Ocean Engineering 147 (2018) 318–332

Contents lists available at ScienceDirect

Ocean Engineering

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

Sea state identification based on vessel motion response learning via multi-layer classifiers

Fangwen Tu [a], Shuzhi Sam Ge [a,b,*], Yoo Sang Choo [c], Chang Chieh Hang [a]

[a] Department of Electrical and Computer Engineering, National University of Singapore, Singapore
[b] Social Robotics Lab, Interactive Digital Media Institute (IDMI), National University of Singapore, Singapore
[c] Centre for Offshore Research and Engineering, National University of Singapore, Singapore

ARTICLE INFO

Keywords:
Sea state identification
Feature extraction
Multi-layer classifier
Marine vessel

ABSTRACT

In order to extend the operational weather window for marine vessels under Dynamic Positioning (DP) control, a novel sea state identification method with multi-layer classifiers is proposed in this paper. Due to the distinction of system responses for various sea states, four motion signals including surge, sway, roll and yaw are adopted for classification purpose. Firstly, preprocessing techniques, like filtration and k-means clustering are performed to the raw data to filter out the “corrupted” low frequency (LF) information and generate the band-pass filter bank. Then, the processed data is decomposed into 20 categories via Hilbert-Huang transform (HHT), filter bank method and wavelet transform and 11 statistical features are extracted for each category. Subsequently, Max-relevance Min-redundancy (mRMR) method helps to select salient features with best trade-off between relevance and redundancy. With these selected features, a newly developed three-layer classification structure with Adaptive Neuro-Fuzzy Inference System (ANFIS), Random Forest (RF) and Particle Swarm Optimization (PSO) based combination classifiers is proposed to derive the current sea state. The simulation results demonstrate that the proposed identification system can achieve satisfactory classification accuracy. Moreover, the multi-layer classifier outperforms single layer classifier and can rapidly classify the sea state in real-time implementation.

1. Introduction

Due to the increasingly serious global energy crisis, during the past few decades, people focused on offshore resources development, say, oil and gas. While, recently, offshore operations have been moving towards more challenging environments such as ultra-deep waters and arctic areas where richer resources are detected and to be mined. However, in deepwater environment, the traditional mooring system is not so efficient. Hence, there is a large demand to use the DP control system for a floating vessel. DP system keeps a vessel in fixed position or following a predefined trajectory through the active thrusters (Nguyen et al., 2007) so that a smooth and continuous offshore operation can be guaranteed.

The first DP system dates back to 1960s. This control system used an SISO PID controller to regulate the horizontal modes of motion (Sørensen, 2011). In 1980, a Kalman filter based optimal multi-variable control was proposed to cope with the slow oscillating motion of vessels based on model adjustments and parameter tuning rules (Balchen et al., 1980). A detailed mathematical model of vessel was required to optimally estimate the vessel motions and environmental forces. In 1990s, nonlinear controller such as fuzzy control and nonlinear feedback linearization based backstepping were designed in Stephens et al. (1995), Godhavn et al. (1998) and Berin et al. (2000) for DP system. Later, sliding mode control in combination with an easy tuning methodology were proposed in Tannuri et al. (2010) to handle the variations in environmental and loading conditions. However, all these control theories consider only a limit of weather condition. In Lindegaard (2003), the author proposed an acceleration feedback using IMU to improve the performance under severe sea conditions. To ensure the vessel stability during the ocean condition transition from calm to extreme, a supervisory-switched control was designed in Dong (2005); (Nguyen et al., 2007), Nguyen et al. (2008); Nguyen and Sørensen (2009); Hassani et al. (2012a,b). This hybrid control strategy increased the operation window by making it possible to realize all-year marine operations using the integration of a set of models and controllers. These works identify the sea state by using spectral analysis of the position measurement which is completely model free and based on signal processing only. In practical, due to the randomness of the environmental forces, this method which only depends on the recent collected data may easily lead

* Corresponding author. Department of Electrical and Computer Engineering, National University of Singapore, Singapore.
E-mail address: samge@nus.edu.sg (S.S. Ge).

https://doi.org/10.1016/j.oceaneng.2017.08.047
Received 25 December 2015; Received in revised form 23 August 2017; Accepted 29 August 2017
Available online 5 November 2017

to chattering or incorrect identification output. The model based sea state identification works can be found in Hassani et al. (2012a,b), (2013). Other sea state estimation researches are presented in Bitner-Gregersen et al. (2016); Eckert-Gallup et al. (2016); Nielsen (2017). Traditionally, sea state can either be assessed by an experienced observer, like a trained mariner, or through instruments like weather buoys, wave radar or remote sensing satellites (Calla, 2011). These schemes depend heavily on extra instruments or sensors which makes the results either inaccurate or uneconomical. In (Nguyen and Quek, 2010), the peak frequency of waves is estimated and the corresponding sea state is classified through the estimated peak frequency. But this method has innegligible probability of wrong condition estimation which may lead to the failure of the switching system. To address the above mentioned problems, a novel sea state identification system is proposed in this paper to accurately identify the sea state with the mounted motion sensors that are originally used for DP control purpose. The output of the proposed approach is the classified sea state levels (Calm, Smooth, High, …) which indicate the general condition of vessels in the ocean with respect to wind waves and swell at a certain location and moment. A detailed elaboration can be found in Section 2.

