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An improved sample projection approach for image watermarking

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ABSTRACT

Very recently, a novel watermarking scheme named sample projection approach (SPA) has been proposed by Akhaee et al. [1] to improve the watermarking performance against gain attacks. The SPA embeds one message symbol into four signal samples by projecting the line segment formed by the four samples on a certain specific codeline. Based on the SPA, this paper presents an improved sample projection approach (ISPA) by introducing a set of modified codelines to decrease embedding distortion and constructing the long line segments to increase robustness. According to our theoretical analysis of document-to-watermark ratio (DWR), the modified codelines result in a lower embedding distortion than the SPA's codelines in the same conditions with regard to payload and robustness. We also derive a theoretical expression for the symbol error rate (SER) of the ISPA against additive white Gaussian noise (AWGN) attack. The numerous experiments conducted on both artificial Gaussian signals and the natural images show that the proposed ISPA outperforms the SPA in terms of robustness against attacks.

1. Introduction

Digital watermarking is seen as a solution to copyright protection by embedding identification information permanently into digital media [2]. Generally, a good watermarking scheme should first be able to resist various unintentional attacks [3,4]. Thus robustness is the key issue for watermarking technique to protect copyrights. The two kinds of watermarking schemes, namely, the spread-spectrum (SS) watermarking [5] and the quantization index modulation (QIM) watermarking [6,7], have been most widely studied regarding embedding distortion, payload, and robustness [8,9]. Compared with the SS method, the QIM method can achieve better rate-distortion-robustness trade-offs. However, the basic QIM algorithm is fragile to gain attacks (i.e., valumetric distortion), such as amplitude scaling and gamma compensation. So far, in the framework of QIM watermarking, three types of solutions have been proposed to deal with the valumetric distortion. The first solution is to insert a pilot sequence into the watermarked signal, and the pilot sequence is shared by the encoder and the decoder [10]. The second one is to design the direction-based embedding schemes, such as the angle QIM (AQIM) [11] as well as the absolute AQIM (AAQIM) [12]. And the last one is to introduce a robust embedding domain being invariant to the gain attacks [13,14]. However, the first solution is very vulnerable to malicious attacks, since the adversaries could easily detect the deterministic pilot sequence and further tamper with it. The AQIM and the AAQIM achieve relatively low robustness against additive white Gaussian noise (AWGN) attack. The problems brought by the works [13,14] are the high peak-to-average power ratio due to their momentarily large quantization step and the high computational complexity. In order to resist the gain attacks, Akhaee et al. [1] proposed a novel watermarking scheme called as sample projection approach (SPA), which is essentially invariant to the gain attacks, meanwhile can obtain lower embedding distortion than the AQIM. But, the SPA still has two main weaknesses: 1) the codelines designed for the SPA are an ineffective coding scheme in terms of embedding distortion; 2) the selected embedding domain is not robust to various attacks. In addition, the authors of [1] have not discussed the document-to-watermark (DWR), which is a fundamental measure for the embedding distortion.

This paper focuses on tackling the above issues. In order to decrease the embedding distortion caused by the messages embedding and increase the robustness of the watermark, we propose an improved sample projection approach (ISPA) for image watermarking by introducing a set of modified codelines and constructing the long line segments. Meanwhile, we give a theoretical DWR analysis for both the SPA's and the modified codelines. The analytical results show that the modified codelines can obtain the lower embedding distortion than the SPA's codelines in the same conditions with regard to payload and robustness. The symbol error rate (SER) of the ISPA against AWGN attack is also derived based on the maximum likelihood (ML) decoder. And the extensive experiments tested on both artificial Gaussian signals and the natural

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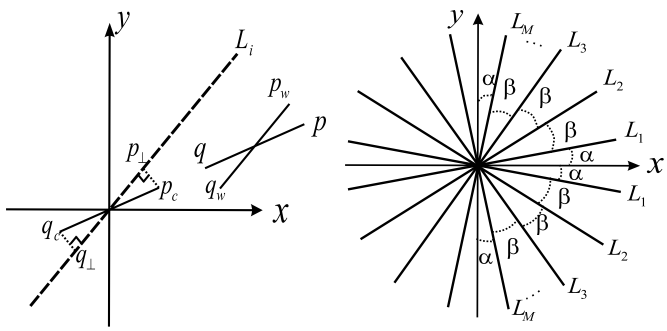

(a) Line segment projection (b) Codelines

Fig. 1. Messages embedding of the SPA.

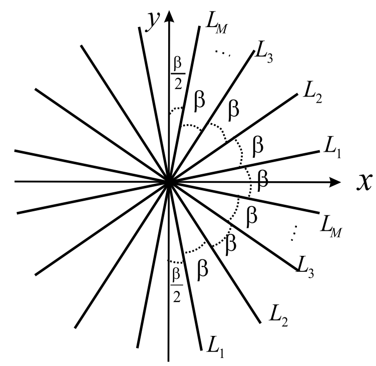

Fig. 2. The modified codelines.

images show that the proposed ISPA outperforms the SPA in terms of robustness against various attacks.

The remainder of the paper is organized as follows. In Section 2, we briefly introduce the SPA. Then, we propose two strategies to improve the SPA in Section 3. Section 4 provides the performance evaluation for the improved SPA, which includes the theoretical analysis of both the DWR and the SER under AWGN attack. The extensive experimental results are demonstrated in Section 5, followed by the conclusions of this paper in Section 6.

