Journal of Systems Engineering and Electronics
Vol. 26, No. 6, December 2015, pp.1309 – 1314

Digital watermarking algorithm based on scale-invariant feature regions in non-subsampled contourlet transform domain

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Abstract: Contraposing the need of the robust digital watermark for the copyright protection field, a new digital watermarking algorithm in the non-subsampled contourlet transform (NSCT) domain is proposed. The largest energy sub-band after NSCT is selected to embed watermark. The watermark is embedded into scale-invariant feature transform (SIFT) regions. During embedding, the initial region is divided into some cirque sub-regions with the same area, and each watermark bit is embedded into one sub-region. Extensive simulation results and comparisons show that the algorithm gets a good trade-off of invisibility, robustness and capacity, thus obtaining good quality of the image while being able to effectively resist common image processing, and geometric and combo attacks, and normalized similarity is almost all reached.

Keywords: multi-scale geometric analysis (MGA), non-subsampled contourlet transform (NSCT), scale-invariant feature region.

DOI: 10.1109/JSEE.2015.00143

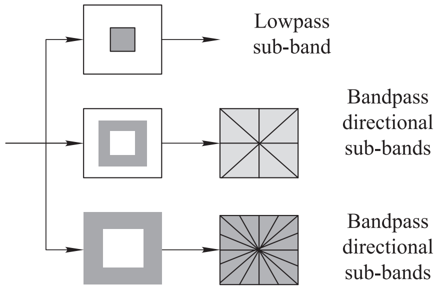
1. Introduction

The past few years have seen an explosion in the use of the digital watermarking technology in copyright protection [1]. And digital watermarking for this purpose must have robustness, security and so on [2]. Thus, the digital watermarking algorithm based on multi-scale geometric analysis (MGA), which is more effective than wavelet analysis to capture the image edge and texture details [3], is getting developed in recent years. Rama et al. presented a watermarking algorithm based on ridgelet transform [4]. Kaviani et al. embedded digital watermark in the contourlet domain [5]. These algorithms taking advantages of MGA [6 – 10] are better than many digital watermarking algorithms based on discrete wavelet transform (DWT) [11 – 14]. However, the watermarking algorithm based on contourlet transform [15, 16] has small redundancy, which is not conducive to selecting the watermark embedding position and has no translational invariance [17]. To overcome these shortcomings, the watermarking algorithm with rotation, scaling, translation invariance and high robustness and invisibility is urgent to be proposed.

Facing the above problems, a digital watermarking algorithm based on the non-subsampled contourlet domain is provided in this paper on the theory of MGA [18].

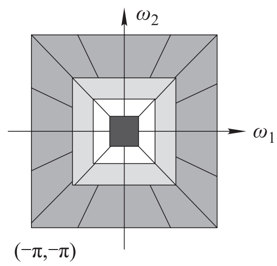
2. Theories of NSCT

Akhaee et al. proposed a new non-adaptive multi-scale geometric representation of image-contourlet transform [19], which is a multi-resolution, multi-direction and local image representation. But it has small redundancy, and it is not conducive to compressing and selecting the watermark embedding position; the upper and lower samplings exist in Laplace pyramid (LP) and the directional filter banks (DFB) make the contourlet transform do not have the translational invariance. To overcome these shortcomings, Cunha proposed a translation invariance, multi-scale, multi-direction conversion non-subsampled contourlet transform (NSCT) [20]. There is no upper and lower sampling, so all sub-bands are the same size as the original image, while its redundancy provides us more coefficients to embed watermarks. Their structure and frequency schematic diagram are shown in Fig. 1. Fig. 2 shows the non-sampling filter tower and three-dimensional exploded view schematic sub-band frequency.



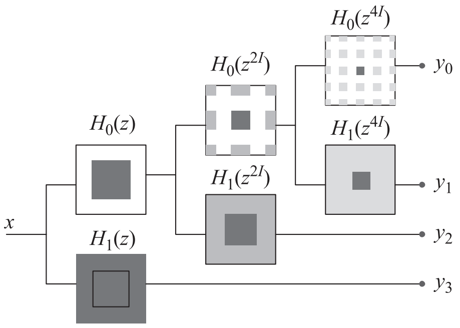
(a) Structure of NSCT's implements

Manuscript received May 06, 2014.
*Corresponding author.
This work was supported by the National Natural Science Foundation of China (61379010) and the Natural Science Basic Research Plan in Shaanxi Province of China (2015JM6293).