This scheme utilizes the onboard motion sensors such as global positioning system (GPS), hydro-acoustic position reference (HPR) unit, gyroscopes and motion reference unit (MRU) (Nguyen and Quek, 2010) to collect the four degree of freedom (DoF) motions (surge, sway, roll and yaw) of a vessel. These four motions contain the response information of wave force excitation and DP control force. Moreover, in order to reduce wear and tear on the thrusters, DP control only considers the LF motion of a vessel (Liu et al., 2008). Therefore, the high frequency (HF) wave-induced motion is relatively "pure" and can reflect the response of the vessel against varying sea state. To obtain the HF motion component,

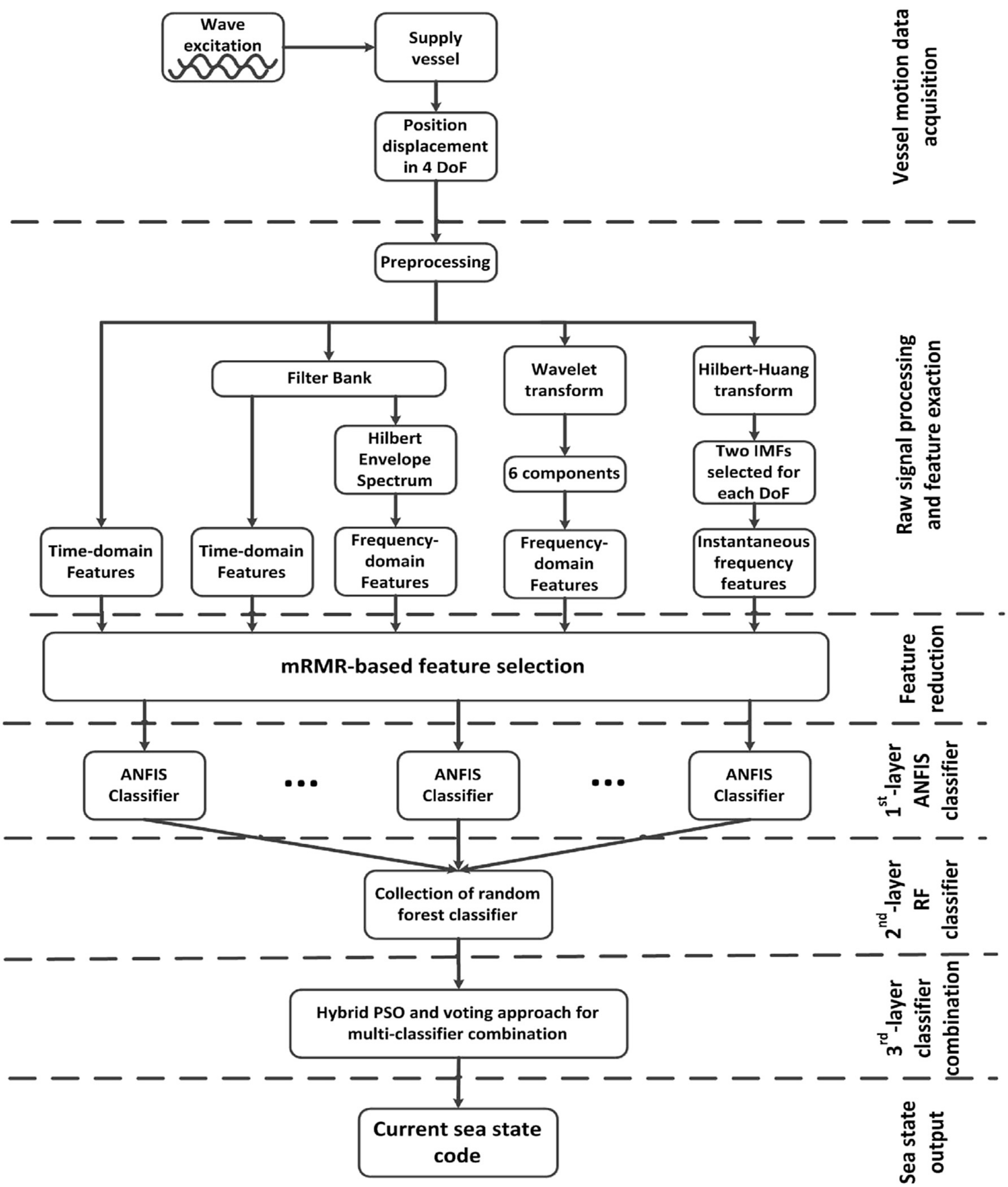

Fig. 1. Flow chart of sea state identification procedure.