2. Sample projection approach

In this section, we briefly describe the main idea of the SPA [1]. Let us denote a group of four samples of the host signal by $\mathbf{u} = [u_1, u_2, u_3, u_4]$, which is used to represent two points $p = [u_1, u_2]$ and $q = [u_3, u_4]$ in a 2-D space. As shown in Fig. 1(a), the SPA embeds messages by the following steps: 1) Translate the center of the line segment pq to the origin to attain $p_c q_c$; 2) Project $p_c q_c$ on one of the M codelines, which are denoted by the lines L_1 to L_M in the first quadrant if the slope of the line segment $p_c q_c$ is larger than 0, otherwise, are denoted by those in the fourth quadrant shown in Fig. 1(b), and then obtain $p_\perp q_\perp$; 3) Translate $p_\perp q_\perp$ back to its original center to further get the watermarked $p_w q_w$. Note that the M codelines correspond to the M-ary messages to be embedded. Fig. 1(a) illustrates the process of embedding message i into its corresponding codeline L_i. Here we emphasize that the SPA embeds an M-ary message by projecting the line segment on the closest codeline corresponding to the to-be-embedded message. In Fig. 1(b), β denotes the angle between two consecutive codelines and α is set to be $(\frac{\pi}{4} - \frac{M-1}{2}\beta)$. Also note that, for image watermarking application, the SPA chooses the parameters $\beta = 40^\circ$ for $M = 2$ and $\beta = 20^\circ$ for $M = 4$, in which cases α is not equal to $\frac{\beta}{2}$. While, the message decoding of the SPA only needs to calculate the slope of the received line segment, which is independent of its length, thus the SPA is essentially invariant to gain attacks [1].

3. Improved sample projection approach

We improve the SPA with two strategies, which are described in detail below.

3.1. Lower-distorted codelines

Let's consider a special case in the embedding of the SPA. Given a line segment pq with a tiny positive or negative slope (i.e., a tiny angle between the line segment and the x-axis), we can see from Fig. 1 that it will result in a relatively large angular distortion if the to-be-embedded message is M. This is because the given line segment needs to be rotated by a large angle to the M-th codeline, no matter in which quadrant the M-th codeline to be projected is. Considering that the SPA embeds the M-ary message by projecting the line segment on the closest codeline corresponding to the to-be-embedded message, thus, as shown in Fig. 2, if we invert the order of the codelines in the fourth quadrant, then the given line segment will be projected on the M-th codeline in the fourth quadrant of Fig. 2. In this case, it is obvious that the angular distortion caused by the embedding is relatively very small. In fact, as analyzed below, the modified codelines shown by Fig. 2 are always superior to the SPA's codelines with regard to the angular distortion.

Here, we first provide an analysis to compare the maximum angular distortion between the SPA's and the modified codelines. To simplify the analysis, we set $\alpha = \frac{\beta}{2}$ for the SPA, thus we can obtain $\beta = \frac{\pi}{2M}$. By referring to Fig. 1(b) and Fig. 2, we can find out that the maximum angular distortion of the SPA's codelines is $(\frac{\pi}{2} - \frac{\pi}{4M})$, but that of the modified codelines is only $\frac{\pi}{4}$, which is independent of the number M. Table 1 gives the comparison of the maximum angular distortion between the two codelines schemes. We can see from Table 1 that for any M, the modified codelines outperform that of the SPA in terms of the maximum angular distortion.

We further qualitatively compare the average angular distortion between the SPA's and the modified codelines. Without loss of generality, we consider the case of $M = 2$, as shown in Fig. 3. It is reasonable to assume that the angle of the line segment is distributed uniformly over $[-\frac{\pi}{2}, \frac{\pi}{2}]$. We can see from Fig. 3(a) that for the codelines of the SPA, only the line segment whose angle is in the ranges of $[0, \angle L_2]$ and $[\angle L_2, \frac{\pi}{2}]$ can cause the angular distortion produced by projecting it on the codeline L_1, where $\angle L_2$ denotes the angle between the codeline L_2 and the x-axis. While, as shown in Fig. 3(b) for the modified codelines, only the line segment in the ranges of $[\angle -L_2, 0]$ and $[0, \angle L_2]$ can cause the above-described distortion, where $-L_2$ denotes the codeline L_2 in the fourth quadrant. It can be easily inferred from Fig. 3 that for both the SPA's and the modified codelines, the line segment in the range of $[0, \angle L_2]$ causes the same distortion. However, the line segment in the range of $[\angle L_2, \frac{\pi}{2}]$ causes a quite larger distortion than that in the range of $[\angle -L_2, 0]$. By the symmetry of the codelines, the analysis on the codeline L_2 has the same results. Therefore, based on the above assumption, we can conclude that the average angular distortion of the SPA's codeline is always larger than that of the modified ones.

We remark that this section aims to propose the modified codelines and also to explain our motivation of the modification by simply analyzing the superiority of the modified codelines over the SPA's codelines in angular distortion. The derivation of theoretical closed-form expression in terms of DWR, which measures the embedding distortion of host signal, will be given in Section 4.1. In fact, we can see from Fig. 2 that the M codelines of the modified codelines repeat two times over the whole of the first and fourth quadrants. We can further extend the repetition to each quadrant