DTU Library

Study on Short-term Variability of Ship Responses in Waves – Part II: Examination of the correlation method

Iseki, Toshio; Nielsen, Ulrik Dam

Published in:
Proceedings of the 139th Conference of Japan Institute of Navigation

Publication date:
2018

Document Version
Publisher's PDF, also known as Version of record

Study on Short-term Variability of Ship Responses in Waves – II. - Examination of the correlation method -

Member ○Toshio ISEKI (TUMSAT)　Member Ulrik Dam Nielsen (DTU, NTNU)

Summary

Short-term variability of ship responses is investigated by cross-spectrum analysis. In a steady state condition, it is well known that a certain length of sampled data is required for stable results of the spectral analysis. However, the phase lag between responses, in terms of the phase angle of the cross-spectra, has not been discussed in detail. Analyzing long stationary time series by direct Fourier transform, the authors pointed out that the short-term variability of the relative phase angle of the cross-spectra was very harmful to sea state estimation of the wave buoy analogy. In this report, the same investigation based on the correlation (Blackman-Tukey) method was applied to the same data. In the results, it was observed that the short-term variability of the relative phase angle was reduced to a certain extent.

Keywords：Seakeeping, wave buoy analogy, aleatory uncertainty, Blackman-Tukey method, relative phase.

1. Introduction

The authors of the present paper are advocates of the wave buoy analogy. In this analogy, measured responses from an advancing ship are used together with corresponding transfer functions to obtain estimates of the sea state at the exact position of the ship [(1), (2), (3)]. In general, results of the wave buoy analogy compare reasonably well with results of other means for wave estimation [(4), (5)] but observations with poor agreement are also found; not to mention which means are the most accurate. This brings into question how much variation, due to aleatory uncertainty [(6)], the sea state itself may exhibit on a short-term scale in 2-5 minutes period.

A direct measure for the aleatory short-term variation of a sea state in time and position could be obtained based on results by the wave buoy analogy. However, an indirect approach is to estimate the sea state variation in terms of measured ship responses, since any change in sea state will be observable in the wave-induced responses of a ship; assuming other operational parameters (speed, heading, etc.) to be constant and neglecting the fact that a ship, to some degree, is a wave filter. The advantage by this indirect approach is that modelling uncertainties, of the wave buoy analogy or other similar means for wave measurement, will not influence results. In case of the wave buoy analogy, notably uncertainty related to the transfer functions of the ship could influence results. 'Modelling uncertainties' may, in this sense, be viewed as a kind of epistemic uncertainty [(6)].

In the previous study [(7)], short-term variability of ship responses was investigated by cross-spectrum analysis of the discrete Fourier transform (in short, DFT). Using stationary time series of full-scale ship responses, details of the transition of the variance and relative phase angles of the cross-spectra were investigated precisely. As the results, short-term variability of the relative phase angle was observed, and it was concluded that the short-term variability of the relative phase angle was very harmful to sea state estimation of the wave buoy analogy.

In this report, the same investigation based on the correlation (Blackman-Tukey) method is applied to the same data. The ship responses are investigated by iterative cross-spectral analysis with a short time shifting. The transition of amplitudes and relative phase angles of the cross-spectra is monitored precisely, and it can be observed that the short-term variability of the relative phase angle was reduced compared to DFT. The short-term variability of the relative phase angle is illustrated, and the problems encountered are discussed.

2. Analysis procedure

In this section, the analysis procedure including the time shifting is explained. Firstly, we introduce the Blackman-Tukey (in short, B-T) method for spectral analysis. If we assume that the sampled time series are expressed by $x(n)$ and $y(n)$ $(n = 0,1,2,\cdots,N-1)$, and their mean values are 0. The auto-covariance and the cross-covariance functions can be defined by the following equations,

$$C_{xx}(l) = \frac{1}{N-l}\sum_{n=0}^{N-l-1} x(n)x(n+l) \quad (1)$$

$$C_{xy}(l) = \frac{1}{N-l}\sum_{n=0}^{N-l-1} x(n)y(n+l) \quad (2)$$

where l is an integer $(0 \le l \le N)$ and called as *lag*.

