Wave Filtering and State Estimation in Dynamic Positioning of Marine Vessels Using Position Measurement

Mehdi Loueipour, Mehdi Keshmiri, Mohammad Danesh, and Mohsen Mojiri

***Abstract*— This paper presents a new approach for wave filtering and state estimation in regulation and dynamic positioning of marine vessels. In this approach, low-frequency (LF) and wave-frequency (WF) motion components, LF disturbance forces, and vessels velocities devoid of oscillation are estimated from the measured position signals. The proposed system is composed of a modified notch filter and a nonlinear observer. In this method, filtering is independent from the vessel and LF disturbances models, and therefore it is not affected from modeling uncertainty. Furthermore, the proposed structure is furnished with an estimation law of fundamental frequency of WF vessel motion that improves its performance considerably. It is shown that the basic structure is globally exponentially stable and its adaptive version is locally asymptotically stable. Simulations illustrate the desirable performance of the proposed methods, the efficacy of modifications and their comparison with the conventional approach.**

***Index Terms*— Adaptive notch filter, dynamic positioning (DP), environment disturbances, marine vessels, nonlinear observer, state estimation, wave filtering.**

I. Introduction

FILTERING and state estimation from position measurement have a significant role in navigation and control of marine, aerial, and land vehicles. They have been used to estimate desired states when they cannot be measured [1]–[3] and to derive generalized position and velocity accurately [4], [5]. They are used in dynamic positioning (DP) of many marine vessels such as ships and offshore rigs, for estimation of environmental disturbances and velocities from vessel position measurement [6].

DP in marine vessels means the usage of propulsion system to regulate the horizontal position and heading [7]. Since 1960 and during the past years, DP system has been developed to improve the performance and reliability. Position and heading measurements are often affected by oscillatory signal due to environmental disturbances such as wind, waves, and ocean currents as well as sensor noise. Using these measurements directly in control loop causes unacceptable operational function, mechanical wear and tear of the propulsion system components, and extra fuel consumption. Therefore, it is required to extract the oscillatory motion from the total position measurement (called wave filtering [8]). In addition, in many operations only control of the low-frequency (LF) motion is required [9]. In most cases, velocities of the vessel and value of disturbances are not available and they should be estimated. On the other hand, estimation of these variables from noisy measurements is not desirable [8].

To satisfy the above mentioned objectives, many techniques have been introduced. These techniques can be classified into two categories.

The first category is based on optimal control and Kalman filtering theory. The Kalman filter is a recursive filter that used in most of the vessels operating in the offshore industry [9]. Initially, Balchen *et al.* [10] have used this theory for wave filtering and state estimation. Later, this work has been developed in [11]–[16]. Application of Kalman filter in DP systems requires linearization of motion equations around the operation points that degrades the system performance. Other drawback of Kalman filter is that it is difficult and time-consuming to tune the state estimator. The main reason for this is that the numerous covariance tuning parameters may be difficult to relate to physical quantities. Moreover, global stability of the whole system is not guaranteed [6], [8].

The second category has used the nonlinear observer to filter the wave frequency (WF) motion and estimate velocities and LF disturbances. The observer contained a linear model for environment disturbances and the nonlinear model for vessel motion. The main motivation of introducing and developing this method is possibility of using the nonlinear model, significantly reducing the number of tuning parameters, simplifying the tuning procedure and guaranteeing global convergence of estimation errors to zero [6]. Also, the nonlinear observer opens the way for controller design more in line with the actual structure of the physical system [6].

This approach is introduced in [8] and later used in [17] and [18]. In these observers, the WF motion model parameters are assumed to be fixed and known which is not true in practice. To solve this problem, Strand and Fossen [19] presented a new observer with adaptive wave filtering. However, the constant gain matrix of the observer causes notch

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M. Loueipour, M. Keshmiri, and M. Danesh are with the Department of Mechanical Engineering, Isfahan University of Technology, Isfahan 84156-83111, Iran (e-mail: loueipour@cc.iut.ac.ir; mehdik@cc.iut.ac.ir; danesh@cc.iut.ac.ir).

M. Mojiri is with the Department of Electrical and Computer Engineering, Isfahan University of Technology, Isfahan 84156-83111, Iran (e-mail: mohsen.mojiri@cc.iut.ac.ir).

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