Kalman estimation of position and velocity for ReaTHM testing applications

Eirill Bachmann Mehammer[1,5], Martin Føre[2], Thomas Sauder[2,4], Valentin Chabaud[3] and Thomas Parisini[1]

[1]Dept. Of Electrical and Electronic Engineering, Imperial College London, SW7 2AZ, UK

[2] SINTEF Ocean, P.O. Box 4762 Torgard, NO-7465 Trondheim, Norway

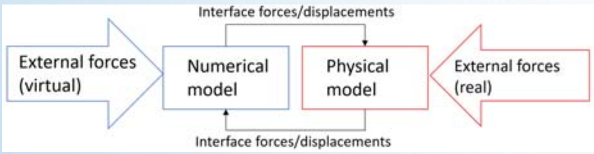
[3]Dept. of Marine Technology, NTNU, NO-7491 Trondheim, Norway

[4]Centre for Autonomous Marine Operations and Systems (NTNU AMOS), Marine Technology Centre, NO-7491 Trondheim, Norway

[5]Present address: SINTEF Energy Research, P.O. Box 4761 Torgarden, NO-7465 Trondheim, Norway

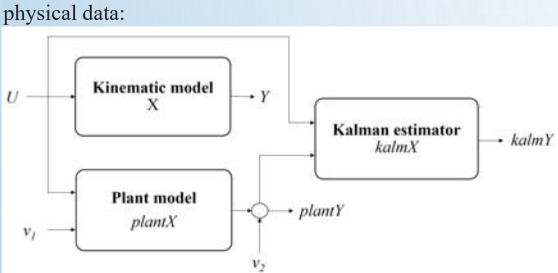
Introduction

- Model testing can reduce the costs of offshore wind turbines (OWTs).
- Real-time hybrid model (ReaTHM) testing provides solution to challenges related to such tests.
- The system is divided into physical and numerical substructure.
- State estimator is designed to estimate and filter the positions and velocities of the physical substructure.

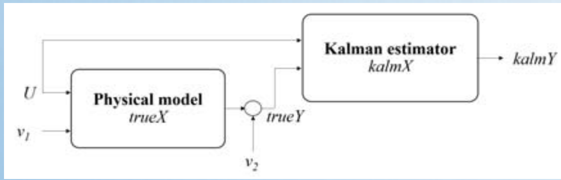


Numerical Model

Two different versions of the system are designed for tests using virtual and physical data:



Virtual data



Physical data

Kinematic model

- Can represent the motion of any floating structure in 6-DOF.
- Plant model intended to simulate the physical system is implemented using the same state-space matrices.
- State vector consists of the variables to be estimated.
- Output vector consists of the variables which can be measured.
- System matrices are defined according to Fossen [1].
- Simplified model for tests with SIMA: linear and time-invariant.

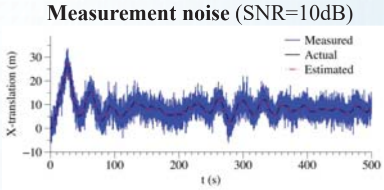
Estimator design

- Kalman estimator chosen since it provides optimal estimates, minimizing the estimation error in the statistical sense.
- Both steady-state and time-varying versions are designed, implemented in MATLAB and tested.

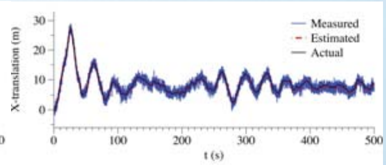
Sensitivity analyses using virtual data

Sensitivity analyses addressing the robustness towards different types of disturbances are performed to identify the limits of the estimator. Time-varying Kalman estimator used for signal loss, otherwise steady-state version is used.

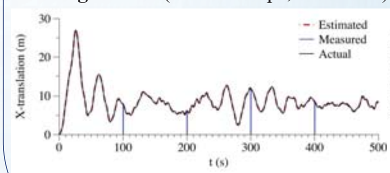
Measurement noise (SNR=10dB)



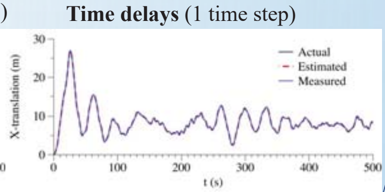
Uncertainties in *R* (x10)



Signal loss (10 time steps, 4 instants)



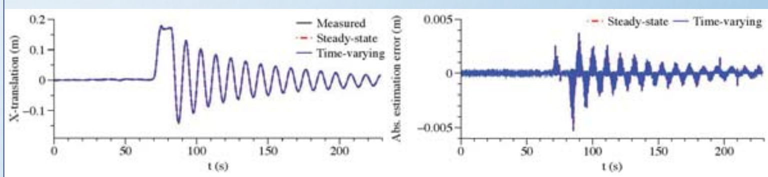
Time delays (1 time step)



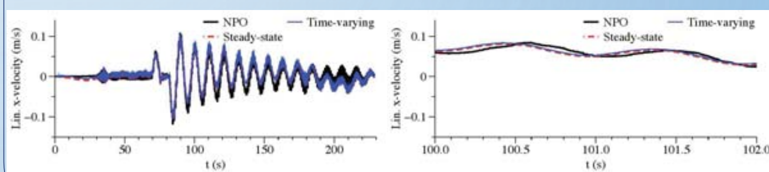
The estimator is robust towards noise, uncertainties, time delays and signal loss.

Validation of estimator using physical data

Both versions of the Kalman estimator are further tested against the laboratory experiments by Vilsen et al. [2]. Knowledge about delays and inaccuracies in the sensors used is taken into account.



Comparison of steady-state and time-varying Kalman estimates with physical data



Comparison of steady-state and time-varying Kalman estimates with NPO

Good results are obtained for both versions of the Kalman estimator.

Conclusions

- The generic kinematic model developed can recreate the SIMA simulated motions with reasonable accuracy.
- A Kalman estimator providing smooth and accurate position and velocity estimates in 6-DOF is designed, implemented and tested.
- The estimator is proven to be robust towards different types of disturbances.
- The estimator is able to estimate the states with a good accuracy, when compared with physical measurements.
- An improvement from the previously implemented estimators is demonstrated.

References

[1] Fossen T I 2011 *Handbook of Marine Craft Hydrodynamics and Motion Control* (Chichester, UK: John Wiley & Sons, Ltd.)

[2] Vilsen S A, Sauder T and Sørensen A J 2017 *Dyn. Coupl. Struct.* **4** 79-92