Multiple domain watermarking for print-scan and JPEG resilient data hiding

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Abstract. In this paper, we propose a print-scan resilient watermarking method which takes advantage of multiple watermarking. The method presented here consists of three separate watermarks out of which two are used for inverting the geometrical transformations and the third is the multibit message watermark. A circular template watermark is embedded in magnitudes of the Fourier transform to invert rotation and scale after print-scan process and another template watermark is embedded in spatial domain to invert translations. The message watermark is embedded in wavelet domain and watermark robustness in both approximation coefficient and detail coefficients is tested. Blind, cross-correlation based methods are utilized to extract the watermarks. The obtained success ratios were at least 91% with JPEG and JPEG200 quality factors of 80-100 and scanner resolution of 300dpi. The BER obtained with the previous settings was less than 1.5%.

Key words: Digital image watermarking, multiple watermarking, inversion, JPEG, JPEG2000

1 Introduction

The grown possibilities (Internet, P2P) of misuse of digital content has raised an interest in so called watermarking techniques for protecting digital content, in addition to conventional data protection methods such as scrambling or encryption. The basic idea of the watermarking techniques is fairly simple; to embed information in the signal itself in an imperceptible way. Since the interest in protecting IPR (Intellectual Property Rights) is high, the most studied applications of watermarking are proving ownership, authenticating and fingerprinting. However, as the embedded information can be generically anything that can be represented by bits, interest in other kinds of applications that take advantage of the watermarking techniques is rising. Among them especially interesting are the ones where the embedded information is beneficial to the user, relaxing the robustness requirements to the unintentional attacks caused by the noisy channel.

Here we consider image watermarking and embedding and extraction of multibit information, in particular, where the information is expected to be reliably extracted from printed and scanned images, i.e., after print-scan process. The print-scan process expresses various severe attacks on the watermarked content, the most serious ones being the synchronization attacks caused by geometrical transformations.

Some methods to overcome the synchronization problem have been proposed. Kutter [1] proposed a method for embedding periodic watermarks, the localization of which can be detected by applying autocorrelation function. Deguillaume et al. [2] utilize a fairly similar approach where the geometrical transforms are detected by interpreting repeated patterns and the watermark is extracted after inversion of geometrical transformations. The previous methods are often referred as self-synchronizing watermarks in the watermarking literature, because the periodic watermark efficiently carries information of the orientation and scale of the watermark and additionally the actual information payload.

Another ways for solving problems related to geometrical transforms are methods where an additional template watermark has been embedded in the image. Examples of these kinds of approaches include the methods proposed by Pereira and Pun [3], Lee and Kim [4] and Chiu and Tsai [5]. Pereira and Pun embed a frequency domain template by modifying midfrequency coefficients in a controlled way to produce local peaks, which are detectable and can be used for inverting geometrical transforms. Lee and Kim utilize also frequency domain template; however in their approach the template is a circularly arranged random sequence. In [5] a local peak in frequency domain is utilized to synchronize the reading of a message arranged in a circular structure. Apart from self-synchronizing watermarks and additional synchronization templates, some approaches using invariant domains have been proposed: O'Ruanaidh and Pun [6] utilize RST invariant domain named FourierMellin transform and Bas et al. [7] use feature points to bind the watermark into signal content, therefore achieving the robustness to geometrical attacks.

In this paper, we investigated the possibility of taking advantage of properties of different domains in designing a print-scan and additionally JPEG resilient water-marking scheme. The disadvantages and advantages of different domains are generally well known. Spatial domain has the advantage of maintaining location information, Fourier domain magnitudes are efficiently translation invariant, and DWT has gain much interest as a multiresolution representation to conquer the format conversions, especially JPEG.

In our approach, the rotation and scale transformations are detected and inverted with a frequency domain template, somewhat similar to the one in [4]. Translation is detected with a spatial domain template embedded, utilizing a JND-model as in [8] for adaptation to HVS. Efficiently the template proposed discards the need for full translation search or manual removal of white background before message extraction. The actual information bits are embedded in the wavelet domain with spread spectrum techniques. The purpose of the chosen DWT-method is twofolded, firstly, to examine the possibility to utilize

DWT as a carrier of message payload when resiliency to print-scan process and JPEG/JEPG2000 compression is expected. Secondly, the success ratio/BER of the DWT-domain watermark gives an objective measure of the accuracy of the detection/inversion of geometrical transforms. As, due to the multi domain approach, the interference caused by different watermarks in each other is minor, and imperceptibility criteria can be fulfilled, as shown by the experimental tests.

