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Decoupling of Free Decay Roll Data by Discrete Wavelet Transform

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이산 웨이블렛 변환을 이용한 자유감쇠 횡요 데이타의 분리

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ABSTRACT: *This study presents the results of decoupling of free decay roll test data by discrete wavelet transform. Free roll decay test was performed to decide the coefficients of damping terms in equations of motion. During the experiment, a slight yaw motion was found while the model was in the free roll decay motion. Discrete wavelet transform was applied to the signal to extract the pure roll motion. The results were compared to those of the Fourier transform. DWT was able to decouple the two signals efficiently while the Fourier transform was not.*

1. Introduction

Decoupling of a signal has drawn significant attention in various fields of engineering. The method can be classified into frequency and time domain approaches. Fourier transform is a well known frequency domain approach. Fourier transform has been used extensively for that purpose. However, Fourier transform is not an appropriate tool when one needs to deal with transient signals. The Fourier analysis yields only the frequency content of the signal as a result of removing the time history. Recently many researchers have been done on the development of algorithms to use wavelet analysis in signal decoupling. Staseweski(1997) adopted wavelet transform to identify damping in multi-degree of freedom system. Wavelet analysis was used to analyze the transient response of spar platforms (Jordan et. al., 1998). The continuos wavelet transform (CWT) was employed in these papers. This study proposes the use of discrete wavelet transform (DWT) to analyzed a free decay roll experimental data. The DWT has advantages over CWT when one wants to take inverse of the decoupled signals.

The traditional way of estimating the various coefficients of equations of ship motion is to use potential flow calculations. The potential flow calculations have proven successful most of the modes of motions. However, it is not a adequate tool in estimating the various components of roll damping. Therefore, experimental validation is needed. The free roll decay test was performed in the towing tank of Pusan National University. The tested model was a semi-submersible pontoon type offshore structure. The experimental results showed that there were extra components added to the signal due to pure roll motion.

DWT was applied in order to decouple the signal. The results showed that the yaw motion was believed to be coupled with roll motion. DWT successfully decoupled the two components. The results of DWT were compared with those of Fourier transform.

2. Discrete wavelet transform

First, the one-dimensional case of the continuous wavelet transforms is considered.

A $s(t)$ is given by CWT of a signal

$$W_s(a,b)=\frac{1}{\sqrt{|a|}}\int_{-\infty}^{\infty}\psi^*\left(\frac{t-b}{a}\right)s(t)dt \tag{1}$$

where $\psi(\cdot)$ is the wavelet function, a is the scaling parameter, and b is the translation parameter. * represents a complex conjugate. It can be stated that the CWT is the sum over all time of real signal $s(t)$ multiplied by the scaled, shifted wavelet function. The parameters a and b vary continuously.

The DWT is introduced because wave directionality is also analyzed by DWT for the comparison purposes. The theory of DWT is only briefly reviewed here. Interested readers are referred to Daubechies (Daubechies 1988, 1992). To understand the theory of DWT, consider equation (1).

For practical applications, the spectral parameter and a the translation parameter b need to be discretized. Consider the DWT for $a=\frac{1}{2^j}$ and $b=\frac{k}{2^j}$.

The wavelet can be expressed as

$$\psi_{j,k}(t)=2^{\frac{j}{2}}\psi(2^j t-k) \tag{2}$$

Introduce a scaling function analogous to $\psi_{j,k}(t)$, as follows

$$\phi_{j,k}(t)=2^{\frac{j}{2}}\phi(2^j t-k) \tag{3}$$

Assume that a function $s(t)$ can be written as

$$s(t)=\sum_{k=-\infty}^{\infty}c(k)\phi_k(t)+\sum_{j=0}^{\infty}\sum_{k=-\infty}^{\infty}d(j,k)\psi_{j,k}(t) \tag{4}$$

