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Sensitivity analysis of submersibles' manoeuvrability and its application to the design of actuator inputs

Dong Jin Yeo[a,*], Key Pyo Rhee[b]

[a]*Maritime & Ocean Engineering Research Institute, KORDI, 171-0, Jang-dong, Yuseong-gu, Daejeon, 305-343, Republic of Korea*
[b]*Department of Naval Architecture and Ocean Engineering, College of Engineering, Seoul National University, San 56-1, Sillim-Dong, Gwanak-Gu, Seoul 151-744, Republic of Korea*

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Abstract

The influences of hydrodynamic coefficients on the prediction of manoeuvrability were examined by sensitivity analysis (SA) of direct method. The equations of motion used were the standard equations of motion for submarine [Gertler, M., Hagen, G.R., 1967. Standard equations of motion for submarine simulation. DTNSRDC Report], and three submersibles with different appendages were considered. Numerical simulations of three types of sea trials are performed to obtain the sensitivities of motions to hydrodynamic coefficients. Since the accuracy of hydrodynamic coefficients' estimates is increased by the use of sensitivity-maximizing inputs, the sensitivity-optimal actuator commands that are sequences of bang-bang type inputs were deduced with genetic algorithm (GA) optimization technique.

Keywords: Direct method sensitivity analysis (SA); Submersibles; Sensitivity-maximizing inputs; Genetic algorithm (GA)

*Corresponding author. Tel.: +82 42 868 7247; fax: +82 42 868 7738.
E-mail address: Lonepier@moeri.re.kr (D.J. Yeo).

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1. Introduction

Sensitivity analysis (SA) is used to predict how the model response will vary with changes in the model parameters. With SA, confidences in models developed to approximate certain processes and their predictions can be increased. To evaluate manoeuvrability, SA has been used to survey the influences of hydrodynamic coefficients on the manoeuvring performances.

SA on hydrodynamic coefficients of a ship was conducted by Hwang (1980). He defined the sensitivity of a hydrodynamic coefficient as maximum differences in state variables. Rhee and Kim (1999) challenged Hwang, arguing that Hwang's method is not suitable to be used for comparing the sensitivities of hydrodynamic coefficients in one trial with those in other trials. Thus, they suggested a method that can be used to compare the sensitivity of hydrodynamic coefficients directly. Sen (2000) conducted SA of hydrodynamic coefficients for submersibles. He defined sensitivity as a measure of changes in the characteristics of several sea trials such as tactical diameter and overshoot angle, resulting from corresponding changes in the hydrodynamic coefficients.

The SAs conducted by the authors above are the types of indirect method. Although indirect method has a merit in that no modification, such as differentiation of mathematical model, is needed, it also has certain demerits such as the total number of simulation to be performed increases with the increase in the number of model coefficients and generalized SA cannot be achieved. These demerits of indirect method are issues that need to be resolved in order to analyse sensitivity of ships' and submersibles' hydrodynamic coefficients to manoeuvering characteristics. Hence, a direct method is needed in SA of hydrodynamic coefficients for submersibles. Although direct method requires differentiation of mathematical models with respect to model coefficients, it shows the sensitivity history of dynamic system during the movement.

As was reported by Kalaba and Spingarn (1982), the accuracy of hydrodynamic coefficients estimates can be increased by using sensitivity-maximizing inputs. Sensitivity-maximizing inputs can be found by genetic algorithms (GA). GAs are search algorithms based on the process of natural evolution (Goldberg, 1989). They operate on a population of solutions to a given optimization problem. Furthermore, GA can find global solution with the operators mimicking natural evolution process, without any mathematical operations such as differentiation of a given problem.

In this paper, we discuss about the direct method SA of submersibles with three different appendages. Changes of sensitivities during sea trials are presented through numerical simulations. With the sensitivity differential equations formulated in SA of direct method, we successfully optimized actuator command by GA, hence maximizing the overall sensitivity during a time set equal to that of conventional sea trials. Once sensitivity-maximizing actuator commands are obtained, their effectiveness are evaluated through the comparison of sensitivities between other sea trials.

2. Mathematical model

A Cartesian earth-fixed coordinate system and body-fixed coordinate system are defined to describe a submersible's six-degree-of-freedom motion (Fig. 1). Let the