Ocean Engineering 93 (2015) 84–97

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

Review

Parameter identification of marine risers using Kalman-like observers

Lizeth Torres [a,*], Cristina Verde [a], Omar Vázquez-Hernández [b]

[a] Instituto de Ingeniería, UNAM, Mexico City, Mexico
[b] Instituto Mexicano del Petróleo, Mexico City, Mexico

ARTICLE INFO

Article history:
Received 3 October 2013
Accepted 5 November 2014
Available online 1 December 2014

Keywords:
State observers
Extended Kalman filter
Nonlinear parameter identification
Marine risers

ABSTRACT

The goal of this paper is to present a nonlinear approach to identify the structural parameters of a vertical riser. To carry out this task, Kalman-like observers are proposed so that they can deal with the nonlinear behavior that is exhibited in the restoring force of a riser and the noise of the measurement signals that are used to perform the identification. The observers are designed from a spatial discretization of a nonlinear model with distributed parameters that is described by a system of quasi-linear partial differential equations. Some results from numerical simulations—showing the feasibility of the proposed approach—are presented.

Contents

1. Introduction

Risers are very important components of offshore platforms for drilling, production, and transportation of oil and other fluids resulting from these activities. Risers are the pipes that connect the subsea wellhead with the process facilities in the floating platform. And due to the operation conditions, they are subjected to environmental loads and motions of the floating platform that can provoke undesirable vibrations, which in turn cause: stresses in the slender body, fatigue problems and propagation of cracks. In particular, this last issue could generate serious consequences, because even the smallest undetected crack can, in time, become larger and start a structural or leaking problem. Following from this, any failure incident in risers could cause unquantifiable environmental disasters, turning the care of their integrity into an essential requirement to be covered.

* Corresponding author.
E-mail addresses: ftorreso@iingen.unam.mx (L. Torres), verde@unam.mx (C. Verde), ovazquez@imp.mx (O. Vázquez-Hernández).

http://dx.doi.org/10.1016/j.oceaneng.2014.11.003
0029-8018/

In order to monitor the state conditions of structures, there are different methods based on nondestructive tests, some based on detailed visual inspection and others on vibration analysis. The latter method employs parameter identification techniques to estimate[1] (to identify) the structural parameters of the system like damping, modal parameters, and stiffness.

For the identification of structural parameters, several approaches have been developed. Among these works, one finds: (Ghanem and Shinozuka, 1995; Doebling, 1996; Shinozuka and Ghanem, 1995) , which are widely used—mainly in the case of land structures—to treat the parameter identification in a linear dynamical context. However, in the case of marine risers, the parameter identification problem must be tackled with nonlinear techniques, because these systems have a strong nonlinear behavior caused by large displacements of the floating system; these displacements in turn are caused by the environmental loads. With regard to this, many identification techniques have been developed for the identification of nonlinear systems, which can be classified according to diverse categories: linearization-based methods, time-domain and frequency-domain methods, modal methods, time-frequency analysis, black-box modeling and structural model updating. Several practical examples of these methodologies have been reported in the engineering literature (Richards and Singh, 1998; Alvin et al., 2003), and readers who seek an indepth overview of their application on structural system identification may consult the survey presented in Kerschen et al. (2006).

Within the time-domain methods to identify parameters of nonlinear systems, one encounters the approaches based on state observers (Busvelle and Gauthier, 2002; Jiang et al., 2004; Besançon and Ţiclea, 2007; Farza et al., 2009), which have been already employed in structural parameter identification, e.g., Lin and Betti (2004), Garrido et al. (2004), Angeles et al. (2005), and Jiménez-Fabián and Alvarez-Icaza (2010). There are many types of nonlinear observers presented during the last three decades, but one of the more representative is the extended Kalman filter (EKF), which allows to estimate—in real time—the state vector of a nonlinear dynamic system from indirect measurements.

