DISCRETE POLYNOMIAL TRANSFORM FOR DIGITAL IMAGE WATERMARKING APPLICATION

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ABSTRACT

In this study, we propose a new way to detect the image watermark messages modulated as linear chirp signals. The spread spectrum image watermarking algorithm embeds linear chirps as watermark messages. The phase of the chirp represents watermark message such that each phase corresponds to a different message. We extract the watermark message using a phase detection algorithm based on Discrete Polynomial Phase Transform (DPT). The DPT models the signal as polynomial and uses ambiguity function to estimate the signal parameters. The proposed method not only detects the presence of watermark, but also extracts the embeded watermark bits and ensures the message is received correctly. The robustness of the proposed detection scheme has been evaluated using checkmark benchmark attacks, and we found a guaranteed maximum bit error rate of 15%, which watermark message is correctly detected using DPT.

Keywords: *Image Watermarking, Spread Spectrum, Data Hiding, Discrete Phase Polynomial Transform, Hough-Radon Transform, Chirp Modulation*

1. INTRODUCTION

Chirp signals are present ubiquitously in many areas of science and engineering, so the Discrete Polynomial Phase Transform (DPT) [1][2] has been extensively studied in recent years to estimate the phase parameters of the chirp signals. One of the recent applications of chirp signals is in data watermarking. The huge success of the Internet allows for the transmission, wide distribution, and access of electronic data in an effortless manner. Watermarking is one of the possible solutions to the problem that content providers are faced with the challenge of how to protect their electronic data. Thereby, multimedia data creators and distributors are able to prove ownership of intellectual property rights without forbidding other individuals to copy the multimedia content itself. In this study, we propose a chirp-based detection method to detect watermark messages in an image watermarking scheme [3][4] which embeds linear chirps as imperceptible and statistically undetectable watermark messages. Different chirp rates, i.e., phases, represent watermark messages such that each phase corresponds to a different message. The narrowband watermark messages are spread with a watermark key (PN sequence) across a wider range of frequencies before embedding. The resulting wideband noise is added to the perceptually significant regions of the original image. We use the block-based discrete cosine transform (DCT) scheme for inserting the watermark. As a result of image manipulations some message bits are extracted by the detector may be in error potentially resulting in the detection of the wrong watermark message. The proposed watermarking detection algorithm detects the presence of watermark, and extracts the embeded watermark message bits even at presence of bit error in the received watermark message. Our motivation to use DPT technique as watermark detector is to achieve high estimation accuracy with less computational complexity.

2. DISCRETE POLYNOMIAL PHASE TRANSFORM (DPT)

DPT is a parametric signal analysis approach for estimating the phase parameters of polynomial phase signals. The phase of many man-made signals such as those used in radar, sonar and communications can be modeled as a polynomial. The discrete version of a polynomial phase signal can be expressed as:

$$x(n) = b_0 exp\left\{ j \sum_{m=0}^{M} a_m (n\Delta)^m \right\} \tag{1}$$

where M is the polynomial order ($M = 2$ for chirp signal), $0 \leq n \leq N-1$, N is the signal length and Δ is the sampling interval. The principle of DPT is as follow. When DPT is applied to a mono-component signal with polynomial phase of order M, it produces a spectral line [1] . The position of this spectral line at frequency ω_0 provides an estimate of the coefficient $\hat{a}_M$. After $\hat{a}_M$ is estimated, the order of the polynomial is reduced from M to $M-1$ by multiplying the signal with $exp\left\{-j\hat{a}_M(n\Delta)^M\right\}$. This reduction of order is called *phase unwrapping*. The next coefficient $\hat{a}_{M-1}$ is estimated the same way by taking DPT of the polynomial phase signal of order $M-1$ above. The procedure is repeated until all the coefficients of the polynomial phase are estimated. DPT order