2 Print-scan process

The print-scan process produces various attacks to the watermarked image such as geometrical distortions, pixel distortions, DA/AD transform and noise addition due to the scanner/printer properties and human interaction. Fig. 1 shows the user interface of a scanner where the user defines the scanning area with a dash line quadrilateral. Along the watermarked image, a large portion of the scanner background is also being cropped. The size of the scanned image depends on the user settings and therefore the watermark cannot be assumed to be located in the centre of the scanned image, nor is the watermark perfectly straight and scaled in the scanned image obtained. Therefore the watermark should endure through geometrical transforms and be readable after the userdependent scanning operations.

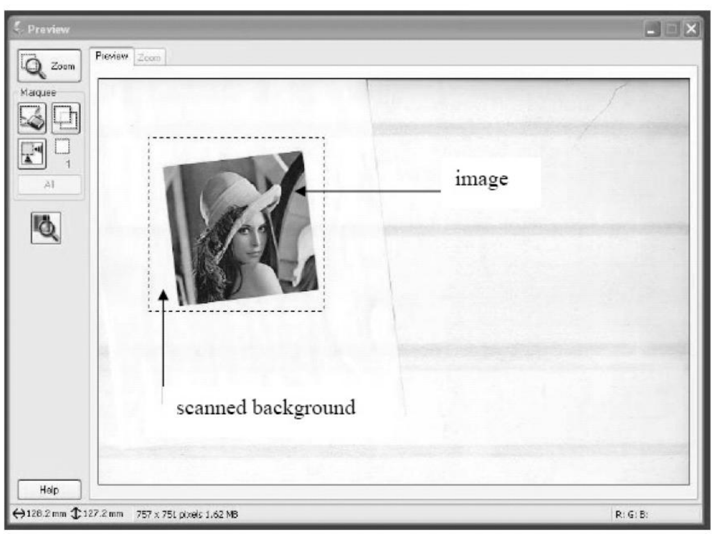

Fig. 1. A scanning area selected by the user.

In the print-scan process, the devices used in the experiments must be chosen carefully. The print-scan process is printer/scanner-dependent and time-variant - even for the same printer/scanner [9] [10]. Perry et al. [11] concluded that the printing quality varies between different manufacturers and even between identical models from the same manufacturer.

3 Print-scan resilient watermarking method

Solanki et al. [10] studied the print-scan process by examining watermarking in Fou-rier transform magnitudes and noted that the low and mid frequency coefficients are preserved much better than the high frequency ones. Inspired by these results, we take advantage of the properties of the Fourier domain magnitudes and embed there a template to recover from rotation and scaling attacks, as was done in [3] by Pereira and Pun and in [4] by Lee and Kim. However, the Fourier domain magnitudes are invariant to shifts in spatial domain and thus another template is required to recover the watermark from translation attack. For this task, a template watermark was designed and embedded in the spatial domain. The message watermark was embedded in the wavelet domain because of its robustness and superior HVS properties.

The watermarks are embedded in the luminance values of the image, and, as can be seen from the block diagram in Fig. 2, the message watermark is embedded last. This order of embedding the watermarks was chosen because every watermark em-bedded can be considered as an attack against previously embedded watermarks. If the message watermark had been embedded first, the template watermarks could have worsened the BER of the message watermark when extracted.

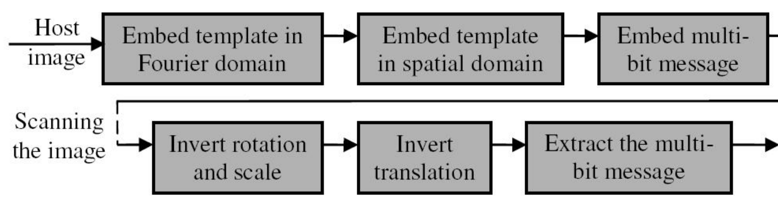

Fig. 2. Block diagram of the proposed print-scan robust method.

3.1 Inverting rotation and scale

To invert rotation and scale, a template watermark is embedded in the magnitudes of the Fourier domain which are invariant to translations in spatial domain. This invari-ance makes it easier to determine the rotation angle and scaling factor of the image because the translation needs not to be considered.

