Course in Probabilistic Methods in Wind Energy: Assignment 2.

In this exercise, the aim is characterizing the behaviour of the extreme loads at the root of a wind turbine blade and determining what is the dependence between these loads and environmental conditions (mean wind speed, turbulence, and wind shear).

You are provided with a script (MysteriousLoadFunc) which, given an input of wind speed, turbulence, and wind shear exponent, will provide a quick estimate of the 10-minute extreme blade root flapwise moment for a virtual wind turbine. The syntax for calling the function is:

$$\mathrm{y} = \mathrm{MysteriousLoadFunc(X)}$$

Where $\mathrm{X} = \begin{bmatrix} u_1 & \sigma_{u_1} & \alpha_1 \\ u_2 & \sigma_{u_2} & \alpha_2 \\ u_3 & \sigma_{u_3} & \alpha_3 \\ \vdots & \vdots & \vdots \\ u_n & \sigma_{u_n} & \alpha_n \end{bmatrix}$,

and u, σ_u, α are 10-minute mean wind speed, standard deviation of wind speed, and wind shear exponent respectively. The output y is the extreme blade root flapwise bending moment in kNm.

Please note that just like in typical load simulation tools with turbulent wind input the load output is uncertain – i.e., the load output function will give slightly different results each time it is called.

Your task is to:

- Calibrate a simplified (surrogate) model of the extreme load function which maps the dependence between the loads and the environmental conditions
- Devise a procedure which can determine the expected value of the blade root extreme load, as function of a given joint distribution of wind speed, turbulence and wind shear
- Estimate what is the uncertainty in the estimated expected value of the extreme load - e.g. due to model uncertainty and realization-to-realization uncertainty

The joint distribution of the environmental conditions is the following:

Mean wind speed u: Weibull-distributed with A = 11.28 and k = 2;

Turbulence σ_u: Lognormally distributed with mean $\mu_{\sigma_u} = 0.14(0.75u + 3.8)$ and standard deviation $\sigma_{\sigma_u} = 0.1657$

Wind shear exponent α: Normally distributed with mean $\mu_\alpha = 0.1$ and standard deviation $\sigma_\alpha = \min\left[1, \frac{1}{u}\right]$

Suggested procedure:

1) Set up programs needed to generate random samples (a Monte Carlo sample) from the joint distribution of the environmental conditions. The dependence between variables is taken into account using a Rosenblatt transformation
2) Run a crude Monte-Carlo simulation to obtain a reference for the expected value of the function.
3) Choose the type(s) of surrogate models you want to calibrate – and select an appropriate experimental design (e.g. a grid or just a crude Monte Carlo) to generate your training dataset.
4) Calibrate the surrogate model(s) of your choice
5) Evaluate the model performance and adequacy. Make e.g. one-to-one plots of true outputs vs. model predictions, make a residual analysis (plot residuals vs. variables), calculate error terms (e.g. r-square, RMS error, MAE) to evaluate the quality of the model fit and estimate model uncertainty

6) Run a numerical simulation with the surrogate model to determine the expected value of the function and compare with the results of the Monte Carlo

Report format guidelines

Please submit one report per study group, in pdf format. The report should normally be written using a word processor. Including the code in the report is in general not required – if for some reason (e.g. explaining a specific bug or a choice of function) you want to include large pieces of code, please do that in an appendix. It is also acceptable to submit printouts of Jupyter notebooks as a report – as long as they maintain the same standard of details, presentation quality and readability as a normal report. This would mean that the code should be accompanied by thorough explanations and formulas described in markdown cells, and that all unnecessary code is removed.

We recommend that the following information is included in the report:

- Short problem description (e.g. could be a reference to the assignment text or a summary).
- Solution methods – how do you approach the problem, what kind of methods and actions have you applied in order to obtain the solution.
- Results (possibly including figures, tables) showing the outcomes of your analysis
- Discussion of your results. Try to explain the observations and provide potential interpretations.

The above is not necessarily a definition of the structure of the report. The structure could be adjusted depending on your preferences, and e.g. if you have several steps which could require separate theory descriptions and separate result/discussion sections for each step.

Normally 5-10 A4 pages will be sufficient for a report with an approximately even split between figures and text and without listing of programming code.