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CORROSION DETECTION AND PROGNOSTICS FOR OFFSHORE WIND-TURBINE STRUCTURES USING SWITCHING KALMAN FILTERING

Robert Brijder, Stijn Helsen, Agusmian Partogi Ompusunggu

Flanders Make vzw, CoreLab DecisionS, Belgium

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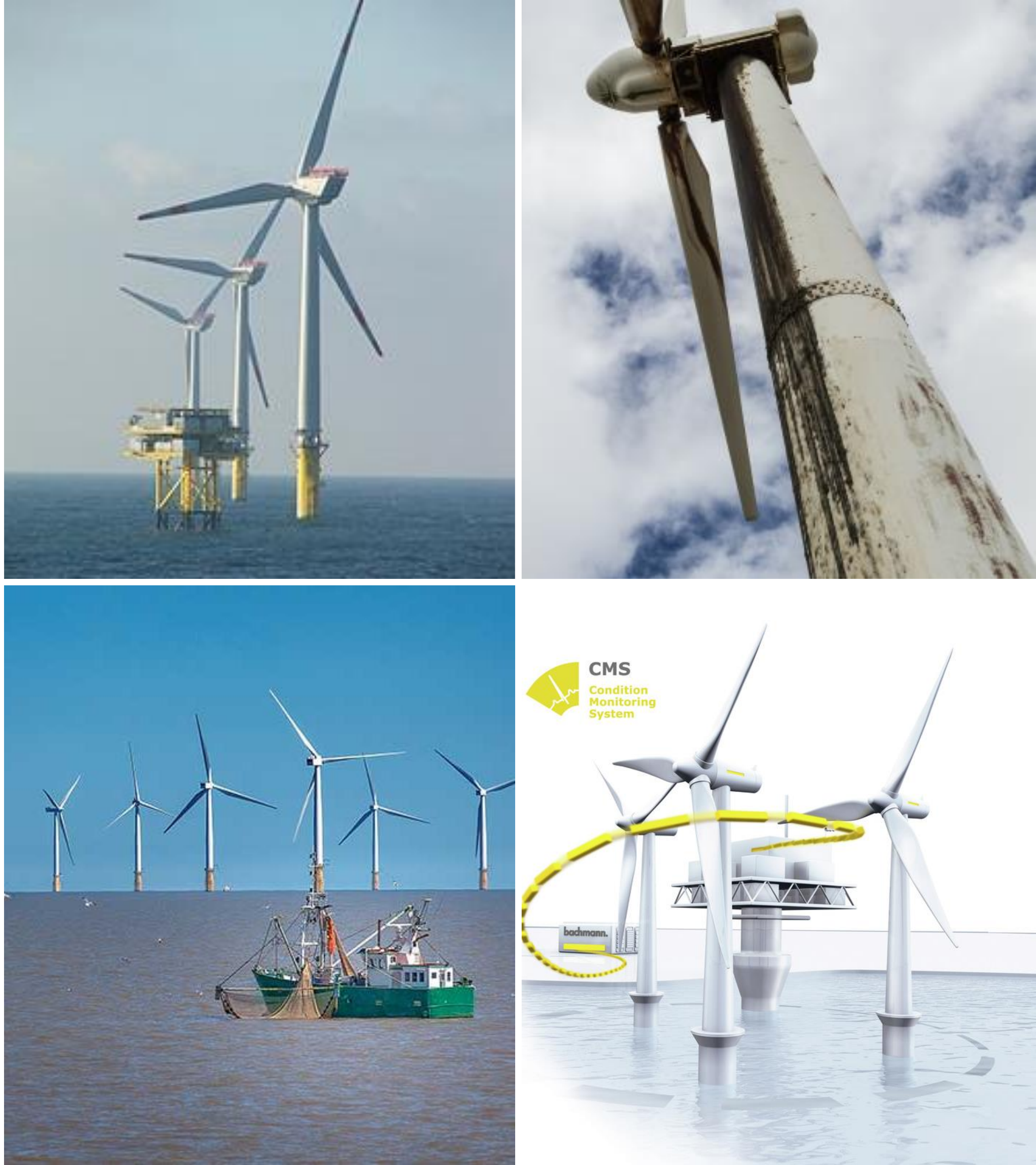
DRIVING INNOVATION IN MANUFACTURING



Motivation

- Manual inspections of far offshore wind farms are costly
  ➔ remote monitoring of critical components/sub-systems.
- Prognostics is vital for scheduling maintenance while avoiding system faults and escalation of damage.
- Uniform corrosion is a major cause of failure of offshore structures.
- Monitoring of uniform corrosion by continuously measuring wall thickness using ultrasound sensors.