The first summation in equation (4) represents a coarse approximation of $s(t)$. The second term provides a function that is a finer resolution. The orthogonality of the wavelet and the scaling function can be used to obtain the coefficients in equation (4), as follows

$$c(k)=<s(t),\phi_k(t)> \tag{5}$$

$$d(j,k)=<s(t),\psi_{j,k}(t)> \tag{6}$$

In practical application, however, the wavelets and the scaling functions are not used to find the coefficients. To avoid the expected complication, basic recursion equations need to be introduced as in the following

$$\phi(t)=\sum_n h(n)\sqrt{2}\phi(2t-n) \tag{7}$$

where n is an integer. This means that the lower space vector can be expressed by combinations of higher space basis functions. The coefficients $h(n)$ are called the scaling function coefficients. By the same analogy, wavelets can be expanded by the next narrower space scaling function as follows

$$\psi(t)=\sum_n h_1(n)\sqrt{2}\phi(2t-n) \tag{8}$$

The $h(n)$ and $h_1(n)$ are related to each other

$$h_1(n)=(-1)^n h(1-n) \tag{9}$$

For an even length of data N, equation (9) can be written as

$$h_1(n)=(-1)^n h(N-1-n) \tag{10}$$

Equation (4) can be rewritten at a scale of j

$$s(t)=\sum_k c_j(k)2^{\frac{j}{2}}\phi(2^j t-k)+\sum_k d_j(k)2^{\frac{j}{2}}\psi(2^j t-k) \tag{11}$$

Using orthogonality, we can obtain the expression as follows by changing the variable $m=2k+n$

$$\begin{aligned} c_j(k) &=<s(t),\phi_{j,k}(t)>=\int s(t)2^{\frac{j}{2}}\phi(2^j t-k)dt \\ &=\sum_m h(m-2k)\int s(t)2^{\frac{j+1}{2}}\phi(2^{j+1}t-k)dt \\ &=\sum_m h(m-2k)c_{j+1}(m) \end{aligned} \tag{12}$$

In a similar fashion, the following is obtained

$$d_j(k)=\sum_m h_1(m-2k)c_{j+1}(m) \tag{13}$$

The unknown coefficients in equation (4) can be calculated without dealing with wavelets or scaling functions.

The reconstruction of the original sequence can be obtained by using the following relation

$$c_{j+1}(k)=\sum_m c_j(m)h(k-2m)+\sum_m d_j(m)h_1(k-2m) \tag{14}$$

These relations are called Mallats algorithm.

The coefficients of the expansion can be obtained by a matrix operation only.

3. Experimental results and discussion

The tested model was a semi-submersible pontoon type offshore structure. The dimension and the shape of the model are shown in Fig 1. The units are in mm. The draft of the model was 170mm and the initial roll angle for the test was 14 °. The model was completely free during the roll decay test.

The image processing technique was used to detect roll angle variation. Three points were marked on the model as shown in Fig 2(a) and (b). These points were used for detecting roll angle. The movements of these points were recorded with video camera. By thresholding these for suitable RGB value, we can detect the points of these points as shown in Fig 2(c). The computer program was developed to calculate the angles for every frame. The time history roll angle variation is shown in Fig 3. One can immediately notice that the signal is not zero mean process. Another problem was the presence of noise components.

The Fourier transform and DWT were used to solve the problem. First, Fourier transform was applied. The process of Fourier transform applied is presented in Fig 4(a) through 4(f). The first step of this method was to apply fast Fourier transform to the signal. And then, proper bands of low and high frequencies were cut off, for each real and imaginary part of the transformed data. Finally, real and imaginary part of remained data and added inverse Fourier transform was performed.

When it comes to Fourier transform, no definite guideline for the cut off frequency can be proposed. The noise components were disappeared as shown in Fig 4(f). However, the vertical shift of the signal did not disappear.