M of a continuous phase signal $x(n)$ is defined as the Fourier transform of the higher order $\mathcal{DP}_M\left[x(n),\tau\right]$ operator:

$$\begin{aligned} DPT_M\left[x(n),\omega,\tau\right] &\equiv \mathcal{F}\left\{\mathcal{DP}_M\left[x(n),\tau\right]\right\} \\ &= \sum_{(M-1)^{\tau}}^{N-1} \mathcal{DP}_M\left[x(n),\tau\right] exp^{-j\omega n\Delta}, \end{aligned} \tag{2}$$

where τ is a positive number and:

$$\mathcal{DP}_1\left[x(n),\tau\right] := x(n) \tag{3}$$

$$\mathcal{DP}_2\left[x(n),\tau\right] := x(n)x^*(n-\tau). \tag{4}$$

$$\mathcal{DP}_M\left[x(n),\tau\right] := \mathcal{DP}_2\left[\mathcal{DP}_{M-1}\left[x(n),\tau\right],\tau\right] \tag{5}$$

The coefficients a_M (a_1 and a_2) are estimated by applying the following formula [1]:

$$\hat{a}_M = \frac{1}{M!(\tau_M\Delta)^{M-1}} argmax_{\omega}\left\{\left|DPT_M\left[x(n),\omega,\tau\right]\right|\right\}, \tag{6}$$

where

$$DPT_1\left[x(n),\omega,\tau\right] = \mathcal{F}\left\{x(n)\right\}, \tag{7}$$

$$DPT_2\left[x(n),\omega,\tau\right] = \mathcal{F}\left\{x(n)x^*(n-\tau)\right\}, \tag{8}$$

and

$$\hat{a_0} = phase\left\{\sum_{n=0}^{N-1} x(n) exp\left\{-j\sum_{m=1}^{M} a_m(n\Delta)^m\right\}\right\} \tag{9}$$

$$\hat{b}_0 = \frac{1}{N}\sum_{n=0}^{N-1} x(n) exp\left\{-j\sum_{m=1}^{M} a_m(n\Delta)^m\right\} \tag{10}$$

The estimated coefficients are used to synthesize the polynomial phase signal:

$$\hat{x}(n) = \hat{b}_0 exp\left\{j\sum_{m=0}^{M} \hat{a}_m(n\Delta)^m\right\} \tag{11}$$

3. CHIRP-BASED WATERMARKING

The watermarking method used in this study is a novel watermarking method using a linear chirp based technique applied on image and audio signal[3][4]. The chirp signal $x(t)$ (or $\underline{\mathbf{m}}$) is quantized and having value -1 and 1 as in $\mathbf{m}^q$. $\mathbf{m}^q$ is then embedded into the multimedia files. The quantization process introduces harmonics in the time-frequency representation, but the slope of the quantized chirp is the same as that of the chirp signal $x(t)$. The detail of the embedding and extracting of watermark is followed.

3.1. Watermark embedding

Each bit m_k^q of $\mathbf{m}^q$ is spread with a cyclic shifted version $\mathbf{p_k}$ of a binary PN sequence called watermark key. The results are summed together and generate the wide band noise vector $\mathbf{w}$:

$$\mathbf{w} = \sum_{k=0}^{N-1} m_k^q \mathbf{p_k}, \tag{12}$$

where N is the number of watermark message bits in $\mathbf{m^q}$. The wide band noise $\mathbf{w}$ is then carefully shaped and added to the audio or DCT block of the image so that it will cause imperceptible change in signal quality. In the audio watermarking application, to make the watermark message imperceptible, the amplitude level of the wideband noise $\mathbf{w}$ is scaled down to be about 0.3 of the dynamic range of the signal. In the image watermarking application, the length of $\mathbf{w}$ to be embedded depends on the perceptual entropy of the image. To embed the watermark into the image, the model based on the *just noticeable difference* (JND) paradigm was utilized. The JND model based on DCT was used to find the perceptual entropy of the image and to determine the perceptually significant regions to embed the watermark. In this method, the image is decomposed into 8×8 blocks. Taking the DCT on the block b results in the matrix $X_{u,v,b}$ of the DCT coefficients. The watermark encoder for the DCT scheme is described as

