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用于二值图像认证的数字水印技术

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摘要: 为实现对二值图像的认证保护,提出了一种基于数字水印的用于图像完整性和所有者认证的算法. 首先利用像素扩展差(PSD)判断准则将图像块中的像素分为"可翻转"和"不可翻转";然后利用混沌映射对图像块进行置乱;最后根据加密后的所有者水印信息,对图像块中 4 部分的"可翻转"像素进行修改,完成水印的嵌入. 实验结果表明,本算法具有良好的视觉透明性,能对图像的内容篡改进行定位,并解决了二值图像中均匀区域的保护这一难点问题.

关 键 词: 图像认证; 所有者认证; 数字水印; 二值图像; 混沌
中图分类号: TP309. 2 **文献标志码**: A

An Authentication Watermarking Technique for Binary Images

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Abstract: In order to authenticate the binary images, a fragile watermarking technique for image authentication and ownership verification is proposed. The pixels are firstly divided into two groups according to pixel spread difference (PSD), one is the "flippable" pixels and the other is the "unflippable" pixels. Then, the image block is permutated by a chaotic sequence. According to the encrypted ownership watermarks, the "flippable" pixels in the four parts of the image block are altered to get the watermarked image block. Experiments show the imperceptibility of the watermarking process, the proposed algorithm can successfully localize the content modifications, and protect the uniform regions that is the key problem in binary image authentication. The photonic crystal structures with excellent slow light properties can be achieved through designing the waveguide based on the conclusion.

Key words: image authentication; ownership verification; digital watermarking; binary images; chaos

0 引言

随着计算机网络通信和多媒体技术的发展,数字产品的版权保护以及内容认证越来越受到重视. 数字水印作为保护数字图像版权和完整性的有效手段,已成为信息安全领域的研究热点[1-8].

随着二值图像的广泛应用,二值图像水印技术也越来越受到国内外学者的重视,近年来一些学者进行了诸多探索,设计出了一些可行的数字水印算法[1-5]. 文献[1]提出了一种有效的衡量像素点可翻转性的方法(简称 Min Wu 评分准则). 文献[2]定义了区域的最不重要像素块(LSPB),用于评价像素点的可翻转性(简称 LSPB 评分准则). 文献[3]提出了度量图像中像素点"可翻转性"的 PSD,能较准确地对像素点的可翻转性进行评价,且易扩展. 在篡改定位方面,文献[1]算法不具有篡改定位能力;LSPB 算法[2]具有篡改定位能力,但是没有对图像的均匀区域进行保护. 为了保护图像的均匀区域,文献

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[4]对图像的均匀区域和非均匀区域用标记符号进行区分,可以定位对图像均匀区域的篡改,但需传送和管理额外的附加信息,且附加信息较大.

另外,目前仅有少量的文献[7-8]能在不需要附加信息的情况下,同时实现图像的完整性认证和所有者认证,且都是针对灰度图像. 本文通过对所有者信息进行加密生成水印信号,可以在不需要任何附加信息的情况下,同时实现对二值图像的完整性认证并获取所有者信息.

1　PSD[3]

为了度量像素点 d 的"可翻转性",首先考察一个以 d 为中心、大小为 $w \times w$ 的图像块 $\boldsymbol{B}$,其中 $w = 3,5,7,\cdots$. $\boldsymbol{B}$ 中所有像素点的值记为 $\boldsymbol{B}(m,n)$,其中 (m,n) 为像素点的坐标,$m,n = 1,2,\cdots,w$. 那么点 d 坐标为 (m_c,n_c),$m_c = n_c = \frac{w+1}{2}$. 假设图 $\boldsymbol{B}$ 的均值为 μ,那么 $\boldsymbol{B}(m,n)$ 的偏差为 $\delta(m,n) = |\boldsymbol{B}(m,n) - \mu|$. 引入 1 个和 $\boldsymbol{B}$ 大小相同的权重矩阵

$$\boldsymbol{W}(m,n) = \begin{cases} 1 & m = m_c, n = n_c \\ \dfrac{1}{\sqrt{(m-m_c)^2 + (n-n_c)^2}} & \text{其他} \end{cases} \tag{1}$$

