Efficient double-layered steganographic embedding

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Adding/subtracting one into/from pixel values can be used to hide secret data into the least significant bit plane of a cover image. A double-layered embedding scheme that introduces the wet paper coding mechanism to determine the selection of addition or subtraction is proposed. In this way, the second LSB plane can be exploited to carry additional secret data, leading to improved embedding efficiency and embedding rate. By combining the double-layered embedding method with various steganographic coding techniques, even higher embedding efficiencies can be achieved while keeping low embedding rates.

Introduction: By altering the most insignificant components of an innocuous host signal, steganography aims to embed secret messages into host media for covert communication. For example, the LSB embedding method is realised either by simply replacing the LSBs of all pixels in a cover image with the secret data, or by randomly increasing/decreasing the pixel values by one [1]. In the latter scheme the secret data are also carried in the LSB plane, and distortion caused in these two cases is the same. In practice, a data-hider always hopes to reduce the number of alterations introduced to a cover image or to increase the embedding capacity at a given distortion level, i.e. to improve embedding efficiency. To achieve this goal, two embedding methods are presented in [2] and [3], in which the choice of adding or subtracting one to/from a pixel is not random, but depends on the original pixel values as well as the secret data to be hidden. Thus the directions of modifications on pixel values are exploited for improving embedding efficiency. This Letter proposes a novel double-layered embedding scheme using the wet paper coding mechanism to determine whether to add or subtract one to/from a pixel, providing better performance than [2] and [3].

Double-layered embedding: Suppose that a cover image contains N pixels. In the first layer of the embedding, we insert one secret bit into each host pixel. If a secret bit is identical to the LSB of the corresponding pixel, no modification is made. Otherwise, the pixel value should be added or subtracted by one, and the choice of addition or subtraction will be determined in the second layer embedding. Obviously, either adding or subtracting one changes the LSB. If a pixel value is odd, adding and subtracting one flips and keeps the second LSB, respectively. If a pixel value is even, on the other hand, the two operations cause opposite results in the second LSB. We will show that the second LSB plane of the cover image may be exploited to carry additional data by selecting suitable operations for addition/subtraction.

Collect all second LSBs of pixel values and use them as additional cover data. By adding or subtracting one, we can flip those at the positions where the LSBs of original pixel values do not coincide with the secret bits, while the rest are unchangeable. A wet-paper coding model [4] can be used to perform the second-layer embedding, in which the changeable and unchangeable second LSB are considered ‘dry’ and ‘wet’ elements, respectively. Suppose the number of changeable second LSB is M, the expectation of which is $N/2$. By modifying only the changeable elements, we can embed on average M secret bits into all N elements. Although a receiver does not know the position of the changeable elements, he can still extract the embedded bits. An implementation of wet paper encoder/decoder is given in [4]. So, on average we can embed a total of $3 \times N/2$ secret bits into N pixels using $N/2$ operations of adding or subtracting one. Two parameters are used as the performance metrics: embedding efficiency E, which is the ratio between the number of embedded bits and the distortion energy caused by data embedding, and embedding rate R, which is the number of secret bits embedded in each cover pixel. For the double-layered embedding scheme, $E = 3$ and $R = 3/2$. Both of them are better than the embedding efficiency 2 and the embedding rate 1 in the plain LSB embedding method.

Incorporating steganographic coding: Various steganographic coding techniques have been proposed to reduce the numbers of alterations to cover data when the number of secret bits is significantly less than that of the available host pixels. These may be used in conjunction with double-layered embedding. In matrix encoding [5], k secret bits are embedded into $2^k - 1$ pixels by changing only one LSB with a probability $(1 - 1/2^k)$, where k is a positive integer. Similarly, we can add/subtract one to change the LSB and to keep/flip the corresponding second LSB. As such, there are $N/2^k$ changeable elements on average in an N-pixel image for the second layer embedding. Therefore we can embed a total of $N k/(2^k - 1) + N/2^k$ secret bits on average by using $N/2^k$ operations of adding/subtracting one. It is easy to show that $E = 2^k\, k/(2^k - 1) + 1$ and $R = k/(2^k - 1) + 1/2^k$. If $k = 1$, we have plain double-layered embedding, as described in the previous Section. In the running coding technique [6], one secret bit is embedded into 2^t pixels by changing only one LSB with a probability $1/(t + 2)$, where t is a positive integer. So, there are on average $N/(t \times 2^t + 2 \times 2^t)$ changeable second LSBs. By using the double-layered embedding method, the same number of additional secret bits can be embedded. In this case, embedding efficiency $E = t + 3$ and embedding rate $R = 1/2^t + 1/(t \times 2^t + 2 \times 2^t)$. Similarly, plain double-layered embedding results with $t = 1$.

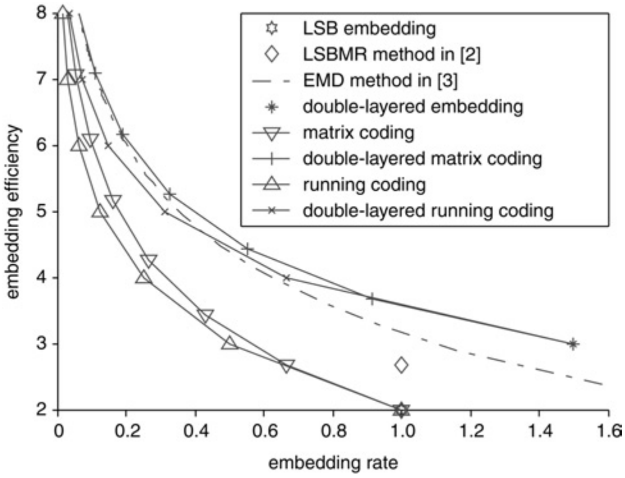

Fig. 1 *Performance comparison between eight embedding methods*

Performance comparison: Comparison of performance has been made between the plain LSB embedding, LSBMR method [2], EMD method [3], the proposed double-layered embedding, matrix coding [5], double-layered matrix coding, running coding [6] and double-layered running coding, and the results are shown in Fig. 1. The abscissa represents the embedding rate, while the ordinate is the embedding efficiency. It is observed that both the embedding efficiency and the embedding rate of the double-layered embedding are higher than those of LSB embedding and LSBMR method, and by introducing the double-layered mechanism, the performance of matrix coding and running coding is significantly improved. In particular, the double-layered matrix coding can provide the best embedding efficiency at any given embedding rate.

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