LETTER

Development of Compression Tolerable and Highly Implementable Watermarking Method for Mobile Devices

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SUMMARY This paper reports on the image compression tolerability and high implementability of a novel proposed watermarking method that uses a morphological wavelet transform based on max-plus algebra. This algorithm is suitable for embedded low-power processors in mobile devices. For objective and unified evaluation of the capability of the proposed watermarking algorithm, we focus attention on a watermarking contest presented by the IHC, which belongs to the IEICE and investigate the image quality and tolerance against JPEG compression attack. During experiments for this contest, six benchmark images processed by the proposed watermarking is done to reduce the file size of original images to 1/10, 1/20, or less, and the error rate of embedding data is reduced to 0%. Thus, the embedded data can be completely extracted. The PSNR value is up to 54.66 dB in these experiments. Furthermore, when the smallest image size is attained 0.49 MB and the PSNR value become about 52 dB, the proposed algorithm maintains very high quality with an error rate of 0%. Additionally, the processing time of the proposed watermarking can realize about 416.4 and 4.6 times faster than that of DCT and HWT on the ARM processor, respectively. As a result, the proposed watermarking method achieves effective processing capability for mobile processors.

key words: watermark, max-plus algebra, morphological wavelet transform, JPEG, compression tolerance, mobile device

1. Introduction

Mobile devices, such as cellular phones and smartphones, have spread due to the rapid development of semiconductor integration and embedded LSI technology. Thus, several types of mobile applications execute digital content in real-time to satisfy user-requirements. To protect the ownership of digital data, the Digital Rights Management (DRM) is a typical technology that is used for commercial digital content. However, a dedicated device is often needed for accessing this content. The end-user has difficulty applying DRM technology used for private content. Thus, the legal ownership of digital content is often dependent on the morals of the end-users. Therefore, to protect the ownership of digital content, watermarking technology has recently attracted attention. However, since embedded processors used for mobile computing devices have a limited amount of hardware, it is difficult to apply conventional complicated watermarking algorithms to maintain function and reduce cost. In this paper, to overcome this problem, we primarily focus on ownership protection of digital content and develop a watermarking algorithm that uses the Max-plus algebra-based Morphological wavelet Transform (MMT). MMT watermarking does not require special equipment or complex processing and enables efficient processing in mobile computing devices. For objective and unified evaluation of the capability of the proposed MMT watermarking algorithm, we focus attention on a watermarking contest presented by the committee for Information Hiding and its Criteria (IHC) [1], which belongs to the IEICE. Additionally, several watermarking algorithm implementation results for verifying the processing speed are measured on a well-known embedded processor.

2. Conventional Watermarking Algorithms for Mobile Devices

Since mobile devices like cellular phones and smartphones have spread across society, it is now possible to directly take several pictures, which is obtained by integrated cameras. To protect the ownership of such digital content, recent research has been focused on mobile-dedicated watermarking algorithms. Mobile devices can deal with several types of multimedia data, and lots of research for example has applied watermarking algorithms for digital images [2], [3], analog images [4], movies [5], and audio content [6]. Thus, mobile devices especially need to execute several operations in real-time for end-users. This paper proposes a novel mobile-dedicated watermarking algorithm for compatibility with compression tolerability and implementability on embedded processors.

3. Max-Plus Algebra-Based Morphological Wavelet Transform Watermarking

The morphological wavelet transform combines the inherent properties of the conventional wavelet transform and mathematical morphology. The MMT can be defined by nonlinear operation (maximum or minimum search) and standard sum, and integer representation can be used for all variables [7], [8]. The MMT has three novel features: lack of quantization error, high affinity with hardware implementation, and efficient edge image compression. Consequently, the algorithm for the MMT is assumed to be suitable for embedded low-power processors. Utilizing these features, MMT watermarking has been proposed for mobile embedded devices in our papers [9], [10]. Figure 1 shows the watermarking flow using the MMT for a $2 \times 2$ pixel sampling window.
can be represented in the equations [11] constructed from the four pieces. Then, all signals are gathered in accordance with the same case. Four pixel values are decomposed into four signals. The decomposition operation in a sampling window can be represented in the equations [11] \(a = \min(x, y, z, w)\), \(h = y - x\), \(v = z - x\), and \(d = w - x\). The reconstruction operation can also be represented in the equations [11] \(x = a + \max(-d, -h, -v, 0)\), \(y = a + \max(h - v, h - d, h, 0)\) = \(a + \max(-d, -h, -v, 0) + h = x + h\), \(z = a + \max(v - h, v - d, v, 0) = a + \max(-d, -h, -v, 0) + v = x + v\), and \(w = a + \max(d - h, v, d, 0) = a + \max(-d, -h, -v, 0) + d = x + d\). Here, the four variables \(x, y, z,\) and \(w\) correspond to the pixel values of the coordinates \((i, j)\), \((i + 1, j)\), \((i, j + 1)\), and \((i + 1, j + 1)\) in an original image. The variables \(a, h, v,\) and \(d\) are decomposed images, viz., scaled, horizontal, vertical, and diagonal signals. The horizontal low-frequency band and the vertical low-frequency band are located in the scaled signal group (LL). Similarly, the horizontal signal group, vertical signal group, and diagonal signal group represent the horizontal high-frequency band and the vertical low-frequency band (HL), the horizontal low-frequency band and the vertical high-frequency band (LH), and the horizontal high-frequency band and the vertical high-frequency band (HH), respectively. Generally, the HH signals contain high-frequency components. These can be utilized in the information data watermarking operation.

