Dynamic Mode Decomposition with Time-Delaying Embedding for Time-Series Forecasting of Ships Operating in Waves

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ABSTRACT

To guarantee the safety of payload, crew, and structures, ships must have good seakeeping, maneuverability, and structural-response performance, also when they operate in adverse weather conditions. In this context, the availability of forecasting methods and model-predictive control approaches may represent a decisive factor. Here, a data-driven and equation-free modeling approach for forecasting of trajectories, motions, and forces of ships in waves is presented, based on dynamic mode decomposition (DMD). DMD is a data-driven modeling method, which provides a linear finite-dimensional representation of a possibly nonlinear system dynamics by means of a set of modes with associated frequencies. Its use for ship operating in waves was discussed in [1] and a systematic analysis of its forecasting capabilities was presented in [2]. Here, the DMD approach to forecasting ship responses is extended to time-delaying embedding [3], which enables an accurate modeling of nonlinear responses by augmenting (and therefore increasing in dimensionality) the system state matrix. Specifically, time-shifted copies of time series are added to the data matrix (forming the so-called Hankel matrix of time-series data). Finally, the singular value decomposition is used to provide an optimal low-rank representation of the Hankel matrix and the desired modeling of the ship response aimed at forecasting trajectories, motions, and forces. The assessment of the forecasting capabilities is based on four metrics: normalized root mean square error, Pearson correlation coefficient, average angle measure, and normalized average minimum/maximum absolute error. Two test cases are used for the assessment: the course keeping of a self-propelled 5415M in irregular stern-quartering waves and the turning-circle of a free-running self-propelled KRISO Container Ship in regular waves. Results are overall promising and show how time delaying embedding improves the DMD forecasting capabilities for ships operating in waves. Furthermore, DMD provides the identification of the most important dynamic modes, shedding light onto the physics of the underlying system dynamics.

REFERENCES

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