Multichannel Color Image Watermark Detection Utilizing Vector-based Hidden Markov Model

Marzieh Amini, *Student Member, IEEE,* Hamidreza Sadreazami, *Member, IEEE,* M. Omair Ahmad, *Fellow, IEEE,* and M. N. S. Swamy, *Fellow, IEEE*
Department of Electrical and Computer Engineering
Concordia University, Montreal, Quebec, Canada H3G 1M8
E-mail: {ma_amini, h_sadrea, omair, swamy}@ece.concordia.ca

***Abstract*—Multimedia data piracy in the Internet is a growing problem, since it provides easy and fast data transmission. Watermarking is regarded as a solution to restrain unauthorized duplication or distribution data. Image watermarking research mostly focuses on grayscale images with an extension to color images. However, most of these techniques ignore dependencies between color channels. In view of this, in this work, a multichannel color image watermarking technique and its corresponding detector in the wavelet domain is proposed. The inter-channel dependencies between RGB channels and inter-scale dependencies of the wavelet coefficients of color image are taken into account by employing the vector-based hidden Markov model. We conduct experiment on a set of color images to assess the performance of the proposed watermark detector. The results show that the performance of the proposed detector is superior to that of the other detectors in terms of the imperceptibility of the embedded watermark and the detection rate. It is also shown that the proposed detector has better performance in presence or absence of different kinds of attacks in comparison to the other existing methods.**

***Index Terms*—Watermarking, vector-based hidden Markov model, optimum detector, receiver operating characteristics.**

I. Introduction

Image watermarking is realized by hiding a secret message in the host image for protecting intellectual property and facilitating copyright protection. Most of the image watermarking research focuses on grayscale images [1], [2]. In order to watermark color images, one can take advantage of grayscale watermarking techniques by embedding the watermark only into the luminance channel. However, it has been shown that the performance of a watermarking technique for color images can be improved by considering correlation between RGB channels [3]. In [3], a watermarking technique has been proposed by considering a global correlation measure for dependencies between the RGB channels. In [4], a non-blind color image watermarking technique has been proposed using a quaternion Fourier transform. In [5], a wavelet-based color image watermarking has been proposed by using visual masking in Yuv color space. In [6], a color image watermarking technique has been proposed using the Weibull distribution for modeling the Fourier coefficients of images and a correlator detector has been designed to capture correlation between color channels. In [7], a blind color image watermarking based on wavelet-tree has been proposed. In [8], a wavelet-domain color image watermarking scheme has been proposed where inter-channel dependencies have been captured using the multivariate power-exponential (MPE) distribution. In [9], a multiplicative watermark detector has been designed for RGB color images by utilizing the multivariate Cauchy distribution. The Bessel-k form (BKF) model has been used in [10] to develop a watermark detector in the wavelet domain.

It is known that the vector-based hidden Markov model (HMM) can very closely fit to the distribution of the image wavelet coefficients. This model can capture the peakiness and heavy tails of the empirical distribution as well as the inter-scale dependencies of the image wavelet coefficients. In light of this, in this work, a new multichannel watermark detector for color images is proposed utilizing the vector-based HMM. Using this model in the wavelet domain, the inter-channel dependencies of RGB channels can be captured and used to design a watermark detector with an improved performance. To this end, the likelihood ratio criterion is used to establish the decision rule which results in deriving an efficient closed-form expressions for the test statistics. The performance of the proposed detector, in terms of the receiver operating characteristics (ROC) curve, is investigated through several experiments and compared with that of the other existing detectors with or without presence of attacks.

II. Color Image Watermarking Scheme

The proposed watermarking scheme is comprised of two stages: embedding and detection. In the former, each individual channel of the original RGB color image is decomposed using 3-level wavelet transform into several subbands. The subband with the highest entropy value in the third scale of each channel is selected for hiding the watermark. Selected subband in each channel has N coefficients. Using a pseudo random sequence generator, the watermark W is generated,

This work was supported in part by the Natural Sciences and Engineering Research Council (NSERC) of Canada and in part by the Regroupement Strategique en Microelectronique du Quebec (ReSMiQ).