DWT was applied to the signal. The DWT map which transformed by Danbechies 20 coefficients wavelet is presented in Fig5. Here, x-axis presents translation in time and y-axis presents level. The three major contribution of the signal can be clearly noticed from Fig5. The level 7 through 9 were due to notice. The level 4 through 6 were from pure roll motion. Finally, the level 1 to 3 were believed to the due to yaw effect. The reconstitution of the pure roll motion was easily accomplished just by adding the signals from level 4 through 6. The resulting pure roll motion and yaw motion are presented in Figs 6 and 7. One can immediately notice that the vertical shift in the roll signal has disappeared as shown in Fig 6. The straight line in Fig7 indicates the roll angle variation.

4. Conclusion

The application of DWT to the signal decoupling was demonstrated. The Fourier transform turned out to be an inadequate tool in decoupling a signal like yaw motion which is transient in time history. On the other hand, DWT was prove to be an efficient tool in decoupling pure roll component and yaw component. The DWT mean square map clearly showed the three regions due to pure roll, yaw, and noise. It is concluded that DWT can be a very efficient tool in decoupling laboratory signals whose time domain characteristics shows transient behavior. The calculation of separated roll time history can be clearly defined and easy to perform.

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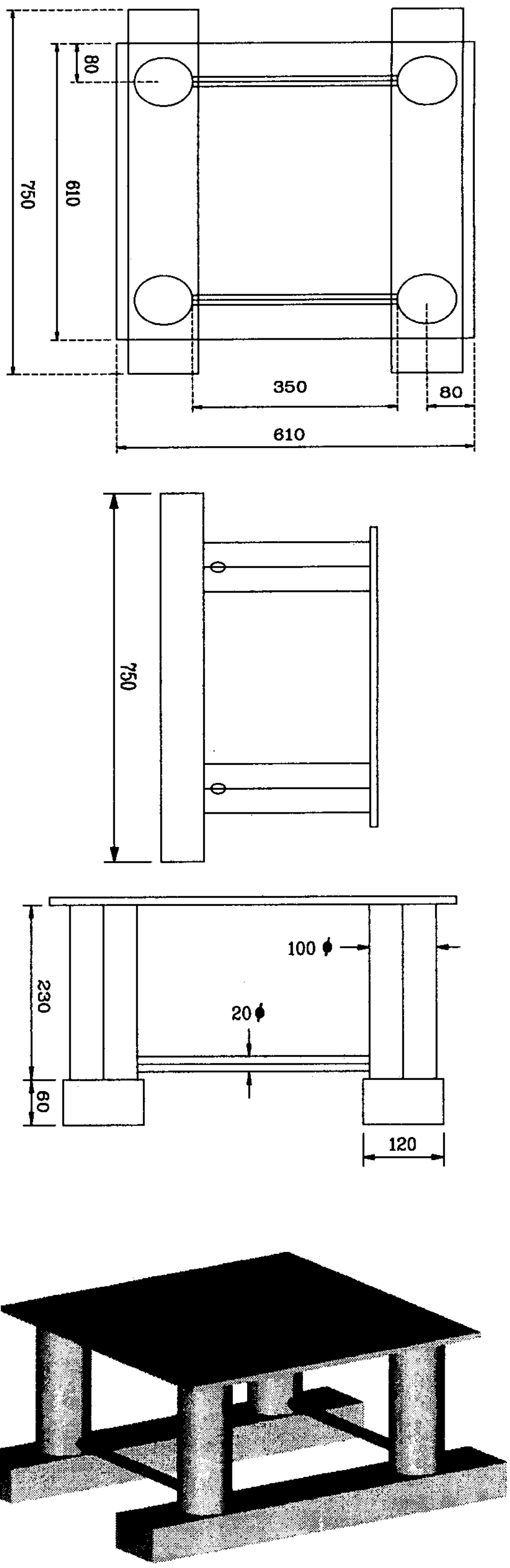
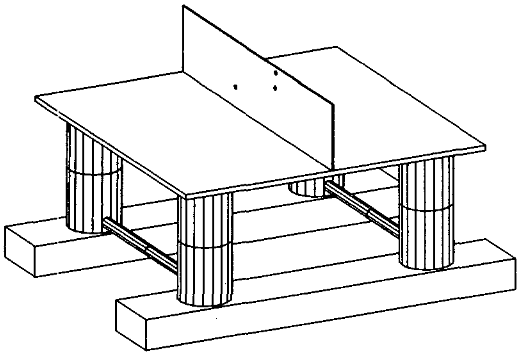
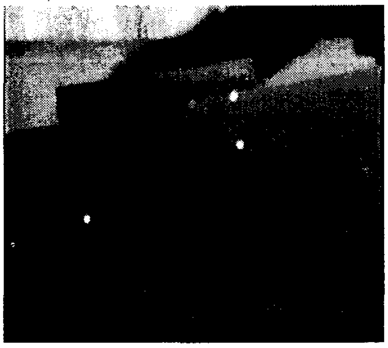


