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RESEARCH ARTICLE

Robust Digital Image Watermarking (DIW) using SWT and Spread Spectrum Circular Symmetric Watermark

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Abstract: The objectives of this study were to create a Digital Image Watermarking (DIW) robust to geometric transformation. The watermarking technique embeds a watermark in digital data for copyright protection. A novel digital image watermarking is proposed. Using the Wavelet Transform properties, a circularly symmetric watermark was embedded in an image. Digital Image Watermarking (DIW) is attacked by geometric transformations, namely scaling, rotation, cropping, median filter, and adaptive filter. In the scaling process, the quality of DIW decreases as it becomes larger and smaller, but not significantly. In the rotation and cropping process, the embedded watermark changes slightly, but not significantly. The proposed Digital Image Watermarking (DIW) in the wavelet transform domain is robust to geometric transformation attacks.

Keywords: digital image watermarking, geometric transformation, spread spectrum circular symmetric watermark, wavelet transform domain

1 Introduction

In digital form, dissemination due to copying is very difficult to stop or bring to the court, as the results of the copy are identical to the original. For this reason, certain techniques are necessary to protect copyright as "intellectual property," since the authenticity of data and the illegal distribution can be traced [1].

To solve these problems, other techniques are needed that allow data origin to be traced, known as Watermarking. The purpose of the watermarking technique is to protect copyright by embedding a mark, which is generally useful for identifying legitimate owners.

Mark can be either a register number (such as UPC: Universal Producer Number), the message text, or the logo of the image [2], while the data to be watermarked is generally an image [3].

The main idea of Digital Image Watermarking (DIW) [1,4,5]is to embed a signal into the host image where these signals cannot be seen and are safe. If the secret key is used in the embedding process, it is possible to get the signal back. By the same analogy as watermark paper used in banknotes and Digital Image Watermarking inspired by it, in application to protect digital images. To be useful and effective, a watermarking system must have the following properties [6,7]:

1. Invisible, cannot be observed with the human senses, or does not have to change the characteristics of the original image.
2. Robustness, the watermark must be more difficult to remove or erase with common signal operations (median filters and adaptive filters) and geometric transformation (such as rotation, scaling, and cropping).
3. Unambiguous, can identify the source and ownership, can be used to detect counterfeit goods.

So, digital image watermarking (DIW) is a technique for hiding or embedding certain data into other digital data, but it is invisible to the human senses and robust to digital signal processing at a certain stage. In DIW, digital signal processing is called an attack in the watermarking technique. If a watermarked image is attacked and the result is no change, then the watermark is robust against attacks. DIW techniques can be performed in two domains: the spatial and frequency domains.

DIW in the spatial domain, such as the research by Bruyndonckx et al. [8], who proposed the basis for regional pixel calcification. Frequency Domain Watermarking was developed by Cox et al. [6] and Bolland [4]. The Cox approach uses spread-spectrum techniques to combine single bits in an image. However, this technique requires the original image to be readable by the watermark code. Smith et al. [9] refer to the above approaches (when the original image is needed in the code reading process). Koch et al. [10] reported a DCT domain technique that is efficient and robust to JPEG compression.

The expected approach was finally proposed by Ruanaidh et al. [11], where the watermark is hidden in the Fourier–Mellin transform domain. Hiding the watermark in this domain will make the watermark robust to rotation, scaling, and translation. One disadvantage of this method is that mapping the Fourier spectrum in log-polar coordinates can sometimes reduce the quality of the watermarked image. Double watermark placed along the center of circulation in the zero frequency of the Fourier transform of the image, proposed by Pitas et al. [12]. This method is shown to be efficient against no more than 30 rotation attacks and likewise against scaling and translation.

In previous research, robustness to geometric transformation was still a problem for the watermarking technique used. So, the robustness to geometric transformation needs to be improved with another approach. For this reason, an approach is used in the wavelet transform domain, which is expected to hide marks safely but has a limited mark size. In the wavelet transform domain, a watermark robust to geometric transformation can be enhanced.