定义 1　图像块 $\boldsymbol{B}$ 的像素扩展(PS)为

$$P = \sum_{m=1}^{w} \sum_{n=1}^{w} \delta(m,n) \boldsymbol{W}(m,n) \tag{2}$$

定义 2　假设 $\boldsymbol{B}$ 的中心点 d 翻转后的像素扩展为 P',那么 d 的"可翻转性"由其翻转前后图像块的 PSD 来衡量,即

$$P_S = |P - P'| \tag{3}$$

利用式(3)计算每个像素点的 PSD 值. 设定阈值 τ,将 $P_S \leqslant \tau$ 的像素点定为"可翻转", $P_S > \tau$ 的像素点定为"不可翻转".

2　二值图像的认证算法

2.1　水印的嵌入

利用 Logistic 映射生成混沌序列对图像块进行置乱,并利用混沌序列对所有者信息进行加密生成水印,水印嵌入框图如图 1 所示.

将原始图像 $\boldsymbol{X}$ 划分成 M 个大小为 $m \times n$ 的图像块 $\boldsymbol{X}_i$,$i = 1,2,\cdots,M$. 每个图像块的水印嵌入独立进行,算法的具体步骤如下.

步骤 1　计算图像块中每个 $w \times w$ 的块中心点的 PSD,并根据 τ,仅将 $P_S \leqslant \tau$ 的中心点定为"可翻转"像素点,其他定为"不可翻转"像素点.

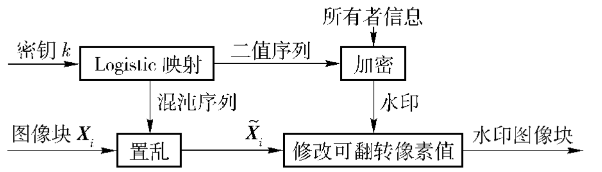


图 1　水印嵌入框图

步骤 2　分别以密钥 k 和 $\frac{k}{2}$ 为 Logistic 混沌映射

$$x_{i+1} = \lambda x_i (1 - x_i) \tag{4}$$

的初始值,生成长度为 m 和 n 的 2 个实值混沌序列. 其中,x_i 为当前值;λ 为混沌控制因子. 由小到大对 2 个实值混沌序列进行排序,生成 2 个相应的位置信息序列 $\boldsymbol{C}$ 和 $\boldsymbol{D}$,$\boldsymbol{C}(p)$ 和 $\boldsymbol{D}(q)$ 指排序前第 p 个位置和第 q 个位置的混沌值在排序后的位置,其中,$p = 1,2,\cdots,m$;$q = 1,2,\cdots,n$. 利用排序前后混沌序列位置信息的变化对二值图像块进行置乱. 置乱后的图像块 $\widetilde{\boldsymbol{X}}_i$ 与原始图像块 $\boldsymbol{X}_i$ 之间的关系为

$$\widetilde{\boldsymbol{X}}_i(p,q) = \boldsymbol{X}_i(\boldsymbol{C}(p), \boldsymbol{D}(q)) \tag{5}$$

步骤 3　将 $\widetilde{\boldsymbol{X}}_i$ 划分为大小相同、互不重叠的 4 部分,按从上到下、由左至右的顺序将这 4 部分分别记为 $\widetilde{\boldsymbol{X}}_i^h$, $h = 1,2,3,4$,每部分像素值之和分别记为 Z_i^h. 根据水印信号对该图像块的可翻转像素点的值进行修改,使修改后图像块的 4 部分像素值和 $\widetilde{Z}_i^h$ 满足如下关系.

