A Study of Sub-band Frequency Combination to Improve the Performance of ICA-Wavelet Watermarking Scheme for Medical Images in Telemedicine Application

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Abstract - **The research for a reliable watermarking scheme for Telemedicine has been done widely. The previous research on watermarking method-using combination of wavelet and Independent Component Analysis produced a reliable watermarking scheme under a low SNR or noisy environment. It is also indicated that the first level wavelet decomposition gives the best combination of performance-complexity trade off in wavelet-ICA method [1]. In this paper, we report the improvement of wavelet-ICA scheme by searching the best combination of wavelet sub-band for several typical linear combinations of data and watermark image. We were using Additive Gaussian White Noise and manipulation by the third party to test the performance of this algorithm. The manipulation here refers to unwanted extra text added by third party. A Computer simulation program using Matlab is used to simulate these effects and evaluate the performance. The encouraging result of this algorithm may recommend this improvement technique for practical application in Telemedicine especially for authentication and security purpose.**

Key words - **Watermarking, Independent Component Analysis (ICA), FastICA, Wavelet, Medical Images, Telemedicine.**

I. INTRODUCTION

1.1. Background

Watermarking is a process to embed information data to a host data. The aim of this process is to indicate the ownership of a document. The information data that embeds to the host data is typically the data that identify the owner of the document such as owner's ID, owner's signature, owner's stamp, etc. The need of watermarking tremendously increases and become more and more important in medical world. This trend is strengthened by the rapid grow of Telemedicine.

In Telemedicine, the interaction and communication from and to the paramedics are done through a communication line. It is often happened that the medical image data is transmitted through insecure telecommunication media such as air. The data corruption due to telecommunication channel or manipulation by the third parties may destroy the authenticity and integrity of the original data. Therefore a robust and reliable watermarking algorithm is of the highest priority. The Independent Component Analysis as an emerging technique for data analysis is proposed the answer of this challenge. Theer previous research indicated that this method is robust at the low SNR or noisy environment (Figure 1).

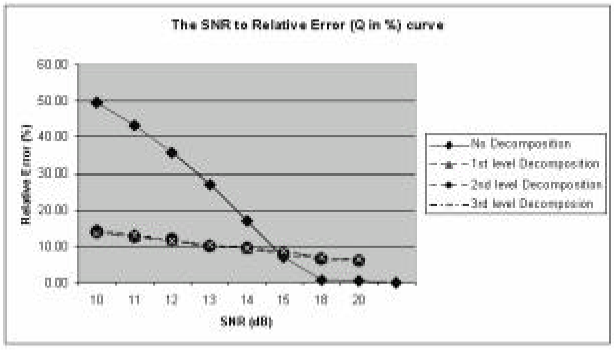

Figure 1: Simulation result from previous research [1] indicates the Relative Error to SNR Performance for each Wavelet decomposition level.

From the Figure 2 above, we observe that the ICA-Wavelet watermarking scheme has a small sensitivity to the SNR change. However, for high SNR, the relative error value of this scheme does not decrease rapidly. This is a disadvantage of this scheme compare to no decomposition scheme.

1.2. Purpose

The purpose of this research is to improve the performance of ICA-Wavelet watermarking in low SNR region and high SNR region. In order to achieve this goal, we propose that the watermarking process be done by combining watermarking at middle frequency sub-band and high frequency sub-band in wavelet decomposition. The idea is improve the watermark signal power over the data, hence it will be more robust against the noise. This process may have side effect, which is the appearance watermark signal at the original data. Using an

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appropriate scaling value for the water marked at the watermarking process solves this problem. In addition, we add a thresholding process to reduce the noise effect. This thresholding process is aimed to improve the watermarking scheme at high SNR region.

1.3 Assumption

The assumptions in this paper are:

i). the grey-scale X-ray image is used,

ii). the watermarked data is a text image,

iii). FastICA is used for ICA analysis, and

iv). Haar Wavelet is used as the wavelet decomposer of the original image before watermarking.

1.4 Independent Component Analysis

Independent Component Analysis is a new technique in statistical signal analysis. This method basically separates the mixture of signal to its independent components. Figure 1 illustrates the mixing process of two independent signal s_1 and s_2 and produce the mixed signal x_1 and x_2.

