Sea State Estimation Using Partial Least Squares Regression and Quadratic Discriminant Analysis

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Objective and Scope

The objective of this project is the development of non-model based methods for sea state estimation. The scope is estimation of the wave direction, distinguishing between port and starboard waves, and estimation of significant wave height and peak wave period for a dynamically positioned vessel, with methods that are independent on the vessel transfer functions.

Introduction

Information about the sea state is necessary for decision making, securing safe marine operations. On board sea state estimation may provide a more accurate sea state than information from wave buoys as it provides information in real time and for the specific position the vessel is in [1]. Sea state estimation covers a wide range of purposes, such as for operational profiles, i.e. whether the ship operates in the conditions it was designed for, fuel performance evaluations, research on added resistance and accident investigations. The sea state is also of interest for autonomous ships, where the control system needs as much information as possible about the vessel surroundings and operational environment. Additionally, the sea state is an important input to the on board decision support system, as it for example can be used when detecting the occurrence of parametric roll [2].

Previous work within the field involve model based calculation both in the time and frequency domain, for ships with forward speed and in Dynamic Positioning (DP). Most of the present day methods can be characterized as the so-called wave buoy analogy. The wave buoy analogy involves using a mathematical model to relate vessel response measurement data to the sea state. The common ground for many present model based methods is that they rely on some knowledge of the vessel's transfer function, which is not always available.