1）如果嵌入的水印信息为 1,则 $\widetilde{Z}_i^h$ 应满足

$$\widetilde{Z}_i^1 + \widetilde{Z}_i^3 \geqslant \widetilde{Z}_i^2 + \widetilde{Z}_i^4 \tag{6}$$

2）如果嵌入的水印信息为 0,则 $\widetilde{Z}_i^h$ 应满足

$$\widetilde{Z}_i^1 + \widetilde{Z}_i^3 < \widetilde{Z}_i^2 + \widetilde{Z}_i^4 \tag{7}$$

图 2 示出了水印嵌入过程,原始图像经置乱后如图 2(b)所示,置乱后的图像 $Z_i^1 + Z_i^3 = 1\,548$、$Z_i^2 + Z_i^4 = 1\,582$. 如果嵌入的水印 $\boldsymbol{W} = 0$,则不需改变任何像素值,得到的水印图像和原始图像一致;如果嵌入的水印 $\boldsymbol{W} = 1$,则需修改可翻转像素点的值,即在第 1 和第 4 部分将值为 0 的可翻转像素修改为 1,而在第 2 和第 3 部分将值为 1 的可翻转像素修改为 0,修改后 $\widetilde{Z}_i^1 + \widetilde{Z}_i^3 = 1\,571$. $\widetilde{Z}_i^2 + \widetilde{Z}_i^4 = 1\,553$,修改图像如图 2(f)所示,还原后的水印图像如图 2(e)所示.

(a) 原始图像 (b) 置乱图像

(c) 水印图像 **W**=0 (d) 修改图像 **W**=0

(e) 水印图像 **W**=1 (f) 修改图像 **W**=1

图 2 图像的水印嵌入

步骤 4 为实现图像所有者信息提取，水印信息必须包含所有者信息 $\boldsymbol{S}$. 为增强水印信息安全性，需对所有者信息加密. 以 $k/3$ 为 Logistic 混沌序映射的初始值生成长度为 M 的混沌序列，再利用阈值函数

$$n_{\mathrm{o}} = \begin{cases} 1 & x \geqslant 0.5 \\ 0 & \text{其他} \end{cases} \tag{8}$$

将实值混沌序列生成二值序列 $\boldsymbol{B}$；再将 $\boldsymbol{S}$ 重复编码扩展成长度为 M 的序列 $\boldsymbol{S}'$，水印信号 $\boldsymbol{W}=\boldsymbol{S}'\oplus\boldsymbol{B}$；最后将水印信号按步骤 3 嵌入到每个图像块中，完成水印的嵌入，得到水印图像 $\boldsymbol{X}_{\mathrm{w}}$.

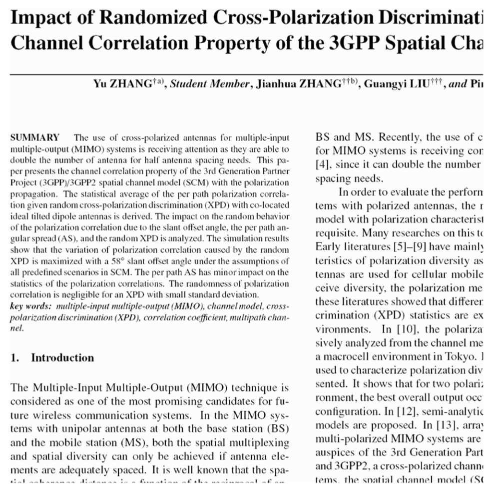
2.2 水印的提取与图像认证

水印的提取和水印的嵌入方法一致. $\boldsymbol{X}_{\mathrm{w}}$ 经过同样的图像块划分，并利用密钥 k 对图像块进行置乱，根据置乱后图像的 4 部分像素值提取水印信号，如果 $\widetilde{Z}_i^1+\widetilde{Z}_i^3 \geqslant \widetilde{Z}_i^2+\widetilde{Z}_i^4$，则 $\boldsymbol{W}=1$；如果 $\widetilde{Z}_i^1+\widetilde{Z}_i^3 < \widetilde{Z}_i^2+\widetilde{Z}_i^4$，则 $\boldsymbol{W}=0$. 将提取的所有者信息与 $\boldsymbol{B}$ 进行异或，可得扩展后的所有者信息 $\overline{\boldsymbol{S}}$.

