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Analysis of the dynamic characteristics for the change of design parameters of an underwater vehicle using sensitivity analysis

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ABSTRACT

In order to design the hull form of an underwater vehicle in the conceptual design phase, the dynamic characteristics depending on the hull form parameters should be identified. Course-keeping stability, turning ability, yaw-checking ability, and mission competence are set to be the indices of the dynamic characteristics, and the geometric parameters for the bare hull and rudder are set to be the hull form design parameters. The total sensitivity of the dynamic characteristics with respect to the hull form parameters is calculated by the chain rule of the partial sensitivity of the dynamic characteristics with respect to the hydrodynamic coefficients, and the partial sensitivity of the hydrodynamic coefficients with respect to the hull form parameters. Based on the sensitivity analysis, important hull form parameters are selected, and those optimal values to satisfy the required intercept time of mission competence of a specific underwater vehicle and turning rate are estimated.

1. Introduction

The underwater vehicle is widely used in the fields of military weaponry and commercial use, such as exploitation of mineral resources, seabed surveying, and investigation of offshore pipelines (Kim, 2011). Many kinds of underwater vehicles, like torpedo, anti-torpedo torpedo, and self-propulsive mine, run very fast, and they require excellent dynamic characteristics. When a military underwater vehicle is designed in the conceptual design phase, principal dimensions, like length-to-diameter ratio, nose shape, tailcone angle, total fin area, and movable fin area, should be determined only from the inputs of the running speed and the maximum turn rate.

Dynamic characteristics of an underwater vehicle consist of course-keeping stability and maneuverability. In general, these would be estimated by the sign of the solution of the characteristic equation, and maneuvering simulation after establishing the six Degrees of Freedom (DOF) equations of motion. Gertler and Hagen (1967) and Feldman (1979) suggested the hydrodynamic force model acting on a maneuvering submarine. Healey and Lienard (1993) and Prestero (2001) established the equations of motion of the Autonomous Underwater Vehicle (AUV). While most of the hydrodynamic force models acting on an underwater vehicle are described as first or higher order polynomial functions, some of them are modeled using the neural network method (Yoon et al., 2006; Ahn, 2005). When the model structure of hydrodynamic force is adopted as the polynomial functions, the parameters, the so-called hydrodynamic coefficients, should be estimated theoretically or experimentally. In order to experimentally estimate the hydrodynamic coefficients of an underwater vehicle, the Vertical Planar Motion Mechanism (VPMM) (Jung et al., 2014a,b), rotating arm (Lewis, 1989), and coning motion (Park et al., 2015; Lewandowski, 1991) tests are performed. Since a large budget would be required to perform the model test, empirical formulae to estimate the hydrodynamic coefficients developed using many model test results are used in the conceptual design phase, when many design parameters could be changed (Jeon et al., 2016; HDW, 2002; Prestero, 2001; Fossen, 1994).

Many researches to relate the dynamic characteristics to the design hull form parameters and the hydrodynamic coefficients using sensitivity analysis have been performed (Sen, 2000; Kim et al., 2014). Bae et al. (2007) analyzed the sensitivity of maneuvering characteristics of a Manta-type underwater vehicle due to the hydrodynamic coefficients. Yeo et al. (2006) identified the most

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Nomenclature

A	Cross-sectional area of bare hull
A_E^{rd}	Effective aspect ratio of rudder
A_{tot}^{rd}, A_{mp}^{rd}	Total and movable areas of rudder, respectively
b^{rd}	Span length of rudder
c_t^{rd}, c_r^{rd}	Tip and root chord lengths, respectively, of rudder
D	Diameter of bare hull
G_h	Stability gain margin
L	Length of bare hull
L_{midd}	Length of parallel middle body
m, I_z	Mass and mass moment of inertia, respectively
$O-x_0y_0$	Earth-fixed coordinate
$o-xy$	Body-fixed coordinate
R'	Nondimensional turning radius
r_{ss}	Steady turning rate
S_G^M	Total sensitivity of dynamic characteristics with respect to hull form parameter
S_H^M	Partial sensitivity of dynamic characteristics with respect to hydrodynamic coefficient
S_G^H	Partial sensitivity of hydrodynamic coefficient with respect to hull form parameter
T_{op}	Intercept time
U	Speed of underwater vehicle
u, v, r	Surge and sway velocities, respectively, and yaw rate
X, Y, N	External force and moment
x_G	x coordinate of center of gravity of a vehicle
x_{tot}^{rd}, x_{mp}^{rd}	x coordinates of centers of total area and movable area of rudder, respectively
β	Drift angle
δ_r	Rudder angle
λ^{rd}	Taper ratio of rudder ($=c_t^{rd}/c_r^{rd}$)
ψ	Yaw or heading angle
ψ_1, ψ_2	1^{st} and 2nd overshoot yaw angle, respectively
ρ	Fluid density
Θ	Tailcone angle