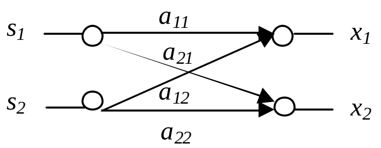

Figure 2 : The mixing process of original independent signals s_1 and s_2 to produce dependent signals x_1 and x_2.

The mixing process is represented by linear combination of the original signal s_1 and s_2 as indicated by the mixing coefficient a_{11}, a_{12}, a_{21}, and a_{22}.

The mixed signals x_1 and x_2 is given by:

$$x_1 = a_{11} \cdot s_1 + a_{12} \cdot s_2 \qquad (1)$$

$$x_2 = a_{21} \cdot s_1 + a_{22} \cdot s_2 \qquad (2)$$

or in matrix form:

$$\mathbf{x} = \mathbf{A}.\ \mathbf{s} \qquad (3)$$

The $\mathbf{A}$ matrix is called mixing matrix.

The ICA problem is to find the demixing matrix $\mathbf{w}$, so that:

$$\mathbf{w}\ .\ \mathbf{x} = \mathbf{w}.\ \mathbf{A}.\ \mathbf{s} = \mathbf{y} = \mathbf{s}' \qquad (4)$$

In Equation (4), the value of $\mathbf{y}$ must be as closed as possible to the original signal $\mathbf{s}$.

Since the original signal $\mathbf{s}$ and the mixing matrix $\mathbf{A}$ are not known, the Equation (3) cannot be solved by classical linear algebra. The ICA algorithm is used to solved this equation statistically by exploiting the fact that the original signal $\mathbf{s}$ are independent and the mixed signal $\mathbf{x}$ are dependent. The demixing matrix $\mathbf{w}$ is obtained iteratively by maximizing the independency of the mixed signal $\mathbf{x}$.

There are many ICA algorithms. In this paper, we use the FastICA algorithm developed by Aapo Hyparinen[1]. This algorithm utilizes the Negentropy as a quantitative measure of independency, and Newton iteration method to find $\mathbf{w}$. This algorithm is superior in computation speed compare to other algorithms and relatively easy to implemented[1].

The following are the steps in FastICA algorithm:

1). Whitening the mixed signal $\mathbf{x}$, by shifting the *mean* of $\mathbf{x}$ to *0* and normalize the variance to *1*.

2). Select initial demixing $\mathbf{w}$ randomly other than zero.

3). Calculate $w^+ = E\{x \cdot g(w^T \cdot x)\} - E\{g'(w^T \cdot x)\} \cdot w$

4). Let $w^+ = \dfrac{w^+}{\|w\|}$

5). If w^+ is not convergent, then repeat step *3*.

The function g in step 3 can be chosen $g(u) = tanh(a_1.u)$ or $g(u) = u.exp(u^2/2)$. The value of a_1 in the first function is chosen to be 1.

The word '*convergent*' in step 5 means that the new value of $\mathbf{w}$ obtained at step 4 is the same to the previous value.

In this research, ICA algorithm is used to separate the mixing signal of data signal and watermark signal at the dewatermarking process.

1.5. Discrete Wavelet Transform (DWT)

The Discrete Wavelet Transform (DWT) will decompose the signal into frequency sub-bands. In one dimension signal such as voice signal, the typical result of DWT is a low frequency sub-band (L) and high frequency sub-band (H). Each frequency sub-band can be further decomposed into two frequency sub-bands. For example, decomposition of *L* sub-band produce *LL* and *LH* sub-bands, whereas *H* sub-band can be further decomposed into *HL* and *HH* sub-bands. For two-dimensional signal such as image, the wavelet transform produces four frequency sub-bands, which are low frequency sub-band *L*, medium frequency sub-bands L_H, and H_L, and high frequency sub-band *H*. Further decomposition of L sub-band produces LL, LL_H, LH_L, and LH sub-bands.

The wavelet transform in practical implementation is done by passing the signal to a low pass (LPF) and high pass filter (HPF) and down-sampling the output of each filter. The *L* band corresponds to the output of down sampling at LPF path and *H* band at HPF path.

Figure 3 depicts the *N-level* wavelet decomposition of one-dimensional signal.

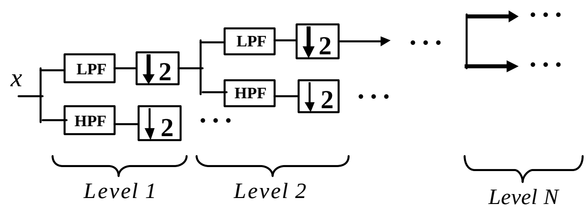

Figure 3: N-Level Discrete Wavelet Transform (Decomposition) implemented using N stage low pass and high filtering of signal x.