Embedding the Fourier domain template After Fourier transforming the image, the low frequencies are moved to the centre. The template is a pseudorandom sequence consisting of 0's and 1's arranged around the origin symmetrically, as depicted in Fig. 3. The template is embedded in the middle frequencies of the magnitudes of the Fourier domain in a form of a sparse circle in which the 1's of the pseudorandom sequence form peaks and 0's appear as gaps. The strength at which the peaks are embedded varies with local mean and standard deviation, because the embedding strength should clearly be larger close to the low frequencies, where, in general, are the highest values of the Fourier transform. Every point on the circle is embedded in the Fourier domain at an angle pi/20 from each other, where the value pi/20 is chosen for convenience.

By taking into account the results obtained by Solanki et al. [10] and He and Sun [9], we settled down to the middle frequency band of the Fourier domain. Low fre-quencies were discarded because the low frequencies contain most of the energy in the image and thus all the changes made to the low frequencies are highly visible in the image. On the other hand, robustness against JPEG compression is required and consequently the high frequencies were also discarded.

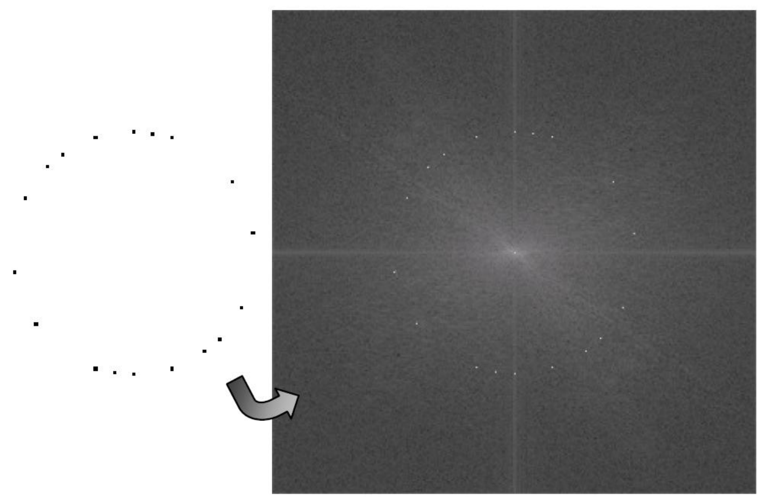

Fig. 3. Block diagram of the proposed print-scan robust method.

Extracting the Fourier domain template The extraction of the template watermark is conducted with cross-correlation. First, the image is padded with zeros to its original geometry, a square. This is done in order to prevent the template from being stretched to an ellipse. After zero padding, Fourier transform is applied to the image and the obtained Fourier magnitudes are filtered with a Wiener filter. The result of the filtering is then subtracted from the magnitudes of the scanned image to reduce the effect of the image itself. The Wiener filter minimizes the mean square error between an estimate and the original image and is thus a powerful tool in noise reduction, or noise extraction, as is the case in most of the watermarking techniques.

To reduce noise that does not contain watermark information even more, the Wiener filtered values are thresholded. If a point exceeds certain predefined limit, the point is divided with the local mean to achieve better comparability between points in different locations in the magnitudes of the Fourier transform. If the point does not exceed the limit, the point is replaced with a zero.

To find the circle around the origin, an annulus between two predefined frequen-cies f1 and f2 is chosen, as in the paper by Pereira and Pun [3]. The first frequency f1 is chosen such that the 'noise' of the image in the low frequencies does not disturb the detection process of the circle and the second frequency f2 is selected such that the calculations stay well within image boundaries.

The circle is detected by calculating a cross-covariance value between the embed-ded pseudorandom sequence and a one dimensional sequence correspond-ing to a ra-dius between f1 and f2. The cross-covariance value is related to cross-correlation value and can be defined as a cross-correlation of mean removed sequences

$$c_{xy}^{*}(m) = \begin{cases} \sum_{n=0}^{N-|m|-1} \left(x(n+m) - \frac{1}{N} \sum_{i=0}^{N-1} x_i \right) \left(y_i^{*} - \frac{1}{N} \sum_{i=0}^{N-1} y_i^{*} \right) \ , \ m \geq 0 \ , \\ c_{yx}^{*}(-m) \ , \ m < 0 \end{cases} \quad (1)$$

,where x is a sequence of the image at some radius with length N and y is the pseudo-random sequence interpolated to the length N. The maximum of each of the resulting cross-covariances is saved to a vector. After all the integer radii between frequencies f1 and f2 are examined, the maximum is selected from the vector shown in Fig. 4.