Secondly, based on the *Wiener - Khintchin* theorem, the auto-power spectrum $S_{xx}(f)$ and the cross-power spectrum $S_{xy}(f)$ can be calculated by Fourier transform.

$$S_{xx}(f) = \Delta t \sum_{l=0}^{N-1} C_{xx}(l) e^{-i2\pi fl\Delta t} \quad (3)$$

$$S_{xy}(f) = \Delta t \sum_{l=0}^{N-1} C_{xy}(l) e^{-i2\pi fl\Delta t} \quad (4)$$

where f is the frequency (of encounter), Δt the sampling time.

Considering that the cross-power spectrum is complex-valued, phase angle (i.e. the argument) of the cross-power spectrum can be defined as follows;

$$P_{xy}(f) = Arg\left(S_{xy}(f)\right) \quad (5)$$

The phase angle represents the phase difference between the two responses and has indeed importance, especially focus is on the wave buoy analogy. Therefore, the phase angle of the cross-spectrum is denoted the “relative phase angle” in this study.

Finally, the spectral analysis is applied to the time series, which are assumed to be stationary. The concrete application is illustrated in Figure 1. The top blue colored bar denotes the measured steady state time series of ship responses. The spectral analysis is applied to the time series of constant time span and iterated many times with constant time shifting. Each shorter bar in the figure indicates a single spectral analysis. Based on the assumption of the stationary time series, therefore, all the results of the spectral analysis must coincide with each other. An investigation of the aleatory short-term variation of the results is the core objective of this study.

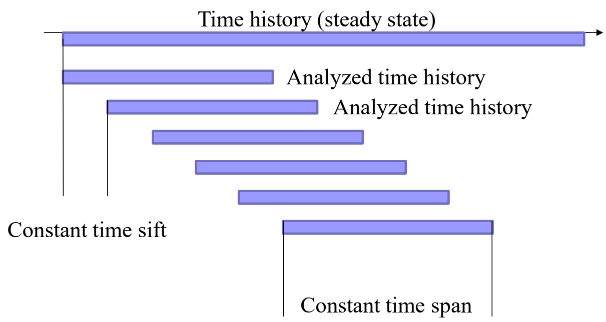

Figure 1 Concrete procedure of the Fourier analysis of stationary time series.

3. Full Scale Ship Experiment

The full scale ship experiment was carried out on October 17th 2013 using the training ship Shioji-maru of Tokyo University of Marine Science and Technology. The principal particulars and a photo of the ship are shown in Table 1 and Figure 2, respectively. The location of the experimental area was off Sunosaki cape in Chiba Prefecture, Japan. Ship motions and the position were measured using a fiber optic gyro and a GPS system. The data was sampled every 0.1s (10Hz) and recorded in the hard disk of a notebook PC through the RS-232C port.

Table 1 Principal particulars of T.S. Shioji-maru

Length (P.P.)	46.00(m)
Breadth (M_{LD})	10.00(m)
Depth (M_{LD})	6.10(m)
Draught (M_{LD})	2.65(m)
Displacement	659.4(t)
Main engine	4 cycle diesel 1,030 kw × 700 rpm

Figure 2 The training ship Shioji-maru.

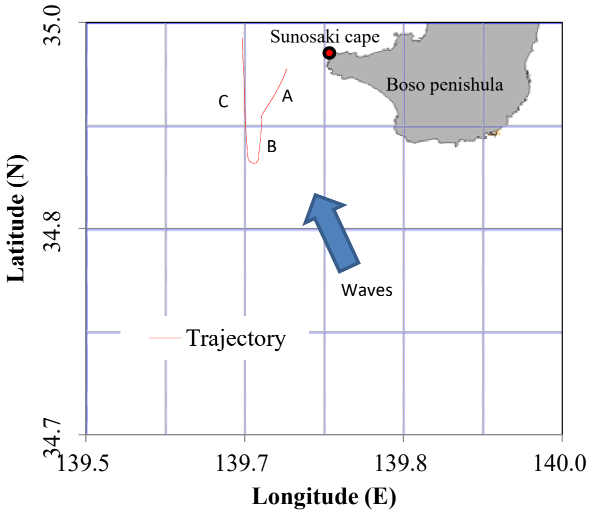

Figure 3 The experimental area at off Sunosaki cape and the ship trajectory.

