DOCTOR
OF
PHILOSOPHY

NONLINEAR DYNAMICS IN THE MODELING OF HELICOPTER ROTOR BLADE LEAD/LAG MOTION

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Until recently, computer simulations of helicopter rotor dynamics have employed equations of motion that have been linearized or simplified. These modified equations of motion did not allow for the evaluation of nonlinear material properties in the rotor since higher order terms in the dynamics had been modified in the simplification process. With recent advances in both computer simulation hardware and symbolic mathematic manipulation software, the full nonlinear equations of motion may be utilized in helicopter rotor simulations. This dissertation reports on the use of the full nonlinear equations of motion in the analysis of rotor blade lead/lag motion and its effect on rotor hub and rigid body fuselage motion. Nonlinear modeling methods are implemented using Maple symbolic mathematic manipulation software and Matlab and Simulink computer simulation environments. Results are compared to the RAH-66 Comanche Froude scale wind tunnel article and new methodologies evaluated in the search for a damperless rotor system that is free of ground and air resonance mechanical instabilities.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Modeling and Simulation

KEYWORDS: Helicopter Rotor Dynamics, Nonlinear Dynamics

SEAWAY LEARNING AND MOTION COMPENSATION IN SHALLOW WATERS FOR SMALL AUTONOMOUS UNDERWATER VEHICLES (AUVS)

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The continual development of computer technology has enabled the expansion of intelligent control into the field of underwater robots, where potential uses include oceanographic research, environmental monitoring, and military mine countermeasures. With the naval focus shifting to operations in the littorals, and the need to lower cost of operations, tetherless autonomous vehicles are now being proposed for use in very shallow water minefield reconnaissance. These areas are dominated by a highly energetic

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environment arising from waves and currents. Motion control in such an environment becomes a difficult task and is the subject of this work.

The main objective of this dissertation, is to show through modeling and simulation, and in-ocean experimental validation, that intervention tasks performed by intelligent underwater robots are improved by their ability to gather, learn, and use information about their working environment. Using a new generalized approach to the modeling of underwater vehicles, which directly includes disturbance effects, a new Disturbance Compensation Controller (DCC) is proposed. The DCC, employing onboard vehicle sensors, allows the robot to learn and estimate the seaway dynamics. This self-derived knowledge is embedded in a non-linear sliding mode control law which allows significantly improved motion stabilization. The performance of the DCC has been verified in Monterey Harbor using the Naval Postgraduate School *Phoenix* AUV.

DoD KEY TECHNOLOGY AREAS: Command, Control, and Communications, Computing and Software, Sensors, Surface/Under Surface Vehicles - Ships and Watercraft, Modeling and Simulation

KEYWORDS: Disturbance Rejection, Sliding Mode Control, Seaway Learning, Autonomous Underwater Vehicles, Control Systems

ENTRAINMENT, DETRAINMENT, AND LARGE-SCALE HORIZONTAL GRADIENTS IN OCEANIC DEEP CONVECTION

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The theory of oceanic convection and entrainment has been developed mainly in horizontally homogeneous regimes, yet large-scale spatial variability is known to control the sites and intensity of deep convection. Wintertime Greenland Sea conditions were selected to simulate convection and quantify the interplay between local forcing and large-scale gradients. Here circulation and preconditioning produce horizontal gradients in the stratification; some of the resulting stratification is conducive to the formation of thermobaric convective instabilities.

A large eddy simulation (LES) model modified to include large-scale horizontal density gradients was used to study the effects of the gradients on turbulence. Horizontal turbulent kinetic energy (TKE) and scalar variances increased compared to simulations with no large-scale gradient. The additional horizontal TKE is created at scales larger than the convective plume scale. A mean horizontal circulation develops in response to the large-scale overturning. The balance between convection and overturning increases stratification in the lower region of the mixed layer, and plumes may undergo slantwise convection.

One-dimensional bulk TKE model results were compared to a large eddy simulation of wintertime Greenland Sea convection. One-dimensional and LES results were similar in the distribution of TKE components and in the ratio A_R of entrainment buoyancy flux to surface buoyancy flux for the winter period modeled. The value of AR was large because of strong shear production, 0.42 for the one-dimensional model, and 0.36 for the LES. Detraining thermobaric plumes were simulated by LES under various conditions of rotation and stratification. A critical depth h_{cr} and critical velocity w_{cr} hypothesized by Garwood et al. (1994) were shown to be predictors for onset of detrainment. The skewness of vertical velocity in a horizontal slice just below the mixed layer is shown to be an indicator for detrainment events. The fraction of mixed-layer water present at depth quantifies plume transport below the layer.

DoD KEY TECHNOLOGY AREA: Other (Ocean Environment Prediction)

KEYWORDS: Ocean Mixed Layer, Oceanic Deep Convection, Large Eddy Simulation, Geophysical Turbulence, Entrainment, Termobaric, Plumes

MAXIMUM-LIKELIHOOD ESTIMATORS FOR THE TIME AND FREQUENCY DIFFERENCES OF ARRIVAL OF CYCLOSTATIONARY DIGITAL COMMUNICATIONS SIGNALS

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Advanced techniques have been employed for decades in the location of emitted communications signals. The use of cyclostationary maximum-likelihood estimators (MLE) applied to time difference of arrival (TDOA) and frequency difference of arrival (FDOA) techniques for target emitter location is a newly developed approach. This dissertation provides an introduction to traditional TDOA and FDOA methods and the underlying cyclostationary theory of pseudo-random signals. A survey of current cyclostationary TDOA and FDOA methods, the description of new maximum likelihood estimators (MLEs) and descriptions of Monte Carlo simulations follow this.

By comparing performance results to those of the Complex Ambiguity Function (CAF), it is shown that the new MLE(s) outperform the CAF in nearly all cases. Also, by comparison to the Cramer-Rao lower bound, the new MLE(s) provide a hint of the ultimate power of cyclostationary techniques over stationary techniques, exceeding this stationary theoretical lower bound on performance in many cases. Finally, the new MLE(s) perform comparably in the measurement of TDOA to those cyclostationary algorithms previously derived, when adjustments are made for the different signal environments used in the heritage work.

DoD KEY TECHNOLOGY AREAS: Electronic Warfare, Sensors

KEYWORDS: Cyclostationary, Time Difference of Arrival, TDOA, Frequency Difference of Arrival, FDOA, Maximum Likelihood Estimation