a watermark image [5, 10].
- **Verifiability:** It refers to the ability of obtaining some proof of who owns copyright-protected data through the watermark. This assists in authenticating any digital material and even preventing unauthorized copying [2].

3. Classification of digital watermarking

The classification of digital watermarking techniques is determined according to different categories. These categories are robustness, perceptibility, domain, detection process, and multimedia; Fig. 3 shows this classification.

The widely used watermarking categories are briefly discussed as follows:

- **Robustness:** If the embedded watermark is unharmed even after some attack, this indicates robustness and resistance to numerous assaults. A robust watermark is useful for

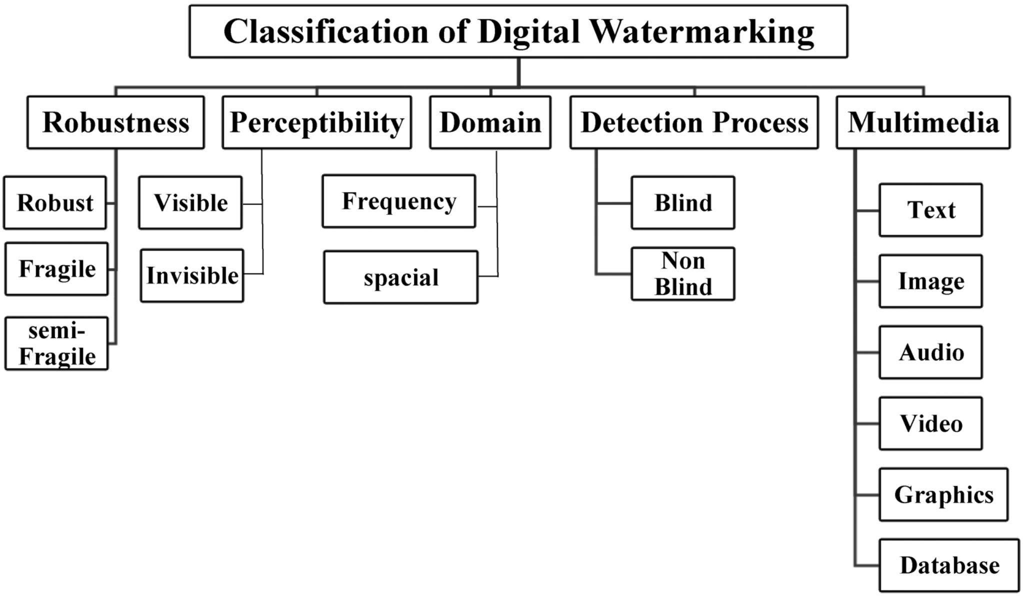

Fig. 3. Classification of digital watermarking categories.

copyright protection. Fragile, if the data has been altered, is simple to determine from the watermark's condition. This watermark is the best option for integrity protection. A semi-fragile watermark can withstand some degree of alteration [2, 7].

- **Perceptibility:** Perceptible refers to a visible watermark. A watermark is referred to as being imperceptible if it is invisible. With the use of a barely noticeable watermark, one might demonstrate ownership of an image in such cases [11].
- **Domain:** There are many types of transformation domains where the image is converted to the frequency domain. Discrete Cosine Transform (DCT), Discrete Fourier Transform (DFT), Singular Value Decomposition (SVD), and Discrete Wavelet Transform (DWT) are different transformation domains used in this sort of watermarking [12]. In the spatial domain, no transformation is used. The watermark is put into the host image and only slightly alters the value of pixels in arbitrarily chosen areas of the image. Some of the well-known spatial domain-based approaches include the Least Significant Bit (LSB), the patchwork method, and Spread Spectrum Modulation (SSM) [2, 13]. In general, a watermark performed in the frequency domain is more reliable and robust than in the spatial domain.
- **Detection Process:** This category is divided into two types: blind and nonblind. In blind, removal of the embedded information requires only the watermarked image. Its applications can be voting and copyright protection. In nonblind, the procedure copies the host image, the text data, and the inserted data for retrieval of the watermark, which is utilized in the application of copyright protection [12].
- **Multimedia Type:** There are many types of digital media used in watermarking. Words, punctuation, phrases, and other elements make up text watermarking. One of these components transforms, and the result is embedded as a watermark [11]. In image watermarks, robust and imperceptible watermarks are required, and images must be large-sized to carry a watermark [14]. In a video watermarking situation, getting an undetectable watermark is challenging [15]. Graphic watermarking means a watermark is incorporated into 2D or 3D digital graphics; it offers copyright defense [7].

