Artificial Intelligence Machine Learning in Marine Hydrodynamics

by

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Machine Learning Disciplines

- Statistics (Frequentist & Bayesian)
- Information Theory (Shannon Entropy – Kullbak-Liebler Divergence)
- Convex Optimization Theory (Lagrangian & Fenchel Dual)
- Computation (Gradient Descent, Markov-Chain Monte Carlo)
- Functional Analysis (SVM-Positive Definite Kernels)
- Physics (Field Methods, Variational Bayesian Formulations)

Formulation of ML Algorithms

$$Design\ Matrix: [\vec{X}^T_{1,\ldots,D}, Y]_{n=1,\ldots,N};\ N(Samples)\times(D+1)\,(Input\ Features + Output);$$

$$p(Y,\vec{X}) = p(Y\,|\,\vec{X})\,p(\vec{X})$$

$$Bayes\ Rule: \qquad p(\vec{X}\,|\,Y) = \frac{p(Y\,|\,\vec{X})\,p(\vec{X})}{p(Y)} = \frac{p(Y\,|\,\vec{X})\,p(\vec{X})}{\int d\vec{X}\,p(Y\,|\,\vec{X})\,p(\vec{X})}$$

$$p(Y\,|\,\vec{X}): Supervised\ Learning; Density\ of\ Output\ Conditional\ on\ Observed\ Input$$

$$p(\vec{X}) \quad : Unsupervised\ Learning\ of\ \vec{X};\ Density\ Estimation\ /\ Prior$$

$$p(\vec{X}\,|\,Y): Density\ of\ Input\ Conditional\ on\ Observed\ Output\ /\ Feature\ Selection$$

$$\hat{Y} = F(\vec{X}) = \sum_{i=1}^{M} \beta_i\, h_i(\vec{X};\alpha_i)$$

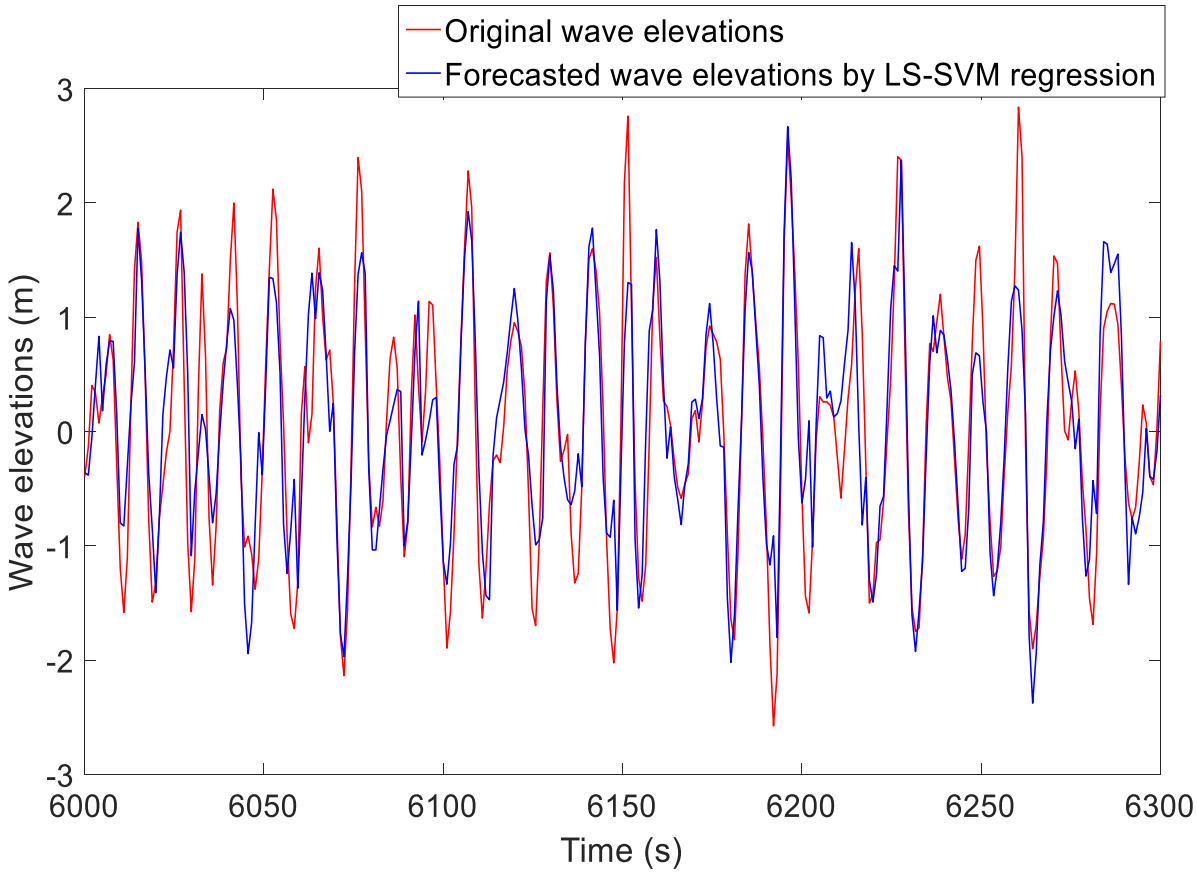
$$h: Linear, Spline, Sigmoid, Gaussian, Decision\ Tree$$

$$\min_{\alpha,\beta,\lambda,M}\left[\sum_{n=1}^{N_{Train}} Loss\,[Y_n,\hat{Y}_n] + \lambda\left\|h\right\|_p\right],\ p-Norm\ Penalized\ Loss$$

Machine Learning Algorithms

- Linear & Polynomial Regression (Ridge L2, Lasso L1, Splines)
- Artificial Neural Networks – Deep Learning
- Support Vector Machines – L2 Norm Kernel “Trick”
- Decision Trees – Boosting (AdaBoost, XGBoost, DeepBoost)
- Random Forests (Bootstrapping, Random Subsampling)

Model-Predictive Control of Floating Wind Turbines and Wave Energy Converters
SVM Forecasts of Seastate Elevations: RMS Error 5-10% Hs



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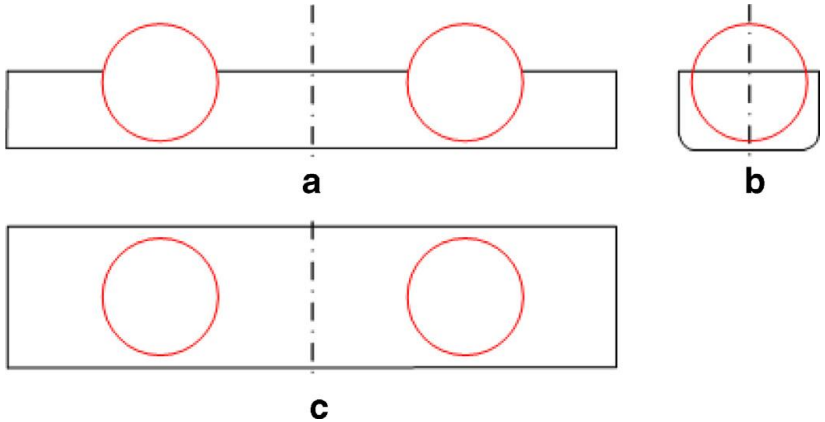
Viscous Loads on a Liquefied Natural Gas Carrier



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Free-Decay Test – Liquid LNG
Gaussian SVM Kernel Model for Viscous Load