Point-based POMDP Risk Based Inspection of Offshore Wind Substructures

P.G. Morato, Q.A. Mai & P. Rigo
Department of ArGENCO,
University of Liege (Belgium)

J.S. Nielsen
Department of Civil Engineering,
Aalborg University (Denmark)

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Introduction – Offshore Wind Substructures

Far away from shore

...Complex O&M tasks
Reduce LCOE...

Information available

....Inspections
Monitoring...

Figure 3.2: O&M cost per turbine for 3 classes of O&M strategy broken down by function

Source: CroweState Report; A Guide to UK Offshore Wind Operations and Maintenance

Source: EY Report; Offshore wind in Europe Walking the tightrope to success

Source: https://www.researchgate.net/figure/Optical-strain-gauges-as-installed-at-a-Belwind-and-b-Northwind

Maintenance Decision Problem

‘Pre-posterior Decision Analysis’ …

$12^{20} = 3.8 \times 10^{21}$ branches
1 second per branch = $1.24 \times 10^{14}$ years

Computational Requirements!
**Heuristic Rule:** ‘Constant intervals of time’

- Every 6 years: Year 6, Year 12, Year 18
- Every 5 years: Year 5, Year 10, Year 15, Year 20

**More simplifications…**
- Perfect inspections
- Repair if detected
MDPs & POMDPs

**Decision problem** ➔ **Dynamic programming**

**Markov Decision Process (MDP)**

- **Easy to solve**

**Partially Observable Markov Decision Process (POMDP)**

- **Solution?**

**Belief State / Action / Observation: Cost**
Solving POMDPs

Decision problem:

`Belief State → Action`

**‘Grid-based’ technique**

- Finite set of belief points
- Extrapolation/interpolation

**‘Point-based’ technique**

- ‘Optimally’ reachable beliefs
- Large state space (Robotics)
Proposed Methodology

‘Fatigue Deterioration’

Deterioration Model + Inspection Model + Cost Model

SN Diagram / Miner’s Rule
Fracture Mechanics

PoD
Transition Matrix

Observation Matrix

Rewards

POMDP Policy
Example: Tubular Joint (1)

‘Probabilistic Fatigue Deterioration’

\[
g_{SN}(t) = \Delta - \frac{\nu_0 t}{\eta} \left[ \frac{q^{m_1}}{a_1} \Gamma \left( 1 + \frac{m_1}{h}; \left( \frac{S_1}{q} \right)^h \right) + \frac{q^{m_2}}{a_2} \gamma \left( 1 + \frac{m_2}{h}; \left( \frac{S_1}{q} \right)^h \right) \right]
\]

\[
g_{FM}(t) = a_c - \left[ (1 - \frac{m_2}{2}) C K^m \pi^\frac{m}{2} q^m \Gamma \left( 1 + \frac{m}{h} \right) \Delta n + a_{t-1} \left( 1 - \frac{m}{2} \right) \right]^{\frac{2}{2-m}}; \text{ given } a_0
\]

Transition Matrix

60 states
Example: Tubular Joint (2)

‘SARSOP Algorithm’: POMDP 60 states

POMDP Simulation

POMDP Result

Heuristic Result

Good Agreement

0.32 seconds
Discussion & Conclusions

• Point-based POMDP - Reasonable CPU Time

• Applied to Offshore Wind Substructures

• Future:
  ▪ System-level
  ▪ Monitoring
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Questions?

P.G. Morato
pgmorato@uliege.be

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