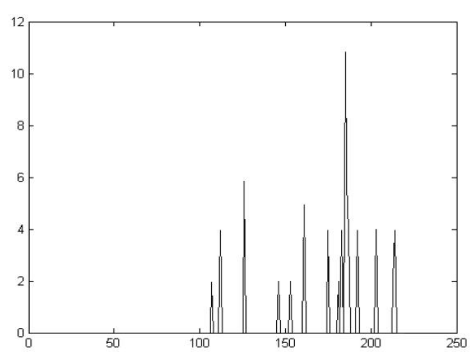

Fig. 4. The vector containing maximums of the cross-correlations.

The maximum of the vector is an estimation of the radius of the circle. The exact radius is found by finding the locations of the template peaks by examining the space at wide 2 pixels around the estimation of the radius. The search of the peaks is performed by using adaptive thresholding and the final threshold value is found by iterating the calculations until the correct amount of the peaks is found. The pseudorandom sequence used in embedding is known and thus the number of peaks that should be found is also known. The point is selected to be a peak if the value in that point exceeds the threshold value and if the peak is a maximum on that area. The locations of the peaks are specified further by interpolating a small area around the peak and selecting the maximum value of the interpolation as the peak.

Some of the peaks located this way may be discarded because we know that the peaks should be located at angle pi/20 from each other. The points at pi/20 from each other are selected as template peaks and the other are discarded. The obtained piece of sequence is then cross-correlated with the embedded pseudo-random se-quence and the maximum of the cross-correlation signal shows the amount of rotation in a multiple of pi/20.

From here on the scaling factor and rotation angle are straightforward to determine. The scaling factor is calculated by taking a trimmed mean of the radii of the peaks and dividing this value by the original radius of the embedded pseudorandom sequence. The rotation angle is obtained by subtracting the original angles of the peaks from the angles of the detected peaks and taking a median from the resulting values. Fig. 5 shows the watermarked image after print-scan process and after the corrections have been made.

Fig. 5. a) Watermarked image after print-scan process. b) Watermarked image after correction of rotation and scale.

3.2 Inverting translation

The magnitude domain of the Fourier transform is invariant to shifts in spatial do-main and thus, if we want to apply watermarking techniques that are robust against translation attack, we need to find the amount of translation with a different way. Here, the problem is solved by introducing a second template watermark which is embedded in spatial domain and which is capable of finding the amount of translation after rotation and scale have been found. Therefore full search is not needed and the translation is found efficiently. The method for finding the translation was developed in [12], where a template watermark is embedded in the spatial domain and extracted after print-scan process with cross-correlation tech-niques. The shape of the template watermark is illustrated in Fig. 6, in which it can be seen that the template consists of two parts, horizontal and vertical segments. Both of the segments are built with a pseudorandom sequence of size 127 which is repeated over the image to form the template pattern. The embedding strength of the watermark was chosen based on the JND (Just Noticeable Difference) model, proposed by Chou and Li [8], in which a separate JND threshold for each pixel in the image was calculated.

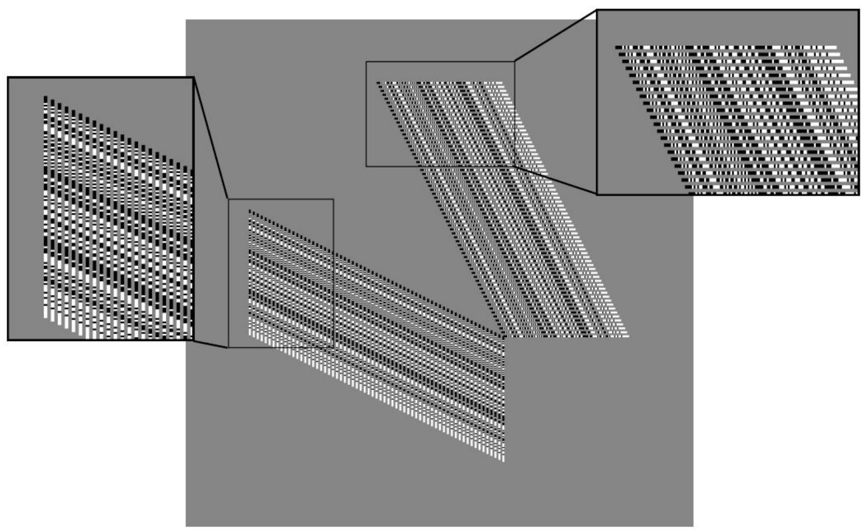

Fig. 6. The template embedded in the image in order to recover the message watermark from a translation attack.