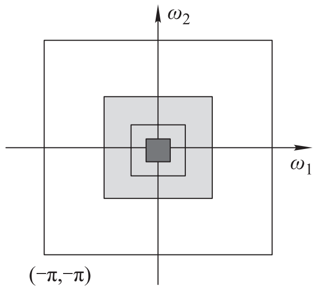


(b) Frequency partitioning

Fig. 1 Transformation diagram of NSCT



(a) Three-stage pyramid decomposition



(b) Sub-bands on the 2-D frequency plane

Fig. 2 Three-stage decomposition of NSCT and frequency plane

3. Proposed watermark embedding and extraction algorithm

Because of NSCT with multi-scale, multi-direction and translation invariance, embedding watermark can embed watermark in more detail information. The scale-invariant feature transform (SIFT) is scale invariant, rotation invariant, and local descriptors [21] to achieve a good watermark locality. So this paper proposes a novel digital watermarking algorithm based on SIFT in NSCT. Extracting SIFT feature points to construct feature regions, watermark embeddedness and extraction are conducted in the NSCT domain.

3.1 Proposed watermarking algorithm

The following details are about the odd-even quantization algorithm embedding watermark.

Quantization function is used to assign each $I(x,y)$ to symbol "0" or "1":

$$Q(x,y)=\begin{cases}0, & k\varDelta\leqslant I(x,y)<(k+1)\varDelta; k=0,\pm2,\pm4,\dots\\ 1, & k\varDelta\leqslant I(x,y)<(k+1)\varDelta; k=\pm1,\pm3,\pm5,\dots\end{cases} \tag{1}$$

where $\varDelta$ denotes the quantization step.

Firstly, calculate the quantization noise of quantization regions:

$$r(x,y)=I(x,y)-\lfloor I(x,y)/\varDelta\rfloor\cdot\varDelta. \tag{2}$$

Then, the coefficient is determined by the following formula:

$$\mu(x,y)=\begin{cases}-r(x,y)+0.5\varDelta, & Q(x,y)=\omega_i\\ -r(x,y)+1.5\varDelta, & Q(x,y)\neq\omega_i;\ r(x,y)>0.5\varDelta\\ -r(x,y)-0.5\varDelta, & Q(x,y)\neq\omega_i;\ r(x,y)\leqslant0.5\varDelta\end{cases} \tag{3}$$

where ω_i represents the watermarking value. Finally, the modified NSCT coefficient value of $I^*(x,y)$ is

$$I^*(x,y)=I(x,y)+\mu(x,y). \tag{4}$$

3.2 Procedure of the proposed embedding and extraction scheme

Before the watermark embedded, the watermark image is preprocessed [22].

(i) Extract SIFT feature points of the carrier image and constitut stable circular regions;

(ii) The characteristic regions conduct two layers of NSCT;

(iii) Calculate energy of the second layer in all directions after NSCT decomposition, and choose the largest sub-band energy pattern to embed watermark and record the sub-band chart, the formula that calculating the energy is as follows:

$$E^k=\frac{1}{mn}\sum_{i=1}^{p}\sum_{j=1}^{q}(A^k(i,j))^2. \tag{5}$$

(iv) The selection of the directional sub-band is divided into cirque sub-region to embed watermark. The formulas used in the process of constituting the concentric annular characteristic region are (6) and (7). Each ring embedded a watermark signal using the algorithm proposed in Section 3.1, is shown in Fig. 3.

$$\rho_{x,y}=\sqrt{x^2+y^2},\quad \theta_{x,y}=\arctan(y/x) \tag{6}$$

$$R_i=\left\{(x,y)\middle|(i-1)\cdot\frac{R_0}{N}\leqslant\rho_{x,y}<i\cdot\frac{R_0}{N}\right\},\quad i=1,2,3,\dots,N. \tag{7}$$

(v) The above steps are done circularly for all feature regions, producing the whole watermarked image.

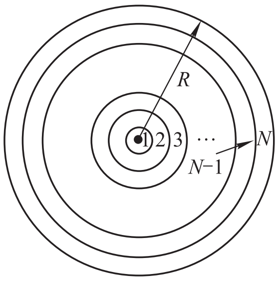


Fig. 3 Cirque sub-region to embed watermark

(vi) The embedded watermark pattern instead of the original sub-band pattern, can restore the carrier image after inverse NSCT transform, completing watermark embedding.

In this paper, the watermark extraction algorithm is the inverse process of the watermark embedding process.

The quantization function used in the embedding process is used to calculate the quantization function value of the coefficients within the region, and note that the number of the function value equalled 0 is NUM_0 the number of the function value equalled 1 is NUM_1, by the following formula to extract the watermark:

$$\omega_i' = \begin{cases} 0, & NUM_0 > NUM_1 \\ 1, & NUM_0 < NUM_1 \end{cases} . \tag{8}$$

4. Experimental results and discussion

Many images are used in experiments in this paper. Here taking "Lena" and "peppers" gray images as examples. The original image is the size of 512×512, the watermark image is a size of 32×32 binary image. The feature region for a 2-level NSCT transform, odd-even quantization step is $\Delta = 6$. Fig. 4 shows the watermark images, Fig. 5 shows the original images.