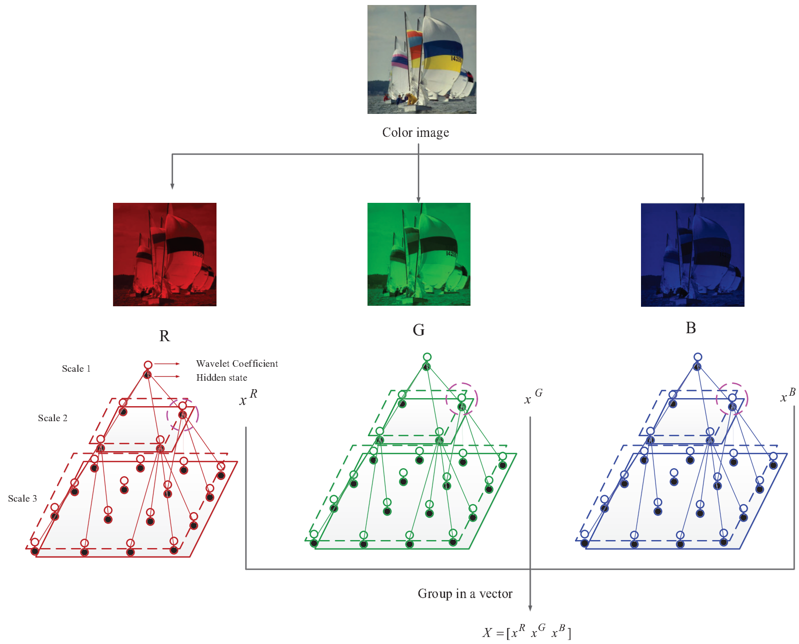

Fig. 1. RBG color image decomposition using the wavelet transform.

taking values $\{-1,+1\}$ with equal probabilities. The embedding part of watermarking is by the following

$$Y = X + \xi X W \tag{1}$$

where $X = [X^R, X^G, X^B]$, $Y = [Y^R, Y^G, Y^B]$ are the coefficients of the host and watermarked RGB channels, $W = [W^R, W^G, W^B]$ is the watermark sequence of size $N \times 3$ and ξ is a weighting factor providing a trade-off between the robustness of the watermarking scheme and the invisibility of the hidden watermark. The watermarked wavelet coefficients are then inversely transformed to obtain the watermarked image.

In order to realize a blind watermark detection, and since HMM is capable of accurately fitting the empirical distribution of the image wavelet coefficients [11]-[17], the wavelet coefficients of RGB color channels are modeled using the vector-based HMM distribution. In other words, we take advantage of the statistical properties of the color image wavelet coefficients to design a blind watermark detector. The probability density function of the M-state zero-mean vector-based HMM for a wavelet coefficient of the three RGB channels is expressed as

$$f(X_j) = \sum_{i=1}^{M} \frac{p_q^i \exp\left\{\frac{-1}{2} X_j^T \left(\Sigma_q^i\right)^{-1} X_j\right\}}{\sqrt{(2\pi)^3 \left|\Sigma_q^i\right|}} \tag{2}$$

where j represents the node in the q^{th} scale, p_q^i is the probability of a coefficient being in state i, and Σ_q^i is the covariance matrix representing the inter-channel cross-correlation between the image wavelet coefficients. It should be noted that, to estimate the parameters of the vector-based HMM, we resort to the expectation maximization (EM) algorithm [20].

We now establish a binary hypothesis testing to formulate our proposed watermark detection technique, where the two hypotheses, indicating whether or not the watermark exists, are expressed as

$$\begin{aligned} H_1 &: Y = X + \xi X W \\ H_0 &: Y = X \end{aligned} \tag{3}$$

It then reduces to a log-likelihood ratio test given by [18]

$$\Lambda(Y) = \ln \frac{f_Y(Y|H_1)}{f_Y(Y|H_0)} = \ln \prod_{j=1}^{N} \frac{f_Y(Y_j|H_1)}{f_Y(Y_j|H_0)} \underset{H_0}{\overset{H_1}{\gtrless}} \tau \tag{4}$$

where τ is the threshold and

$$f_Y(Y_j|H_1) = \frac{1}{1+\xi W} f_X\left(\frac{Y_j}{1+\xi W}\right) \tag{5}$$

and $f_Y(Y_j|H_0) = f_X(Y_j)$. After inserting the M-state vector-based HMM distribution in (5), the log-likelihood ratio is rewritten as

$$\Lambda(Y) = \sum_{j=1}^{N} \ln \frac{\frac{1}{1+\xi W} \sum_{i=1}^{M} \frac{p_q^i \exp\left\{\frac{-1}{2(1+\xi W)^2} Y_j^T \left(\Sigma_q^i\right)^{-1} Y_j\right\}}{\sqrt{\left|\Sigma_q^i\right|}}}{\sum_{i=1}^{M} \frac{p_q^i \exp\left\{\frac{-1}{2} Y_j^T \left(\Sigma_q^i\right)^{-1} Y_j\right\}}{\sqrt{\left|\Sigma_q^i\right|}}} \tag{6}$$