The extraction problem is illustrated in Fig. 7, where four unknowns determine the amount of translation in four directions. The extraction of the watermark information is performed first for horizontal direction and then for the vertical direction. Before the extraction process the image is interpolated with quarter pixel interpolation to achieve better precision and Wiener filtering to remove noise, i.e. the effect of the image.

The location of the template is known in the original image and the information is utilized in determining the translation. The translation template is found by calculating cross-correlations with every other line in the image and the pseudorandom sequence used in embedding. There is no need to calculate cross-correlations with every line, because of the design of the watermark and this saves time and processing power, but does not affect robustness significantly.

Due to the shape of the template watermark, the cross-correlation peaks obtained are not located in the same location, and in order to place the peaks to the same posi-tion relative to each other, each of the cross-correlation results should be shifted. After the cross-correlation sequences have been shifted into the same position, the sequences are then summed up and consequently the peaks are strengthened.

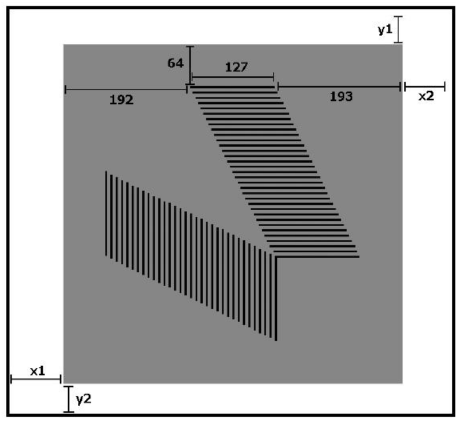

Fig. 7. The translation template after spatial shift.

The location of the maximum of the cross-correlation sequence contains the information about the translation. The cross-correlations are calculated in two directions which results in two cross-correlation sequences. However, the locations of the two maximums do not tell the amount of translation straightforwardly because of all the shifts and additions. The translation is found by first subtracting the known location of the template in the original image from the two locations of the peaks and then combing the two values in order to find the exact values for the translation. There are, however, four unknown parameters that determine the location of the image, one for each side, as shown in Fig. 7, and therefore the location of the maximum peak is calculated from both directions of the cross-correlation sequences. This results in four values which can be combined with the following equations to find out the exact values of the translation:

$$\begin{array}{l} val1 = x_2 + \frac{1}{2}y_1 \\ val2 = \frac{1}{2}x_1 + y_2 \\ val3 = x_1 + \frac{1}{2}y_2 \\ val4 = \frac{1}{2}x_2 + y_1 \end{array}. \tag{2}$$

,where the val1, val2, val3 and val4 are the four values calculated from cross-correlation peaks. After the translation parameters are calculated, the image can be extracted from the background and the actual value-adding watermark can be read.

An algorithm of the extraction method is as follows:
1. Apply quarter-pixel interpolation to the image;
2. Process horizontal part of the template;
2.1. Calculate cross-correlation with every other row of the image;
2.2. Shift every cross-correlation result with one more that the result of the previ-ous row so that the peaks are in the same line;
2.3. Add all the results together;
2.4. Find the maximum peak and calculate the distance from both ends of the sequence;
2.5. Remove the location information of the template in the original image;
3. Process vertical part of the template;
4. Solve the amount of translation from the received results.

3.3 Embedding and extracting the multibit message

In our method, we have applied the method by Keskinarkaus et al. [13] for embedding and extracting the message watermark. In their method, the watermark is em-bedded in the approximation coefficients of the Haar wavelet transform to gain better robustness. Detail coefficients of the wavelet transform, on the other hand, might offer better imperceptibility properties [14]. In our method, the robustness of both of the coefficient domains have been experimented. The watermark is embedded with

$$\begin{cases} Y^{**}_{l,f}(n) = Y^{*}_{l,f}(n) + \beta \cdot m(k), \ messagebit = 1 \\ Y^{**}_{l,f}(n) = Y^{*}_{l,f}(n) - \beta \cdot m(k), \ messagebit = 0 \end{cases} \tag{3}$$

,where Y* l,f is an image which has already been watermarked with the templates in Fourier and spatial domain. Y*l,f(n) is the sub-band of Y* in the lth resolution level and fth frequency orientation. Y**l,f(n) is a new watermarked sub-band, where ** means that multiple watermarking has been applied. b is a scaling coefficient to control the embedding strength and m(k) is the m-sequence the length of which controls the chip rate for spreading.