In this study, we propose the use of the discrete wavelet transform domain to enhance the robustness of watermarks against geometric transformations [13]. The wavelet transform domain is also used for image compression [14], so that the storage is not too large.

The image compression process aims to produce lower memory usage or reduce the memory usage of the file by removing redundant information from each pixel. Maintaining image quality after the compression process is a challenge for the image compression process [15].

The proposed DIW system is to embed a circular symmetric circular watermark in the spread spectrum in an image, taking advantage of the properties of the Wavelet Transform [13,16]. DIW in the wavelet transform domain methods aim to improve the robustness of watermarks against common attacks such as compression, filtering, and geometric transformation [17]. The robustness of the watermark remains detectable even after the image undergoes various manipulations [18]. DIW in the Wavelet Transform domain for security, advanced algorithms incorporate cryptographic techniques to enhance the security of the watermark [19]. This involves ensuring that unauthorized users can easily remove or manipulate the watermark without the appropriate key. DIW in the invisibility domain of the wavelet transform, efforts are made to improve the imperceptibility of watermarks [20], ensuring that they are visually less noticeable to the human eye. This is crucial to maintain the quality and aesthetics of the watermarked image. So, in this study, we combine SWT and a circular symmetric watermark with spread spectral to enhance the resistance to geometric transformation.

2 Research Method

2.1 Watermarking System Model in General

The watermark (W) embedded in image (I) using a special key (k) produces I_w as the watermark image. Watermarked image (I_w) after an attack, symbolized by $\hat{I}_\omega$. In the detection process, the result is the original image (I). In the extraction process, it can be done by adding the watermarked image (I_w) or the watermarked image after the attack $\hat{I}_\omega$, thus producing a watermark that has been attacked (W). This is done to determine whether or not there is a watermark in the image. This is done during the detection process in Figure 1

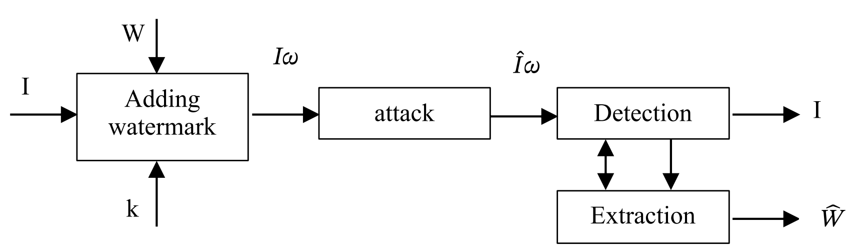


Figure 1: Watermarking system model.

2.1.1 Watermarking insertion process

The watermark insertion processes are shown in Figure 2. It was mentioned earlier that a watermark can be embedded through 2 domains, the spatial domain or the frequency domain of an image. We can also embed a watermark into a significant component of the image to add strength to the watermark. Figure 2 shows a straight line that shows the embedding process of the watermark. The dashed line indicates the selection operation, which is a model that can embed a watermark in the spatial or frequency domain. Selected perceptual analysis and methods used to embed watermarks are usually easy. Research is carried out to cover the shortcomings of human vision [21].

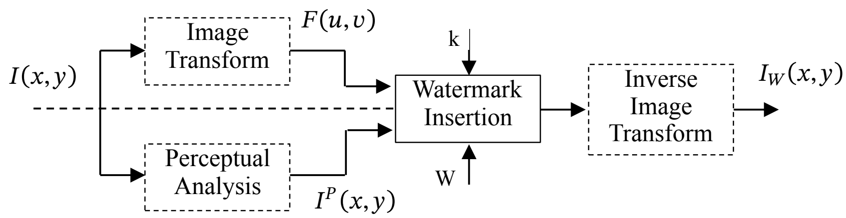


Figure 2: Watermark insertion process.