In view of the central limit theorem, $\Lambda(Y)$ is assumed to have a normal distribution under hypotheses H_0 and H_1 with parameters (m_0, σ_0^2) and (m_1, σ_1^2), respectively. Then, the mean and variances under H_0 hypothesis is theoretically obtained as

$$
\begin{aligned}
m_0 =& \sum_{j=1}^{N} (\ln \sqrt{\sum_{i=1}^{M} \frac{p_q^i \exp\left\{\frac{-1}{2(1+\xi)^2} X^T \left(\Sigma_q^i\right)^{-1} X\right\}}{\sqrt{\left|\Sigma_q^i\right|}}} \\
&+\ln \sqrt{\sum_{i=1}^{M} \frac{p_q^i \exp\left\{\frac{-1}{2(1-\xi)^2} X^T \left(\Sigma_q^i\right)^{-1} X\right\}}{\sqrt{\left|\Sigma_q^i\right|}}} \\
&-\ln \sum_{i=1}^{M} \frac{p_q^i \exp\left\{X^T \left(\Sigma_q^i\right)^{-1} X\right\}}{\sqrt{\left|\Sigma_q^i\right|}} \\
&-\ln\sqrt{1-\xi^2}) \qquad (7)
\end{aligned}
$$

and

$$
\begin{aligned}
\sigma_0^2 =& 0.25(\sum_{j=1}^{N} \ln \left(\sum_{i=1}^{M} \frac{p_q^i \exp\left\{\frac{-1}{2(1+\xi)^2} X^T \left(\Sigma_q^i\right)^{-1} X\right\}}{\sqrt{\left|\Sigma_q^i\right|}}\right) \\
&-\ln \left(\sum_{i=1}^{M} \frac{p_q^i \exp\left\{\frac{-1}{2(1-\xi)^2} X^T \left(\Sigma_q^i\right)^{-1} X\right\}}{\sqrt{\left|\Sigma_q^i\right|}}\right) \\
&+\ln \left(\frac{1-\xi}{1+\xi}\right))^2 \qquad (8)
\end{aligned}
$$

Similarly, the mean and variance under H_1 can be obtained, where $m_1 = -m_0$ and $\sigma_1 = \sigma_0$. The ROC curve is then obtained by relating the probability of detection P_{Det} to a predefined probability of false alarm P_{Fa} as given by

$$
P_{Det} = Q\left(Q^{-1}\left(P_{Fa} + 2\frac{m_0}{\sigma_0}\right)\right) \qquad (9)
$$

where $Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^{\infty} \exp\left(\frac{-t^2}{2}\right) dt$.

III. Simulation Results

The performance of the proposed vector-based HMM watermark detector is assessed through conducting experiments on a set of Kodak images of size 256×256 pixels. We first decompose the RGB channels using the three level wavelet transform. We then insert the watermark bits into the selected subband of each color channel using (1). In order to evaluate the invisibility of the proposed algorithm, the peak signal-to-noise-ratio (PSNR) between the original and watermarked images is computed. Fig. 2 shows the original and watermarked color images when $\xi = 0.8$. It is seen from this figure that there is no noticeable difference between the watermarked and original images. The high PSNR values for the watermarked images also reinforce the proposed watermarking technique's imperceptibility.

To validate the theoretical expressions for the detector in (7) and (8), we compare the theoretical ROC curves and the experimental ones using Monte Carlo simulations. Fig. 3 shows the experimental and theoretical ROC curves averaged over a set of color images. From this figure, it is seen that the theoretical and experimental ROC curves are very close,

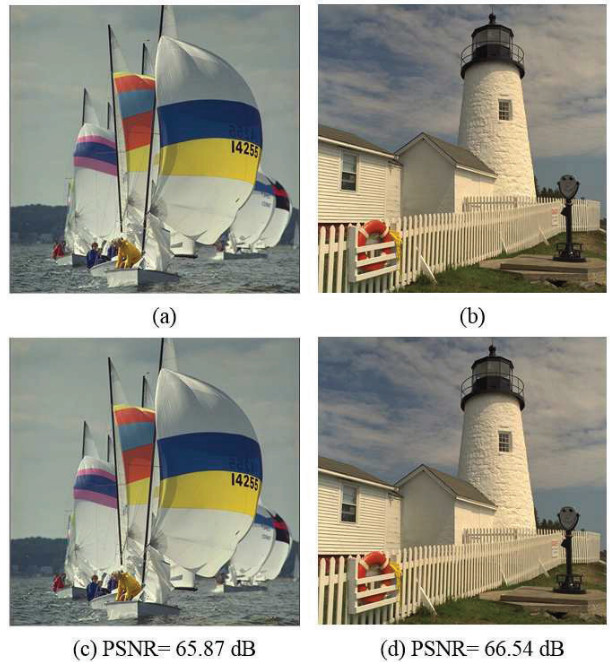

Fig. 2. (a)-(b) Original and (c)-(d) watermarked images.

