The Journal of Systems and Software 84 (2011) 923–929

Contents lists available at ScienceDirect

The Journal of Systems and Software

journal homepage: www.elsevier.com/locate/jss

A novel image watermarking in redistributed invariant wavelet domain

Li Li[a,*], He-Huan Xu[a], Chin-Chen Chang[b], Ying-Ying Ma[a]

[a] Institute of Computer Graphics and Image Processing, Hangzhou Dianzi University, 2nd Street, Xiasha, Hangzhou 310018, China
[b] Department of Information Engineering and Computer Science, Feng Chia University, Taichung 20724, Taiwan, ROC

ARTICLE INFO

Article history:
Received 16 September 2010
Received in revised form
21 December 2010
Accepted 10 January 2011
Available online 19 January 2011

Keywords:
Image watermarking
Haar wavelet
Copyright protection
Geometric attacks

ABSTRACT

Most existing digital watermarking algorithms, which are based on the Discrete Wavelet Transform, are not robust to geometric distortions, even if for some special distortions, such as multiples of 90° rotation of integers and image flipping, which change the location of pixels but have no effect on the value of the image. Therefore, to solve the problem, according to Haar wavelet transform theory, the redistributed invariant wavelet domain is constructed and proofed in this paper; a novel image watermarking algorithm, based on the invariant domain, is proposed to eliminate such distortions. The experimental results showed that the proposed algorithm not only can resist the common image processing operations, but also successfully resist the distortions that result from multiples of 90° rotations of integers and image flipping.

1. Introduction

The rapid development of information technologies has created an urgent demand for copyright protection of digital media, since it can be reproduced and manipulated in many convenient ways. Therefore, watermarking techniques were introduced to solve these problems, and these techniques have been studied extensively.

Image watermarking, which is a powerful technique for protecting the copyright of images, slightly modifies the host digital images to embed the copyright information. Currently, many researchers are committed to this filed and lots of new methods are continually proposed. Chang et al. (2009) presented a novel removable watermarking algorithm utilizing the Just Noticeable Distortion (JND) technique and the correlation difference between two selected subsampling images. Wang et al. (2010) proposed a steganographic scheme to improve the hiding capacity of EMD method (Zhang and Wang, 2006). Huang and Fang (2010) discussed about the practical implementation of robust watermarking with the EXIF metadata.

According to the processing domain in which the watermark is embedded, image watermarking techniques can be divided into two categories, i.e., spatial domain (Schyndel et al., 1994; Bender et al., 1996) and frequency domain (Cox et al., 1997; Bami et al., 1998; Premaratne and Ko, 1999; Xie and Arce, 2001). Generally speaking, frequency domain watermarking schemes are more robust to tampering and attacks than those in spatial domain. The discrete cosine transform (DCT), discrete Fourier transform (DFT) and discrete wavelet transform (DWT) domains are three common frequency domains that are commonly used in most image watermarking schemes. In addition, watermarking in DWT domain has drawn extensive attention for its good time-frequency features and its accurate matching of the human visual system (HVS).

For a watermarking system to be successful, the watermark must resist a variety of possible attacks. Usually, attacks on a watermarking scheme can be classified as common image processing operations and geometric distortions (Zheng et al., 2007). Although most existing watermarking schemes based on DWT have been demonstrated to be effective against common image processing, it is still inadequate in facing the challenge of resisting geometric distortions. This is because the DWT coefficients are not invariant under geometric transforms. For example, rotating an image by 90°, 180°, or 270° will not affect the value of the image, but any of the three rotations may lead to failure in detecting the watermark.

There are three procedures that are used in existing watermarking methods to address the issue of geometric distortions (Gao et al., 2010). The first procedure is to embed a template along with the watermark as side information. Pereira and Pun (2000) proposed a method based on the use of a template in the DFT domain. Before the detection of the watermark, the affine geometric attacks in the image were estimated and corrected by the embedded template. A major problem is that the template-based methods are incapable of estimating the attack parameters for some complicated geometric attacks.

* Corresponding author. Tel.: +86 13666632945; fax: +86 0571 86871632.
E-mail addresses: lili2008@hdu.edu.cn, lilihzdz@gmail.com (L. Li), xhhjin@gmail.com (H.-H. Xu), ccc@cs.ccu.edu.tw (C.-C. Chang), m7051986@163.com (Y.-Y. Ma).

0164-1212/$ – see front matter © 2011 Elsevier Inc. All rights reserved.
doi:10.1016/j.jss.2011.01.025

The second procedure is to use feature-based watermarking techniques. Bas et al. (2002) utilized the Harris detector to extract the feature points. Then, they defined a number of triangular regions, and both the watermark embedding and detection were conducted in these triangles. The problem with such watermarking techniques is the excessive computational burden incurred in the detection due to the use of a robust descriptor (Xiang et al., 2008).

In the third procedure, the watermark is embedded into the geometric invariant domain. In Ruanaidh and Pun (1998), Lin et al. (2001) and Farzam and Shirani (2001), the researchers embedded the watermark in an invariant domain, such as the Fourier–Mellin transform or Zernike moments, as opposed to using affine transforms. However, watermarking schemes that involve an invariant domain are usually difficult to implement.

The introduction above demonstrates that it is still an open problem to deal with geometric attacks. In addition, considering the widespread use of DWT in image watermarking techniques, it would be useful to determine ways to enhance the robustness of wavelet-based image watermarking schemes against geometric distortions.

