An Adaptive Content Based Localized Watermarking Algorithm for Remote Sensing Image

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ABSTRACT:

In this paper, we proposed a new adaptive content-based localized watermarking algorithm for remote sensing images based on DWT, which adaptively embeds corresponding watermarks into the local regions of the remote sensing image instead of the entire one. In order to improve watermarking capability against attacks in the frequency area, we selected some stable feature points in the remote sensing image, then used them to identify the locations where we inserted the local watermarks, namely we embedded the watermarks into the local sub-images centered by those feature points. When the remote sensing image is cropped , we can also detect and orient watermarks by the feature points in the remaining one. Moreover the algorithm took the new watermarking-embedding strategy based on DWT domain to embed the local watermarks, namely watermarks should be embedded into the low frequency space firstly, and the remains are embedded into the high frequency spaces according to their significance. And different embedding strength for watermarks should be applied to the low frequency space and the high ones respectively. In order to further improve robustness of watermarks, the embedded local watermark is designed to be orthogonal to the feature vector of the low frequency space (LL3) in DWT area of the corresponding sub-image, which means that watermarking casting is remote sensing image content dependent. In addition, the algorithm exploited the Neymann-Pearson criterion to detect watermarks. Experimental results show that the watermarking algorithm is robust to all kinds of attacks, especially cropping.

1. Introduction

The demand for remote sensing data has increased dramatically mainly due to the large number of applications capable to exploit remotely sensed data and images. Along with the popularization of Internet and the development of multimedia techniques, people can embezzle remote sensing images lawlessly through the Internet. But by embedding watermarks into remote sensing image, we can effectually prevent such problems as copyright violation, illegal copying, easily forging and so on.

Recently watermarking technique has developed very rapidly, but there is still a large distance from practical application and a lot of practical problems not resolved (Wentong CAI, 2001a; Hong Heather, 2000a; Hyung-Woo Lee, 2001a). There have been many watermarking algorithms, most of which can be classified into spacial algorithms (Hua Xiansheng, 2001a; Yi Kaixiang, 2001a) and frequency algorithms (He Renya, 2001a; Kutter M., 1999b; Christine I, 1997b; Podilchuk C I, 1998a; Xia X, 1997b; Pei Wang, 2002a). Generally speaking, spacial algorithms have poorer robustness against compressing, noise adding and filtering, and as for frequency algorithms, it would be very hard to resist cropping attack if we embed watermarks into the frequency area of the whole image, because now we have only part of image, and can't get the size of the original remote sensing image and the position of the cropping image in the original remote sensing image, then it's difficult to ensure the position of watermarks embedding.

In addition, in order to ensure the robustness of watermarking algorithms, we think watermarks should be embedded into the most remarkable weight of remote sensing image. So watermarks should be bound together with the feature collection of the image, and namely, the coefficient collection chosen to accommodate watermarks can generally be seen as the feature vector collection of a remote sensing image (Cox I J, 1997b). At present, in most of watermarking algorithms the choice of watermarks has nothing to do with the image content, which in fact is quite disadvantageous to robustness and security of an algorithm, because when the remote sensing image with watermarks suffers from intentional (for instance malignantly destroying or watermarks deleting) or unconscious attacks (for example remote sensing image compression, filter, scan, copy, noise pollution and size change), if the embedded watermarks is not related to the image content, attackers would easily remove watermarks in the case of not destroying the basic quality of the remote sensing image.

Given the above two reasons, in this paper we proposed an adaptive content-based localized watermarking algorithm for remote sensing images. The algorithm utilized the relatively stable feature points in the remote sensing image to mark the position to embed watermarks, then independently and adaptively embedded watermarks into that local area corresponding with each feature point, so when there is only part of the image, we can also orient and detect watermarks without the participation of the original remote sensing image. Therefore this algorithm can effectively resist cropping (In this paper, cropping refers to detecting watermarks in the remaining image after cropping, and the size of the original image and the position of the remaining image in the original image are unknown). In addition, the algorithm binds the watermarks together with the feature of the corresponding sub-image, namely the algorithm is remote sensing image content-based, so when the watermarks are destroyed, the features of the remote sensing image is also destroyed, then the remote sensing image would count for nothing.

And in section 2 of the paper, we presented the adaptive embedding algorithm of the image content-based localized watermarks; in section 3 and 4, we respectively discussed the choice and detection of the localized watermarks and experimental results and our conclusion were presented respectively in section 5 and 6.