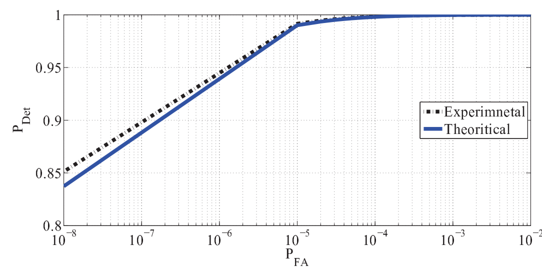

Fig. 3. Theoretical and experimental ROC curves obtained using the proposed color image watermark detector.

incidating the validity of the theoretical expressions for the test statistics.

We now compare the performance of the proposed color image watermark detector using the vector-based HMM with that of the MPE [8], Cauchy [9], BKF [10] and GG-based [19] detectors. To this end, the corresponding values for the area under ROC (AUROC) curve are obtained. Table I gives AUROC curve values averaged over a number of test images for a given P_{Fa} in $[10^{-8}, 10^{-2}]$. It is seen from this table that the proposed vector-based HMM detector provides the highest area under ROC values, i.e., a detection rate higher than that of the other detectors for a given P_{Fa}, indicating its superior performance. In order to study the robustness of the proposed detector against various attacks, we obtain the ROC curves of the proposed watermark detector when images are contaminated by JPEG compression, median filtering and additive Gaussian noise. In Table II, the average area under ROC curve obtained using the proposed watermark detector as well as those obtained using the other detectors are JPEG-

TABLE I
AVERAGE AUROC VALUES OBTAINED USING VARIOUS WATERMARK DETECTORS FOR THE REGION $[10^{-8}, 10^{-2}]$.

	AUROC
Proposed	0.9989
MPE [8]	0.9769
Cauchy [9]	0.9952
BKF [10]	0.9822
GG [19]	0.8180

TABLE II
AVERAGED AREA UNDER ROC CURVE VALUES OBTAINED USING VARIOUS DETECTORS OVER A NUMBER OF TEST IMAGES, WHEN THE WATERMARKED IMAGES ARE UNDER VARIOUS ATTACKS.

	Proposed	[9]	[19]	[10]	[8]
	JPEG Compression				
QF = 5	0.7132	0.5693	0.3612	0.5293	0.5017
QF = 15	0.9761	0.9532	0.6061	0.8717	0.8431
QF = 35	0.9923	0.9852	0.7310	0.9422	0.9279
	Median Filtering				
3×3	0.9948	0.9901	0.6914	0.9229	0.9165
5×5	0.9903	0.9898	0.6603	0.9187	0.8831
7×7	0.9781	0.9559	0.6133	0.9015	0.8590
	Gaussian Noise				
$\sigma_n = 10$	0.9854	0.9638	0.6423	0.9542	0.9515
$\sigma_n = 20$	0.9632	0.9415	0.6180	0.9140	0.9076
$\sigma_n = 40$	0.6547	0.5683	0.5691	0.8906	0.8748
	Salt & Pepper Noise				
p = 1%	0.9987	0.9921	0.8029	0.9801	0.9686
p = 10%	0.9785	0.9584	0.7732	0.9227	0.9174
p = 20%	0.6892	0.5947	0.5159	0.5719	0.5603

compressed with different quality factors (QF), median filtered with various window sizes, corrupted by Gaussian noise with different noise standard deviations, and contaminated by salt and peppers noise with different noise levels. It is seen from this table that the proposed detector is more robust than the other detectors against any of the attacks considered by providing higher values of AUROC.

IV. CONCLUSION

In this work, a novel multichannel watermark detector for color images has been proposed by taking advantage of the vector-based HMM to capture inter-channel and also inter-scale dependencies of the wavelet coefficients of the color image. The imperceptibility of the watermarking technique has been studied through experiments, which show no visible difference between the original and watermarked images. Theoretical expressions for test statistics have been validated experimentally. The performance of the proposed detector has been studied in terms of the ROC curves and area under ROC curves and compared with that of the other existing detectors. It has been shown that the proposed detector provides a performance superior to that of the methods based on power-exponential or Cauchy and GG distributions. The robustness of the proposed watermarking scheme against JPEG compression, median filtering, Gaussian and salt and pepper noise has also been studied and shown to be more robust than the other existing schemes.