Table 2 Ship course and the sea conditions

Run	Ship course (deg)	Ship speed (knot)	Dura-tion (min)	Wind dir.	Wind speed (m/s)
A	200	11.0	10	NNE	3.0
B	180	11.0	10	NNE	3.0
C	0	10.5	20	NNE	5.0

Figure 3 shows the trajectory of the T.S. Shioji-maru during the experiment. To measure changes in ship motions with respect to the encounter angle of waves, the propeller pitch angle was set to 15 degrees. Measurement was carried out for 60 minutes involving three straight sections and changes in course. The sections A and B have 10 minutes duration and the section C has 20 minutes duration. The wave direction was SE as reported by Japan Meteorological Agency.

Table 2 shows the ship courses and the mean speeds-through-water, measurement duration, true wind directions and wind speeds are also summarized. During the experiment, the observed waves were: height 1.0-1.5m, directions 150-160 and 335-350 degrees (mixed sea condition).

4. Results of the analyzes

The computer software, which can continuously estimate auto and cross-spectra with constant time (data points) shifting, has been improved for the present research work. A screenshot of graphical results produced by the software is shown in Figure 4. The three components of the power spectra and the time series are

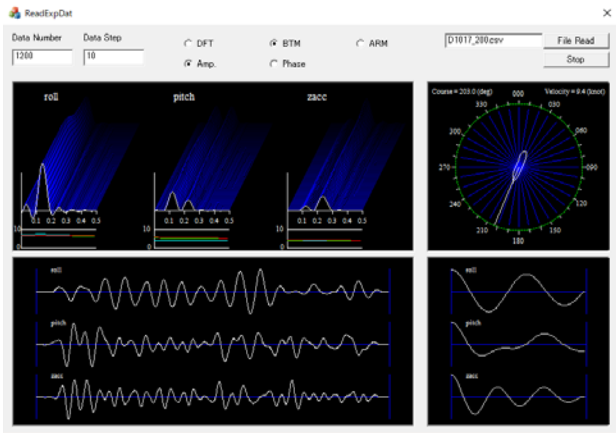

Figure 4 Screen shot of the developed software (run A).

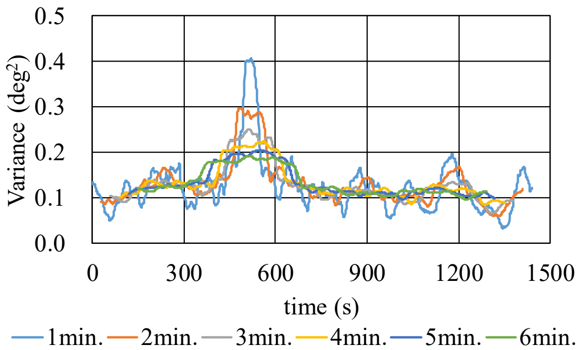

Figure 5 Transition of the pitching variance (run C).

shown in the left part of the dialog box. In the calculation of this figure, each analyzed time series has 1200 data points with tapered cosine bell type data window and 1s (10 data points) time shifting. The most recent spectra are plotted by white color and the past spectra are drawn by blue color in the upper left part. In the right part of the screen, the ship course, speed and the covariance functions are indicated.

4.1 Auto-spectral analysis

Figure 5 shows the transition of the pitching variances with respect to the "constant time shifting". The data was measured on the "run C" and can be considered as a stationary time series. Theoretically speaking, therefore, the variance must take constant value regardless of the time shifting. The total number of data points is 15000 (i.e., duration is 25 minutes) and the variances were calculated as the area of pitching auto-spectra. The horizontal axis denotes the shifted time in second. The six colored lines indicate results based on the time span of the analysis, for instance, the blue line "1 min." was evaluated by 1-minute time span (600 data points). The maximum lag numbers of the auto-covariance functions were set to one-tenth of the data points. There are some large fluctuations around 500s and the longer time span provides the smoother line. This tendency is almost same with the previous report [7] based on the direct method (DFT).