2. Embedding of Localized Watermarks

In our algorithm we exploited the spacial feature points to orient watermarks, then adaptively embedded watermarks of different strength into the wavelet domain of the only sub-image which corresponds with the feature point and detected watermarks to realize localizing of watermarks. We considered to choose those angle points (including crossed points, Y-shape points and T-shape points) as the feature points, because those points have good stability. After finding those feature points, we can embed the localized watermark into the $D \times D$ sub-image which is centered by each feature point.

2.1 Strategy of Secrete Watermarks Embedding Based on DWT

According to the distributed character and the qualitative and quantitative characters of breadth of wavelet coefficients, we exploited the new strategy presented in Document (Huang Daren, 2002a), namely watermarks should be firstly embedded into the low-frequency wavelet coefficients and then embedded into those high-frequency coefficients according to their important orders if there are still surplus watermarks. Furthermore watermarks should be embedded into the low-frequency and high-frequency coefficients by different embedding strength.

2.2 Adaptive Watermarking Algorithm Based on HVS

In addition to the position of watermark embedding, the robustness of watermarks also depends on the embedding strength of watermarks. So we should make adequate use of vision characters, namely under the condition of invisibility, we should rationally distribute the embedded watermarking energy and improve the strength of the local embedded watermarking weight as large as possible. And adaptive watermarking algorithms are just based on this idea.

Given the above embedding strategy, in this paper we exploited the adaptive watermarking algorithm which introduced vision system characters into watermark embedding procedure, namely organized anew the wavelet coefficients into wavelet blocks, then according to the texture-hiding characters of vision system, classified those wavelet blocks and by the classification results, embedded the watermarking weights of different strength into different wavelet coefficients.

2.2.1 Characters of Wavelet Blocks and the Relation with Low-frequency Coefficients: We made wavelet decomposition of the original remote sensing image, then each pixel is corresponding with some blocks in the wavelet domain, the relation among which can be denoted by a four-branch tree, namely a wavelet sub-tree. The root of a wavelet sub-tree lies on the low-frequency domain and we can organize all the three four-branch wavelet sub-trees of different orientations and the same root to form a block of the fixed size. All the blocks of the fixed size are called as wavelet blocks.

2.2.2 Classification of Wavelet Blocks: In order to improve as high as possible the watermark embedding strength, we classified wavelet blocks into 2 classification: classification 1 is the wavelet blocks of weaker textures, marked as *s1* and classification 2 is the ones of stronger textures, marked as *s2*. The wavelet coefficients of large breadths are corresponding with the breaking pixels in the original remote sensing image, so the textures of a wavelet block would be stronger if it has more wavelet coefficients of large breadths, otherwise the textures would be weaker. Namely, if *number{* $|F(u,v)| >$ *T1,(u,v)* $\in W_k$ *}* $\leq$ *T2,* then the wavelet block $W_k \in s_1$, otherwise $W_k \in s_2$, and *T1,T2* are the preliminarily designed fields. In this paper, we chose *T1*=0, *T2*=45.

2.3 Embedding Algorithm of Localized Watermarks:

Ruizhen Liu has presented CBWM (Content-Based Watermarking Model) in Document (Ruizhen Liu, 2001a) 'Image Content-based Watermarking Model'. CBWM makes no hypothesis to the original remote sensing image and is an addition watermarking model and because in CBWM the chosen watermark is orthogonal to the feature vector, it's also an image content-based watermarking model. CBWM is a universal watermarking model based on frequency domain and can be combined with any watermarking algorithm based on frequency domain. The image content-based localized adaptive watermarking algorithm presented in this paper is just an adaptive watermarking algorithm which applied CBWM to DWT of the local area (sub-image).

The watermarking algorithm presented in this paper is remote sensing image content-based, namely each chosen local watermarking sequence is orthogonal to the feature vector of the corresponding sub-image, so we chose the low-frequency coefficients of DWT as the choosing space of the feature vectors and according to formula (1), adaptively embedded the watermark W into the feature vector in the low-frequency domain. And we can exploit the texture-hiding character of vision system by adjusting the factor α. By a large amount of experiments, we found: letting

$$\tilde{d}_k = d_k + a w_k, \quad k=1,2,\ldots,K$$

where

$$a = \begin{cases} 0.02 & W_k \in s2 \\ 0.005 & W_k \in s1 \end{cases} \qquad (1)$$

the watermarked remote sensing image would have a good robustness. *F(u,v)* is the wavelet low-frequency coefficient, and in our algorithm it is the weight d_k of the feature vector in the low-frequency domain and *Wk* is the wavelet block in which d_k lies.