The output of filter having impulse response *h(n)* and input *x(n)* is:

$$x(n) * h(n) = \sum_{k=-\infty}^{\infty} x(k) \cdot h(n-k) \qquad (5)$$

The outputs of HPF and LPF after down sampling are:

$$y_{HPF}(k) = \sum_n x(n) \cdot g(2k - n) \quad (6.a)$$

$$y_{LPF}(k) = \sum_n x(n) \cdot h(2k - n) \quad (6.b)$$

Where *g(n)* and *h(n)* are impulse response of HPF and LPF respectively.

In order to make a perfect reconstruction of original signal from its frequency sub-bands, the filter response *h(n)* and *g(n)* must fulfill:

$$g(L-1-n) = (-1)^n \cdot h(n)\,, \quad (7)$$

where L is the length of impulse response.

The reconstruction of original signal from its sub-bands frequency is done by up-sampling, low pass and high pass filtering and adding the output of each filter output. Figure (4) depicts the reconstruction process.

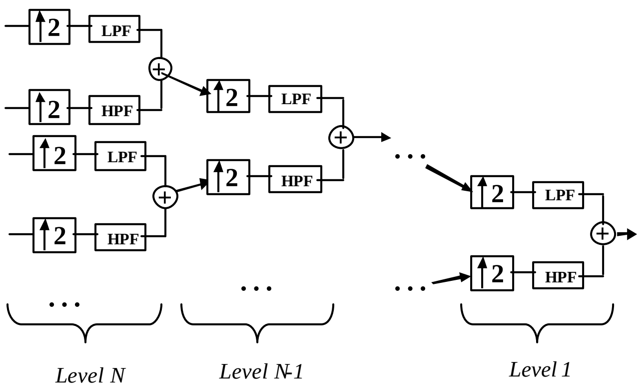

Figure 5: N level wavelet construction.

The output of HPF and LPF filter are:

$$y_{HPF}(k) = \sum_n x(n) \cdot g(-n + 2k) \quad (8.a)$$

$$y_{LPF}(k) = \sum_n x(n) \cdot h(-n + 2k) \quad (8.b)$$

And after addition we obtain the output at each reconstruction level as:

$$x(n) = \sum_{k=-\infty}^{\infty} \left(y_{HPF}(k) \cdot g(-n+2k) + y_{LPF}(k) \cdot h(-n+2k) \right) \quad (9)$$

In this watermarking scheme, we use wavelet to decompose the image into its frequency sub-bands. Since the ICA-wavelet watermarking performance does not depend on the level of wavelet decomposition as indicated in [1], we only decompose the image up to first level, and do the watermarking on the combination on L_H, H_L, and H sub-bands, and evaluate the watermarking result of each combination.

2. METHODOLOGY

Figure 1 shows the block diagram of the watermarking process. The original image *S* is a gray-scale 8 bits image. The length of this image is 256 pixel and the width is 512 pixel. The watermark stamp *P* is a text image. The data S is decomposed using wavelet transform, and the mixing operation to embed the watermark stamp P is done by using an appropriate mixing matrix.

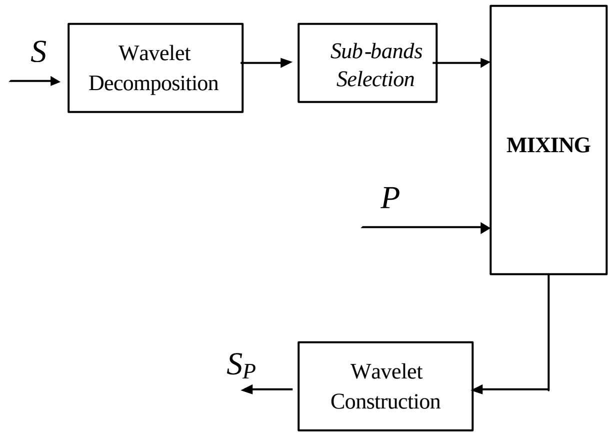

Figure 6: Block Diagram of the Watermarking Process.