2.1.2 Wavelet transformation

The wavelet is a small wave that has the ability to classify image-concentrated energy into small coefficients. However, the other coefficients contain only small amounts of energy that can be eliminated without reducing the value of the information [22, 23]. The original wavelet is called the mother wavelet.

$$W_{a,b}(x) = \frac{1}{\sqrt{a}} W\left(\frac{x-b}{a}\right) \tag{1}$$

In Eq. (1), W represents the wavelet function. The parameter a is the dilation factor that determines the scale or expansion of the signal, while the parameter b is the translation factor that controls the shifting of the signal in the time domain. The term $\frac{1}{\sqrt{a}}$ is used as an energy normalization factor to ensure that the energy of the transformed wavelet remains equal to the energy of the mother wavelet.

The mother wavelet is scaled and translated, separated into sub-sections according to frequency. To get the signal back, the wavelet reconstruction is performed. For example, an image is divided into high- and low-frequency components, using the Daubechies filter in Figure 3.

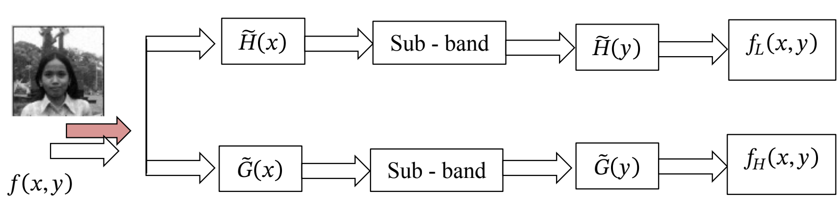


Figure 3: Block diagram of the frequency splitting.

For G, G represents the low-pass filter, while for H, H represents the high-pass filter. The subband is obtained through the processes of dissimilation and interpolation. The frequency reconstruction process is illustrated in the block diagram shown in Figure 4.

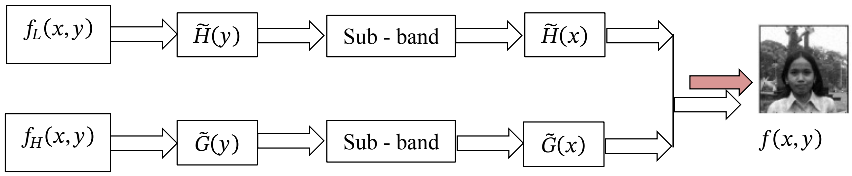


Figure 4: Block diagram of frequency reconstruction.

2.2 Attack in watermarking

Attacks on watermarking techniques [24,25] are all efforts made to eliminate the data mark. After the data marks are removed, an image can be copied and distributed. Attacks the watermarking technique that is common in geometric transformations (scaling, rotation, cropping, and compression).

2.2.1 Scalling

The axis scaling in the spatial region that causes wavelet inverse scaling in the region, i.e., for two scalar a and b, is expressed as follows :

$$I(ax, by) \quad \longleftrightarrow \quad \frac{1}{|ab|}\, F\Big(\frac{u}{a}, \frac{v}{b}\Big) \tag{2}$$

The function used to perform scaling in MATLAB is the imresize function. The imresize function is used to resize images using the interpolation method. In standard conditions, interpolation uses nearest-neighbor interpolation. If the output size does not have the same aspect ratio as the input, it is called a distorted output. To reduce image size with bilinear and bicubic interpolation, the imresize function uses a low-pass filter, which is then interpolated. This is done to reduce the presence of moire patterns, namely patterns in the form of small waves (ripples) produced during resampling.