Let $A=\{a_{ij}\} \in F^{D\times D}$ be the original remote sensing sub-image and $B=\{b_{ij}\} \in F^{D\times D}$ be the adaptively watermarked remote sensing sub-image, then the procedure of the CBWM localized adaptive watermarking algorithm is as follows:

1) making three-level DWT of the original remote sensing sub-image (with the size of $D \times D$)

$$f: A \rightarrow \tilde{A};$$

2) establishing the low-frequency coefficient (LL3) matrix $C^{\#}$ in the wavelet domain $\tilde{A}$ of the remote sensing sub-image A;

3) choosing a feature vector D={ d_k } $\subset C^{\#}$ from the low-frequency coefficient matrix;

4) according to formula (1), embedding the watermark W={ w_k } into { d_k } and obtaining the new feature vector $\tilde{D}$={ $\tilde{d}$ k} $\subset \tilde{B}$;

5) reconstructing the watermarked remote sensing sub-image B with the new transform field matrix $\tilde{B}$

$$f^{-1}: \tilde{B} \rightarrow B.$$

In addition, we should notice that for different remote sensing sub-images, the watermark bits embedded in them are also different, namely the embedded watermark bits are based on the special content of each sub-image and different from each other.

3. Choice of localized watermarks

In order to guarantee robustness and security of watermarking algorithm, a nature choice is to combine localized watermarks with the feature of remote sensing sub-images. To the feature vector of a remote sensing sub-image D={ d_k }, generally the corresponding watermarking space $F_W \subset F^k$ orthogonal to D can be found:

$$F_W = \{W : \sum_k d_k w_k = 0, k=1,2,\ldots K\} \qquad (2)$$

namely, to any vector W={ w_k } $\in F_W$, we have

$$D^T \quad W = 0 \qquad (3)$$

We can see that there are countless watermarks meeting W={ w_k } $\in F_W$, however, in fact the establishment of watermarking space F_W is a controlled optimized process, namely

$$W = \arg \min_{W \in F^K} \left| D^T W \right| \qquad (4)$$

when D is the feature vector of the original remote sensing sub-image.

The ending condition of optimization is

$$\left| D^T W \right| \le \theta \qquad (5)$$

and θ (θ >0) is the beforehand defined threshold in the optimizing process. Here we choose $\theta = 10^{-6}$.

Repeating the above process for each remote sensing sub-image which corresponds to each feature point, we can obtain the watermarked remote sensing image

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4. Detection Frame of Localized Watermarks

We exploited the Neymann-Pearson criterion to detect watermarks. We made edge-detection to the watermarked remote sensing image, chose the angle points in the edge image as the candidate points, then detected watermarks in each D×D sub-image, in the center of which is the candidate points. As long as in one sub-image corresponding to some feature point, the watermark can be detected, we think there be localized watermarks in the image.

5. Results of Simulative Experiments

In this paper, we exploited MATLAB to simulate the experiments and made experiments to a 600×800 partial SPOT5 image of Shanghai. In order to evaluate robustness of the algorithm, during the experiments we exploited the testing software of watermark attacks-StirMark. The testing method is similar to COX method (Cox I J, 1997a). Firstly we exploited db8 wavelet and thinning algorithm of mathematic morphology to extract the edges of the original remote sensing image. The size of those local areas has an important influence on the robustness of watermarks: smaller areas can make watermarks better resist cropping, but also decrease robustness of the local watermarks; and bigger areas can increase robustness of the local watermarks but would result in no complete watermark-extracting areas in the remaining partial remote sensing image after cropping. In the experiment, we chose the maximum number of feature points as 20 and the size of the area corresponding with each feature point as 96×96. Then to each 96×96 remote sensing sub-image we take the same process as follows: making three-level DWT of the remote sensing sub-image by bior2.6 wavelet, establishing the low-frequency matrix $C^{\#}$ (12×12) in DWT transform field, obtaining the feature vector D = {d k}, which consisted of the anterior 12 coefficients in $C^{\#}$ which had the maximum breadths (or the maximum angles) (not including the direct current weight), then according to formula (5) , making optimized repetition to work out the localized watermark W={ w_k } which is a 12×1 two-value vector orthogonal to D = {d k}, namely W={ w_k }$\in$ { 1, -1}, i= 1,2,…,12. From the experimental results, we can see because the watermarking space $F_{W^{\#}}$ =