4.2 Cross-spectral analysis

The relative phase angle of a cross-spectrum defined by Eq.(5) was also investigated by the "constant time shifting". The index based on the concept of standard deviation is defined to evaluate the total movement of phase movement (in short, P.M.) at the n shifted time. The definition is expressed as follows;

$$I_{PM}(n) = \sqrt{\frac{1}{N_f}\sum_{i=0}^{N_f}\left\{P_{xy}(f_i;n) - P_{xy}(f_i;n-1)\right\}^2} \quad (6)$$

where N_f denotes the total number of discrete frequencies and $P_{xy}(f_i;n)$ represents the relative phase spectrum at the n shifted time. Fluctuation of the index can be interpreted as the short-term variability [7].

Figure 6 shows the transition of the index $I_{PM}(n)$ of rolling-pitching. Rough fluctuation of the index $I_{PM}(n)$ and no periodic transition can be seen. It can be observed that the longer time span degrades the level of the index, but it cannot remove the fluctuation itself. Compared to the previous report [7], however, the level of the index has been reduced. This conclude that the B-T method can provide better results from the view point of the wave buoy analogy.

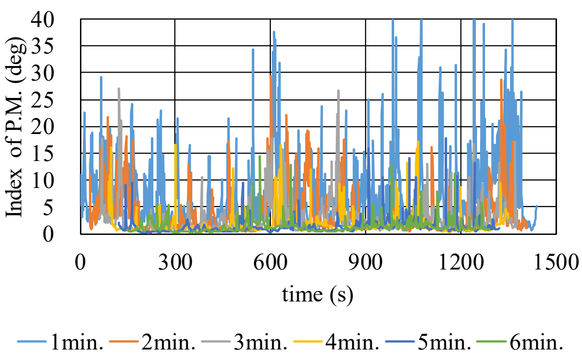

Figure 6 Transition of $I_{PM}(n)$ of roll- pitch cross-spectra for each time span (run C).

5. Conclusions

Short-term variability of ship responses was investigated by cross-spectrum analysis. Using stationary time series, details of the transition of the variance and relative phase angles of the cross-spectra have been investigated with time shifting. The results obtained in this report are summarized below:

- In analyzes of (statistical) variance, the tendency is almost same with the direct method (DFT).
- Short-term variability of the relative phase angle is reduced by introducing the B-T method.

The short-term variability of the relative phase angle is harmful to sea state estimation by the wave buoy analogy. Hence, in future work, the short-term variability should be investigated more precisely.

This work is partly supported by JSPS KAKENHI Grant Number 17K06960 and the Centre for Autonomous Marine Operations and Systems (AMOS) through the Centres of Excellence funding scheme, Project number 223254-AMOS. The authors express sincere gratitude to the above organizations.

References

(1) Iseki, T. and Ohtsu, K.: Bayesian estimation of directional wave spectra based on ship motions, Control Engineering Practice, 12, pp. 25-30, 2000.

(2) Iseki, T.: An Improved Stochastic Modeling for Bayesian Wave Estimation, Proceedings of 31st OMAE, 2012.

(3) Nielsen, U.D. and Iseki, T.: A Study on Parametric Wave Estimation Based on Measured Ship Motions, Journal of Japan Institute of Navigation, 126, pp.171-177, 2012.

(4) Nielsen, U.D. and Stredulinsky, D.C.: Sea state estimation from an advancing ship - A comparative study using sea trial data, Applied Ocean Research, 34, pp. 33-44, 2012.

(5) Nielsen, U.D., Andersen, I.M.V. and Koning, J.: Comparisons of Means for Estimating Sea States from an Advancing Large Container Ship, Proceedings of 12th PRADS, 2013.

(6) Skjong R., Bitner-Gregersen E., Cramer E., Croker A., Hagen Ø., Korneliussen G., Lacasse S., Lotsberg I., Nadim F., Ronold K.O.: Guidelines for offshore structural reliability analysis – General, DNV Report No. 95 – 2018, Høvik, Norway, 1995.

(7) Iseki, T. and Nielsen, U, D.: Study on Short-term Variability of Ship Responses in Waves, Journal of Japan Institute of Navigation, 132, pp.51-57, 2015.