脆弱水印能定位出恶意篡改的区域. 首先将 $\overline{\boldsymbol{S}}$ 划分成大小与 $\boldsymbol{S}$ 一致的不重叠图像块，然后将各图像块进行对比，将图像块之间不同的位置映射为水印图像被篡改的位置，即将所有者信息图像块之间不同的位置按由上至下、由左到右的顺序记为 (a,b)，那么水印图像中对应位置为 (a,b)、大小为 $m\times n$ 的图像块将标记为被篡改，以此实现对篡改的定位. 另外，如果水印图像未被篡改，则 $\overline{\boldsymbol{S}}=\boldsymbol{S}'$.

3 实验结果

为说明本文算法的有效性，下面给出仿真结果. 大小为 1 082 ×1 082 的二值英文图像[9] 和大小为 30 ×30 的所有者图像如图 3 所示. 首先将原始图像划分为 18 ×18 的图像块，取 $k=0.3$、$\lambda=4$、$w=3$ 和 $\tau=1.8$，此时原始图像中可翻转的像素点数为 6 606.



Impact of Randomized Cross-Polarization Discriminati
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Yu ZHANG†a), *Student Member*, **Jianhua ZHANG††b)**, **Guangyi LIU†††**, *and* **Pi**

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(a) 二值英文图像

(b) 所有者图像

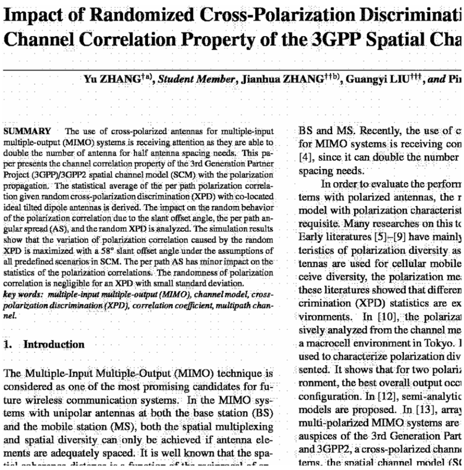
图 3 原始图像

3.1 篡改的检测与定位

为了测试本文算法对恶意篡改的定位能力，特别是对均匀区域的添加和删除攻击，对如图 4(a) 所示的水印图像进行了不同的篡改攻击. ① 删除作者信息中的“Student”；② 篡改摘要右下方的图像块；③ 在“1. Introduction”后面的空白处添加了 MIMO；④ 将参考文献“[4]”改为“[10]”，篡改后的图像如图 4(b) 所示. 对内容篡改的定位结果如图 4(c) 所示，其中黑色小块指示被篡改的图像块.

由图 4 可知，本文算法能实现对二值图像的完整性认证，并对图像内容的篡改具有良好的定位能力，对图像块篡改的检测率为 50%，特别是实现了对二值图像均匀区域的保护.

如果要提高对二值图像均匀区域的保护，第一，可通过在 1 个图像块中嵌入多个水印. 该算法中 1 个图像块只嵌入 1 个水印，检测到攻击的概率为 50%，如果嵌入 2 个，能提高到 75%，但是增加水印数的代价是降低水印的可视性，所以需根据实际要求设计嵌入水印数. 第二，可缩小图像块的尺寸，更小的图像块能提高对均匀区域的保护，但会带来计算量的大幅增加. 另外，如果所有者图像的像素数为 N，根据水印的篡改定位算法，至少需在原始文本图像中嵌入 2 个所有者图像，而 1 个图像块中只嵌



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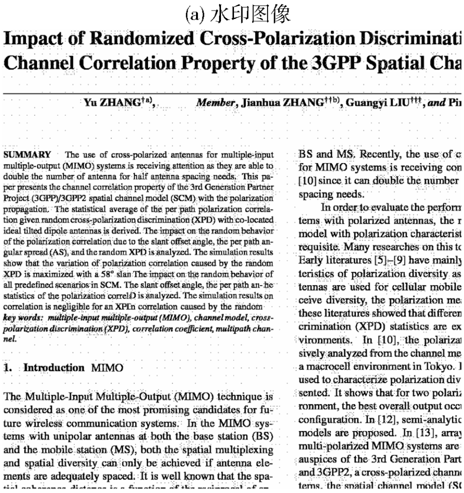