2.2.2 Rotation

When SWT and ISWT couples presented in polar coordinates [12] as follows :

$$x = r\cos\theta, \quad y = r\sin\theta \tag{3}$$

$$u = w\cos\emptyset, \quad v = w\sin\emptyset \tag{4}$$

The notation $I(x, y)$ and $F(u, v)$ can be expressed in polar coordinates as $I(r, \theta)$ and $F(w, \emptyset)$. An image rotation by an angle θ_0 leads to the watermark being rotated by the same angle, that is,

$$I(r, \theta + \theta_0) \;\longleftrightarrow\; F(w, \emptyset + \theta_0) \tag{5}$$

Matlab uses the imrotate function to rotate the image using the nearest-neighbor interpolation method. Angle units are in degrees, and a positive value entered means counterclockwise, while a negative value means clockwise. So that the entire original image can be rotated, imrotate places the edges of the image to form a pad and creates a background connection between the edges, so that the output image is larger than the input. To equalize the size, you can add the 'crop' option.

2.2.3 Cropping

If $F(u, v)$ and $I(x, y)$ are periodic functions with period N, then there is a relation as follows:

$$F(u, v) = F(u + N, v + N) \tag{6}$$

$$I(x, y) = I(x + N, y + N) \tag{7}$$

Furthermore, in conjugation symmetry, it is shown that

$$|F(u, v)| = |F(-u, -v)|$$

so as to apply cropping ties:

$$I(x - N, y - N) \longleftrightarrow F(u - N, v - N) \tag{8}$$

Matlab uses the imcrop function to extract part of an image box. The determination is done via an input box or selection with a mouse. If the input is not specified, the mouse changes to a cross-hair shape over the image to be cropped, so that the user is free to create a box for the desired image crop size.

2.3 Spread spectrum circular symmetric watermark

The spread spectrum technique [16] uses a system that transmits signals over a short distance and in all directions, where the amount of energy spread over each frequency component of the spectrum is minimal. By analogy, the frequency domain $F(u, v)$ of the image $I(x, y)$ can be described as a channel, and the watermark w can be considered as the transmitted signal. The watermark is emitted in all directions with various frequencies, spreading in all directions without being detected, unless someone knows the exact location where it is hidden and also possesses the required key k.

Figure 5 shows a dotted line diagram of the distribution of the watermark spectrum in the frequency domain. First, the image enters the perceptual analysis process to maintain the invisibility of the watermark. The result of this process is a mask that regulates the strength of the watermark to be embedded in the image. The watermark W is a pseudo-random number vector with length L generated by a pseudo-random number generator (PRN) using key k. This vector is multiplied by the perceptual mask and then added to the elements of the image transformation $F(u, v)$. The results of this operation are then transformed back to the original form $I_w(x, y)$.

2.4 Method

The research data consists of six images, each with a resolution of 256×256 pixels. One of these images was selected as the original image to be embedded with a circular symmetric

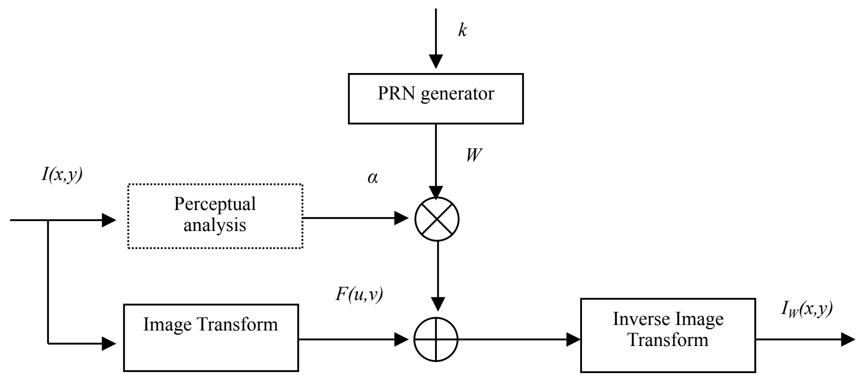


Figure 5: Spread spectrum watermarking in the frequency domain.

spread-spectrum watermark. The watermark is represented in the form of circular bits of data.