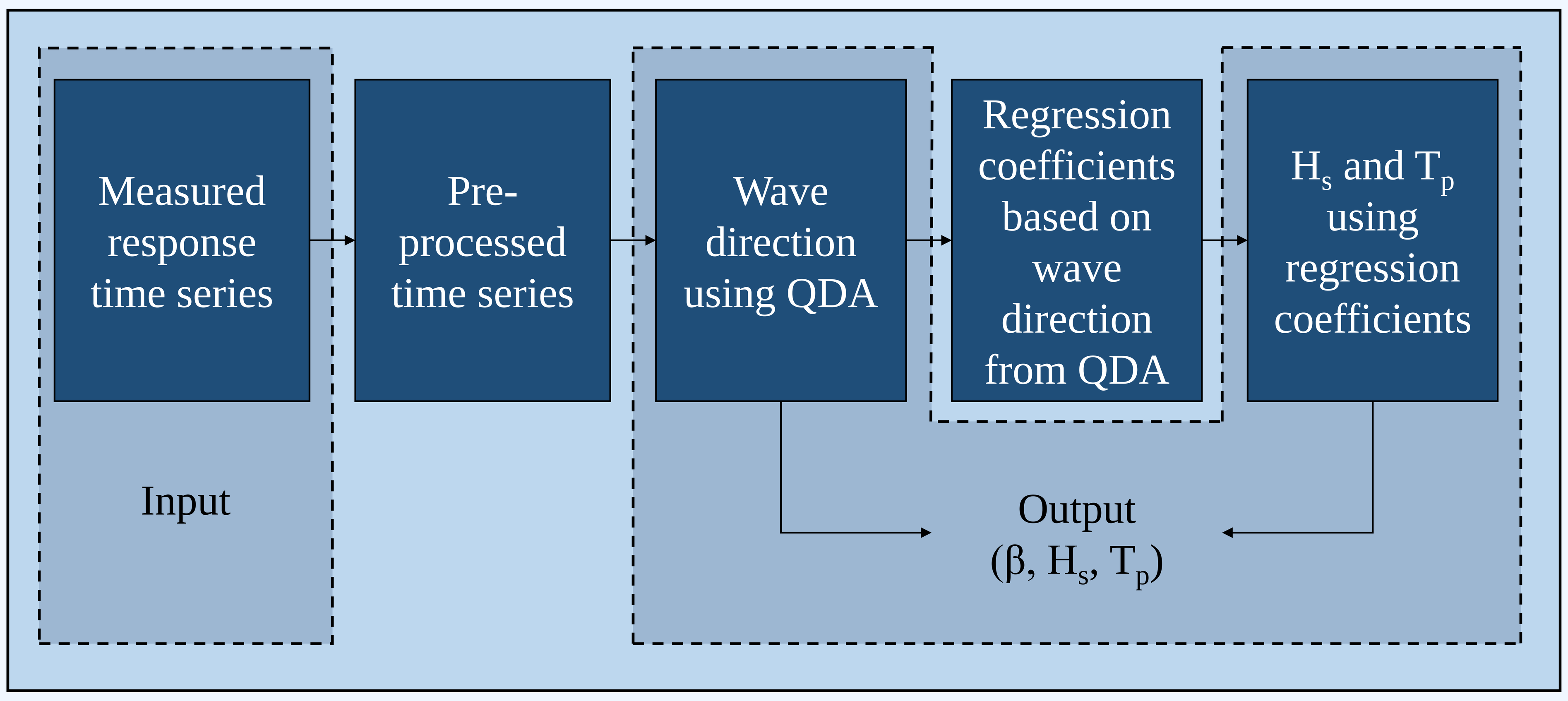
References

[1] Ulrik D. Nielsen. A concise account of techniques available for shipboard sea state estimation. *Ocean Engineering*, 129:352–362, 2017.

[2] Roberto Galeazzi, Mogens Blanke, Thomas Falkenberg, Niels K. Poulsen, Nikos Violaris, Gaute Storhaug, and Mikael Huss. Parametric roll resonance monitoring using signal-based detection. *Ocean Engineering*, 109(C):355–371, 2015.

Methodology

The approach for estimating the sea state is based on a few steps, as shown in the flow chart below. Firstly, the quadratic discriminant model is trained to find the wave direction. The response of the vessel varies with varying wave directions, so PLSR is done for each of the wave directions. In practice, this means that each wave direction has an associated set of regression coefficients that can be used to estimate the significant wave height and peak wave period.



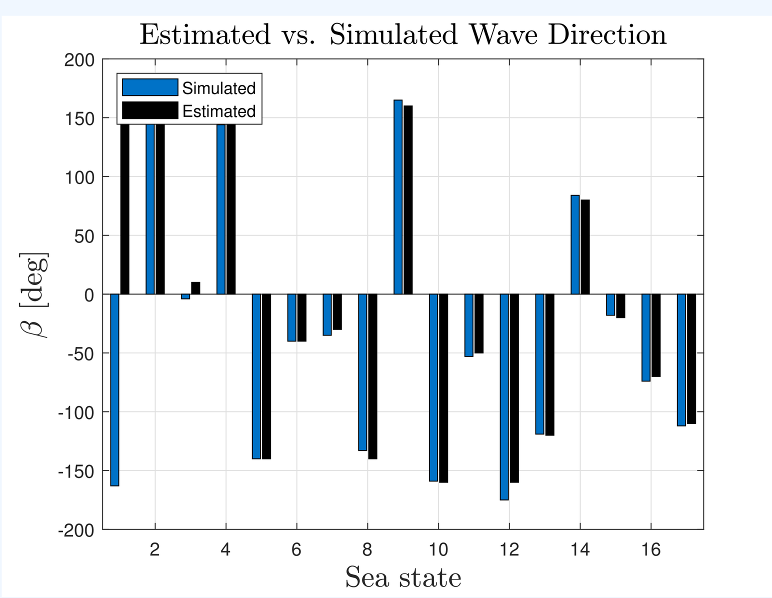
The wave direction is first found using the trained model. Based on the output from this model, the regression coefficients for the wave direction closest to this output are chosen and used to estimate the significant wave height and peak wave period.

