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# Robust-to-Modeling-Uncertainties Nonlinear Control Design for Offshore Structures

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**A controller design methodology for offshore structures is investigated. Because stochastic simulation is used for evaluation of the system's performance in the design stage, nonlinear characteristics of the structural response and excitation can be explicitly incorporated into the assumed system model. Model parameters whose values are uncertain are probabilistically described. In this context, the controller is designed for optimal reliability, quantified as the probability that the performance will not exceed some acceptable bounds over some time duration. The methodology is illustrated with an example involving the control of a tension leg platform in an uncertain sea environment.**

## INTRODUCTION

Under severe sea and wind conditions, offshore structures such as jacket-type or tension leg platforms (TLP) may experience large response amplitudes that affect their serviceability and structural integrity. Active and passive control techniques have been considered for reduction of the effects of such dynamic loadings (Ahmad and Ahmad, 1999; Alves and Batista, 1999; Nakamura et al., 1997; Suhardjo and Kareem, 2001; Spil1ane et al., 2007). Most of the studies in offshore structure control have adopted linear methodologies for the controller design, typically $H_2$ control. However, the models used for the prediction of the behavior of offshore structures typically involve various types of nonlinearities. In particular, nonlinearities may come from:

• modeling the dynamic response of the structure—for example, in the case of TLP, as discussed in Angelides et al. (1982);

• characterizing the excitation forces acting on the structure—for example, the spectrum for a "random" sea environment or for the wave particle kinematics (Goda, 2000).

One of the main challenges in controller design for offshore applications has been the explicit consideration of these nonlinearities.

Enhanced linearization techniques have been suggested for addressing the second type of nonlinearity when applying linear control methodologies (Suhardjo and Kareem, 2001). While this approach has the potential to adequately capture important nonlinear characteristics of the response, the application is usually not straightforward for complex systems. The first type of nonlinearity, which is more important, is commonly ignored. The controlled system is usually designed based on a linear model that does not take into account nonlinear characteristics (Ahmad and Ahmad, 1999; Alves and Batista, 1999). Only the performance of the system is evaluated, using at a later stage a nonlinear model (Ahmad and Ahmad, 1999). This approach might however lead to a suboptimal design in terms of the actual (nonlinear) system performance.

Another challenge related to offshore structure control has been the efficient description of the uncertainties involved in the system model. In maritime applications, as in most other engineering applications, there are model properties that involve some level of uncertainty (for example, the characteristics of the sea environment). This uncertainty can be quantified by a probabilistic description of the model parameters (Mathisen and Bitner-Gregersen, 1990; Papadimitriou et al., 2001). Such an approach logically incorporates into the model the available knowledge about the system and allows for a robust-to-uncertainty design. Typically, though, a nominal model is adopted when designing the controlled system, using the most probable values for the model parameters. Uncertainties are not taken into account.

This study considers a controller design for offshore applications that addresses these challenges. Simulation is used for evaluating the model response at the controller design stage, which allows explicit treatment of the system's nonlinear characteristics. Uncertainty about the model parameters is treated by assigning them probability density functions (PDF). In this context, reliability criteria are used to evaluate the performance of the controlled system and for the controller optimization. The methodology is illustrated in an example involving the control of a TLP in an uncertain sea state. The control force is provided by tuned mass dampers, placed inside the columns of the platform's hull. Both passive and active applications are discussed. A realistic setting is considered for the latter; assumed are actuator saturation, availability of only noisy acceleration measurements, and time delays in the control loop. Multiple nonlinearities are taken into account for the platform's response, and a probabilistic description is adopted for the system model.

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