REFERENCES

[1] H. Sadreazami, M. O. Ahmad and M. N. S. Swamy, "Optimum multiplicative watermark detector in contourlet domain using the normal inverse Gaussian distribution," *IEEE International Symposium on Circuits & Systems (ISCAS),* pp. 1050-1053, 2015.

[2] H. Sadreazami, M. O. Ahmad and M. N. S. Swamy, "A study of multiplicative watermark detection in the contourlet domain using alpha-stable distributions," *IEEE Transactions on Image processing,* vol. 23, no. 10, pp. 4348-4360, 2014.

[3] M. Barni, F. Bartolini and A. Piva, "Multichannel watermarking of color images," *IEEE Transactions on Circuits and Systems for Video technology,* vol. 12, no. 3, pp. 142-156, 2002.

[4] T. Tsui, X. Zhang and D. Androutsos, "Color image watermarking using multidimensional Fourier transforms," *IEEE Transactions on Information Forensics Security,* vol. 3, no. 1, pp. 16-28, 2008.

[5] K. Liu, "Wavelet-based watermarking for color images via visual masking," *Inter. J. of Elect. and Commun.,* vol. 64, no. 2, pp. 112-124, 2010.

[6] M. Barni, F. Bartolini, A. DeRosa and A. Piva, "Color image watermarking in the Karhunen-Loeve transform domain," *Journal of Electronic Imaging,* vol. 11, no. 1, pp. 87-95, 2002.

[7] H. M. Al-Otum and N. A. Samara, "A robust blind color image watermarking based on wavelet-tree bit host difference selection ," *Signal Processing,* vol. 90, no. 8, pp. 2498-2512, 2010.

[8] R. Kwitt, P. Meerwald and A. Uhl, "Color-image watermarking using multivariate power-exponential distribution," in *Proc. IEEE International conference on Image processing (ICIP),* pp. 4245-4248, 2009.

[9] H. Sadreazami, M. O. Ahmad and M. N. S. Swamy, "A robust multiplicative watermark detector for color images in sparse domain," *IEEE Transactions on Circuits and Systems II: Express Briefs,* vol. 62, no. 12, pp. 1159-1163, 2015.

[10] M. Rabizadeh, M. Amir Mazlaghani and M. Ahmadian-Attari, "A new detector for contourlet domain multiplicative image watermarking using Bessel K form distribution," *Journal of Visual Communication and Image Representation,* vol. 40, pp. 324-334, 2016.

[11] M. S. Crouse, R. D. Nowak and R. G. Baraniuk, "Wavelet-based statistical signal processing using hidden Markov models," *IEEE Transactions on Signal Processing,* vol. 46, no. 4, pp. 886-902, 1998.

[12] M. N. Do and M. Vetterli, "Rotation invariant texture characterization and retrieval using steerable wavelet-domain hidden Markov models," *IEEE Transactions on Multimedia,* vol. 4, no. 4, pp. 517-527, 2002.

[13] M. Amini, M. O. Ahmad and M. N. S. Swamy, "Image Denoising in Wavelet Domain Using the Vector-Based Hidden Markov Model," in *Proc. New Circuits and Systems Conference (NEWCAS),* pp. 29-32, 2014.

[14] M. Amini, M. O. Ahmad and M. N. S. Swamy, "A new blind wavelet domain watermark detector using hidden Markov model," in *Proc. Inter. Symposium on Circuits and Systems (ISCAS),* pp. 2285-2288, 2014.

[15] M. Amini, M. O. Ahmad and M. N. S. Swamy, "A new locally optimum watermark detection using vector-based hidden Markov model in wavelet Domain," *Signal Processing,* vol. 137, pp. 213-222, 2017.

[16] M. Amini, M. O. Ahmad and M. N. S. Swamy, "Digital watermark extraction in wavelet domain using hidden Markov model," *Multimedia Tools and Applications,* vol. 75, no. 21, pp. 3731-3749, 2016.

[17] M. Amini, M. O. Ahmad and M. N. S. Swamy, "A robust multibit multiplicative watermark decoder using vector-based hidden Markov model in wavelet Domain," *IEEE Transactions on Circuits and Systems for Video Technology,* 2016.

[18] S. A. Kassam, *Signal detection in non-Gaussian noise,* New York, USA: Springer-Verlag, 1988.

[19] J. R. Hernandez, M. Amado and F. Perez-Gonzalez, "DCT-domain watermarking techniques for still images: detector performance analysis and a new structure," *IEEE Transactions on Image Processing,* vol. 9, no. 1, pp. 55-68, 2000.

[20] G. McLachlan and T. Krishnan, *The EM algorithm and extensions,* John Wiley & Sons, 2007.