$$X^*_{u,v,b} = \begin{cases} X_{u,v,b} + t^C_{u,v,b} w_{u,v,b}, & \text{if } X_{u,v,b} > t^C_{u,v,b}; \\ X_{u,v,b}, & \text{otherwise} \end{cases} \tag{13}$$

where $X_{u,v,b}$ refers to the DCT coefficients, $X^*_{u,v,b}$ refers to the watermarked DCT coefficients, $w_{u,v,b}$ is obtained from the wideband noise vector $\mathbf{w}$, and the threshold $t^C_{u,v,b}$ is the computed JND determined for various viewing conditions such as minimum viewing distance, luminance sensitivity and contrast masking. Fig.1 shows the block diagram of the described watermark embeding scheme.

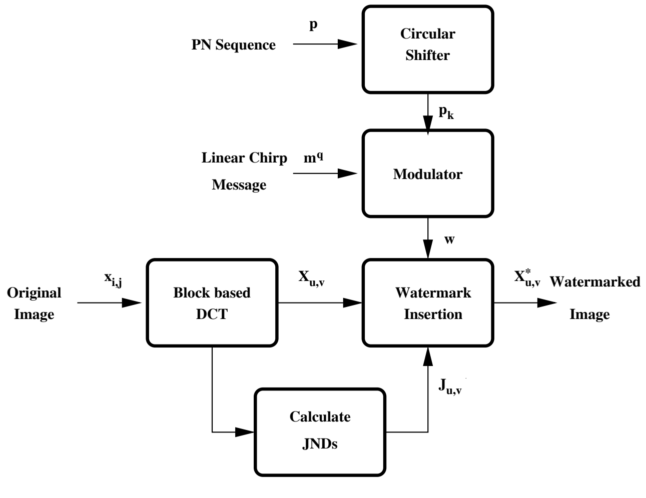


Fig. 1. Watermark embedding scheme.

3.2. Watermark detection

Fig.2 shows the block diagram of the described watermark decoding scheme. The detection scheme for the DCT based watermarking can be expressed as

$$\hat{w}_{u,v,b} = \frac{X_{u,v,b} - \hat{X}^*_{u,v,b}}{t^C_{u,v,b}} \tag{14}$$

$$\hat{\mathbf{w}} = \begin{cases} \hat{w}_{u,v,b}, & \text{if } X_{u,v,b} > t^C_{u,v,b}; \\ 0 & \text{otherwise} \end{cases} \tag{15}$$

where $\hat{X}^*_{u,v,b}$ are the coefficients of the received watermarked image, and $\hat{\mathbf{w}}$ is the received wideband noise vector. Due to intentional and non-intentional attacks such as lossy compression, shifting, down-sampling the received chirp message $\hat{\mathbf{m}}^q$ will be different from the original message $\mathbf{m}^q$ by a bit error rate BER. We use the watermark key, $\mathbf{p_k}$ to despread $\hat{\mathbf{w}}$, and integrate the resulting sequence to generate a test statistic $\langle \hat{\mathbf{w}}, \mathbf{p}_k \rangle$. The sign of the expected value of the statistic depends only on the embedded watermark bit m^q_k. Hence the watermark bits can be estimated using the decision rule:

$$\hat{m}^q_k = \begin{cases} +1, & \text{if } \langle \hat{\mathbf{w}}, \mathbf{p}_k \rangle > 0; \\ -1, & \text{if } \langle \hat{\mathbf{w}}, \mathbf{p}_k \rangle < 0. \end{cases} \tag{16}$$

We repeat the bit estimation process until we have an estimate of all the transmitted bits. Though it is possible to form an estimate of the chirp sequence from the received bits, we improve the robustness of the detection algorithm by detecting the chirp using Discrete Polynomial Phase Transform (DPT) a phase detection algorithm.