The ocean sciences pose numerous opportunities for applied estimation theory, being a field with numerous challenges, because of the complexity of the marine systems, the cost of sensors, the high amount of perturbations with their respective effects. Estimation applications range from tracking objects, positions and state estimates to navigation and heave compensation. Some works—in ocean engineering—have been developed using the EKF to estimate: (i) the maneuvering coefficients of a ship (Hwang, 1980), (ii) the hydrodynamic coefficients of autonomous underwater vehicles (AUV) (Kim et al., 2002), (iii) the structural parameters of undersea vehicles for control navigation purposes (Ozimina and Bierman, 1980), (iv) the hydrodynamic coefficient matrices associated with the nonlinear drag and inertia forces appearing in the equations of motion of offshore structures subjected to wave forces (Yun and Shinozuka, 1980), (v) the depth of ocean isothermal layers, to predict the vertical distribution of temperature, and current velocity vectors (Timchenko, 1974). In short, researchers applied Kalman filter techniques to a wide variety of ocean problem domains, and some of these ones are summarized in Porto (2008).

For many years, the engineers successfully used the EKF (e.g., Hoshiya and Saito, 1984; Hoshiya and Sutoh, 1993), which is just the standard Kalman filter described in Kalman and Bucy (1960) for linear time-dependent systems, but applied to linearized systems.

The following is previously known: (i) in the case of incorrect gains of the EKF—because of errors in the assumed noise covariance matrices or because of inaccurate knowledge of the system dynamics—the EKF can be viewed as a time-varying stochastic approximation algorithm; (ii) in the case of having observability conditions in the system and for small initial errors in the state estimates, the EKF is a local observer for systems with deterministic inputs and noisy measurements.

A well-known difficulty arising from the application of the extended Kalman filter is the problem of divergence (see, e.g., Price, 1968; Bryson, 1978). To obtain convergence, one must either have a good initial guess so that the initial estimation error is sufficiently small or permit functions only weakly nonlinear. Nevertheless, some advances on this topic have been given by DeWolf and Wiberg (1993), along with Reif et al. (1998) for the continuous-time case and by Moraal and Grizzle (1995), Song and Grizzle (1992) for the discrete-time case. Furthermore, it was shown a few years ago how convergence of Kalman filter can be guaranteed for a certain class of nonlinear systems by using high gain techniques. In fact, in Gauthier et al. (1992) a Kalman-high gain observer was proposed for uniformly observable systems with exponential convergence of the error. This observer was extended to the kind of systems whose observability is guaranteed by a persistent condition of the inputs affecting it (Deza et al., 1993). Moreover, in Boizot and Busvelle (2007), this observer was improved with a 'switching' function which makes the observer commute between two modes: the Kalman filtering mode to deal with the noise of the measurements and the high-gain mode to manipulate the convergence rate by means of the gain parameter. Finally, in Torres et al. (2012), an EKF-like observer was proposed for more generalized systems.

In this paper, two Kalman-like observers (Reif et al., 1998; Besançon et al., 1996) are proposed to identify the structural parameters of a vertical marine riser. The conception of the observers starts with the spatial approximation of a riser model—described by Partial Differential Equations (PDE)—to obtain a finite model, which in turn is set in a state space form or in a Liénard form. At the beginning, the state space vector of the finite model is composed of two states: position (displacement) and velocity, but subsequently is augmented with the structural parameters to be identified. In this manner, both the states and parameters can be estimated.

The first observer is based on a slight modification of the EKF to alter the estimation dynamics with the aim of increasing the domain of attraction and reducing the time for the error decay. This is done by replacing the system matrix A, which is set up by a standard linearization, with an additive unstable term, as if the original system was unstable. By using the second method of Lyapunov, Reif et al. (1998) proved that the estimation error of this observer will be bounded, and the degree of such stability can be assigned in advance. The second Kalman-like observer can be designed for a specific class of system that encloses the motion equation of a riser. Its exponential convergence is assured by a persistent condition of the inputs.

In Section 2, the unidimensional model used for the conception of the Kalman-like observers is presented. Such a model represents the dynamical behavior of a vertical riser with a nonlinear restoring force characterizing the environmental effects on the system structure. Section 3 presents a short overview of the identification problematic tackled by state observers. In Section 4, a brief review about observers is exposed, including the design of the proposed observers. Section 5 describes the procedure to conceive the observers for the structural parameter identification of a riser. In Section 6, some simulation results are revealed showing the performance of the proposed observers. Finally, in Section 7, some conclusions about the approach of this work are given.

2. Riser physical model

A Riser can be modeled as an extremely long and flexible tensed pipe, suspended from the ocean surface to the sea floor.

[1] In this work, estimation and identification are used as synonymous.