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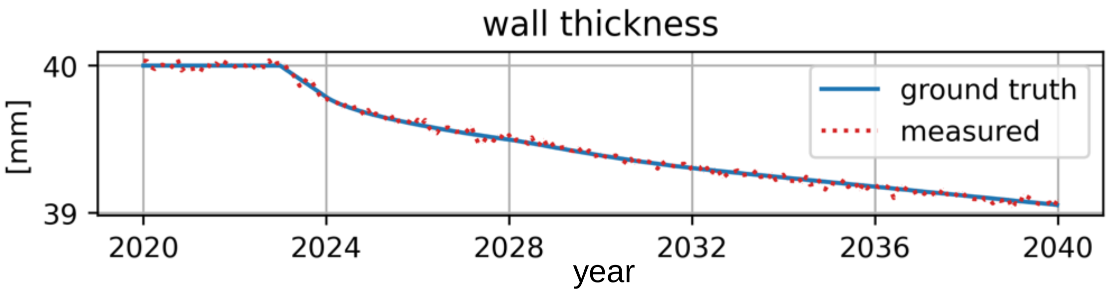
Method: dataset generation and corrosion detection

Simulation of ground truth and measurements

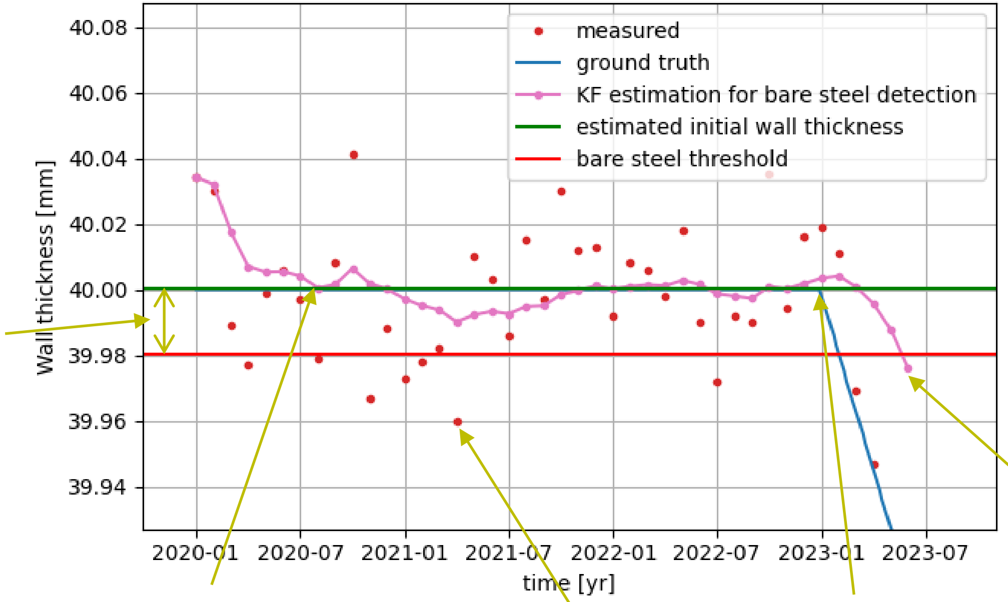
- Unavailability of suitable datasets ➔ simulate ultrasound measurements of wall thickness with corrosion.
- Using empirical bi-modal corrosion model of [Melchers, 2018] suitable for (most severe) splash zone.
- Initial coating degradation phase and relevant measurement/process noise and temperature influence added.



[Melchers, 2018] R. E. Melchers. Progress in developing realistic corrosion models. Structure and Infrastructure Engineering, 14:843–853, 2018.

Corrosion detection

- Kalman filtering with constant state-transition function to estimate initial wall thickness (green) and current wall thickness (pink).
- Corrosion is detected once the current wall thickness (pink) drops below fixed threshold (red).



fixed offset (0.02 mm)

estimated initial wall thickness based on the first *x* measurement points (here, x=8)

robust against measurement noise

bare steel exposed

corrosion detection

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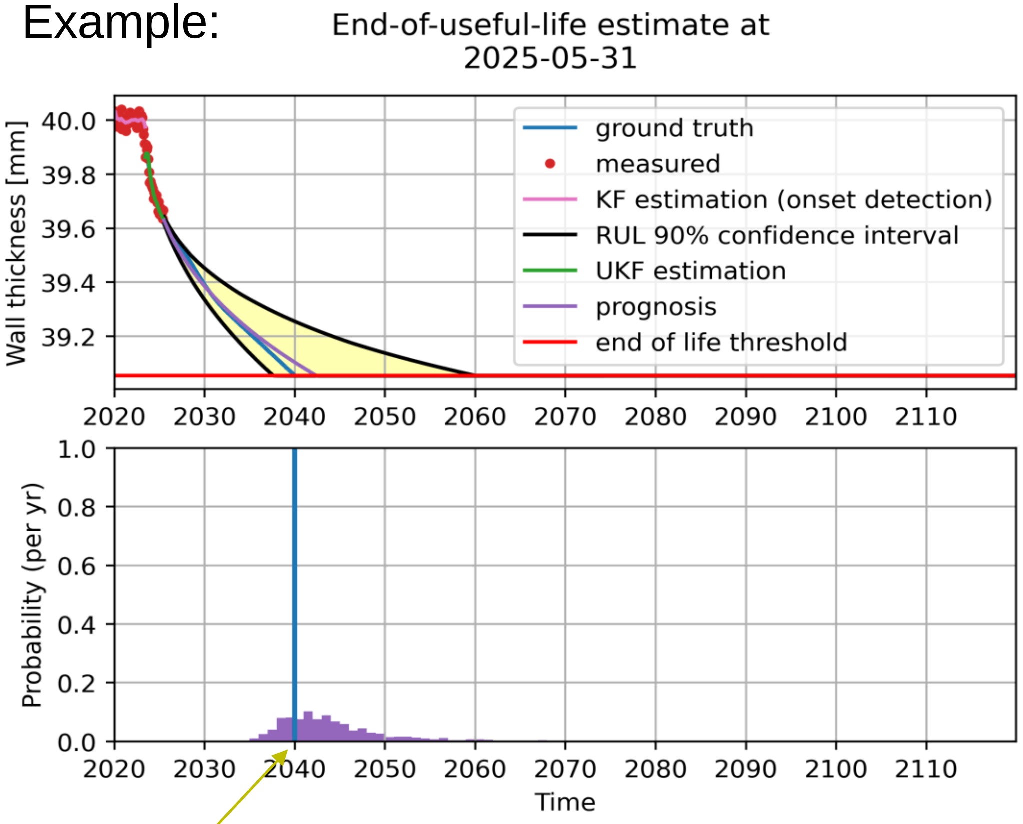
Corrosion Prognostics