$\{ W^{\#} \in F^{k} : \left| D^{T} W^{\#} \right| \le \theta \}$ is a linear sub-space, the watermark meeting the conditions is easy to search. In this paper, we only used the simple randomly seeking algorithm. Given embedding meaningful watermarks, a more complicated optimized method should be exploited, such as inheritance algorithm. Then we organized the wavelet coefficients of the sub-image into wavelet blocks, classified those wavelet blocks according to texture intension, by the classification results and according to formula (1) adaptively embedded the local watermark weights into different weights of the feature vector with different strength to obtain the new feature collection $\tilde{D}=\{\tilde{d}_k\}$ and then made contrary DWT to obtain the watermarked remote sensing sub-image. During the experiment, scale gene is supposed as a=0.25. Making the above process to all sub-images corresponding with all feature points, we can get the entire remote sensing image which was embedded the content-based watermarks. Figure 1 presents the original remote sensing image; Figure 2 is the watermarked remote sensing image, with PSNR=45.012dB.

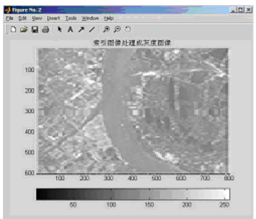


Figure 1. Original remote sensing image

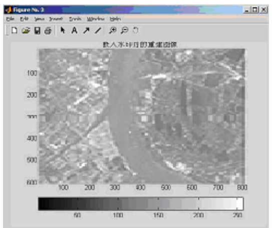
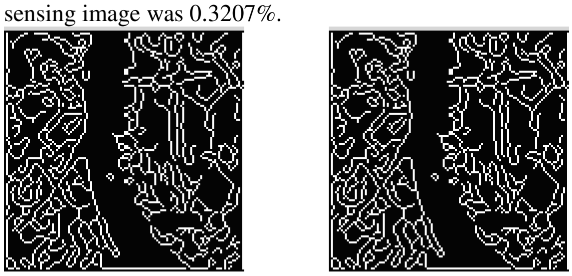


Figure 2. Watermarked remote sensing image (PSNR = 45.012)

Then we emulated 11 kinds of distortion situations of 87 remote sensing images of different resolutions with Stirmark and made watermark detection by the Neymann-Pearson criterion. To verify the robustness and validity of the algorithm, we also exploited Stirmark to make robustness tests for COX algorithm and CBWM watermarking algorithm based on DCT (Discrete Cosine Transform) (Cox I J, 1997b; Ruizhen Liu, 2001a) and the experimental results are listed in Form 1.

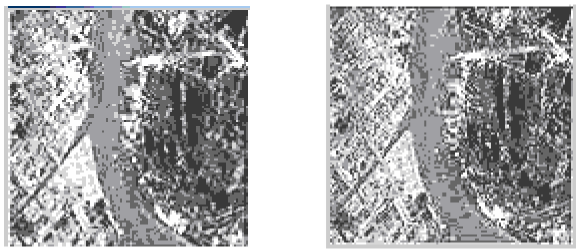
From Table 1, we can see such attacks as median filter, center cropping, geometrical transform, remote sensing image rotation and cropping in x-y directions all result in invalidation of COX algorithm; and CBWM entire watermarking algorithm based on DCT can not correctly detect watermarks only under the two anamorphic conditions of center cropping and remote sensing image rotation and can not detect watermarks when cropping of a remote sensing image exceeds 10% or rotation exceeds 13°; however CBWM localized adaptive watermarking algorithm based on DWT has a strong ability against cropping. Experiments show only when rotation of a remote sensing image exceeds 15°, CBWM localized adaptive watermarking algorithm based on DWT can't detect watermarks, and moreover the algorithm embeds watermarks into many local areas of the entire image, so under StirMark attack, the remote sensing sub-images move a little, but have little entire changes (MSE), therefore the entire image has a good robustness against StirMark attack. In addition, the total correct rate of CBWM localized adaptive watermarking algorithm based on DWT is 78/87=89.66%, respectively higher than CBWM entire watermarking algorithm based on DCT 69/87=79.31% and COX algorithm 59/87=67.81%. Furthermore while making experiments to the remote sensing images of various resolutions, we found that the higher resolution, the more complicated texture information had the remote sensing image, the more robust was the watermarks in it against various attacks.

We made experiments on such applications as edge detection (canny operator) and image classification to the original remote sensing image and the watermarked one respectively and the results has shown in Fig.3-4. During the course of image classification, the number of the mistakably classified pixels in the watermarked remote sensing image was1025 and the percentage of the mistakably classified pixels of the remote sensing image was 0.3207%.



a) Original remote sensing image   b) Watermarked image

Figure 3. .Results of edge detection



a) Original remote sensing image   b) Watermarked image

Figure 4. Results of classification

From the experimental results we can see the CBWM localized adaptive watermarking algorithm based on DWT proposed in this paper has almost no influence on edge detection and classification of remote sensing images and is a practical watermarking algorithm fit for remote sensing images.