When information data is simply overwritten on high frequency components after decomposition, the embedded data is often affected by compression or quantization after reconstruction. To overcome this problem, in the proposed algorithm, information data is embedded as the relative information of a frequency component group. Figure 2 shows an example of how to embed. The MMT watermarking uses two pairs of row data, which includes horizontal diagonal signals (ex.) \(d_0^1, d_1^1, \ldots, d_{m-1}^1\), in HH signals to represent 1-bit information data. When the bit value 1 is embedded, the embedding strength \(\alpha\) is added to the selected upper signal (+\(\alpha\)) and subtracted from the lower signal (–\(\alpha\)). When the bit value 0 is embedded, \(\alpha\) is subtracted from the upper side (–\(\alpha\)) and added to the lower side (+\(\alpha\)). In extracting the 1-bit information, if \(\sum_{k=0}^{m-1/2} d_k^1 \leq \sum_{k=0}^{m-1/2} d_k^0\) is satisfied during the extraction process, so the proposed method can extract the bit value 1. Here, \(d^0\) corresponds to the compressed \(d \pm \alpha\). In contrast, the bit value 0 is extracted when \(\sum_{k=0}^{m-1/2} d_k^0 \geq \sum_{k=0}^{m-1/2} d_k^1\) is satisfied during the extraction process. The larger value of \(\alpha\) is expected to tolerate operation processing and editing, such as compression and filtering, after information data is embedded. The value of \(\alpha\) depends on the trade-off between image quality and extraction accuracy. During experiments with several values of \(\alpha\), we have determined that 5 is practical [9], [10].

4. Experimental Results for Image Compression and Processing Speed

In this section, several experimental results for the proposed MMT watermarking method used for JPEG compression are reported as an attack example. Additionally, conventional algorithm implementation results for verifying the processing speed are measured on a well-known embedded processor.

4.1 Evaluation for Compression Tolerance and Extraction Accuracy

For objective and unified evaluation, this paper evaluated image quality and tolerance against an image data compression attack based on the following criteria defined by the
committee on IHC [1], which belongs to the IEICE. Since the need for an explicit criterion for watermarking algorithms has been discussed in some papers [12], [13], this contest deals with image quality and tolerance to the JPEG compression attack of an image during the use of the watermarking algorithm. To verify the image quality and tolerance against the image data compression attack, this paper implements the following conditions and claims for the 1st competition for the watermarking contest [14].

- Six original images use the bitmap (BMP) format, which are 4,608 × 3,456 pixels (Fig. 3).
- The watermark information to embed is the fixed 64-bit string shown below:
  
  0000 0001 0010 0011 0100 0101 0110 0111
  1000 1001 1010 1011 1100 1101 1110 1111

- The images where watermark information data is embedded are coded in JPEG compression to reduce the file size to 1/10 or less of the original without error in extracting information bits (Experimental trial 1).
- The images after the above experimental trial 1 are coded in JPEG compression again to reduce the file size to 1/20 or less of the original without error in extracting information bits (Experimental trial 2).
- The image quality is investigated at the highest compression ratio without error in extracting information bits (Experimental trial 3).

Base on these conditions and claims, the experimental flow, which includes three experimental trials, is shown in Fig. 4.

Table 1 lists the experimental results for the 1st watermarking contest claims. This table has three trial results, which include three evaluation factors, respectively. The error rate shows the extraction accuracy of the 64-bit string. The PSNR value, which is the most common distortion measure in the field of image coding for watermarked images, is calculated between an uncoded-original image and an uncoded-watermarked image. The data size is obtained by using the JPEG compression result. The error rates become 0% when all six images are compressed in the JPEG algorithm to reduce the file size to 1/10 or less of the original images (Experimental trial 1). Furthermore, the compressed file size of 1/20 or less for the original images is reduced to 0% for the error rates (Experimental trial 2). In other words, we succeed in completely extracting 64-bit string data and can attain a 100% detection rate. Moreover, the PSNR value is up to 54.66 dB in the above trials. Generally, if the value of PSNR is higher than 30 dB, these differences are unable to be detected by the human eye. When the iheval-04 image is compressed the most to 0.49 MB (Experimental trial 3), the PSNR value is about 52 dB. Furthermore, since the MMT watermarking is executed before the compression process, it can use any conventional compression libraries without modifying the source code. This characteristic is a bigger advantage than those of other conventional watermarking methods. Therefore, the proposed MMT watermarking algorithm can satisfy all claims of the 1st watermarking contest and is a very effective watermarking technology.