The message watermark is extracted with cross-correlation after the geometrical distortions have been corrected. The cross-correlation is calculated with the m-sequence used for embedding the message and a small segment of wavelet coefficients of the same size as the m-sequence. The results of the cross-correlations are analyzed: if the correlation value is above certain value the message bit is chosen to be 1 and otherwise 0.

4 Experiments and results

The method was tested with a 512x512 Lena image by embedding an error coded message of size 135 bits to the image. The message size was chosen large enough for the application but small enough to enhance robustness. The error-correction coding applied to the message was (15,7) BCH coding which is capable of correcting 2 bits. The Lena image was watermarked and tested both embedding the message in the detail coefficients and embedding the message in the approximation coefficients of the wavelet domain. This results in two message watermark embedding methods which are examined in the following section.

The watermarked images were compressed with JPEG and JPEG2000 algorithms with Matlab quality factors of 100, 80, 60 and 40. The quality factors correspond approximately to compression ratios 3.3, 16.2, 26.0 and 36.1, respectively. The qualities of the images were examined by calculating PSNR (Peak Signal to Noise Ratio) and PSPNR (Peak Signal to Perceptible Noise Ratio) values [8] for each image. The PSPNR value takes into account only the part of the distortion that exceeds the JND threshold calculated earlier. Thus the PSPNR value gives a better description of the quality of the image. The obtained values were gathered to Table 1, and as seen, the qualities of the images stayed fine through the embedding process.

Table 1. PSNR and PSPNR values for the images where the message watermark is embedded in different domains

JPEG	PSNR	PSPNR
approximation coefficients	40.5	59.3
detail coefficients	38.4	53.3
JPEG2000		
approximation coefficients	38.0	51.0
detail coefficients	37.6	50.6

The watermarked and compressed images were printed with Hewlet Packard ColorLaserJet 5500 DTN printer. One JPEG compressed image was also printed out with Hewlet Packard ColorLaserJet 4500 DN printer, and it was noted that the result was significantly darker and fuzzier than the corresponding image printed with ColorLaserJet 5500 DTN printer, as shown in Fig. 8.

The scanner used in the experiments was Epson GT-15000, and every image was scanned 100 times with 300dpi and then 100 times with 150dpi and saved to uncompressed tiff-format. The printed and watermarked images were scanned by rotating the image manually on the scanner plate between degrees -45 and 45 and the scanning area was chosen around the image by hand, as illustrated in Fig. 1. The embedded watermarks were extracted from each of the images and the results obtained were collected to following tables. The reliability of the method is shown with success ratios that is, percentage of times when the message was extracted correctly and BER (Bit Error Rate) information.

The properties of the wavelet transform complicate the comparison of the two embedding domains as the values in detail and approximation coefficients represent different things. Thus to make the methods comparable, the embedding

Fig. 8. The translation template after spatial shift.

strengths were chosen for each based on the similar PSNR values. The results obtained after the print-scan process are quite good, as seen from the Tables 2 and 3, and the method is robust against heavy JPEG compression and JPEG2000 compression. It seems that the method where the watermark was embedded in the approximation coefficients of the wavelet transform is more robust against JPEG2000 compression than the method where the watermark was embedded in the detail coefficients but lose in comparison with robustness against JPEG compression. The method in which the watermark was embedded in the detail coefficients shows very strong robustness against JPEG compression, as seen from Tables 2 and 3.

Table 2. Success ratio with different JPEG quality factors and scanning settings

	approx. coefficients		detail coefficients	
Quality factor	300dpi	150dpi	300dpi	150dpi
100	98%	98%	100%	99%
80	97%	94%	100%	99%
60	97%	91%	98%	98%
40	49%	46%	90%	85%

Table 3. Success ratio with different JPEG2000 quality factors and scanning settings

	approx. coefficients		detail coefficients	
Quality factor	300dpi	150dpi	300dpi	150dpi
100	96%	100%	98%	99%
80	100%	99%	91%	91%
60	84%	79%	23%	12%
40	0%	4%	0%	0%

The BER values of the tests are shown in Tables 4 and 5 where the value in the brackets indicates the BER after error correction. The BER values show that a stronger error correction coding might improve the results significantly.