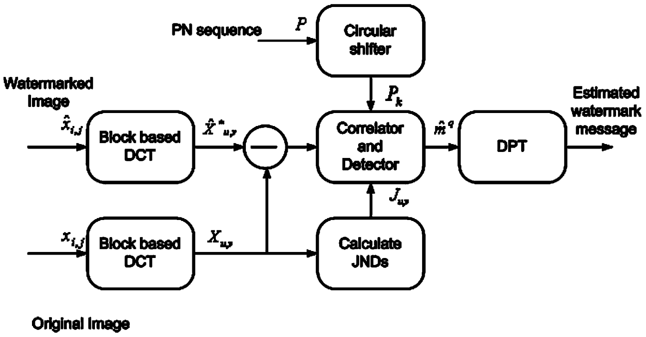


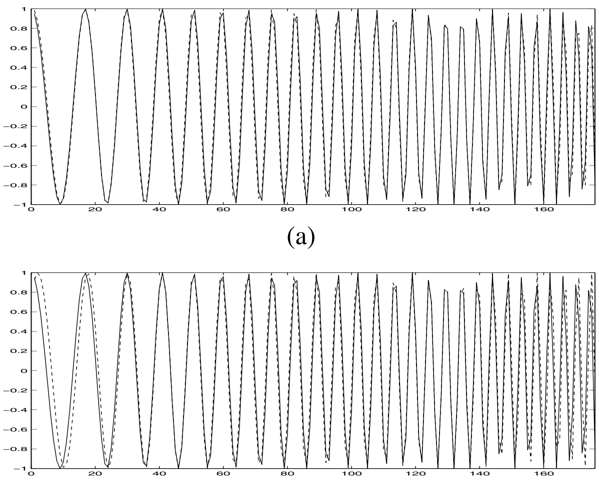
Fig. 2. The proposed watermark detection scheme.

3.3. DPT-based watermark estimation method

The embeded watermarks in this algorithm are linear chirps, and the received watermark can be represented as

$$x(n) = exp(a_1(n\Delta)j + a_2(n\Delta)^2 j) \tag{17}$$

Since DPT method is able to estimate the polynomial coefficients of chirp signals with a very short computation time, we apply DPT to estimate a_1 and a_2 coefficients. Fig.3 shows the original and estimated watermark messages at bit error rates of 13.6% and 19.3%; the correlation coefficients of the original and estimated watermarks are 0.9891 and 0.9516 respectively. Our computer simulation shows that the required calculation time is 630 times faster than the other similar chirp watermark detection scheme[3][4][5].



(a)

(b)

Fig. 3. Original and Estimated Watermark at (a)BER of 13.6% and correlation coefficient of 0.9891 (b)BER of 19.3% and correlation coefficient of 0.9516

4. RESULTS AND DISCUSSION

We evaluated the proposed scheme using 10 different images of size 512×512. The sampling frequency f_{sb} of the watermarks equals to 1 kHz. Hence the initial and final frequencies, f_{0b} and f_{1b} of the linear chirps representing all watermark messages are constrained to [0-500] Hz. We embed these chirps into the images for a chip length of 10000 samples, In our tests, we used a single watermark sequence having 182 message bits. To measure the robustness of the watermarking algorithm, we performed the attacks specified in the checkmark benchmark attacks[6]. Table 1 shows the watermark detection results for ten watermarked images after performing the attacks specified in the checkmark benchmark attacks. The numbers in the brackets under category 'Attack' represent the number of attacks in that particular class of attacks. The 'Detection Average' represents the percentage of attacks for which the watermark is detected under each class of attacks. We make decesion on the correct detection of watermark based on the correlation between the estimated chirp and the embedded watermark. Experimentally, the threshold for correlation coefficient is set to 0.9. The maximun BER for MAP attack with 100% detection rate is 15%, and for the case of JPEG attack, in which the maximum BER is 19.9%, DPT was able to detect 100% of watermark messages. Table 2 shows DPT-based technique performance for one of the images under the specified attacks. The results demonstrate the fact that the proposed scheme based on DPT-based technique promises to estimate the watermark messages up to a BER of 15%; also in many cases it shows the ability of watermark detection up to a BER of 19%.