Matlab matrix values are a Grayscale image. An image of size 256×256 pixels is represented as a matrix of 256 rows and 256 columns. The text data are composed of characters from the set $\{a, \ldots, z, 0, \ldots, 9\}$ along with commonly used punctuation and spaces. The selected character string is then converted to binary values $\{0, 1\}$, with one character encoding replaced by 6 bits.

Using the wavelet transform, the original image I is decomposed into approximation coefficients and three detail components. (vertical, horizontal, and diagonal). Subsequently, the watermark data W and the security data (PRN) are embedded during the wavelet transform, a process known as watermarking. At a certain energy threshold, the SWT decomposition process is ended when the appearance of the watermarked image I_W is visually indistinguishable from the original image, as illustrated in Figure 6.

The final result of the watermarking is saved after it is merged into one. Then the correlation value between the original image and the watermark image is calculated. If the changes are not as visible in his appearance, it is said that the watermarking process is successful. After the successful merger, the reverse process is then performed to extract the images inserted back into the image watermarking. To recover the data, marks are inserted, which is shown in Figure 7

3 Results

The mark to be made must be determined by determining the shape of the data marks and then determining the value of R, that is, the radian value to look for in order to mark the data as desired. Then calculate the constant value amplifier (Alpha), used to improve the shape of the data view mark, and get the maximum number of characters that can be written. From several experiments carried out, the correct R value was obtained, which was around 100, the correct alpha value was 12.000, and 32 was the number of characters that could be written. Then, mark the data that had been created and embed it in the original image (Figure 8).

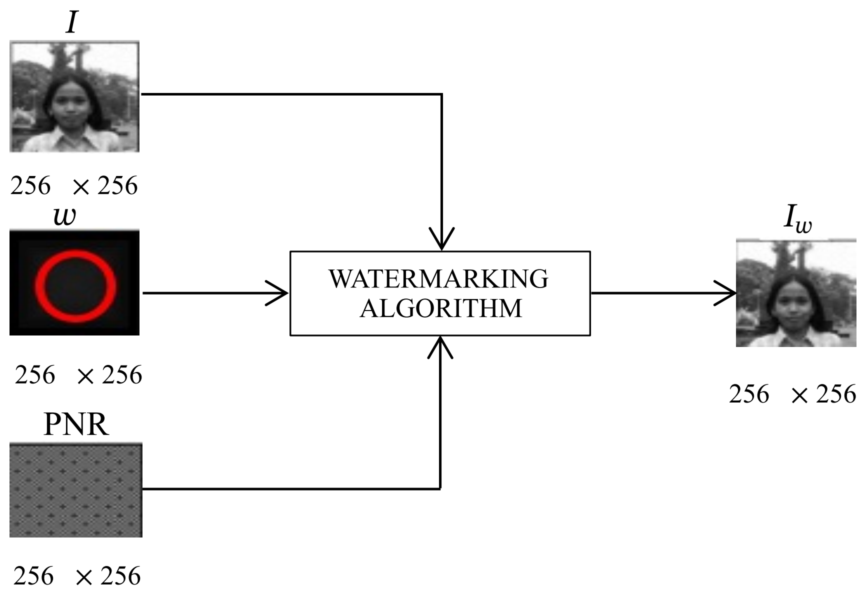


Figure 6: Watermark embedding process.

3.1 Attacks in Watermarking

Watermarking an image that has been generated in the SWT decomposition process given some attacks. The purpose of this paper is to test the robustness of the watermarking technique that has been generated from external influence. Attacks in the watermarking technique are geometric transformations, namely scaling, rotation, and cropping. Other attacks are the adaptive filter and the median filter.

3.2 Median Filter

In general, filtering an image aims to remove certain features. A filtering technique used to remove noise from images and signals. Filtering in digital images is a technique for modifying or improving image quality. Filtering in watermarking techniques is usually used to weaken or eliminate the data contained in it.