4.2 Evaluation for Processing Speed

Due to the rapid growth in mobile devices in recent years, the performance required of watermarking algorithms has become an important factor in the processing efficiency of embedded LSI functionality. To test the efficiency of mobile-dedicated watermarking, two conventional watermarking methods and the proposed MMT watermarking method are implemented on a typical embedded processor. This paper uses an ARM Cortex-A8 at 1 GHz, which is a well-known conventional embedded processor and exploited in the BeagleBoard-xM [16]. Table 2 shows three sets of average processing times for experimental trial 1 for the Discrete Cosine Transform (DCT), the Haar Wavelet

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Table 1: Evaluation results for compression tolerance and extraction quality.

| File name | Data size [MB] | Data size [MB] | Data size [MB] | Error rate [%] | PSNR [dB] | Error rate [%] | PSNR [dB] | Error rate [%] | PSNR [dB] |
|-----------|----------------|----------------|----------------|----------------|-----------|----------------|-----------|----------------|-----------|
| iheval-01 | 0.08           | 4.46           | 0              | 53.03          | 2.18      | 0.78           | 51.76     | 0.75           | 50.80     |
| iheval-02 | 0.08           | 4.57           | 0              | 53.08          | 2.18      | 0.78           | 51.76     | 0.75           | 51.76     |
| iheval-03 | 0.08           | 4.33           | 0              | 54.36          | 2.11      | 0.77           | 51.30     | 0.68           | 51.29     |
| iheval-04 | 0.08           | 4.87           | 0              | 54.87          | 1.97      | 0.67           | 52.42     | 0.66           | 52.42     |
| iheval-05 | 0.08           | 4.32           | 0              | 54.32          | 2.08      | 0.68           | 53.64     | 0.74           | 53.46     |
| iheval-06 | 0.08           | 4.45           | 0              | 52.75          | 2.22      | 0.78           | 51.23     | 0.85           | 51.20     |

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† Our proposed MMT watermarking establishes a certified watermarking method for the 1st competition for watermarking algorithm presented by the IHC [15].
Table 2  Evaluation results for processing speed with ARM core implementations.

| Operation | DCT | HWT | MMT |
|-----------|-----|-----|-----|
| ARM core (default) | 3.29 | 1.46 | 0.99 |
| ARM core (OS) | 2.84 | 1.90 | 1.05 |
| ARM core (PM-NEON) | 2.85 | 1.96 | 0.95 |
| Transform | 547.75 | 291.93 | 275.78 |
| Input/Output | 1,798.11 | 2,013.45 | 946.77 |
| Data input | 0.54 | 0.57 | 0.67 |
| Total | 3,949.69 | 3,907.38 | 1,224.11 |

Transform (HWT), and the MMT watermarking methods with three ARM core implementations, which are default setting, optimizing compiler option -O3, and using the NEON general-purpose 128-bit SIMD circuit [17]. The DCT has been widely studied as a watermarking algorithm and embeds information data inside JPEG images. While the DCT often deals with trigonometric functions for computing coefficients, watermarking in the DCT domain offers the possibility of directly achieving the embedding operator in the compressed domain in order to minimize the computation time. The HWT, which consists of addition, subtraction, and division operations, has the advantage of being easier to calculate than other watermarking algorithms. The MMT algorithm mainly consists of simple calculations that require only addition, subtraction, and searching the maximum and minimum integers. A $2 \times 2$ sampling window operation can achieve highly-parallel processing. Thus, the value of the MMT watermarking processing time for an ARM core with NEON can be drastically reduced to about 81% smaller than that of the default operation. Furthermore, the MMT watermarking processing time can realize about 416.4 and 4.6 times faster than that of the DCT and HWT, respectively. As a result, the proposed MMT watermarking method achieves effective processing capability for mobile embedded processors.

5. Conclusion

In this paper, max-plus algebra-based morphological wavelet transform watermarking is proposed, which can realize compression tolerance and highly implementability with mobile devices. For the JPEG algorithm, image compression is done to reduce the file size of original images to 1/10, 1/20, or less, and the error rate of embedding data is reduced to 0%. Thus, the embedded data could be completely extracted. When the smallest image size is attained 0.49 MB, and the PSNR become about 52 dB, the proposed algorithm maintains a very high quality with an error rate of 0%. Additionally, the processing time of the proposed watermarking algorithm can realize about 416.4 and 4.6 times faster than that of the DCT and HWT on the ARM core processor with the NEON circuit, respectively. Since the MMT algorithm is executed before the compression process, it can use any conventional compression libraries without modifying the source code. Consequently, the proposed MMT watermarking method achieves effective processing capability for mobile embedded processors.

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