(a) Original watermark (b) Arnold scramb

Fig. 4 Watermark images

(a) Lena (b) Peppers

Fig. 5 Original images

Fig. 6 shows the sub-bands of 2-level NSCT of the original image (here taking "Lena" as an example).

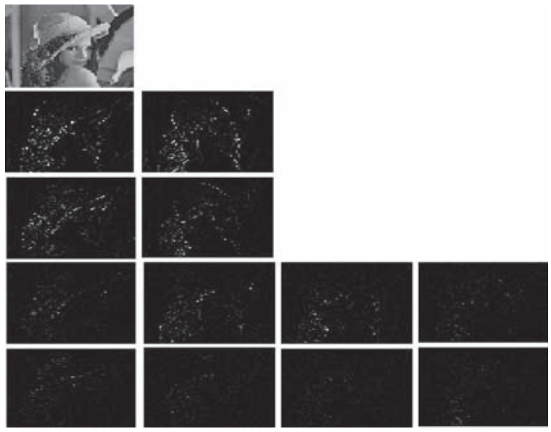


Fig. 6 Sub-bands of 2-level NSCT of "Lena"

4.1 Invisible watermark

Fig. 7 describes the contrast of the original image of "Lena" and the watermarked image; Fig. 8 illustrates the contrast of the original image of "peppers" and the watermarked image. Fig. 7 and Fig. 8 show that there is no significant difference between the original image and the watermarked image from the subjective perspective. Meanwhile, Fig. 7 and Fig. 8 use "Lena" and "peppers" images respectively, it can be seen that different host images have good results, showing that the proposed algorithm applied to the host image have different textures.

(a) Original image (b) Watermarked image

Fig. 7 Contrast of "Lena"

(a) Original image (b) Watermarked image

Fig. 8 Contrast of "peppers"

With the peak signal to noise ratio (PSNR) [23] to evaluate invisibility from the objective aspect, PSNR represents an objective evaluation of the degree of the image's deterioration. The PSNR value between the two images is larger which tends to be no deterioration. It is defined as

$$\mathrm{PSNR} = 10\lg \frac{MN255^2}{\sum_{i=0}^{M-1}\sum_{j=0}^{N-1}(I'(i,j) - I(i,j))^2} \quad (9)$$

where $I'(i,j)$ represents the watermarked image, $I(i,j)$ represents the original image, and the image size is $M \times N$.

In this paper, a number of experiments like embedding watermark and attacking the watermarked image are performed with typical digital watermarking algorithms based on the DWT domain [24 – 26] or contourlet transform domain [27 – 29]. Meanwhile, the results of experiments above are compared with the result of the proposed algorithm based on NSCT. Literature [25] and literature [27] regarded as examples are shown here. This algorithm's PSNR (dB) is shown in Table 1. This table also lists the literature [25] and literature [27] algorithms' PSNR values.

Table 1 Values of watermarked PSNR dB

PSNR	This paper	Literature [25]	Literature [27]
Lena	58.756	44.54	47.17
Peppers	53.980	40.09	40.45

Table 1 shows that PSNR values obtained in the proposed algorithm is much larger than those in the literature [25] and [27] algorithms', the proposed algorithm has very good invisibility. Because the proposed algorithm based on the NSCT domain, which has multi-scale and multi-direction, can be a good description of the outline and detail information of an image. When embedded watermark information, watermark can be hid in the carrier image for more detailed information, thereby enhance the invisibility. The proposed algorithm and literature algorithms' figure "Lena" obtained PSNR values larger than the figure "peppers", because the image of "Lena" has more texture and detail information than the image of "peppers". The advantages of the proposed algorithm in the embedded watermark are also illustrated.

4.2 Robust watermarking

Available normalized similarity (NC) [30] is selected to evaluate the robustness. $\omega'(i)$ represents the extracted watermark image, and $\omega(i)$ means the original watermark image. The larger the NC value between the two images, the better the robustness. It is defined as

$$\mathrm{NC} = \frac{\sum_{i-1}^{N}\omega(i)\omega'(i)}{\sqrt{\sum_{i=1}^{N}\omega^2(i)}\sqrt{\sum_{i=1}^{N}\omega'^2(i)}}. \quad (10)$$

Fig. 9 shows the corresponding extracted watermark image after watermarked the image subjected to conventional signal processing, geometric attack and combinations attack.