3.3 Adaptive Filter

Adaptive filters are a type of filter that is generally the most reliable in removing noise (Toolbox Image Processing: 2001). The watermarking process is considered robust to attacks if the image resulting from the Adaptive Filter Process has a shape that matches the watermarking image.

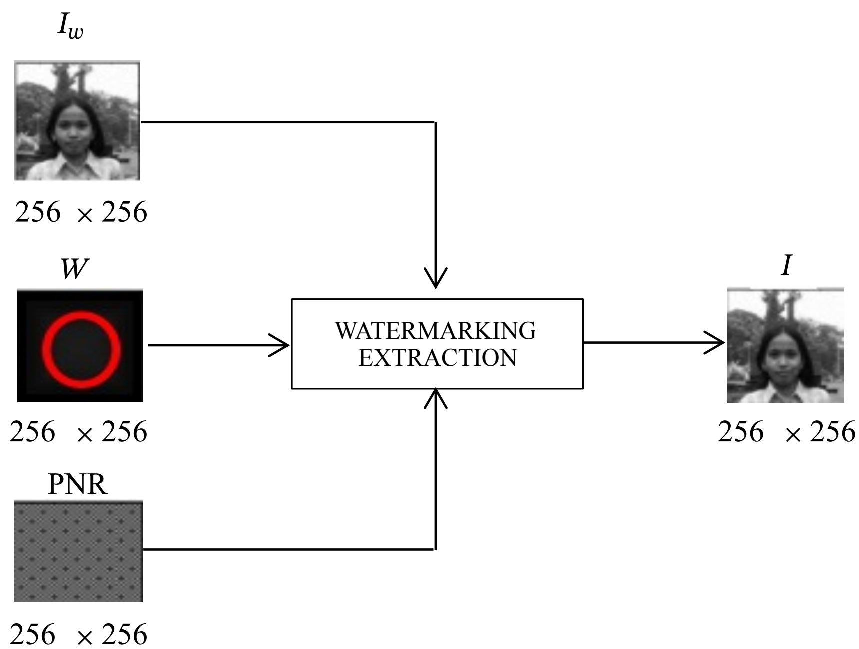
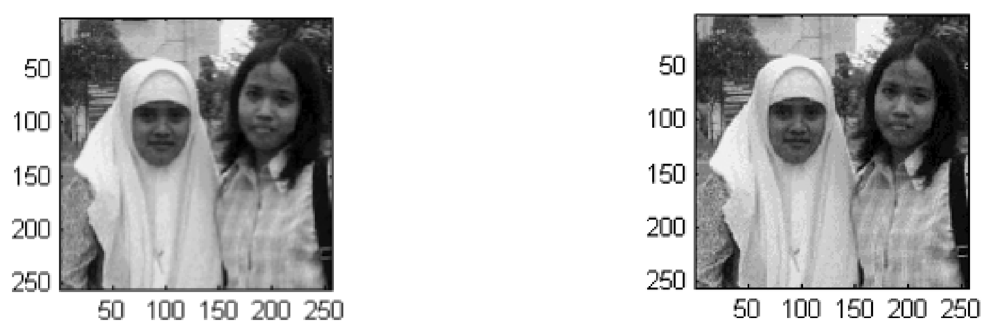


Figure 7: Watermark detection process.



(a) Original image

(b) Watermarked image

Figure 8: Comparison between original and watermarked images.

4 Discussion

Digital image watermarking (DIW) in the proposed wavelet transformation is considered robust to geometric transformation attacks, such as scaling, rotation, truncation, median filter, and adaptive filter. This is indicated by the watermark in the form of a circular text with 32 characters, capable of withstand geometric transformation attacks, and not damaged. During the watermark extraction process, the watermark shape remains the same as during the watermark insertion process. DIW experiences a decrease in image quality

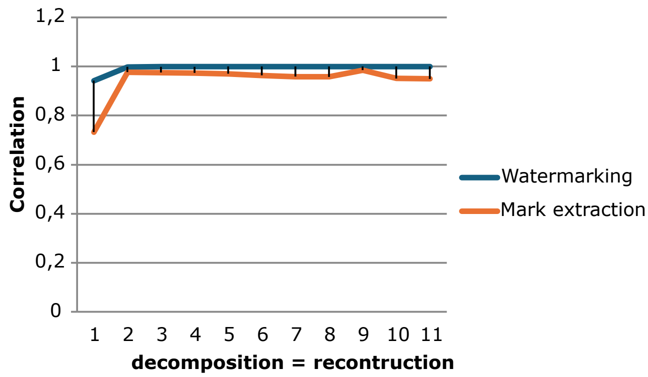
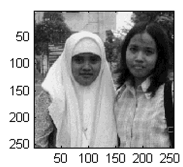
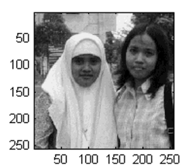
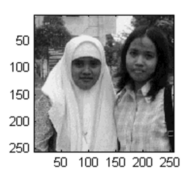


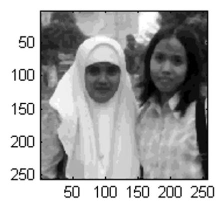
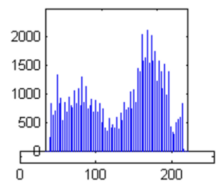
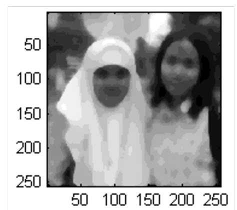
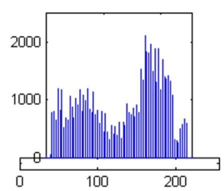
Figure 9: The value of the watermarking coefficient and mark extraction on the influence of the magnitude of SWT2 decomposition-reconstruction.

Table 1: Attack in digital image watermarking

Attack (goemetric transformation)	**DIW**	**DIW after being attacked**
Scalling		
Rotation		
Cropping		

when scaling and truncation attacks are applied, but the decrease in quality is not significant. In the rotation attack, there is no decrease in image quality up to a certain angle limit. For the media filter and adaptive filter processes, DIW experiences a decrease in quality along with the increasing size of the block used.

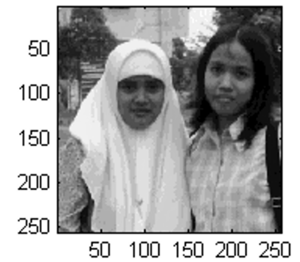
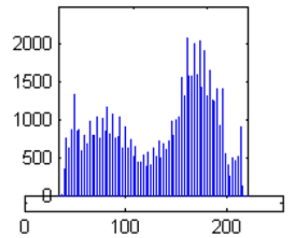
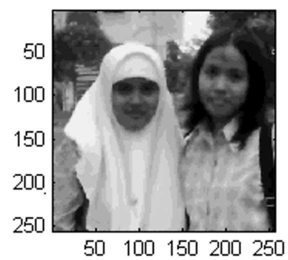
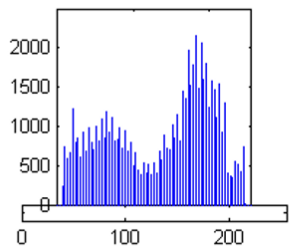
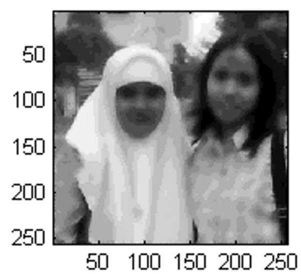
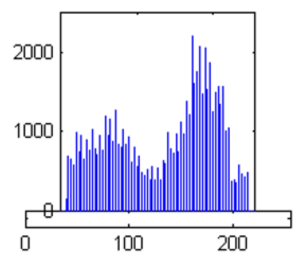
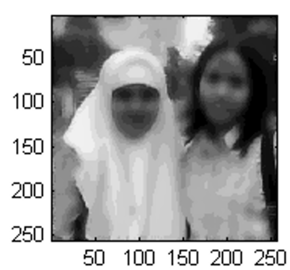
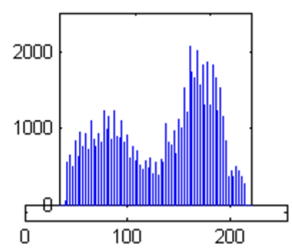
Table 2: Attack in digital image watermarking

Median Filter	**DIW**	**DIW after being attacked**
Display of watermarked images that have undergone the Median Filter Process with a block capacity of 5 × 5 in the watermarking technique		
Display of watermarked images that have undergone the Median Filter Process with a block capacity of 11 × 11 in the watermarking technique		

This study uses the circular symmetric watermark technique of the spread spectrum, as previous studies stated that the watermarking process using the imperceptible spread spectrum watermark technique can be improved [13]. The DIW proposed in this study can be used to track the spread of illegal digital data, data authentication, and maintain copyright as intellectual property. In the previous article, it was also mentioned that the proposed digital image watermarking technique has successfully ensured authenticity, integrity, and confidentiality [26]. In this study, DIW in wavelet transformation can increase resistance to geometric transformation attacks, as mentioned in previous studies [27]. Unlike the research conducted by Eko Hari et al., which utilized DCT transformation [28]. DIW in wavelet transformation has better resistance than using DCT, but DCT can be used to avoid complicated computations. DIW in wavelet transformation is considered robust to geometric transformations, including scaling, rotation, truncation, median filtering, and adaptive filtering. However, there is a decrease in image quality in the cropping process, which causes the embedded mark data to be truncated, and the results of mark extraction have only a few characters, depending on the size of the crop. In the median filter process, there will be a decrease in quality when using blocks [5 5] and so on, along with increasing block size. The embedded watermark will lose its characters one by one.

Watermarking images that are subjected to this median filter process will experience a decrease in quality when using blocks [5 5] and so on, as the block size increases. The watermark you insert will lose its character one by one. This can be overcome by providing

Table 3: Adaptive filter

Adaptive Filter	DIW	DIW after being attacked
Watermarked image that has been subjected to an Adaptive Filter Process with a block capacity of 2 × 2 in the watermarking technique		
Watermarked image that has been subjected to an Adaptive Filter Process with a block capacity of 5 × 5 in the watermarking technique		
Watermarked image that has been subjected to an Adaptive Filter Process with a block capacity of 8 × 8 in the watermarking technique		
Watermarked image that has been subjected to an Adaptive Filter Process with a block capacity of 11 × 11 in the watermarking technique		

a character length of no more than 13 characters. For adaptive filters, with a block size of [3 3], the watermarked image has the same shape as the original image. Thus, it can be said that the watermark hiding in the wavelet area is robust to adaptive filter attacks, but the watermarked image will have a quality that decreases with increasing block size used. However, the embedded watermark is not affected by increasing the block size.

5 Conclusion

The proposed Digital Image Watermarking (DIW) has been proven to be robust to geometric transformation attacks, median filters, and adaptive filters when a circular symmetric watermark of the spread spectrum is embedded in the wavelet transform domain (SWT). Digital Image Watermarking (DIW) is created by utilizing wavelet transform domain robust to geometric transformation. The DIW created by embedded a spread spectrum circular symmetric watermark, then given geometric transformation attacks, namely scaling, rotation, cropping, median filter, and adaptive filter. The result was DIW robust to geometric transformation attacks. DIW experiences a decrease in image quality when given scaling and cropping attacks, but the decrease in quality is not significant. In the rotation attack, there is no decrease in image quality up to a certain angle limit. For the media filter and adaptive filter processes, DIW experiences a decrease in quality along with the increasing size of the block used. For further research, it can be used with colored images and multiple watermarks to prevent illegal duplication.

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