Assessment of profitable operation and maintenance strategies

Adaptive surrogate model fitting for the NOWIcob model

Marius Rise Gallala

Department of Mathematical Sciences, NTNU. Contact: marius.gallala@gmail.com

NTNU

Introduction

Reducing the operation and maintenance (O&M) cost is essential in order to reduce the cost of energy from wind farms. Finding good O&M strategies are a complex problem: the strategies involve many decisions that interacts and develop over time. Simulation models enable us to evaluate the performance of different O&M strategies. The set of all possible strategies is very large, so we can only explore small parts of it.

In the following, a method that effectively explore and identify favorable O&M strategies is presented. The method guides the search of optimum towards regions with high predicted performance and/or regions with little knowledge. The method iteratively performs simulations and select the next input point for simulation.

Main Objectives

Identify O&M strategies which ensures a high amount of produced energy compared to the associated O&M cost. The trade off between these and other performance measures is specified by the user and represented with an objective function to be maximized. The process should be applicable to any well-defined wind farm and choice of decision variables.

Setting - stochastic simulation model

The NOWIcob model is used to simulate the failure of turbines and the related maintenance and logistic operations. The associated output is typically a measure of produced energy and related O&M costs.

Input (x)	Description
Weather	Time series for wave height and wind speed.
Turbine type	Properties as power curve, physical dimensions, cut-in and cut-off speed etc.
Distance to location	The shortest distance from to the location(s) with personnel accommodation.
Simulation horizon	The simulated lifetime of the wind farm-.
Failure rates	The different failure types are assumed to occur randomly with some intensity.
Personnel available	The average number of technicians available each shift.
Vessel fleet	Vessels are used in the various O&M tasks.

Table 1: Examples of input parameters.

The observed output y of the objective, e.g. profit or another perfomance measure, may be viewed as a realization of

$$y = f(\mathbf{x}) + \epsilon(\mathbf{x}) \quad (1)$$

where $f(\mathbf{x})$ may be interpreted as the true input-output relation. The noise term $\epsilon(\mathbf{x})$ is due to stochastic treatment of time between failures and weather.

Method

We use an adaptive approach for exploring favorable O&M strategies. The procedure is called adaptive since an input point for simulation is selected based on existing information, and new information is obtained through simulation. This is repeated iteratively.

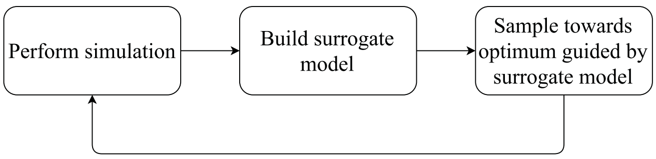


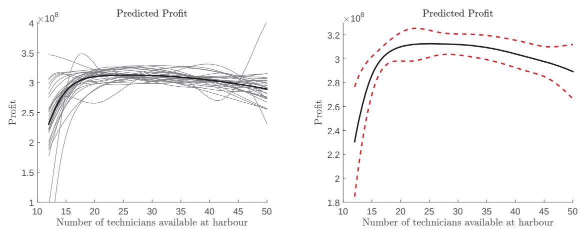
Figure 1: Adaptive fitting of surrogate model.

Perform simulation

Any O&M strategy may be represented by a set of input parameters $\mathbf{x}_{new}$. The resulting output y_{new} gives us information of the performance of the strategy. The new information is appended to previous simulation data, e.g. $\mathbf{D} = \{\mathbf{D}, (\mathbf{x}, y)_{new}\}$

Fit surrogate model - Prediction and quantification of uncertainty

A surrogate model $\hat{f}(\mathbf{x})$ mimics the input-output relation $f(\mathbf{x})$. We model the relation as a two layer feedforward neural network fitted to all available simulation data $\mathbf{D}$.



(a) 30 single neural network predictions varies around the surrogate model prediction.

(b) Surrogate model prediction and a measure prediction uncertainty $\epsilon(\mathbf{x})$.

Figure 2: Surrogate model prediction and a measure of uncertainty.

A more stable and accurate surrogate model is formed by combining the prediction of several neural networks, each fitted to a bootstrap sample of $\mathbf{D}$. Moreover, this technique enables us to quantify the uncertainty $\epsilon(\mathbf{x})$.

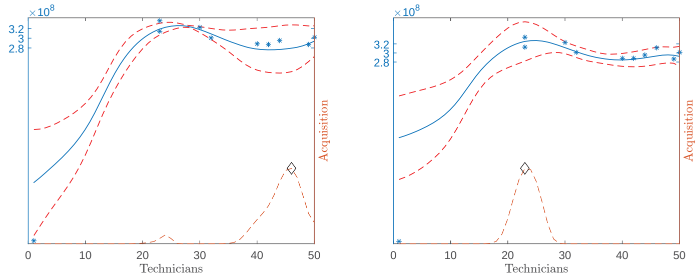
Sample towards optimum: balance exploitation and exploration

We want to gain knowledge of O&M strategies which are likely to maximize the objective. To avoid finding local optimums, we aid the search towards regions with high uncertainty as well as high predicted objective. The two aspects

1. exploitation - high predicted objective
2. exploration - high predicted variance

are balanced by an acquisition function $u(\mathbf{x})$.

$$\mathbf{x}_{new} = \underset{\mathbf{x} \in \Omega}{\text{argmax}} \; \{u(\mathbf{x}) \mid \mathbf{D}\} \quad (2)$$

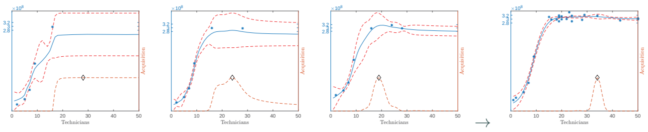


(a) 6. iteration $\mathbf{x}_{new} = 46$ **(b)** 7. iteration $\mathbf{x}_{new} = 23$

Figure 3: Balancing exploitation and exploration.

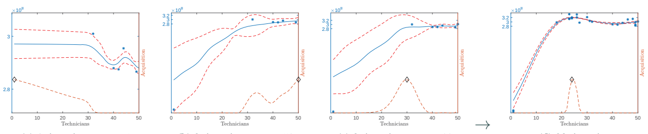
Results

The method for finding optimal strategies should ideally converge to approximately the same solution, regardless of sampling path. By starting with initial samples in opposite regions, the method is able to identify the same favorable region in less than 20 iterations.



(a) 1. iteration $\mathbf{x}_{new} = 28$ **(b)** 2. iteration $\mathbf{x}_{new} = 24$ **(c)** 3. iteration $\mathbf{x}_{new} = 19$ **(d)** 20. iteration

Figure 4: Starting with samples in left region (few technicians).



(a) 1. iteration $\mathbf{x}_{new} = 1$ **(b)** 2. iteration $\mathbf{x}_{new} = 50$ **(c)** 3. iteration $\mathbf{x}_{new} = 30$ **(d)** 20. iteration

Figure 5: Starting with samples in right region (many technicians).

Conclusions

The adaptive method of iteratively performing simulation, fitting surrogate model and selecting the next point for simulation has been tested for cases with a low number of decision parameters.

- The adaptive approach is able to identify reasonable strategies for the test cases.
- By balancing exploitation and exploration the method avoids getting stuck in local optimums.
- The process of simulating, fitting and selecting is performed automatically. This reduces the need of manually initialize and analyze a large number of simulations.

Forthcoming Research

The adaptive approach is further studied in a Master's thesis during the spring of 2016. The thesis aims at giving a deeper understanding of the abilities of the suggested approach.