All the BER values are beneath 50%, which indicates that the watermark is not destroyed entirely under heavy JPEG and JPEG2000 attacks.

Table 4. BER with different JPEG quality factors and scanning settings

	approx. coefficients		detail coefficients	
Quality factor	300dpi	150dpi	300dpi	150dpi
100	1.9% (0.56%)	1.4% (0.1%)	0.8% (0%)	1.2% (0.5%)
80	2.6% (1.0%)	2.9% (1.0%)	0.7% (0%)	1.0% (0.5%)
60	3.0% (0.6%)	5.0% (2.8%)	1.8% (0.6%)	1.8% (1.0%)
40	8.3% (4.3%)	8.7% (4.0%)	6.2% (3.6%)	6.8% (4.2%)

Table 5. BER with different JPEG2000 quality factors and scanning settings

	approx. coefficients		detail coefficients	
Quality factor	300dpi	150dpi	300dpi	150dpi
100	2.5% (1.1%)	1.3% (0%)	1.3% (0.6%)	0.9% (0.3%)
80	1.3% (0%)	1.7% (0.5%)	3.6% (1.5%)	2.4% (0.8%)
60	8.7% (4.9%)	9.2% (5.7%)	20.2%(12.5%)	21.8%(15.3%)
40	26.8%(24.1%)	28.6%(26.0%)	41.4%(38.6%)	42.2%(39.6%)

Solanki [10] and He and Sun [9] showed in their papers that the printer should also be considered when designing a print-scan robust watermarking system. The results obtained with different printers are collected to Tables 6 and 7. The pictures were printed with HP LaserJet 5500 DTN and HP LaserJet 4500 DN printers. Both printed images were compressed with JPEG quality factor of 100 and scanned with the same scanner.

The tables show the importance of finding the template peaks correctly from the magnitudes of the Fourier domain. When the interpolation is not used while determining the exact locations of the template peaks, the amount of scale and rotation are not found accurately enough. This clearly affects the performance of the algorithm. From the tables, it can be seen that the interpolation does not strongly affect watermark extraction when a printer with a good quality is used but destroys the watermark when a different printer, possibly with lower quality, is used.

Comparison of the method with other print-scan robust watermarking techniques is difficult, because print-scan robustness has not been extensively researched and the watermarking algorithms depend heavily on the application and properties required. Many of the print-scan robust methods focus on detecting watermarks [7] [15] and multibit message watermarking methods are rare. In nearly every paper, the robustness has been tested with a different way or the testing process has not been explained properly, thus preventing others to repeat the experiments. In some papers, there is no information about the strength of the distortions inflicted [5] [9] and it is difficult to compare the methods. For comparison it is important to know if the image has been scanned in random

Table 6. Success ratio with different printers and JPEG quality factor of 100

	without interpolation		with interpolation	
Printer	300dpi	150dpi	300dpi	150dpi
5500 DTN	96%	96%	100%	99%
4500 DN	86%	80%	96%	99%

Table 7. BER with different printers and JPEG quality factor of 100

	without interpolation		with interpolation	
Printer	300dpi	150dpi	300dpi	150dpi
5500 DTN	3.0% (5.3%)	3.2% (2.0%)	0.8% (0%)	1.2% (0.5%)
4500 DN	8.6% (5.3%)	14.5% (11.0%)	4.1% (3.9%)	2.7% (0.1%)

alignment or by placing the image on the scanner plate straight. In this method, the alignment of the image does not matter and the robustness against large angles of rotation and JPEG compression is high. All the distortions are inflicted to the image simultaneously thus simulating the real world situation. He and Sun [9] exchanged robustness with capacity and the results were thus significantly worse than in the proposed method. They reported BER values of 15% while in the proposed method the BER values were mostly below 5% with worse scanning resolutions than He and Sun applied in their method. PSNR values were approximately the same in both of the methods.

5 Conclusion

The experiments show that the method proposed is robust against rotation, scaling and translation attacks, as well as JPEG and JPEG2000 compressions, and is thus robust against a print-scan attack. In this system, multiple watermarking was used successfully where each of the watermarks was embedded in different domain and each had a purpose of its own. The quality of the watermarked image stayed fine through the embedding process in spite of multiple watermarks embedded, and the template watermarks were able to correct geometrical distortions. The method also worked well under JPEG and print-scan attacks. It is shown that even the ordinary methods such as spread spectrum methods can survive through print-scan process and no special equipment or method is required.