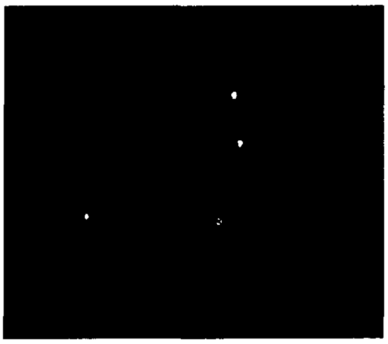
Fig. 1 Dimension and configuration of the model



(a)



(b)



(c)

Fig. 2 The process of image processing to detect roll angle variation

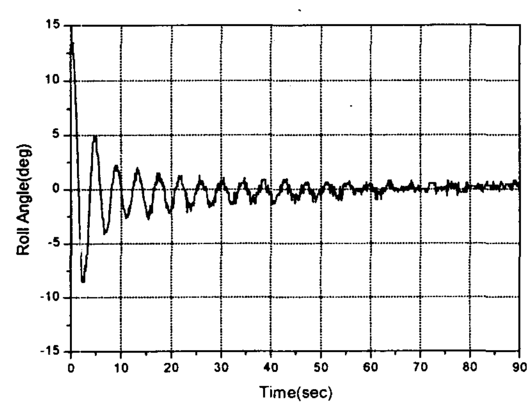
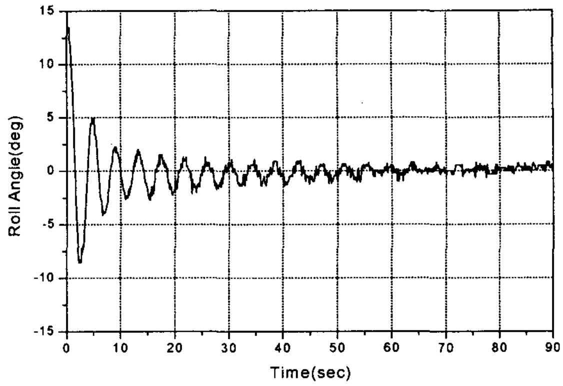
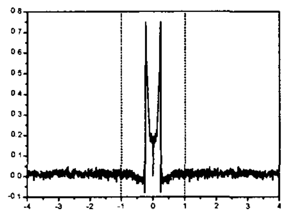


