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Nonlinear Filtering for Estimating Flow Speed around a Vibrating Rigid Circular Cylinder

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This study proposes a method to estimate flow speeds around a submerged vibrating body by measuring the dynamic variables of the body and performing a filtering computation. The proposed method is based on the mechanics of the vortex-induced vibration of a rigid circular cylinder and a nonlinear filtering theory (unscented Kalman filter). Three types of dynamic variables (displacement, acceleration, and hydrodynamic force) are assumed to be measured with sensors. By conducting identical twin numerical experiments, this study examines whether the proposed method accurately estimates the flow speeds with combinations of the three measured variables.

INTRODUCTION

Flow velocity in the ocean is important for understanding the marine environment in deep seas. Demands for information on flow velocity stem from accelerated developments in place for exploiting various types of mineral resources and fossil fuels. To produce these resources, deep-sea equipment, such as risers, underwater pipelines, and subsea structures, need to be constructed based on reliable designs.

When designing this equipment and assessing its performance at sites where this equipment is installed, the fluid and structural mechanics of these structures are investigated by theory, simulation, and experiment to provide solutions used for the assessment. Obtaining such solutions requires specifications of boundary conditions. Among the boundary conditions, one closely related to the above technologies is seawater flow velocity, which comprises constitutive ocean current and periodical tidal flows. Numerous past assessments on the mechanics of deep-sea technology were made under an assumption of flow velocity; a typical example is the simulation of vortex-induced vibration (VIV) of a riser pipe, in which a velocity distribution along the pipe is assumed to be spatially smooth compared with actual velocity distributions. Flow velocity measurements referred to for these assumptions were made with a small number of sensors. Flow velocities at the deepest layer had to be extrapolated from measurements obtained at other sites or shallower layers.

To accurately evaluate the performance of deep-sea technologies, particularly flexible riser pipes subject to seawater flow and vibration for a long time, significant attention must be given to flow velocity distribution around the riser. A riser pipe connects a wellhead on the sea floor with a floating platform; thus, it always vibrates owing to the surrounding fluid flows.

Physical oceanographers typically adopt an acoustic Doppler current profiler (ADCP), which has provided information on flow velocities useful for scientific investigations. Arranging multiple ADCPs may accomplish the vertical profiling of the flow velocities. To realize the estimation of flow velocities at whole water depths and use them for the engineering purposes, this study proposes a novel method for obtaining a vertical profile of flow velocities that is sufficiently spatially dense to be useful for designing underwater structures, such as risers.

This study considers an elastically supported rigid circular cylinder subject to a flow. It undergoes VIV, the magnitude of which depends on flow speed (e.g., Bearman, 1984; Sarpkaya, 2004; Williamson and Govardhan, 2004). We assume that the flow speed is unknown whereas the motion of the circular cylinder is measurable. The question arises as to whether it possible to estimate the flow speed using the circular cylinder motion. Succeeding in that estimation using the rigid circular cylinder encourages us to promote the method developed in this study to a method applicable to a long flexible structure.

Aiming to offer a solution to the above issue, this study constructs a theory of fluid–structure interaction involved in VIV of the circular cylinder, implements computational code for robustly identifying the unknown flow speed using the unscented Kalman filter (UKF), and examines the properties of the method through identical twin numerical experiments, the details of which are discussed later. UKF has been applied in the estimation of unknown parameters in a variety of dynamic systems. Sitz et al. (2002) used it for Lotka-Volterra, Lorents, and stochastic van der Pol systems. Kandepu et al. (2008) investigated the computational performances of UKF applied to van der Pol systems and an induction machine. Takeno and Katayama (2011) demonstrated superiority of the UKF to the extended Kalman filter (EKF) in the Lorents model and orbital motion of an object. Sabet et al. (2014) applied UKF to estimate the coefficients of hydrodynamic forces acting on autonomous underwater vehicles. These previous studies demonstrated that UKF is a promising method for estimating unknown parameters in nonlinear systems. The application of the UKF in nonlinear systems attracted our attention because the dynamic system addressed in this study also involves a high nonlinearity. To the best of our knowledge, no studies have been conducted to date in the estimation of flow speed using filtering theory. This study is an effort to propose a method for achieving such an estimation and examining its performance.

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