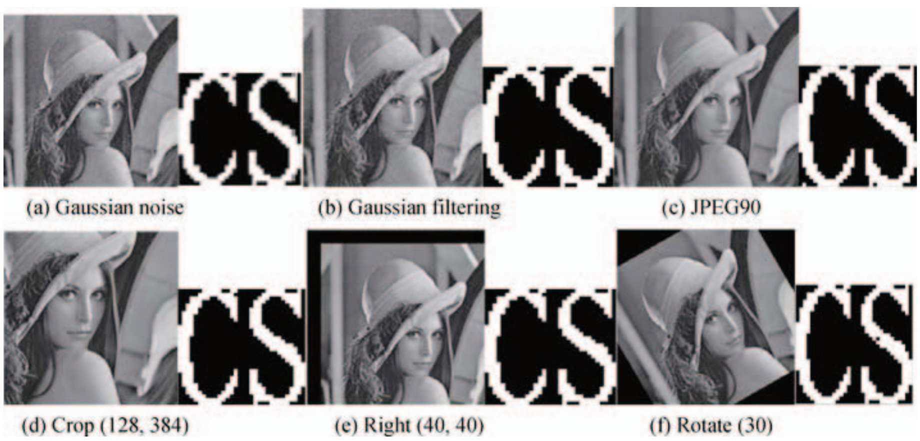


Fig. 9 Corresponding extracted watermark image after watermarked the image subjected to different attacks

The extracted watermark images are all successfully detected. From a visual point of view, the algorithm has good robustness. Because in this paper watermark embedding and extraction are achieved in the NSCT domain, which uses lines mentioned in multi-scale geometric analysis techniques instead of separate points to capture contours, thus improve the watermark extraction quality and get the rapid recovery watermark contours when the watermarked image is attacked.

Table 2 shows the values of the NC of the extracted watermark when the watermarked image subjected to conventional signal processing and geometric attacks, with algorithms of this paper, the literature [25] and literature [27].

Table 2 reflects that when there is no attack, the NC is 1. The watermark extraction algorithm has good reversibility and can accurately extract the watermark. Vertically to see suffering various attacks, NC values are all greater than 0.9. Transverse to see whether "Lena" or "peppers" has a very high NC value. It can be seen from the NC value comparison that, the proposed algorithm's is larger than the literature algorithms', so that the proposed algorithm has a very good robustness. It can be seen from Table 2 that when the center cuts 10%, NC value reaches 1. This is because it has locality in the NSCT domain combined with the SIFT feature region; NC value is also 1 when suffering rotation. The SIFT region has rotational invariance, so do cirque feature regions. Further to see, it can resist scaling attack because of scale invariance in the embedding region, it can be also completely extracted when suffering the zoom.

The results of the proposed algorithm, and literature algorithms are compared. It can be seen from Table 1 and Table 2 that the literature [25]'s PSNR is higher than the literature [27]'s, but the literature [25]'s NC is lower than the literature [27]'s. However, the PSNR and NC of the proposed algorithm are both higher than the literature's. The comparative literature experiments and results prove that the proposed algorithm gets a good trade-off of invisibility and robustness.

Table 2 Values of NC of the watermarked image suffered attacks

Items	This paper	Literature [25]	Literature [27]
No attack	1	0.988 3	0.889 4
G-noise 0.005	0.942 3	0.952 9	0.836 5
Gaussian filter 3×3	1	0.966 8	0.895 6
JPEG Q=90	1	0.942 9	0.939 9
Rotate 30 degrees	1	0.852 7	0.766 5
Rotate 90 degrees	1	0.765 9	0.734 7
Narrow 0.6	0.942 7	0.697 7	0.673 0
Zoom 1.2	1	0.937 3	0.797 4
Rotate 15 + cut	1	0.862 4	0.640 6
Rotate 45 + cut	1	0.721 3	0.622 5
Shift right 20 pixels	1	0.837 6	0.639 8
Center cut 10%	1	0.692 6	0.663 8
Center cut 25%	0.985 4	0.673 8	0.557 9
Rotate 20 + narrow 0.8	1	0.578 4	0.544 9
Rotate 40 degrees + zoom 1.5 times	1	0.639 3	0.618 6

5. Conclusions

This paper presents a digital watermarking algorithm based on NSCT. The core of this algorithm lies at embedding watermark in the NSCT domain, and combining with the SIFT cirque feature region. Due to its multi-scale, multi-direction and translation invariant characteristics, it can embed watermark in more detail information areas which are not sensitive to the vision, thus getting good invisibility. And it can quickly restore the contour lines, which improves the quality of extracted watermark. The SIFT descriptor are scale, rotation invariant, local descriptors, so it can achieve good watermark locality. Experimental results show that the proposed method can not only obtain good quality of the image, but also effectively resist attacks from common signal processing and geometric attacks including rotation, zoom, and translation.

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