It was found out that the message watermark was more robust against JPEG com-pression when it was embedded in detail coefficients than the approximation coefficients of the wavelet domain. On the other hand, when JPEG2000 compression was used, the watermark was more robust when it was embedded in approximation coefficients that detail coefficient of the wavelet domain. It was also discovered that, although the selection of the printer is important in de-signing a print-scan robust watermarking system, some of the effects of the printer can be minimized by improving the watermark extraction process. In the future, a better message watermarking method should be developed, and ro-bustness against JPEG2000 compression algorithms, in particular, should be re-searched more extensively. It can, however, be concluded that the multiple watermarking method, proposed here, can correct rotation, scale and translation accurately for the message watermark extraction.

References

1. Kutter, M.: Watermarking resisting to translation, rotation and scaling. In: Proc. of SPIE Multimedia Systems and Applications, 1998, Vol. 3528, pp.423-431.
2. Deguillaume, F., Voloshynovskiy, S., Pun, T.: Method for the Estimation and Recovering from General Affine Transforms. In: Proc. of SPIE, Electronic Imaging, 2002, Security and Watermarking of Multimedia Contents IV, vol. 4675. pp.313-322.
3. Pereira, S., Pun, T.: Robust Template Matching for Affine Resistant Image Watermarks. In: IEEE Trans. on Image processing, 2000, Vol. 9, Issue 6, pp.1123-1129.
4. Lee, J.-S., Kim, W.-Y.: A Robust Image Watermarking Scheme to Geometrical Attacks for Embedment of Multibit Information. In: Proc. of Advances in Multimedia Information Processing, 5th Pacific Rim Conference on Multimedia, 2004, pp.III-348-355.
5. Chiu, Y.-C., Tsai, W.-H.: Copyright Protection against Print-and-Scan Operations by Watermarking for Colour Images Using Coding and Synchronization of Peak Locations in Frequency Domain. In: WCVGIP 2006, Taiwan, Journal of information science and engineering, vol. 22, pp.483-496.
6. O'Ruanaidh, J.J.K., Pun T.: Rotation, scale and translation invariant digital image watermarking. In: IEEE Proc. of ICIP 1997, vol. 1, pp. 536-539.
7. Bas, P., Chassery, J.-M., Marq, B.: Geometrically Invariant Watermarking Using Feature Points. In: IEEE Trans. on Image Processing, 2002, vol. 11, pp.1014-1028.
8. Chou, C.-H., Li, Y.-C.: A Perceptually Tuned Subband Image Coder Based on the Measure of Just-Noticeable-Distortion Profile. In: IEEE Trans. on Circuits and Systems for Video Technology. 1995, Vol. 5, Issue 6, pp.467-476.
9. He, D., Sun, Q.: A Practical Print-scan Resilient Watermarking Scheme. In: IEEE Proc. of ICIP 2005, vol. 1, pp.I-257-60.
10. Solanki, K., Madhow, U., Manjunath, B.S., Chandrasekaran, S.: Estimating and Undoing Rotation for Print-scan Resilient Data Hiding. In: IEEE International Conference on Image Processing, 2004, vol. 1, pp.39-42.
11. Perry, B., MacIntosh, B., Cushman, D.: Digimarc MediaBridge -The birth of a consumer product, from concept to commercial application. In: Proc. of SPIE Security and Watermarking of Multimedia Contents IV, 2002, vol. 4675, pp.118-123.
12. Pramila, A. Watermark synchronization in camera phones and scanning devices. Master's thesis, Department of electrical information engineering, University of Oulu, Oulu, p.83
13. Keskinarkaus, A., Pramila, A., Seppnen, T., Sauvola, J.: A Wavelet Domain Print-scan and JPEG Resilient Data Hiding Method. In: Proc. of 5th IWDW, LNCS vol. 4283, 2006, pp.82-95.
14. Barni, M., Bartolini, F., Capellini, V., Lippi, A., Piva, A.: A DWT-based technique for spatio-frequency masking of digital signatures. In: Proc. of the SPIE/IS&T International Conference on Security and Watermarking of Multimedia Contents, 1999, vol. 3657, pp.31-39.
15. Lin, C.-Y., Chang, S.-F.; Distortion Modeling and Invariant Extraction for Digital Image Print-and-Scan Process. In: ISMIP 1999.