Attacks	**Detection Average(100%)**	
	DPT	HRT
Remodulation(4)	65	57.5
Copy(1)	100	97
MAP(6)	100	100
Wavelet(10)	84	84
JPEG(12)	100	97.5
ML(7)	57	56
Filtering(3)	100	100
Resampling(2)	85	90
Colour Reduce(2)	35	45

Table 1. Watermark detection results of 10 images for checkmark benchmark attacks.

Attacks	**image1**	
	BER(%)	DPT
dpr(3)	2.84	0.9988
dpr(5)	11.93	0.9954
dprcorr(3)	6.25	0.9871
dprcorr(5)	14.77	0.9916
medfilt(2)	1.7	0.9950
medfilt(3)	3.4	0.9884
medfilt(4)	23.3	0.1355
trimmedmean(3)	13.63	0.9891
trimmedmean(5)	31.82	0.1274
midpoint(3)	3.98	0.9965
midpoint(5)	23.4	-0.0008
dither	6.25	0.9936
thresh	19.31	0.9516

Table 2. Bit error rates and the correlation coefficients of the proposed method respectively.

The performance of the algorithm is compared with another similar approach, Hough-Radon Transform (HRT)[3] [4][5]. Table 1 compares the detection result for DPT and HRT-based methods with the same watermarking capacity. The DPT-based algorithm results in higher or equal detection rate in the seven types of attacks, and has less computational complexity than HRT-based method. Typically, running time of DPT-based is 6000 time less than that of the HRT-based method in Matlab. The watermarking capacity of DPT-based technique depends on the values of coefficients $a1$ and $a2$. As expected, using high resolution of coefficients $a1$ and $a2$ will increase the capacity of the watermarking. However, this would also reduces the robustness of the method. Compared to the previous method based on HRT, the proposed method has high capacity of 182×182; it is also more robust than the HRT-based method as indicated in Table 1.

5. CONCLUSION

In this paper, we proposed a watermark detection method applied in an image watermarking algorithm that embeds linear chirp as watermark messages. The watermark message is added to the perceptually significant regions of the image to ensure robustness of the watermark to common image processing attacks. A phase detection algorithm based on DPT detects the phase of the watermark message. The proposed technique has the ability to detect the chirp message embedded in signals and subjected to different BERs due to attacks on the image watermark and provides a fast deduction with high accuracy. Our studies confirm the robustness of the algorithm to checkmark benckmark attacks.

6. REFERENCES

[1] S. Peleg, B. Friedlander, "The discrete polynomial-phase transform," *IEEE Transactions on Signal Processing*, Vol. 43 Issue 8 , pp. 1901–1914. 1995.

[2] S. Peleg, and B. Friedlander, "Multicomponent signal analysis using the polynomial-phase transform," *IEEE Transactions on Aerospace and Electronic Systems*, Vol. 32 Issue 1 , pp. 378–387. 1996.

[3] S. Erkucuk,S. Krishnan and M. Zeytinoglu, "Robust Audio Watermarking Using a Chirp Based Technique," *IEEE Intl. Conf. on Multimedia and Expo*, vol. 2, pp. 513–616, 2002.

[4] A. Ramalingam and S. Krishnan, "A Novel Robust Image Watermarking Using a Chirp Based Technique," *IEEE Canadian Conf. on Electrical and Computer Engineering*, vol. 4, pp. 1889–1892, 2004.

[5] R.M. Rangayyan and S. Krishnan, "Feature identification in the time-frequency plane by using the Hough-Radon transform," *Trans. Pattern Recognition*, vol. 34, pp. 1147–1158, 2001.

[6] S. Pereira, S. Voloshynovskiy, M. Madueno S. Marchand-Maillet, and T. Pun, 'Second Generation Benchmarking and Application Oriented Evaluation', *Information Hiding Workshop III*, Pittsburgh, PA, USA, April 2001.