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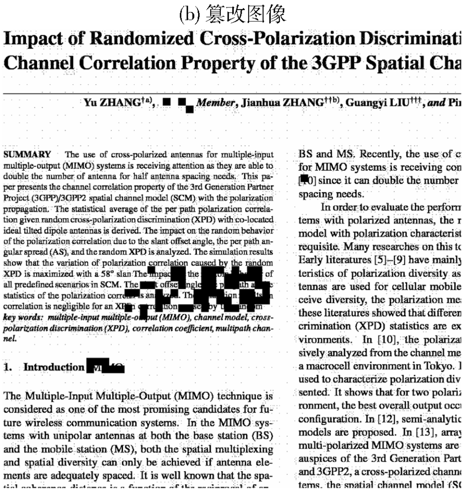

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model with polarization characterist
requisite. Many researches on this tc
Early literatures [5]–[9] have mainly
teristics of polarization diversity as
tennas are used for cellular mobile
ceive diversity, the polarization me
these literatures showed that differen
crimination (XPD) statistics are ex
vironments. In [10], the polarizat
sively analyzed from the channel me
a macrocell environment in Tokyo. I
used to characterize polarization div
sented. It shows that for two polariz
ronment, the best overall output occ
configuration. In [12], semi-analytic
models are proposed. In [13], array
multi-polarized MIMO systems are
auspices of the 3rd Generation Part
and 3GPP2, a cross-polarized chann
tems, the spatial channel model (SC

(c) 定位图像

图 4　水印图像的篡改与定位

入 1 个水印信息，所以图像块尺寸应满足

$$mn \geq Mmn/2N \tag{9}$$

利用正确密钥对未被篡改的水印图像的认证结果如图 5(a)所示，与原始所有者信息一致. 利用正确密钥对如图 4(b)所示篡改图像的认证结果如图 5(b)所示，虽然与原始所有者信息有所不同，但仍能正确显示所有者信息. 然而，利用差异微小的密钥($k = 0.3001$)提取的所有者信息如图 5(c)所示，却没有显示任何所有者的特征，提高了算法的安全性.

(a) 正确密钥未篡改水印图像　(b) 正确密钥已篡改水印图像　(c) 错误密钥未篡改水印图像

图 5　图像的所有者认证

3.2　与现有算法的性能比较

下面从认证水印的重要特性——不可见性、篡改定位、鲁棒性方面阐述现有算法[1-2,4]的优缺点及与本文算法的性能差异.

1) 在水印的不可见性方面，利用了像素扩展差，与具有代表性的 Min Wu 评分准则在图像的水印不可见性方面具有一致性[3].

2) 在水印的篡改定位方面，本文算法对图像的内容篡改具有定位能力，特别是能对图像的均匀区域进行保护，且不需任何附加信息，优于现有算法[1-2,4].

3) 在水印的鲁棒性方面，本文算法没有考虑水印的鲁棒性，与文献[2,4]算法相同，属于完全脆弱水印. 文献[1]算法在水印的鲁棒性方面优于本文算法，水印信息可经受高质量的打印、扫描处理.

4) 本文算法在所有者信息提取方面优于文献[1]算法. 在文献[1]算法中，图像无论经过何种篡改，提取的所有者信息都将无法辨认类似噪声，而本文算法中，图像经过删除、复制和添加等篡改后，仍可辨识出所有者信息.

4　结束语

本文提出了数字水印技术应用在二值图像认证中的一个新算法，通过改变“可翻转”像素点的值，设计了水印嵌入算法. 该算法具有如下优点：① 具有良好的视觉透明性. 根据 PSD，仅修改了“可翻转”的像素点，保证了水印图像的良好视觉品质. ② 内容篡改具有良好的定位能力，并解决了二值图像中均匀区域的保护问题. ③ 实现了所有者信息的提取，如果图像未被篡改或只经过小部分内容篡改，如剪切、复制、删除和添加，都能正确地显示所有者信息，且不需任何附加信息.

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