The mixing operation is given in the following equations:

$$L_H' = a_1 \cdot L_H + b_1 \cdot P \quad (10.a)$$

$$H_L' = a_2 \cdot H_L + b_2 \cdot P \quad (10.b)$$

$$H' = a_3 \cdot H + b_3 \cdot P \quad (10.c)$$

Figure 7 shows the noise contamination in the communication channel.

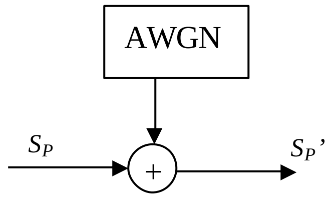

Figure 7: The noise contamination.

Figure 8 shows the dewatermarking process.

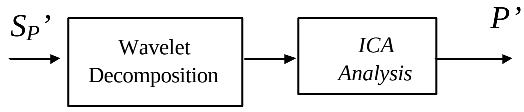

Figure 8: Block Diagram of Dewatermarking Process

IV. SIMULATION RESULT

Figure 9.A shows the original gray-scale x-ray image and Figure 9.B is the watermark text image. Figure 10. A is the watermarked image produced by embedding the text image at the *L* sub-band. Figure 10.B, C, D. E, and F are the images after watermarking process where the mixing coefficients [a_1 , b_1 ; a_2 , b_2 ; a_3 , b_3] are [0.9 , 0.08 ; 1 , 0 ; 1,0], [1 , 0 ; 0.9 , 0.08 ; 1 , 0], [1 , 0 ; 1 , 0 ; 0.9 , 0.08], [0.9 , 0.02 ; 0.9, 0.02 ; 0.9 , 0.04], and [0.9 , 0.02 ; 0.9, 0.04 ; 0.9, 0.02] respectively.

Figure 9. A. Original Image, B. Watermark Text

Figure 10: The watermarked images (A: Watermarking at L sub-band, B: Watermarking using mixing coefficients [0.9 , 0.08 ; 1 , 0 ; 1,0], C: [1 , 0 ; 0.9 , 0.08 ; 1 , 0], D: [1 , 0 ; 1 , 0 ; 0.9 , 0.08], E: [0.9 , 0.02 ; 0.9, 0.02 ; 0.9 , 0.04], and F: [0.9 , 0.02 ; 0.9, 0.04 ; 0.9, 0.02 .]

It is seen that the watermarking at L sub-band produces a visible watermark text at the image, while the watermarking at L_H, H_L, and H produces a relatively invisible watermark text on the result.

We add AWGN noise to the watermarked image. Since 8 bits represent each pixel in the image, then the noise addition can produce the result out of the range. To prevent this we took modulo 256 after addition. Figure 11.*A* shows the watermarked image after noise addition (SNR = 15 dB) and Figure 11.B shows the emulation of unwanted modification on the watermarked image by third party.

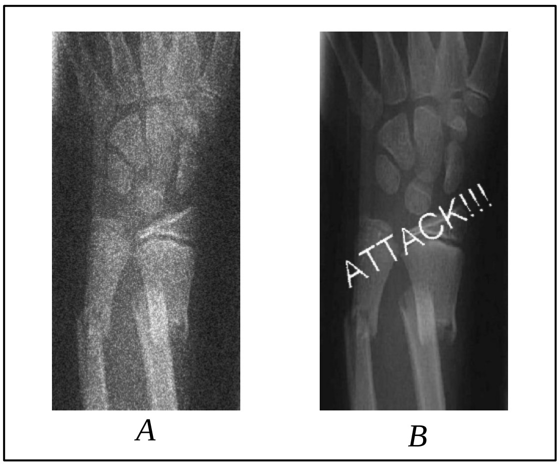

Figure 11:Distortion of the watermarked image. A: Noise addition (SNR 15 dB), B: Distortion by third party.

For each distortion, we measure the quality of the text image after dewatermarking. The Mean Square Error (MSE) is used to assess the quality of the image.

$$MSE(\%) = \frac{1}{256} \cdot \sqrt{\frac{\sum_{(1,1)}^{(M,N)} (E - E')^2}{n}} \cdot 100\% \qquad (11)$$

Figure 12 shows the curve of MSE as function of SNR in dB.