- Switching Kalman filtering: after corrosion detection, switch to another Kalman filter for prognosis.
- We consider three corrosion/degradation models van prognosis:
  - Linear corrosion model (i.e., constant corrosion rate)
  - Power-law corrosion model (Pourbaix)
  - Bimodal corrosion model
- Power-law and bimodal models are nonlinear ➔ use of *Unscented* Kalman Filtering (UKF) here.
- Corrosion is slow ➔ choosing accuracy of UKF over speed of Extended KF.
- Both KF and UKF provide both a state estimation and an uncertainty probability distribution.

Example:



State to RUL estimate mapping is nonlinear ➔ Samples taken from the probability distribution are mapped to RUL estimate to obtain RUL estimate distribution.

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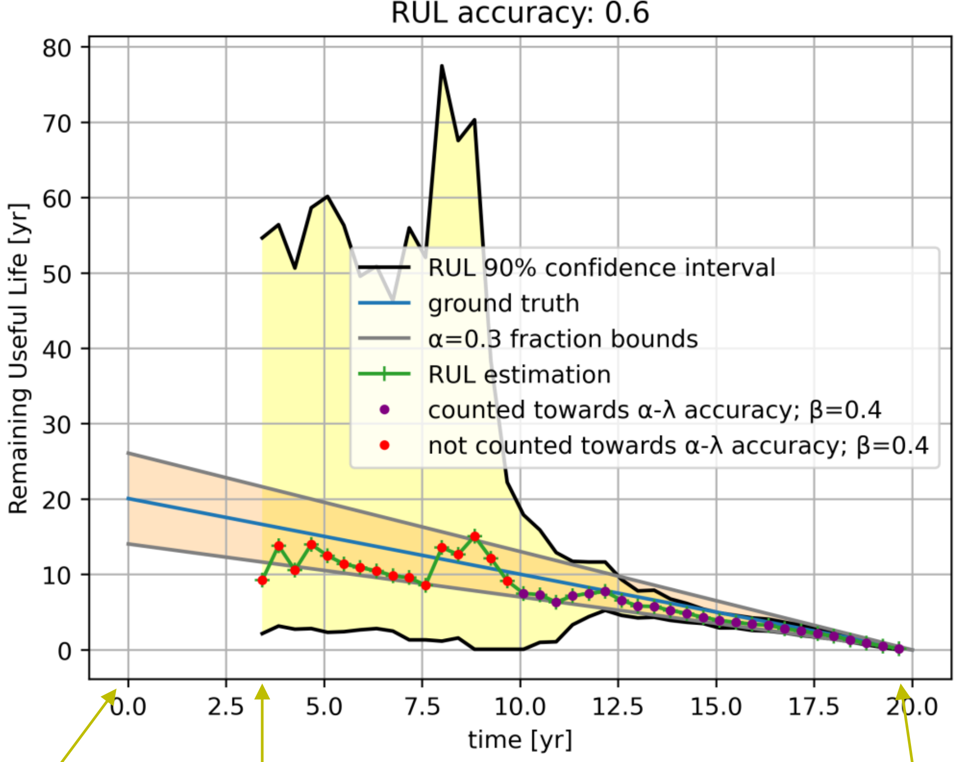
Performance evaluation

α-λ-accuracy = fraction RUL estimations where an area of at least β of the RUL distribution is within $(1 \pm \alpha)$*[ground truth RUL].

Example:



start commissioning wind turbine

corrosion detected; start prognosis

end of life

Results:

We take the mean α-λ-accuracy over multiple datasets with varying relevant measurement noise and temperature variations.

Prognosis algorithm based on corrosion model	**Mean accuracy over 5 datasets**
Linear	0.400
Power law	**0.415**
Bimodal	0.376

best method

* see, e.g., Saxena et al, *Metrics for offline evaluation of prognostic performance*, IJPHM, vol 1, no 1, 2010

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