Fig. 3 Original data of roll decay taken by image processing

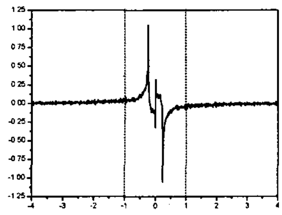


(a) Original Data

FFT

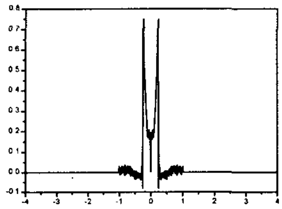


(b) Real of FFT data

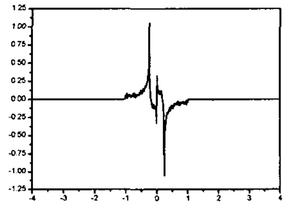


(c) Imaginary of FFT data

Cut off



(d) Real of Cut off data



(e) Imaginary of Cut off

IFFT

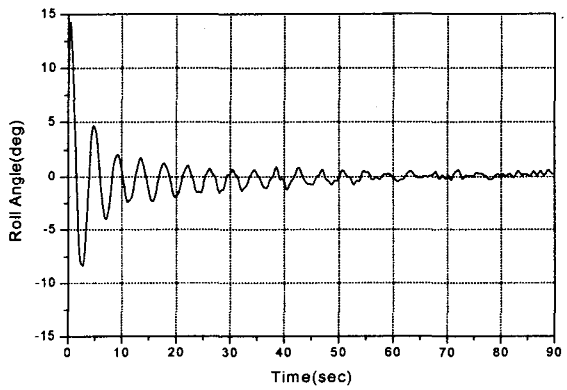


Fig. 4 Signal filtering process by using FFT

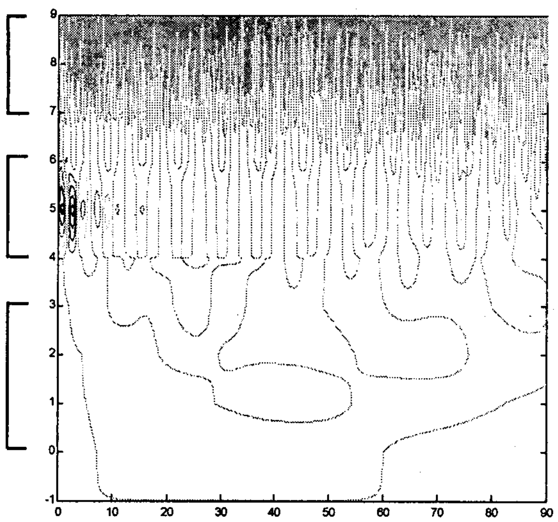


Fig. 5 The DWT map of raw data (db20 wavelet)

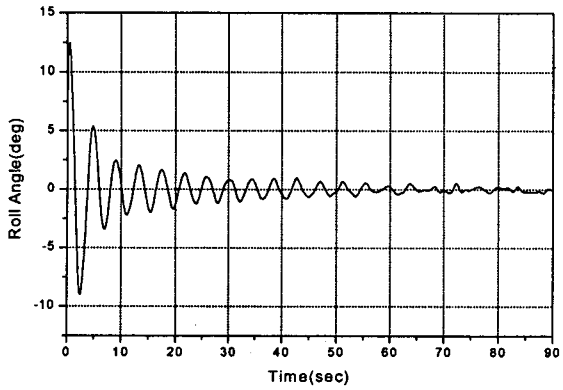


Fig. 6 Decoupled pure roll motion (level 4+level 5+level 6)

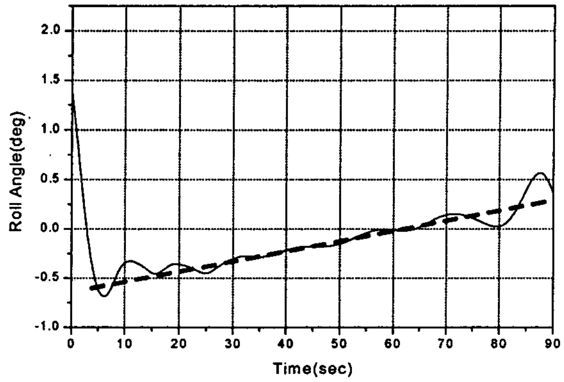


Fig. 7 Yaw effect (level 0 + level 1 + level 2 + level 3)

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