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Optimal and secure audio watermarking scheme based on self-adaptive particle swarm optimization and quaternion wavelet transform

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ABSTRACT

In this paper, a new audio watermarking scheme based on self-adaptive particle swarm optimization (SAPSO) and quaternion wavelet transform (QWT) is proposed. By obtaining optimal watermark strength using a uniquely designed objective function, SAPSO addresses the conflicting problem of robustness, imperceptibility, and capacity of audio watermarking scheme using self-adjusted parameters. To withstand de-synchronization attack, a synchronization sequence generated by chaotic signals is also adopted in our scheme. Furthermore, the utilization of chaotic signals significantly enhances the security of the proposed scheme. The experimental results validate that our scheme is not only robust against de-synchronization attack, but also typical signal manipulations and StirMark attack. Our comparative analysis also revealed that the proposed scheme outperforms the state-of-the-arts audio watermarking schemes.

1. Introduction

In the last two decades, digital watermarking has been demonstrated as an important and ever increasing technique to address multimedia security issue, such as piracy and malicious manipulation of multimedia content [1,2]. Due to its wide application in copy control, broadcast monitoring, device control, and copyright protection, digital watermarking attracts increasing interest in both industrial and academic fields. The most important factors for the effectiveness of watermarking [3] are imperceptibility (transparency and inaudibility), capacity (payload), robustness and security. Since some of these factors impose mutually conflicting requirements, it is highly desirable to achieve a good tradeoff between these factors.

Artificial intelligence techniques based on objective function such as tabu search [25], support vector machine (SVM) [7], differential evolution (DE), and genetic algorithm (GA) [26–28] have been demonstrated to be very effective in solving conflicting requirements of watermarking. For instance, in [7], SVM method was utilized to address the contradictory issue by selecting the optimal position for embedding watermark. In [13], Kumsawat et al. proposed an

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audio watermarking scheme based on digital multiwavelet transform and used GA to determine the optimal watermarking quantization steps. They also attempted to optimize the inaudibility and robustness of the watermark using GA, but the signal-to-noise ratio (SNR) values of watermarked audio signal are slightly higher than 20 dB without any attack and their scheme is not robust. Particle swarm optimization (PSO) is another important artificial intelligence algorithm since it has fast convergence and a few parameters to adjust [29]. PSO is simple to implement and computationally efficient as well. Basic principle of the PSO algorithm is the clever exchange of information between the global and local optimal values. A global optimum is achieved by updating generations based on movement and intelligence in an evolutionary system. Due to its advantage over other global optimization techniques (i.e., GA and tabu search), a myriad of watermarking schemes have been developed and implemented based on PSO [26,27,30–32]. However, many open challenges and drawbacks of the existing artificial intelligence techniques for audio watermarking yet remain, and one of these challenges to be addressed in this paper is the numerous parameters that have to be manually adjusted for optimal performance. To overcome this, an enhancement of the traditional PSO algorithm referred as the self-adaptive PSO (SAPSO) is developed to optimally determine parameters according to audio properties automatically. Differing from previous works, SAPSO strikes a balance between robustness and imperceptibility with self-adjusted objective values.

It is known that watermarking in the transform domain generally shows higher robustness against signal processing attacks compared with that in the spatial domain. The popular transform domain watermarking methods include discrete Fourier transform (DFT), discrete cosine transform (DCT), discrete wavelet transform (DWT) using lifting, integer, complex approaches, and the variants of these transforms [4–13]. Most of wavelet transforms lack the local phase information to be shift invariant. Hypercomplex wavelet transform has one phase [14], but it is unable to describe local structures efficiently. On the other hand, the quaternion method (i.e., quaternion wavelet transform (QWT) [15] and quaternion Fourier transform (QFT) [16]) overcome the common shift variance problem. For this reason, quaternions have been widely applied in the watermarking field for the past two decades. For instance, the color image watermarking scheme based on QFT and least square SVM in [16] demonstrated high robustness against the geometric distortion. In [17], the full 4D QFT had been proposed to address general color image watermarking problems by introducing symmetrical constraints and solving the energy loss issue. In [18], Tsui proposed a non-blind algorithm to embed bit sequence into host signal by QFT. The patterns are modulated to insert the watermark into the QFT coefficients. However, QFT does not have multi-scale characteristics and its real amplitude is still sensitive to the noise attacks. Compared to QFT, QWT not only addresses the common drawbacks of wavelet transforms by providing the shift-invariant feature, but also exhibits superiority over QFT because of its multi-scale property [14,15]. Evidently, QWT is demonstrated to possess good invariance to geometric operations. Singular value decomposition (SVD) has also attracted a lot of interest in the watermarking field due to its high robustness against geometric attack. Watermarking scheme in the transform domain is able to achieve better watermarking performance against a series of attacks with integration of SVD as shown in [4,5,9,10,12,19–24]. Nevertheless, there is no guarantee for high robustness for QWT-based watermarking scheme, and there is no subband and phase information available for SVD-based watermarking scheme. In view of this, QWT and SVD are integrated together to produce superior results than these schemes on their own.

Overall, the main contribution of this paper is threefold: (1) an optimal balance of the contradictory watermarking requirements is determined by the SAPSO algorithm without any watermarking and SAPSO parameters tuning; (2) both QWT and SVD are explored to improve watermarking performance; and (3) a modified spread spectrum (MSS) based watermarking technique is proposed to insert the watermark bit and synchronization code using the four dimensional QWT coefficients instead of previous one or two dimensional QWT coefficients. The rest of this paper is organized as follows. Section 2 introduces the related methodologies of our proposed scheme. Performance analysis such as error, key space, and entropy analysis are presented in Section 3. Our experimental results are presented and analyzed in Section 4. Section 5 summarizes our study.

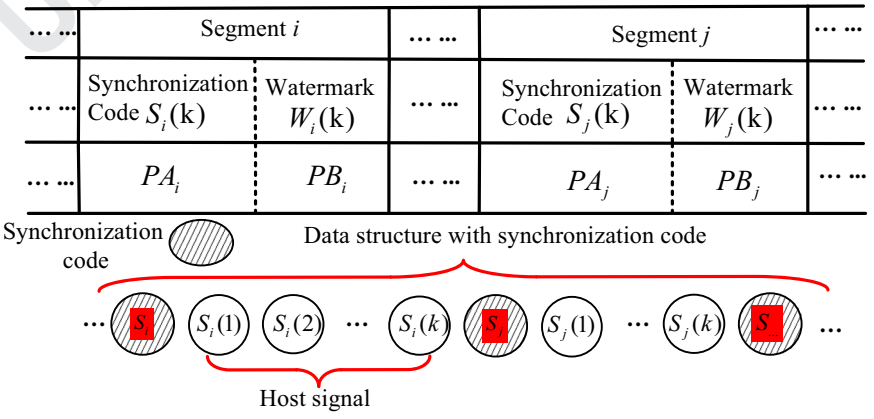

Fig. 1. Data structure of the proposed method with synchronization code insertion.

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