effective design parameters of a submarine on the stability indices, and Yeo and Rhee (2006) designed the most sensitive inputs for identifying the hydrodynamic coefficients by the genetic algorithm. Kim et al. (2014) investigated the effect on the maneuvering characteristics due to the appendage of a war ship by sensitivity analysis. However, previous researches have been conducted to analyze

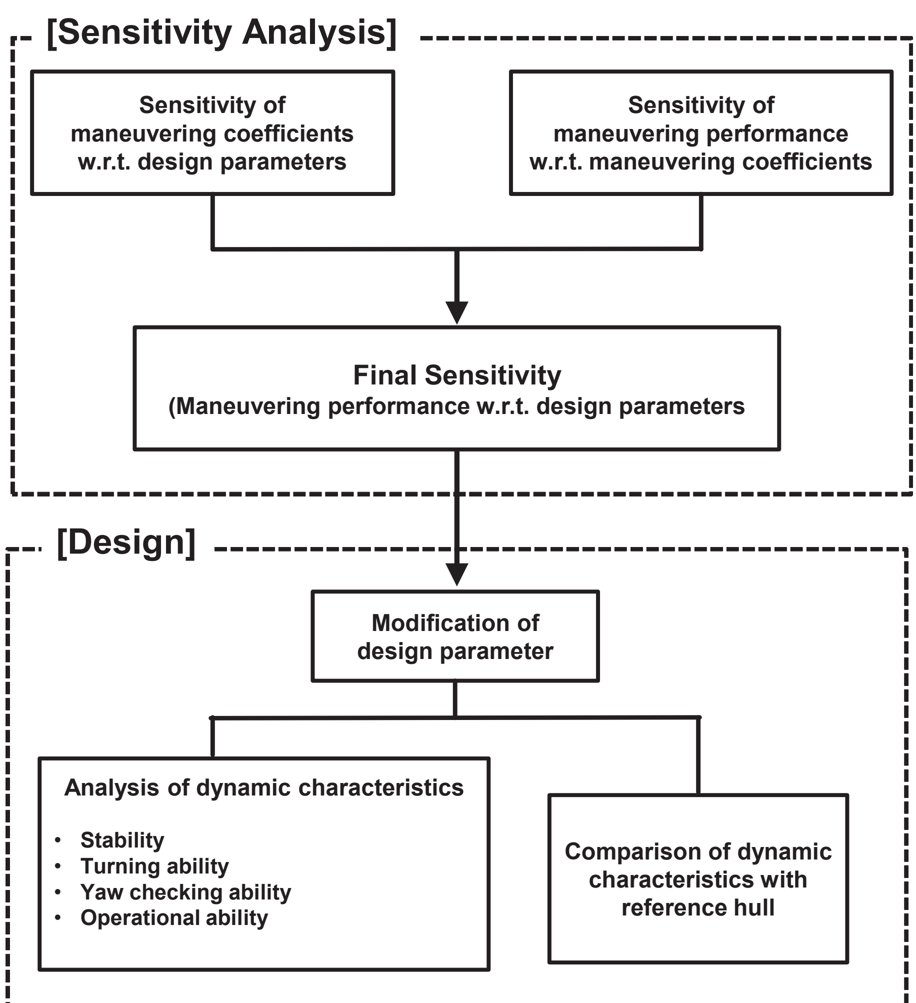

Fig. 1. Procedure for the optimal hull form design of an underwater vehicle.

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