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Bayesian Estimation of Directional Wave Spectra for Ship Guidance System

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ABSTRACT

New techniques are introduced into the Bayesian modeling procedure to estimate directional wave spectra based on ship motion data. In this proposed method, the triple-valued function problem in following seas is strictly taken into account, and the optimum solution is obtained from the stochastic viewpoint. Using the estimated directional wave spectrum, it is shown that the future states of ship motions and longitudinal bending stresses can be evaluated based on the assumption of linear responses. Onboard experiments were carried out to examine the reliability of the proposed method. Comparisons between the results of the proposed method and onboard experiments show good agreements.

INTRODUCTION

In rough seas, it is very important for the mariner to monitor sea conditions and keep both ship and cargo safe by suitable ship maneuvers. Despite recent developments in nautical instruments, estimating sea conditions and choosing the correct maneuver still depend on visual observation and many years' experience. Thus it is considered necessary to develop a ship-borne guidance system for heavy-weather operation.

Going back a little in the past, many onboard guidance systems have been developed. Most of these systems can be described as monitoring systems for responses such as ship motions and induced wave loads that are directly measured by many sensors and strain gauges. Although these systems had some practical value, few of them were adopted on merchant ships because of cost and the difficulty of maintaining the data-acquisition hardware. The most crucial problem for these systems is to obtain data about directional wave spectra that form the basis of theoretical calculations. It is also difficult to transform encounter frequencies into true-wave frequencies; this is the triple-valued function problem. Because, in the case of following seas, 3 true-wave frequencies contribute to the measured power spectrum at certain encounter frequencies, the relationship between encounter and true-wave frequencies can be described as a triple-valued function.

In general, the ship's motion can be measured more easily than wave height. Based on the assumption of linearity between the waves and the ship's motion, several studies were made (Webster and Dillingham, 1981; Hirayama, 1987; Iseki, Ohtsu and Fujino, 1992). Those studies tried to estimate directional wave spectra using ship-motion data, that is, to solve an inverse problem of how to estimate the input from the measured output data. After that, the triple-valued function problem was accurately taken into account by the Bayesian modeling method (Iseki and Ohtsu, 1994), the extended maximum entropy principal method (Yoshimoto and Watanabe, 1994), and the extended maximum likelihood method (Hirayama, Minami and Hiramatsu, 1996, 1997).

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In the Bayesian modeling procedure proposed by Akaike (1980), the spectra can be estimated as coefficients of the multivariate linear regressive model. This procedure has 2 powerful points. The first is that some appropriate prior distributions can be taken into account in order to avoid lack of conditions and to reduce the influence of noise. And the second is that the triple-valued function problem is strictly taken into account (Iseki and Ohtsu, 2000). In order to examine the reliability of the proposed method, towing-tank experiments and onboard experiments were carried out using a model and the full-scale training ship *Shioji Maru*. Applying the proposed method, it was shown that the directional wave spectrum could be estimated from the vector-valued time series recorded on a running ship, even in following seas.

In this paper, the Bayesian estimation is extended to a stochastic procedure for ship guidance systems. Theoretically, using the estimated directional wave spectrum and numerically calculated response functions, many kinds of ship responses can be estimated without direct measurement. Further, not only the present state of ship responses, but also the states in which the ship will be after changing course and speeds, can be estimated on the assumption that the sea state is stationary in time. The objective of the proposed procedure is to approximate the trends of ship responses. Though the assumption of linear responses has some limitations for heavy-weather operations, the trends provide useful information for ship navigation. Based on this concept, the authors tried to estimate the significant values of pitch angle, roll angle and longitudinal bending stresses. From the onboard tests carried out to verify the proposed method, the potential of the proposed method is discussed and the problems encountered are reported.

ESTIMATION OF DIRECTIONAL WAVE SPECTRA

If the seaway is considered to be composed of an infinite sum of component waves from all directions and with all frequencies, the height of the sea surface $\eta(t)$ above a fixed point is expressed by using the directional wave spectra $E(f, \chi)$ as:

$$\eta(t) = \int_{-\pi}^{\pi} \int_{0}^{\infty} \cos\{2\pi f t + \varepsilon(f, \chi)\} \sqrt{2E(f, \chi)\, df\, d\chi}, \tag{1}$$

where $\sqrt{2E(f, \chi)\, df\, d\chi}$ and $\varepsilon(f, \chi)$ are, respectively, the amplitude and the phase angle of the component waves coming from direction χ with frequency f.