Table 1. Comparison of Experimental Results

Testing Type	Testing Number	COX method	DCT Entire algorithm	Our algorithm
Filter（Median, Gauss, FMLR, Sharpening）	5	4	5	5
JPEG compression	10	10	10	10
Symmetrically and non-symmetrically moving rows and lines	5	5	5	5
Current linear geometrical transform	5	3	5	5
Changing x-y axes display scale	10	10	10	10
Scale transform	5	5	5	5
Cropping in x-y directions	5	3	5	5
Circumvolving with cropping and no scale transform	15	8	10	13
Circumvolving with cropping and scale transform	15	7	9	10
Center cropping	10	2	3	8
StirMark random bend	2	2	2	2
Summation	87	59	69	78

6. Conclusions

In this paper, we proposed CBWM localized adaptive watermarking algorithm base on DWT. In this algorithm, we firstly extracted edges and chose feature points in the original remote sensing image, then established each sub-image, in the center of which is the feature point, and embedded the local watermarks into the feature vectors in the three-level DWT low-frequency space (LL3) of sub-images and the local watermark is orthogonal to the feature vector, namely watermark is sub-image content-based. In addition the embedding procedure was adaptive, namely we firstly organized wavelet coefficients into wavelet blocks, classified those wavelet blocks by texture intension and according to the classification results, adaptively embedded watermark weights of different strength into different weights of the feature vector. Furthermore the algorithm exploited the Neymann-Pearson criterion to detect local watermarks. And we exploited StirMark as the testing instrument to verify robustness of the algorithm. And experiments testified that the algorithm has a strong robustness, simultaneously a good resistive ability against filter, noise, geometrical transform, remote sensing image compression, x-y direction cropping and StirMark attack and has a certain robustness against remote sensing image rotation, which needs to improve further. In addition, after embedding watermarks, there is little influence on such applications of the remote sensing image as edge detection and image classification. Therefore the watermarking algorithm is a practical one for remote sensing images.

Moreover, we could improve robustness of CBWM localized adaptive watermarking algorithm based on DWT for remote sensing images from the following 2 aspects:
1) theoretically as long as part of the remote sensing image after cropping contains at least one feature point and the corresponding sub-image, the watermarks can be detected. But after compression and other image processing (such as filter, noise adding), the feature points in the remote sensing image can't all be detected, which would lead to failure of watermarking detection. So when detecting watermarks, we should detect not only from the sub-image of the feature point, but also from all candidate points and the points in the near areas around them. As long as in one sub-image corresponding to some point, the watermark can be detected, we think there be localized watermarks in the image. But that would increase complexity of the computation;
2) the algorithm is more complicated in computation, so we can consider making heuristic search by heuristic knowledge to decrease the computation during the course of optimization computation.

In addition, we can consider to improve robustness of the algorithm from 8 aspects:
1)making feature points possess stronger stability;
2)exploiting the algorithm which is more suitable to embed local watermarks in remote sensing sub-images, consequently improves robustness of local watermarks;
3)choosing more appropriate size of local area to embed watermarks, therefore further increasing the ability to resist cropping and StirMark attack and the robustness of local watermarks;
4)choosing more suitable scale gene 'a' to better control embedding intensity and energy of local watermarks;
5)classification of wavelet blocks can also be done in the spacial area (Huang Daren, 2002a). Each wavelet block all corresponds with a sub-image of the same size in the spacial area and those sub-images are not overlapped and formed a kind of division of the original remote sensing image. In addition edge points represent those breaking points of image pixel grays, therefore if a sub-image has more edge points, it would have stronger texture; and so the texture of the wavelet block corresponding with the sub-image would be stronger. Therefore we can consider to classify the wavelet blocks by exploiting the density of edge points;
6)managing to make watermarks resist cropping as well as zoom and general affine transform;
7)developing the digital watermarking technology based on features (Yi Kaixiang, 2001a). Watermarking technology based on statistical character is easily suffering from such an attack as nonlinear transform, however the one based on edge information would have a good robustness;
8)exploiting Digital Watermarking Agent Technology (Hua Xiansheng, 2001a; Yi Kaixiang, 2001a), the central idea of which is to combine digital watermarking technique with TSA (trusted spotting agent), therefore the digital watermarking agent can roam among servers in the network and play a detective role to detect and validate watermarks and track illegal copies.

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