Preface

Offshore engineering is concerned with the design and operation of systems in harsh marine environmental conditions. It encompasses a whole spectrum of diverse multidisciplinary and complex systems and operations such as offshore installations, structures, foundations, cables and pipelines, moorings, risers, drilling, mining, disposal and salvage operations, etc. The design of mechanical systems to operate in the harsh marine environmental conditions is one of the most challenging tasks in offshore engineering. One part of the challenges is in the modeling and control of such systems. This subject has received increasing attention in recent years with growing energy demands extending oil and gas explorations to deeper and even harsher environments.

The main purpose of the book is to investigate the fundamental issues including dynamical modeling and control design for different mechanical systems in offshore engineering. The book presents theoretical explorations on several fundamental problems for dynamics and control of marine mechanical systems. Motivated by the need to develop a general dynamic modeling and control framework to achieve system performance, concepts from control, mechanical structures, and offshore fields are synthesized via a systematic approach and presented. The basic theoretical framework is formed toward mechanical systems in offshore engineering, which not only extends the theory of mechanical structures, but also applies to realistic problems faced by the industry. A comprehensive study is provided for developing advance strategies for the modeling and control design of the systems with guaranteed stability. By investigating the characteristics of mechanical models, advanced control approaches are presented for marine mechanical systems with specific applications, i.e., installation systems, mooring systems, and riser systems. The control designs are coupled with numerical simulations to illustrate the effectiveness.

Offshore applications are characterized by the time-varying environmental disturbances and the sea conditions. For riser systems, vibration and deformation of the flexible structures due to the ocean current disturbances and the tension exerted at the top can produce premature fatigue problems and failures that require costly repairs. Proper control techniques are desirable for preventing damage and improving the lifespan of these structures. The chapter on structural analysis and riser operations (contributed by Geoff Lyons and Minoo Patel) describing an on-board riser operation management system that provides a real-time guidance for carrying out connected and disconnected mode drilling riser operations on board a vessel as an industrial case study.

The book contains ten chapters, which exploit several independent yet related topics in detail.

Chapter 1 introduces the system description, background, and motivation of the study and presents several general concepts and fundamental observations.

Chapter 2 presents several lemmas and properties used in the subsequent development and derivations of the dynamical models, and further stability analysis for the marine mechanical structures.

In Chap. 3, positioning control in the horizontal plane is investigated for the installation of subsea systems, with thrusters attached, under time-varying irrotational ocean current, when the payload is near to the seabed. Backstepping in combination with adaptive feedback approximation techniques is employed in the design of the control, with the option of high-gain observer for output feedback control. The stability of the design is demonstrated through Lyapunov analysis where semiglobal uniform boundedness of the closed-loop signals are guaranteed. The proposed adaptive neural control is able to capture the dominant dynamic behaviors without exact information on the hydrodynamic coefficients of the structure and current measurements.

In Chap. 4, the model of the coupled crane-cable-payload with nonuniform parameters is presented. Positioning control is derived for the coupled system with uniform parameters using barrier Lyapunov functions. Through Lyapunov analysis, it is shown that the coupled crane, payload flexible system is stable under the control action, the physical limits from operations planning and safety specifications are not transgressed, and positioning of crane and payload is achieved. A stabilizing boundary control is proposed for the coupled system with nonuniform parameters. Rigorous Lyapunov stability analysis is carried out, and uniform boundedness of the system is shown under the proposed control. Finally, the performance of the proposed control is given through numerical simulations.

In Chap. 5, a robust adaptive boundary control of a marine installation system is developed to position the subsea payload to the desired set-point and suppress the cable's vibration. The flexible cable coupled with vessel and payload dynamics is described by a distributed parameter system with one partial differential equation (PDE) and two ordinary differential equations (ODEs). Boundary control is proposed at the top and bottom boundary of the cable based on the Lyapunov direct method. Considering the system parametric uncertainties and the unknown ocean disturbances, the developed adaptive boundary control schemes achieve the uniform boundedness of the steady-state error between the boundary payload and the desired position. The control performance of the closed-loop system is guaranteed by suitably choosing the design parameters.

Chapter 6 is dedicated on the control problem of a thruster-assisted single-point mooring system, in the presence of uncertainties and unknown backlash-like hysteresis nonlinearities. Using backstepping technique and Lyapunov synthesis, and employing neural networks (NNs) to approximate the unknown nonlinear functions, robust adaptive backstepping control is developed for the full-state feedback case. Subsequently, in order to overcome the measure difficulty in the vessel velocity vector, a high-order NN-based observer is constructed to estimate the unmeasurable state vector. It is shown that the proposed observer has an excellent estimation performance in spite of the existence of uncertainties and unknown backlash-like hysteresis nonlinearities. Based on this observer, robust adaptive output feedback control is developed via backstepping design. Under the proposed control, the semiglobal uniform boundedness of all the signals in the closed-loop systems is guaranteed for both full-state and output feedback cases.

In Chap. 7, boundary control for a coupled nonlinear flexible marine riser with two actuators in transverse and longitudinal directions is developed to reduce the riser's vibrations. The dynamic behavior of the flexible riser is represented by a distributed parameter system (DPS) model with partial differential equations (PDEs) and the control is applied at the top boundary of the riser based on Lyapunov direct method to suppress the riser's vibrations. With the proposed boundary control, the uniform boundedness under ocean current disturbances and exponential stability under the free vibration condition is achieved. The proposed control is independent of system parameters, which ensures the robustness of the system to variations in parameters.

Chapter 8 studies the modeling and control of a flexible marine riser with the vessel dynamics. Both the dynamics of the vessel and the vibration of the riser are considered in the dynamic analysis, which make the system more difficult to control. Boundary control is proposed at the top boundary of the riser to suppress the riser's vibration. Adaptive control is designed when the system parametric uncertainties exist. Employing the Lyapunov direct method, the states of the system are proven to be uniformly ultimately bounded. The state of the system will converge to a small neighborhood of zero by appropriately choosing the design parameters. The design is based on the PDEs of the system, thus avoiding some drawbacks associated with the traditional truncated-model-based design approaches.

Chapter 9 serves as an industrial case study in this book. This chapter investigates the structural analysis and the riser operations of fixed and floating offshore structures using pipe connections between surface facilities and seabed as well as pipes laying on or below the seabed for transportation of oil and gas. The analysis of vertical marine risers under the influences of both internal and external forces is described. Four configurations of the marine risers are introduced including free handing mode, connected mode, operational mode, and nonoperational but connected mode. A marine riser can be maintained in an operable condition by ensuring that the lower ball joint angle remains below about 4 degrees. Three operating procedures are given to bring the angle down. The marine riser monitoring system provides information on the behaviors of the platform and the marine riser, and comparisons can be made with previous results for evaluating the projected fatigue life of the riser. BPP-RMS, an example of the comprehensive Riser Management System (RMS) for riser maintenance and inspection, is presented. BPP-RMS is an on-board riser operation management system that provides a real-time guidance for carrying out connected and disconnected mode drilling riser operations on board a vessel.

Chapter 10, the last chapter, makes conclusions on this book.

In summary, this book covers the dynamical analysis and control design for marine mechanical systems. The book is primarily intended for researchers and engineers in the control system and offshore engineering community. It can also serve as a complementary reading on modeling and control of marine mechanical systems at the post-graduate level.

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