4. Watermarking applications

Watermarking techniques are used to add security and owner identification for every digital medium. Here are some of the most recent applications:

- **Copyright Protection:** Digital media are publicly available on the Internet and can be easily distributed [14]. Commercial usage of these media is permitted. Data must, therefore, be protected by copyright, and digital watermarking is highly helpful in this regard. The digital watermark will be used to show who owns the copyright [11, 15].
- **Fingerprint:** Digital watermarking fingerprinting can be proposed as a technique for embedding some individuality. It should be tough to modify the fingerprint. The data entered is associated with the customer. This fingerprinting reveals which authorized customers are participating in the distribution of copyright data in violation of the contract [4].
- **Copy Control:** Digital watermarking can stop unauthorized copying of digital data. Copying devices can recognize these watermarks, report instances of copying, and thus prevent illegal copying [2].
- **Electronic Voting System:** From large cities to small towns, the Internet has become widely available throughout the nation [7]. Elections are carried out with the assistance of electronic voting while taking security into account [11].
- **Remote Education:** Small villages face a serious teacher shortage. Distance learning requires the use of smart technology. In this instance, watermarking contributes to the reliable transmission of educational content over the Internet [12].
- **Broadcast Monitoring:** Digital watermarking is crucial; it has been observed that the accessibility and availability of media content have grown significantly over time. The information is also accessible online. In these circumstances, content owners and copyright holders must be aware of the actual content distributor [11].
- **Medical Application:** The visible watermarking approach can be utilized to prevent the mixing of reports. The patient's name can be embedded via visible watermarking in the Magnetic Resonance Imaging (MRI), or X-ray data. These medical reports determine how the patient receives medical care [2].

5. Comparison of related works

Many papers have been studied to obtain information about robust watermarking techniques. Research papers on image watermarking are provided to convey a comprehensive survey of the subject. Watermarking schemes put forth by several research teams over the past few years are summarized in Table 1.

6. Analysis and recommendations

Based on the comparative analysis of the watermarking techniques which are proposed by different research teams over the past few years (from 2018 till now), many challenges have been considered while studying watermarking research, some of which are as follows:

- **Domain Property:** This includes some common strategies that have been previously investigated: spatial domain and frequency domain techniques. Additionally, it has been found that spatial domain digital watermarking is less reliable and, therefore, less popular. Some studies used a single transformer like in [16, 19, 23–26, 36], while

Table 1. Comparison of various techniques.

Reference no.	Size of host image and watermark	Technique	Methodology
[16]	512 × 512 32 × 32	• DCT • Particle Swarm Optimization (PSO)	• Convert host and watermark image into Red, Green, Blue (RGB) channels. • Decompose the host image into blocks and sort them according to entropy value. • To embed watermarked blocks, select DCT coefficients by applying 2D DCT on the host image. • Using the PSO technique to find scale factor alpha for embedding calculated watermark blocks.
[17]	512 × 512 32 × 32	• DCT • SVD • PSO	• Partitioned host image into four sub-bands Low-Low (LL), High-Low (HL), Low-High (LH), and High-High (HH). • HH is divided into 8 × 8 blocks. • Then DCT is executed on each block and selected the upper left coefficient and apply SVD on it (decomposed into 3 matrices U, S) • The watermark is embedded with a scaling factor k into S (the singular value), where k is obtained through the PSO algorithm for controlling the strength of the watermark embedding.
[18]	512 × 512 128 × 128	• DWT • SVD	• On the original image, apply 2-level DWT. • Apply SVD on (HL2 or LH2) sub-band • On the watermark image, DWT (1-level) is applied • Apply SVD on the watermark image (sub-band chosen (HL2 or LH2)). • Scaling factor α used for modified singular values of the original image.
[19]	256 × 256 64 × 64	• DWT • Arnold Transform (AT) • PSO	• PSO algorithm is used to select the best image to embed the watermark. • To guarantee security, use an Arnold transform. • Haar wavelet transforms (2-level) is applied on the host image.
[20]	512 × 512 32 × 32	• DWT • DCT • PSO	• Apply DWT on the host image then apply DC. • Insert watermark in low-frequency coefficients. • Using PSO to find the best blocks for the embedding watermark.
[21]	512 × 512 32 × 32	• DWT • SVD • Human Visual System (HVS) • PSO	• Apply DWT (one-level) on the host image, and selected LL sub-band for embedding. • LL sub-band is separated into the RGB color components and selected blue channel for embedding. • Partition Blue channel into 4 × 4 blocks, and HVS selected the most suitable blocks for embedding. • Apply SVD on selected blocks to embed two watermark bits in each block.
[22]	512 × 512 32 × 32	• K−means Clustering Algorithm • Points of Interest Set (POIs) • PSO	• Embedding watermark depends on the K-means clustering algorithm, • Improve K−means algorithm using PSO algorithm to find centers of clusters, • From clustered groups, select a POI and mark it as watermark vertices. • Embed watermark into the mesh model.