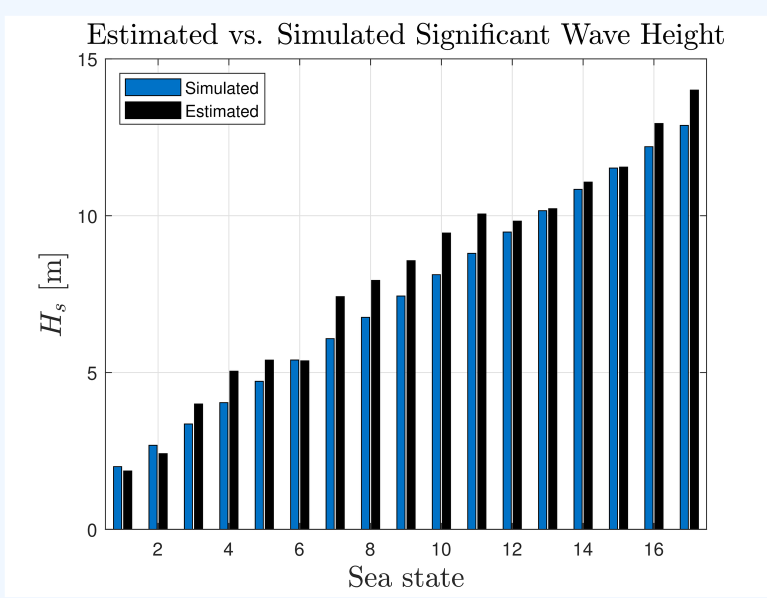
Simulation Results

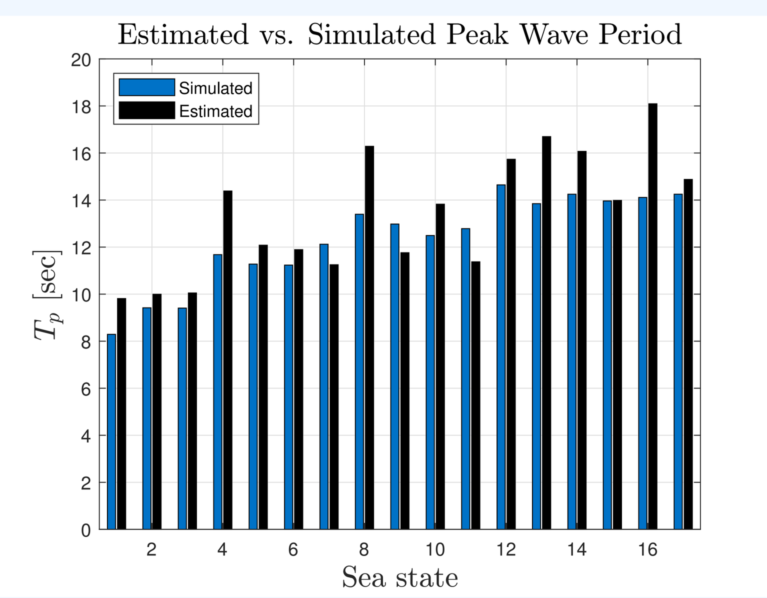
The table shows the sea states used to demonstrate sea state estimation results. Figures below show the estimation of wave direction, significant wave height and peak wave period for all these sea states. Wave direction is estimated accurately for nearly all sea states. As expected, nearly all sea states have an error of less than 10° as the classification algorithm is trained on data for every 10th degree. The exception is sea state 12, which has a deviation of 15°. Distinguishment between port and starboard waves is done with success for all sea states except 1 and 3. These sea states have incoming wave direction of $-163°$ and $-4°$, thus close to head and following sea respectively. The likely reason for the wrong estimation of the wave direction is that for these two sea states the roll motions are low and the heave-roll cross-spectra therefore carries limited information. Results show that the average deviation between simulated and estimated significant wave height is 0.7 m. Sea states 7-11 and 17 largely contribute to increasing this average with deviations up to 1.3 m. Higher deviations for higher sea states is expected as the method used is a linear method and in severe waves there are nonlinear phenomena present.

Sea State	β [deg]	H_s [m]	T_p [s]
1	-163	2.0	8.3
2	161	2.7	9.4
3	-4	3.4	9.4
4	144	4.0	11.7
5	-140	4.7	11.3
6	-40	5.4	11.2
7	-35	6.1	12.1
8	-133	6.8	13.4
9	165	7.4	13.0
10	-159	8.1	12.5
11	-53	8.8	12.8
12	-175	9.5	14.6
13	-119	10.2	13.8
14	84	10.8	14.2
15	-18	11.5	14.0
16	-74	12.2	14.1
17	-112	12.9	14.2

The average deviation in peak wave period is 1.5 s, and many of the sea states are well below this average. However, especially sea state 16 largely increases the average deviation with a deviation of almost 4 seconds.







Conclusion

The sea state estimation algorithm estimated wave direction, significant wave height and peak wave period with promising results. As expected, significant wave height and peak wave period have been estimated with more accuracy for lower sea states, due to nonlinear effects in more severe waves. Interesting continuance of the work presented includes testing the algorithms on full-scale experiments. This could yield a conclusion on whether simplified simulated data for training is in fact sufficient to develop algorithms applicable at sea. Further, changing the spectrum used in simulations and thus allowing for higher variations in sea states would be interesting. Good results with a large variety of sea states would likely yield a more applicable model.