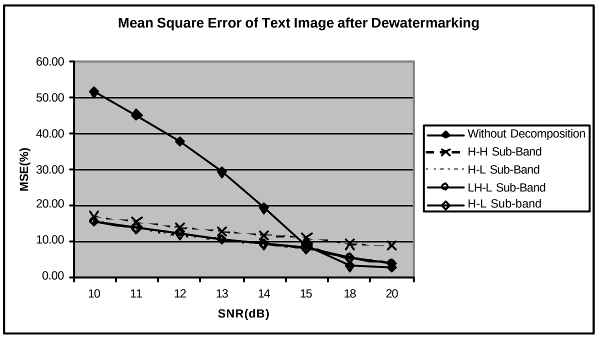

Figure 12: The MSE as function of SNR (dB) for a simple sub-band watermarking.

Figure 13 shows the MSE curve for several combination of sub-band in watermarking process. Figure 14 shows the MSE curve as function of third party distortion.

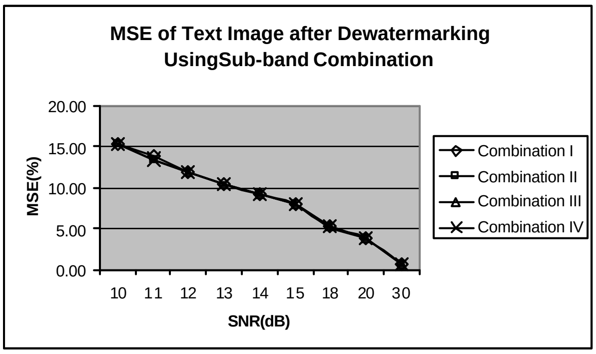

Figure 13: The MSE Curve as function of SNR for several sub-band combinations. (Combination I coefficients [0.9 , 0.06 ; 0.9 , 0.02 ; 0.9,0.02], Combination II: [0.9 , 0.02 ; 0.9 , 0.04 ; 0.9 , 0.02], Combination III [0.9 , 0.02 ; 0.9 , 0.02 ; 0.9 , 0.06], Combination IV: [0.9 , 0.02 ; 0.9, 0.04 ; 0.9 , 0.04])

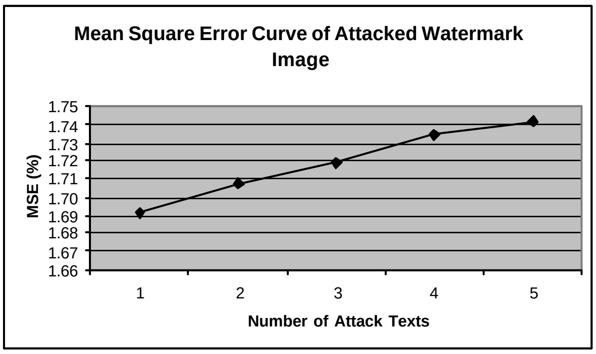

Figure 14: The MSE Curve as function of the number of attack text.

IV. DISCUSSION AND CONCLUSION

In Figure 12, we observe a significant improvement-using sub-band on *L* sub-band of the watermark text in watermarking performance in both low SNR and high SNR region. For example, at SNR 10 dB, the watermarking at *H-H* band produce MSE of 16.88% while on L-H sub-band produce MSE of 15.54%. At high SNR, the advantage is from 8.69% to 3.89%, which is very encouraging result. We also observe that the performance of the algorithm relatively does not change if we do the watermarking at L_H or L_V sub-bands. The effect of the sub-band selection will appear on the visibility of watermark text in the original image. L_H sub-band will produce a trace of horizontal pattern at the image after watermarking, while the H_L sub-band will produce a trace of vertical pattern at the image after watermarking.

As the watermarking performance relatively does not sensitive to the sub-band selection, the result given on Figure 13 is a consequence of this fact. We observe in Figure 13, the linear combination of the sub-band relatively does not produce any significant change on the performance.

The performance of algorithm is very good on third party as indicated in Figure 14. The dimension of the text used is 40 pixel x 228 pixel (6.96% from total image area). The MSE is only 1.69%, while using the same text five times (34.8% of area), the MSE increase only to 1.74%. This result is possible since in the dewatermarking process, the effect of extra text in taken only 10%, further more, the H sub-band chosen of original image spread the power of the text attack over the whole region of image.

Based on this result, if it is required a standard of MSE 10% for Telemedicine application, the we may use the ICA-Wavelet watermarking scheme using a *L-H* sub-band combination, or *L-LH*, *L-HL*. The *L-H* combination can be used for general original image pattern, *L-LH* for more horizontal pattern of original image and *L-HL* for more vertical pattern of original image. This selection will satisfy performance requirement for SNR above 14 dB.

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