(*continued on next page*)

Table 1. (*continued*).

Reference no.	Size of host image and watermark	Technique	Methodology
[23]	512 × 512 32 × 32	• DFT • PSO	• Convert RGB to YCbCr color model and isolate the luminance component Y(x,y). • Apply 2D DFT transform to luminance Y(x,y) component and find information of magnitude M(u,v) and phase P(u,v). • Select a pair of radiuses r1 and r2 in M(u,v). • Scramble the watermark using a secret key to guarantee security. • Particle swarm optimization is used to select the watermark factor.
[24]	512 × 512 32 × 32	• DCT • PSO	• Determine a suitable scaling factor and coefficient for watermark embedding by applying PSO algorithm to the image. • Modifying DCT coefficient of both host image and watermark image. • Using an additive formula for embedding.
[25]	512 × 512 32 × 32	• DCT • Fuzzy C-Means Clustering (FCM) • Least Favorable-based Whale Optimization Algorithm (LF-WOA)	• Watermark is embeded depends on FCM clustering algorithm and DCT, • Improve FCM algorithm using LF-WOA algorithm to find optimal centers of clusters,
[26]	512 × 512 50 × 20	• SVD • Jumping Particle Swarm Optimization (JPSO).	• JPSO was used to determine a suitable scaling factor for improved watermarking robustness. • JPSO used both host's local and global characteristics, and watermark images within the SVD domain.
[27]	1024 × 1024 32 × 32	• DWT • DCT • PSO • Chaotic Logistic Map	• Decompose host image by DWT, then apply discrete DCT to sub-bands (LH and HL) according to the human visual model. • From the DCT domain, choose suitable frequency spectra. • Using chaotic logistic map for shuffled watermark image by modifying the largest singular values of a feature matrix in the SVD domain. • Determine a suitable scaling factor by applying the PSO algorithm to the image.
[28]	512 × 512 32 × 32	• Lifting Wavelet Transform (LWT) • DCT • SVD • Arnold Transform (AT)	• Apply LWT on host image, then on HH sub-band apply DCT • LL is selected for each block to form a matrix. • Apply SVD on matrix. • Apply PSO algorithm to determine a suitable scaling factor for watermark embedding. • For the security of the watermark, Arnold transform is applied.
[29]	512 × 512 64 × 64	• LWT • SVD • Artificial Bee Colony Optimization • Chaotic Logistic Map	• Decompose host image into four sub-bands using LWT (3 levels), and SVD is applied on LH sub-band, then embed the singular value of watermark image into the singular value of LH sub-band • Artificial bee colony optimization (multi-objective) is used for choosing optimal scaling factors. • For the security of the watermark, a chaotic logistic map is applied.

(*continued on next page*)

Table 1. (*continued*).

Reference no.	Size of host image and watermark	Technique	Methodology
[30]	512 × 512 32 × 32	• Stationary Wavelet Transform (SWT) • Bat Optimization Algorithm (BA) • AT	• SWT is applied to the host image. • BA algorithm is applied to determine a suitable scaling factor for watermark embedding. • For the security watermark, Arnold transform is applied.
[31]	512 × 512 64 × 64	• DWT • SVD • PSO • AT	• Apply DWT on the host image to get four sub-bands (LL, HL, LH, and HH). • Then SVD is applied on the LL band. • For the security of the watermark, Arnold transform is applied. • Determine a suitable scaling factor by applying the PSO algorithm to the image. • For the security of the watermark, Arnold transform is applied.
[32]	512 × 512 32 × 32	• DWT • SVD • Fibonacci-Lucas Transform (FLT) • Self-Adaptive Step Firefly Algorithm (SASFA)	• Apply DWT on host image, LL sub-band is divided into blocks, then SVD is applied on selected blocks to form (U, S, and V) matrices. • Watermark is embedded into the first column in the second-row value of the U component. • To balance robustness and transparency, the scaling factor for Embedding is selected by SASFA. • For the security of the watermark, FLT is applied to the binary watermark.
[33]	512 × 512 256 × 256	• DWT • SVD • Firefly Algorithm (FA) • PSO • Step Space-Filling Curve	• DWT is applied on host image, then SVD is applied on LL sub-band, • Convert the watermark image into grayscale, then scramble it using a step space-filling curve, • After that it is embedded in the host image via a suitable scaling factor determined using hybrid PSO and FA.
[34]	512 × 512 32 × 32	• DWT • SVD • PSO • AT	• Improved security and speed of watermark are achieved by using an aging leader-based particle swarm optimization-based SVD approach. • To secure the watermark, scramble it using the Arnold transform.
[35]	512 × 512 256 × 256	• DWT • Integer Wavelet Transform (IWT) • PSO • Least Significant Bit (LSB)	• A novel IWT is presented based on PSO to determine the suitable substitution matrix for converting secret data into their substituted forms, and to obtain a stego image with low distortion using LSB. • Experiments found that a proposed method IWT based PSO outperforms both LSB-based PSO and DDWT-based PSO.
[36]	512 × 512 96 × 64	• DCT • AT	• Watermarked digital videos algorithm is proposed in the frequency domain based on DCT. • The scrambled watermark image (using AT) is embedded into the video (the whole frame). • For embedding, the green channel is selected (from the RGB frame) using DCT.