In this paper, an invariant wavelet domain is constructed and proved, and, then, based on this proven invariant wavelet domain, a novel watermarking technique is proposed. Obviously, our method belongs to the third procedure that embeds the watermark in the geometric invariant domain, and it is quite easy to accomplish. In order to achieve geometric invariance, first, the pixels' locations of the image are redistributed; then, the Haar wavelet transform and some normalized procedures are performed, and, finally, the invariant wavelet domain is obtained. As we have proved in detail in Section 3.2, it is robust to some geometric distortions, such as multiples of 90° rotation of integers and image flipping, which change the positions of the pixels of the image but leave their values unchanged. Consequently, most existing wavelet-based watermarking schemes, blind or not blind, can be redesigned by using the invariant wavelet domain to enhance their robustness to cope with geometric distortions. Experimental results show that the proposed scheme is really robust to geometric attacks, and, more importantly, it is still able to resist common image processing.

The rest of this paper is organized as follows. A brief review of the Haar wavelet transform is given in Section 2. In Section 3, the proposed redistributed invariant wavelet domain is constructed and proved. Section 4 details the novel image watermarking scheme in two subsections, i.e., embedding and detection. Experimental results and analysis are presented in Section 5, and Section 6 concludes this work.

2. Haar wavelet transform

Recently, wavelet-based watermarking schemes have begun to attract greatly increased attention. The main reasons for inserting watermarks in the wavelet domain are that it has good space-frequency localization, superior HVS modeling, and low computational cost. In practice, when a watermark is to be embedded in the wavelet domain, there are many wavelet bases to choose from. Since the different bases have different characteristics, the choice of which base to use to embed the watermark is important. In their research, Liu et al. (2003) found that the Haar wavelet is suitable for watermarking images.

Let $I(x, y)$ denote a digital image of size $2M \times 2N$, if not, boundary prolongation should be used to ensure that the size of the image is divisiable by 2, which is necessary for Haar wavelet transform. The wavelet low-pass and high-pass filters are $h(n)$ and $g(n)$ respectively. Then the image can be decomposed into its various resolutions based on the approximate weight (LL) and the detailed

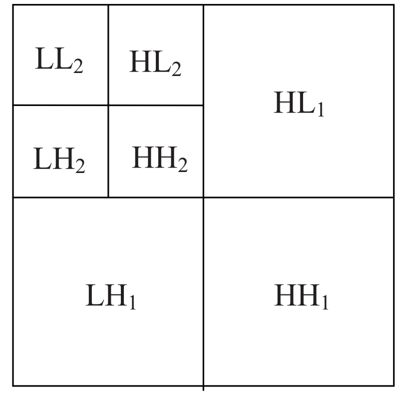

Fig. 1. Two-level wavelet decomposed image.

weights of the horizontal direction (HL), vertical direction (LH), and diagonal direction (HH). The decomposition formula is:

$$\begin{cases} LL(i,j) = \sum_{x,y} h(x-2i)h(y-2j)I(x,y), \\ LH(i,j) = \sum_{x,y} h(x-2i)g(y-2j)I(x,y), \\ HL(i,j) = \sum_{x,y} g(x-2i)h(y-2j)I(x,y), \\ HH(i,j) = \sum_{x,y} g(x-2i)g(y-2j)I(x,y), \end{cases} \quad (1)$$

where $i, j, N \in Z^+$, $x, y \in Z$, $-2L+1 \le x-2i \le 0$, $-2L+1 \le y-2i \le 0$.

On this basis, similar decomposition procedure can be implemented on LL to get the two-level wavelet transformed image, as shown in Fig. 1, and so on. The wavelet image reconstruction is the inverse transform of the wavelet decomposition. The formula is:

$$I(x,y) = \sum_{i,j} h(x-2i)h(y-2j)LL(i,j) + \sum_{i,j} h(x-2i)g(y-2j)LH(i,j) + \sum_{i,j} g(x-2i)h(y-2j)HL(i,j) + \sum_{i,j} g(x-2i)g(y-2j)HH(i,j), \quad (2)$$

where $i, j, N \in Z^+$, $x, y \in Z$, $-2N+1 \le x-2i \le 0$, $-2N+1 \le y-2i \le 0$.

As for the Haar wavelet, the low-pass filter is $\{1/\sqrt{2}, 1/\sqrt{2}\}$, and the high-pass filter is $\{1/\sqrt{2}, -1/\sqrt{2}\}$, so Formula (1) can be rewritten as Formula (3):

$$\begin{cases} I_{LL}(i,j) = [I(2i-1,2j-1) + I(2i-1,2j) + I(2i,2j-1) + I(2i,2j)]/2, \\ I_{LH}(i,j) = [I(2i-1,2j-1) - I(2i-1,2j) + I(2i,2j-1) - I(2i,2j)]/2, \\ I_{HL}(i,j) = [I(2i-1,2j-1) + I(2i-1,2j) - I(2i,2j-1) - I(2i,2j)]/2, \\ I_{HH}(i,j) = [I(2i-1,2j-1) - I(2i-1,2j) - I(2i,2j-1) + I(2i,2j)]/2, \end{cases} \quad (3)$$

where $1 \le i \le M$, $1 \le j \le N$.

3. Our redistributed invariant wavelet domain

In this section, the construction and proof procedures of the redistributed invariant wavelet domain are described in detail in Sections 3.1 and 3.2, respectively.

3.1. Construction of redistributed invariant wavelet domain

For the purpose of invariance to multiples of 90° rotation and image flipping, given an image I, the normalization procedure is formulated as follows:

Step 1: Divide the original image into four (2×2), equal-sized subimages and derive their average intensities matrix, denoted as: