

EMBEDDING WATERMARK ON DIGITAL AERIAL PHOTO IN GEOTIFF FORMAT USING DISCRETE WAVELET TRANSFORM AND DISCRETE COSINE TRANSFORM

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ABSTRACT: Digital watermarking is a technology for granting copyright to digital products. As a marker in digital products, a watermark is one way that can be inserted as additional information on the image, and the inserted information can be invisible, difficult to delete or change. Simulation using python with one image host aerial photo three bands (red, green and blue) 16-bit GeoTiff format with coordinates, image size 4742x4742 pixels with the top left coordinates 106.791 East Long 6.68694 South Latitude and the resolution is 0.01666 seconds for longitude and 0.01666 seconds for latitude. And an image of the one band 8-bit png format of BIG logo watermark in black (0) and white (255) with a size of 50x50 pixels. In this study, six simulations of watermark embedding were carried out by Replacing the maximum values of 255, 50, 25, 10, 5 and 1. The method used to embed watermark images is Discrete Wavelet Transform (DWT) combined with Discrete Cosine Transform (DCT). Watermarked image quality was measured using Peak Signal to Noise Ratio (PSNR), Structural Similarity Index (SSIM), Mean Square Error (MSE) and Visual Information Fidelity (VIF). The optimal watermark image number is at number 25 with a PSNR value of 80.3192, RMSE of 0.3438, VIF of 0.9930, and SSIM of 1.0000. The value of watermark one, which is inserted into the host image, makes the watermark image unrecognizable but has the largest PSNR (81.5050) compared to the others, while RMSE (0.3000) has the smallest value.

1. INTRODUCTION

The rapid development of technology and the internet has made it easier for someone to get digital information, be it images, audio, or video, to access and distribute various information in digital format. But behind the positive things from technological developments, there are negative things that are so significant, namely the activity of changing something from information and disseminating it without regard to the copyright values of the information itself. Watermarking technique is one solution to minimize piracy and provide copyright protection by putting a mark on the copyright. Watermarking is a data hiding technique to protect data that has been inserted with information to protect copyright and the authenticity of the image.

Digital watermarking is a technology for granting copyright to digital products. There are two methods of watermarking 1) Visible Watermarking. This type of watermark can be seen by the five human senses (the naked eye). The nature of this watermark is robust or very strong, and even very difficult to remove its existence even though it is not part of the image. 2) Invisible Watermarking This type of watermark cannot be seen by the five senses, which aims to provide confidential information and protect other people's copyrights from irresponsible people. This type of watermark can be seen through a computational process, namely by extracting an image with a watermark. In this research, the Invisible Watermark is given, where the Watermark will be inserted into the host image so that additional information on the host image cannot be seen with the naked eye without disturbing the original physical data (Tao et al., 2014). Invisible Watermarking like this is very safe to use copyright protection (Pradhan, 2017). Invisible watermarking is used to maintain the original data's ownership and authenticities such as audio, image, video, or even text. Where digital watermarking provides copyright data protection (Sirmour & Tiwari, 2014). Invisible watermarking is the process of embedding information into digital data (such as images, audio and video) that are difficult to remove.

Digital Watermarking can be used as proof of ownership for authentication, copyright protection, fingerprinting, and tamer proofing. Digital watermarks must meet several criteria, namely 1) Imperceptibility: A good watermark is invisible from human vision. 2) Robustness: Watermark must be resistant to manipulating container files, such as file compression and scanning. 3) Security: Watermarks can only be detected by data owners or authorized parties. 4) Recovery: The inserted data must be able to be retrieved (Ikromina, 2020).

Common features of digital watermarking are insensitivity, confidentiality, durability and insurance. Watermarks have benefits in 1) Copyright Protection. The purpose of watermarks in copyright protection is as authentic evidence of the creator's ownership rights to the content created or produced. 2) Fingerprinting, the purpose of the watermark is to identify each use and distribution of content. 3) Protection against duplication, Watermark is useful for protecting content from duplication and piracy. 4) Image authentication, Watermark is helpful in the authentication process to detect modifications of an image.

The current classical algorithm contains spatial domain algorithms, transformed domain algorithms, and a combination of the two techniques. In general, watermark techniques are divided into a. Watermarking technique that works in the spatial domain (spatial domain watermarking) This technique works by inserting a watermark directly into the spatial domain of an image. The term spatial domain itself refers to the pixels that make up an image. This type of watermarking technique operates directly on these pixels. Some examples of techniques that work in the spatial domain are the insertion technique of the Least Significant Bit (LSB) Patchwork method with block streak coding, a method based on district intersections. b. Watermarking technique that works on the transform domain (transform domain watermarking). In the transform domain watermarking (often also called frequency domain watermarking), the watermark is inserted at the frequency coefficient of the original image transformation. There are several transformations commonly used by researchers, namely: Discrete Cosine Transform (DCT), Discrete Fourier Transform (DFT), Discrete Wavelet Transform (DWT) and Discrete Laguerre Transform (DLT). c. Watermarking techniques that work on the two domains above (hybrid techniques watermarking) This type of watermarking technique works by combining the two techniques above. In this technique, the watermark is usually planted in the frequency domain of several image parts that are selected based on spatial characteristics. With the spatial domain algorithm, the insertion and refinement of watermarks on the image by changing direction.

In this study, watermarking based on DCT and DWT was carried out. The watermarking image will be transformed by DWT first, and then the low-frequency matrices will be DCT transformed. Because this DCT modulus contains low-frequency information from the watermarked image, as long as the information is not lost or missing a little, the watermarked image can be appropriately updated. This increases sturdiness and concealment.

The image used as the host in this study is an aerial photo image (Figure 1) with Geotiff format where coordinate information. GeoTIFF is based on the TIFF format with georeferencing information embedded and is widely used. It has TIFF tags including the following raster metadata such as spatial extent, projection, datums, cartographic information, ellipsoid coordinate reference system, resolution in raster format (Wasser and Holdgraf, 2020; NASA Earth Data, 2021; Mahammad & Ramakrishnan, 2003; Huang et al., 2010). And, the watermark used is the BIG Logo (Figure 2) with png format. The provision of watermarks on aerial photo images must also not omit coordinate information.



Figure 1. Aerial Photo Image



Figure 2. BIG Watermark Logo

METHODS

The main image in this study is an aerial photo image of 3 bands (red, green and blue) 16 bit, the image size is 4742x4742 pixels with the top left coordinates 106,791 East Longitude, 6.68694 South Latitude, and the resolution is 0.01666 seconds for longitude and 0.01666 seconds for latitude (Figure 1). While the watermark image size is an image with a size of 50x50 pixels 8 bit, one band png format contains black and white. This watermark image has 2500 pixels to be inserted into the parent image (Figure 2). In this study, six simulations of watermark embedding were carried out by replacing the maximum values of 255, 50, 25, 10, 5 and 1.

The transformation here is a change from the image domain to another domain. The image transformation process can be analyzed, interpreted, or also for further processing. The transformation process is a linear combination of the primary signals. An image that has transformed can be recovered by using a reverse transformation. In image transformation, there are various kinds of transformations including, Fast Fourier Transform (FFT), Discrete Cosine Transform (DCT), Discrete Wavelet Transform (DWT).

The wavelet transform was introduced in the 1980s by Morlet and Grossman as a mathematical function to represent data or functions as an alternative to mathematical transformations that were born before to deal with resolution problems [8]. This transformation has two series in its development: Continuous Wavelet Transform (CWT) and Discrete Wavelet Transform (DWT). The basis of DWT began in 1976 where the technique for decomposing discrete-time signals was discovered (Andono et al., 2017) (Ruswiansari et al., 2016).

In CWT, signals are analyzed using a set of essential interrelated functions with simple scaling and transitions. While in DWT, the depiction of a digital signal time scale is obtained using digital filtering techniques. The process in this technique is to pass the signal to be analyzed on a filter with a frequency and scale. A signal must be passed through two DWT filters, namely a highpass filter and a lowpass filter so that the signal's frequency can be analyzed. Signal analysis is carried out on the results of highpass filter and lowpass filter, where highpass filter is used to analyze the high frequency, and lowpass filter is used to analyze low frequency. This splitting of signals is known as decomposition. Technically, an image with two dimensions (rows and columns) can be decomposed, as shown in Figure 3.

Discrete Wavelet Transform (DWT) is a decomposition of the subband frequency of the image. The subband component of the wavelet transform is generated by decreasing the level of decomposition. In discrete wavelet transform, the digital signal time scale representation is obtained by using the digital filtering technique. The process in this technique is to pass the signal to be analyzed on a filter with a different frequency and scale. In general, discrete wavelet transformation is an image decomposition at the subband frequency of the image. The subband component of the wavelet transform is generated by decreasing the level of decomposition. The implementation of discrete wavelet transform can be done by passing the signal through a lowpass filter and a highpass filter and downsampling the output of each filter. A highpass filter is used to analyze the high frequency, and a lowpass filter is used to analyze the low frequency. The decomposition process can go through one or more stages. One-level decomposition can be written as equation 1:

$$\begin{aligned} y_H[k] &= \sum nx [n]h[2k - n] \\ y_L[k] &= \sum nx [n]g[2k - n] \end{aligned} \dots\dots\dots (1)$$

$y_H[k]$ and $y_L[k]$ are the results of the highpass filter and lowpass filter, respectively, are the original signal, $h(x)$ is the highpass filter, and $g(x)$ is the lowpass filter. In this discrete wavelet transformation, the Inverse Discrete Wavelet Transform (IDWT) process can be carried out to reconstruct the original signal as in equation 2:

$$X[n] = \sum_k (y_H[k]h[-n + 2k] + y_L[k]g[-n + 2k]) \dots\dots\dots (2)$$

The reconstruction process is the opposite of the decomposition process according to the level of the decomposition process. The two-dimensional discrete wavelet transform can be described as in Figure 3.

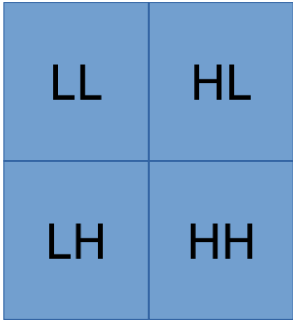


Figure 3. Two Dimensional Discrete Wavelet Transform

The implementation of discrete wavelet transformation can be done by passing the signal into two DWT filters, namely highpass filter (HPF) and lowpass filter (LPF), so that the signal's frequency can be analyzed and then downsampling on the output of each filter. Signal analysis is carried out on the results of highpass filter (HPF), and lowpass filter (LPF), where HPF is used to analyze high frequencies and LPF is used to analyze low frequencies. Analysis of the frequency is done by using the resolution generated after the signal passes through the filtering. This analysis of different frequencies using different resolutions is called multi-resolution analysis.

The DCT transformation is one of the codings transforms that will change the data bytes from the spatial domain to the frequency domain and separate the data bytes into two parts, namely high frequency (DC coefficient) and low frequency (AC coefficient). In DCT, the DC coefficient is used as a place to insert messages (Reva et al., 2016). This is because the DC coefficient has a higher perceptual capacity than the AC coefficient, so that the embedding process will not change the image quality visually. In addition, the processed signal and image distortion has a lower effect on the DC coefficient than the AC coefficient.

Image transformation is done using Discrete Cosine Transform (DCT), so it can be said that the insertion is done in the DCT domain. Insertion is performed on a bitmap image with a colour depth of 24 bits. DCT is used to transform the intensity value of the 8x8 pixel block sequentially from the image into 64 DCT coefficients into its fundamental frequency. The coefficients are changed and then transformed again with Inverse Discrete Cosine Transform (IDCT). Horizontal and vertical spatial frequencies characterize each base matrix.

The advantages of data compression using Discrete Cosine Transform, among others: a. DCT can count the quantity of image data bits where the message is hidden inside. b. Sturdy against manipulation of stego-objects. Meanwhile, the disadvantages of data compression using DCT include: a. Can't stand the change of an object because the message is quickly deleted because the insertion place is known by the DCT method. b. The implementation of the algorithm is lengthy and requires a lot of calculations.

In the image context, this shows a level of significance perceptually. The base function with a low frequency has a more significant contribution to changes in image appearance than the base function with a high frequency. The value of the constant of the basis function located at the top left is often called the basis of the DC function, and the DCT coefficient corresponding to it is called the DC coefficient (DC coefficient). Input the DCT process in the form of a matrix. The DCT equation for a matrix of size can be written as Equation 3:

$$S(u, v) = \frac{2}{\sqrt{nm}} C(u)C(v) \sum_x \sum_y S(x, y) \cos \frac{(2x+1)u\pi}{2n} \cos \frac{(2y+1)v\pi}{2m} \dots\dots\dots (3)$$

The output of the DCT function is the value of a specific frequency component. The output of this function is determined by two parameters, namely u and v. The way to decide which is low frequency and which is high frequency is to add up the values of u and v. So if u+v is higher, it means that S(u,v) represents a higher frequency component.

The input and output of the DCT function are also a matrix of size n by m. P(x,y) is the pixel value in the coordinates (x,y). The index starts from 0.

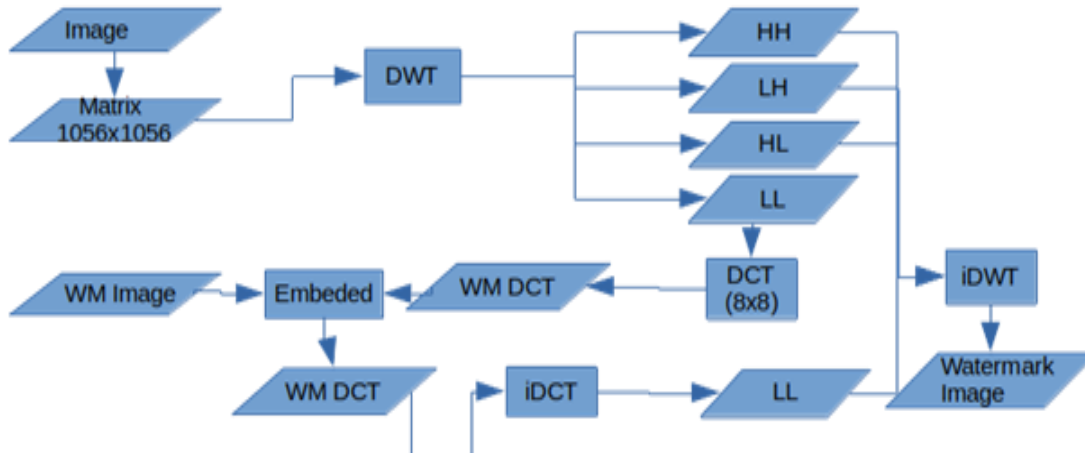


Figure 4. Watermarking process flowchart

In the process of giving the watermark in this study, each pixel of the watermark image will be inserted into an 8x8 matrix that has been transformed by DCT in the 6th row and 6th column. The 8x8 matrix was transformed with DCT spread in a DWT-transformed matrix with low frequencies (LL). A matrix is needed for this DWT transformation matrix where all 8x8 DCT matrices of 50x50 of watermark pixels in DWT matrices can be accommodated. The number of pixels required for this DWT is 50x8 columns and 50x8 rows multiplied by two, so the number is 800x800 pixels.

Watermarked image quality was measured using Peak Signal to Noise Ratio (PSNR), Structural Similarity Index (SSIM), Mean Square Error (MSE) and Visual Information Fidelity (VIF). PSNR is a method that is quite popular in measuring video and image quality objectively. This method uses the image signal as an objective parameter. This method compares the quality of the image that has been inserted with a watermark (watermarked image) with the original image (host image). PSNR is formulated as in equation 4:

$$PSNR = 10 \log_{10} \left(\frac{2^M - 1}{MSE} \right)^2 \dots\dots\dots (4)$$

Where 2M-1 is the maximum pixel value for the M-bit image. Interpretation of the PSNR value on image quality can be said to be very good if the PSNR value is greater than 33 dB and is said to be bad if the PSNR value is less than 30 Db (Syahbana et al., 2015).

SSIM is a method for predicting digital television and cinematic images' perceived quality and other types of digital photos and videos. SSIM is used to measure the similarity between two images. The SSIM index is a complete reference metric; in other words, measurement or prediction of image quality based on an uncompressed or distortion-free initial image as a reference.

In statistics, the MSE (Vault, 2021) or the mean squared deviation of the estimator (a procedure for estimating an unobserved quantity) measures the mean square of the error. That is, the difference in the mean squared between the estimated value and the true value. MSE is a risk function corresponding to the expected value of the squared error loss. The fact that MSE is almost always strictly positive (and not zero) is either due to randomness or because the estimator does not consider the information that can be obtained to produce more accurate estimates (Lehmann & Casella, 2006). MSE is a measure of the quality estimator. Since it is derived from the Euclidean distance, it is always a positive value, decreasing as the error approaches zero or needs clarification.

MSE is the second moment (about the origin) of error, and by combining the variance of the estimator (how broad is the estimate from one sample of data to another) and its bias (how far from the calculation the mean is from the true value). For an unbiased estimator, the MSE is the variance of the estimator. Like variance, the MSE has the same unit of measurement as the estimated quantity. In the standard deviation analogy, taking the square of the MSE results in the root-mean-square or root-mean-square deviation (RMSE or RMSD) error, which has the same units as the estimated quantity; for an unbiased estimator, the RMSE is the square root of the variance, which is known as the standard error.

SSIM is a perception-based model that considers image degradation as a perceived change in structural information while incorporating important perceptual phenomena, including luminance masking and contrast masking. The difference with other techniques such as MSE or PSNR is that this approach estimates absolute error. Information construction is the idea that pixels have strong interdependencies, especially when they are spatially close together. These dependencies carry essential information about the structure of objects in the visual scene. Luminance masking is a phenomenon where image distortion (in this context) tends to be less noticeable in bright areas, whereas contrast masking is a phenomenon where distortion becomes less noticeable where there is a significant activity or "texture" in the image.

VIF has interesting similarities with HVS-based QA methods. In particular, distorted image information (VIF numerator) can be demonstrated by a division normalization-based masking model for HVS, including channel decomposition and exponential response. Similarities and differences between the VIF numerator and the perceptual distortion criterion of Figure 2 above.

- A number of similarities are immediately apparent: space-orientation-scale channel decomposition, exponential response, masking effect modelling, local error pooling, suprathreshold effect modelling, and final pooling into quality scores.
- Some HVS components are not modelled in Figure 2, such as the optical point spread and contrast sensitivity functions.
- Masking effects are modelled differently from some HVS-based methods. While QA methods have used the split normalization mechanism for modelling the masking effect, most methods normalize the signal in a fragmentary manner with a crushing split threshold in the environmental signal strength.
- Minkowski error pooling occurs in two stages: first local pooling in localized MSE calculations (with an exponent of 2) and then global pooling after suprathreshold modelling with unity exponents. So perceptual considerations differ from most methods in that they occur in two stages with a suprathreshold effect in between.
- In VIF, nonlinearity dependent on MSE to suprathreshold-MSE is logarithmic nonlinearity and mixed MSE to suprathreshold distortion, which is then combined into a quality score. Some methods apply suprathreshold nonlinearity after pooling as if the suprathreshold effect only plays a role at the global quality level. The VIF formulation suggests that suprathreshold modelling is done before the global unification stage but after the local unification, and it affects the visual quality at the local level.
- The vector model for landscape statistics allows us to model linear dependencies between subband coefficients
- The dependence of perceived quality on the correlations between these coefficients is challenging to investigate or model using HVS error sensitivity, but the task is greatly simplified by approaching the same problems with NSS modelling. So we feel that HVS-based QA methods need to consider the fact that landscapes are correlated in the subbands and that the inter-coefficient correlations in these reference signals influence human perceptions of quality.
- Another significant difference between dual VIF and other HVS-based methods is the different signal attenuation modelling. Other HVS-based methods ignore signal gain and attenuation and treat all distortions as additional signal errors as well. In contrast, the general improvement in the VIF formulation ensures that signal gain is handled differently from the additional noise component.

RESULTS AND DISCUSSION

This study uses python 3.8.10, which in python uses several packages, namely numpy for arrays, pywt for DWT transformations and inverse DWT, PIL to open and save watermark images in png format, osgeo gdal to open and save host images in GeoTiff format, scipy fftpack for DCT and inverse DCT transformations, osgeo gdal for opening and saving aerial images, vifp for calculating vifp_mscale for calculating VIF, and skimage.metrics structural_similarity for calculating SSIM.

Simulation using python with one image host aerial photo three bands (red, green and blue) 16-bit GeoTiff format with coordinates, image size 4742x4742 pixels with the top left coordinates 106,791 East Long 6.68694 South Latitude and the resolution is 0.01666 seconds for longitude and 0.01666 seconds for latitude. And an image of the one band 8-bit png format of BIG logo watermark in black (0) and white (255) with a size of 50x50 pixels.

In the simulation that has been carried out, replacing the maximum number (white) with 1, 5, 10, 25, 50 and 255. The watermark image is embedded into the host image using two methods, namely the discrete wavelet transform (DWT) and then the discrete cosine transform (DCT). The simulation results of this method show differences in several


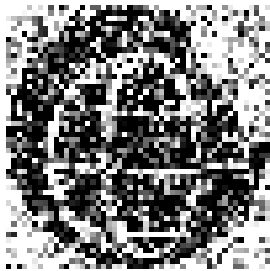
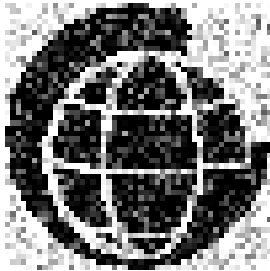
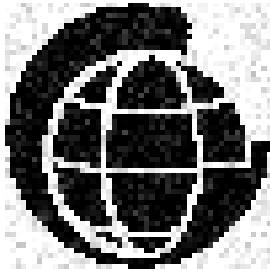
things, such as PSNR, SSIM, RMSE and VIR. In this simulation, it still ignores attacks. The watermark extraction process uses the same value.

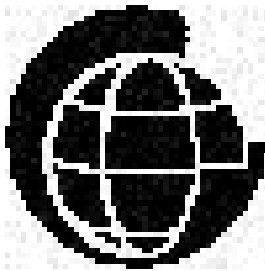
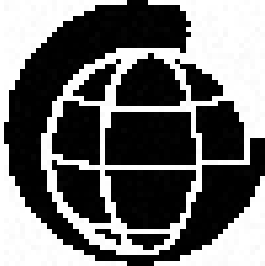
Table 1: The value of PSNR, RMSE, VIF, and SSM of the 6 simulations

	1	5	10	25	50	255
PSNR:	81.5050	81.4466	81.3008	80.3192	77.8811	65.9766
RMSE:	0.3000	0.3020	0.3071	0.3438	0.4552	1.7925
VIF:	0.9930	0.9930	0.9930	0.9930	0.9929	0.9923
SSIM:	1.0000	1.0000	1.0000	1.0000	0.9999	0.9988

Embedding a watermark will reduce the quality of the host image. This decrease in quality can be seen in the table 1 with the more significant the price of the watermark inserted into the host image, the PSNR, VIF, and SSIM are getting smaller, but the RMSE is getting bigger. This insertion has little effect on the prices of VIF and SSIM and will have a significant impact on PNSR and RMSE. Watermark extraction from aerial photo images generally decreases in quality, with a value of 255, especially a value of 1.

Table 2: Watermark Image from embeded number.

Embedded Number	Watermark Image
1	
5	
10	
25	

Embedded Number	Watermark Image
50	
255	

The recovery of the watermark that is inserted into the host image will be clearer according to the number of watermarks before it is inserted. A low number will make the recovery watermark not recognized, as shown in Table 2. The value of watermark one, which is inserted into the host image, makes the watermark image unrecognizable. Still, the host image has the largest PSNR (81.5050) compared to the others, while RMSE (0.3000) has the smallest value. The watermark value of 255, which is inserted into the host image, makes the watermark image clearer, but the host image has the smallest PSNR (65.9766) compared to the others, while RMSE (1.7925) has the largest value. The optimal watermark image number is at number 25 with a PSNR value of 80.3192, RMSE of 0.3438, VIF of 0.9930, and SSIM of 1.0000.

Besides that, it is no less important in storing watermarked host images that require a particular python package to be able to open and save images without losing coordinate information. Several python packages can do this, but in this study, using the python package osgeo gdal. The host image is opened using osgeo gdal and stored in an array as a host for watermark embedding. After being inserted into the host image, the watermarked host image is then stored again using osgeo gdal again.

CONCLUSION

This study uses the DWT method combined with DCT for embedding watermark images by performing six simulations to embed the number of the watermark image (255, 50, 25, 10, 5 and 1). The Watermarked host image quality was measured using Peak Signal to Noise Ratio (PSNR), Root Mean Square Error (RMSE), Visual Information Fidelity (VIF), and Structural Similarity Index (SSIM). The lowest watermark image number 1 produces PSNR 81.5050 dB, RMSE 0.3000, VIF 0.9930 and SSIM 1.0000, making the watermark image unrecognizable. The largest watermark image number 255 produces PSNR 65.9766 dB, RMSE 1.7925, VIF 0.3000 and 0.9930 and makes the best recognize watermark image from this simulation. The optimal watermark image number is at number 25 with a PSNR value of 80.3192 dB, RMSE 0.3438, VIF 0.9923, and 0.9988.

REFERENCES

- Andono, P. N., Sutojo, T., & others. (2017). *Pengolahan citra digital*. Penerbit Andi.
- Ikromina, F. I. (2020). Invisible Watermarking Citra Digital Menggunakan Kombinasi Metode Discrete Cosine Transform Dan Discrete Wavelet Transform. *Jurnal Nasional Pendidikan Teknik Informatika: JANAPATI*, 8(3), 261–271.
- Leah Wasser, Chris Holdgraf, M. M. "About the Geotiff (.tif) Raster File Format: Raster Data in Python". Earth Data Science - Earth Lab 2020. Available at <https://www.earthdatascience.org/courses/use-data-open-source-python/intro-raster-data-python/fundamentals-raster-data/intro-to-the-geotiff-file-format/>
- Lehmann, E. L., & Casella, G. (2006). *Theory of point estimation*. Springer Science & Business Media.
- Mahammad, S.S., & Ramakrishnan, R. "GeoTIFF - A standard image file for-mat for GIS applications". Proceedings of Map India Conference 2003: Image Processing & Interpretation
- NASA Earth Data. "GeoTIFF | Earthdata". Available at <https://earthdata.nasa.gov/esdis/eso/standards-and-references/geotiff>

- Pradhan, D. (2017). *Implementation of Invisible Digital Watermarking Technique for Copyright Protection using DWTSVD and DCT*.
- Reva, E. Y., Susilo, B., & Purwandari, E. P. (2016). Aplikasi Watermark Pada Citra Digital Menggunakan Kombinasi Metode DCT-DWT-SVD. *Rekursif: Jurnal Informatika*, 4(2).
- Ruswiansari, M., Novianti, A., & Wirawan, W. (2016). Implementasi Discrete Wavelet Transform (Dwt) Dan Singular Value Decomposition (Svd) Pada Image Watermarking. *Jurnal Elektro Dan Telekomunikasi Terapan*, 3(1).
- Sirmour, S., & Tiwari, A. (2014). A hybrid DWT-SVD based digital image watermarking algorithm for copyright protection. *International Journal of P2P Network Trends and Technology (IJPTT)*, 6, 7–10.
- Syahbana, Y. A., Yudhystira, W. I., & Yulina, S. (2015). Algoritma Penyisipan Frame untuk Peningkatan Akurasi Metode Aligned Peak Signal-to-Noise Ratio dalam Pengukuran Kualitas Video. *Jurnal Komputer Terapan*, 1(1), 45–56.
- Tao, H., Chongmin, L., Zain, J. M., & Abdalla, A. N. (2014). Robust image watermarking theories and techniques: A review. *Journal of Applied Research and Technology*, 12(1), 122–138. [https://doi.org/10.1016/S1665-6423\(14\)71612-8](https://doi.org/10.1016/S1665-6423(14)71612-8)
- Vault, M. (2021). List of Probability and Statistics Symbols. *Montreal, Canada*:--Available from: <https://mathvault.ca/Hub/Higher-Math/Math-Symbols/Probability-Statistics-Symbols/>.--[Accessed: June, 2020].