others used a multi transformer like in [17, 18, 20, 21, 27–29, 31–35], and the results showed that the hybrid is better.

- **Robustness Property:** To enhance the robustness of the watermark and make it more robust, most research tends to use intelligent methods to achieve this purpose. Most studies used swarm optimization algorithms like PSO, Bee Colony, Firefly, etc that will identify the optimal location to hide the secret data and achieve good results, as in [22, 25, 26, 29, 30, 32, 33], most papers used PSO, as in [16, 17, 19–21, 23, 24, 27, 31, 34, 35]. For future work, other algorithms can be used to robust the watermark, such as the crow optimization algorithm and pelican optimization algorithm.
- **Security Property:** Image encryption is used to prevent perceptual visibility of the embedded secret image. Some studies use the Arnold transform, Fibonacci-Lucas transform, and chaotic logistic maps, as in [19, 27–32, 34, 36]. To achieve more secure results, researchers can combine steganography and encryption techniques.
- **Size of Host Image and Watermark:** According to Table 1, the majority of research has used image and watermark sizes with different lengths. In a very limited number of studies, watermarks with sizes of 32×32, 64×64, and 128×128 pixels are mapped to image sizes of 512×512 pixels. Therefore, researchers can use swarm algorithms to select a suitable scaling factor for the watermark image.
- **Visual Imperceptibility:** The watermarked image's performance is assessed using its robustness, imperceptibility, security, and capacity. The visual imperceptibility of the watermarked image was the most favored criterion. The average optimal Peak Signal-to-Noise Ratio (PSNR) value for imperceptibility as a performance requirement is 50 and above for high metrics, as in [19, 21, 22, 26, 29, 33–36], and values from 40 to 49 for medium metrics, as in [16, 17, 25, 27, 28, 30, 32], and less for low metrics, as in [18, 20, 23, 24, 31].

Furthermore, to improve security as well as robustness, researchers should focus on developing more practical approaches. In future work, the implementation of the three crucial requirements of robustness, imperceptibility, and capacity might be fulfilled by integrating multiple methodologies, such as artificial intelligence, to identify the optimal solutions. Additionally, the scope of future work could be expanded to incorporate video watermarking.

7. Conclusion

Digital watermarking is a common technique used by organizations to provide security against modification or manipulation and prevent data from leaking into the public domain. In this paper, various recent watermarking techniques are analyzed, and this analyzation based on a comprehensive study of the classification and characteristics of these techniques. Different algorithms are being used to develop watermarking techniques. The primary objective of these various techniques is to enhance the robustness and imperceptibility of the embedded watermark. Several application fields, including healthcare, distance learning, and electronic voting systems, have been discussed in this paper. Due to the widespread transmission of digital data, data security has been elevated to the top of the priority list. Robustness, imperceptibility, security, and capacity are used to assess how well the watermarked images operate. A PSNR is used to analyze them. It was found that the favored criterion was robustness. Invisible watermarking is employed for the purpose of verifying the authenticity of content and providing evidence of ownership. Research teams have used frequency domain methods and endeavored to achieve a balance between visual imperceptibility and robustness.

For future work, the potential is to combine techniques and employ them in a hybrid form to not only improve the robustness of the watermarked image but also to mitigate the shortcomings of each methodology taken independently.

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