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Reply on RC2

Pablo Noever-Castelos et al.

Author comment on "Model updating of a wind turbine blade finite element Timoshenko beam model with invertible neural networks" by Pablo Noever-Castelos et al., Wind Energ. Sci. Discuss., https://doi.org/10.5194/wes-2021-84-AC2, 2021

Dear Sarah Barber,

On behalf of all authors, I gratefully thank you for reading the paper and providing valuable constructive criticism, which we believe has helped to develop and strengthen this work significantly. Please find our answers to all your comments, by either correcting or adding text sections or comments on your suggestions/concerns. We hope to have correctly understood and adequately accommodated all your concerns. Thank you again for your contribution.

Specific comments
1. INTRODUCTION

- Line 52: can you quantify "computationally expensive" in terms of computational time as well as just number of iterations? How long does one iteration typically take?

This is impossible to quantify in a general manner, as it depends on the every model itself and the hardware you are using. The model generator we are using in this publication needs about: "…on average approx. 80 s on a single-core device." (As mentioned in Sec. 4.5) I will include this number as exemplary reference in the introduction: "Iterations are always model dependent, but as a reference for the real time consumption, the model generator used in this publication (Noever-Castelos et al., 2021a) takes on average approx. 80s on a single-core device for one iteration, i.e., model creation."

- Section 1.2: it would be better to introduce the three "problems" and then describe them, rather than describing one of them and then introducing the three problems.

This makes totally sense. Thank you! The order was swept, starting with the three bullet points introducing the issues and describing them afterward.

2. SENSITIVITY ANALYSIS

- Introduction: Usually one would expect the text at the start of a section before

the first sub-section to introduce the section. Instead, you just talk about a previous paper, which is confusing. I would suggest inserting a proper introduction to the section here, and/or just moving the existing text into the first sub-section.

As suggested, the section was moved into Sec. 2.1 and a proper introduction is added.

- Section 2.1: Please explain briefly why you are using the Sobol method.

"This method is widely used in research and is used here, as it also applies globally to non-linear models and analyzes interaction of input parameters on the model response."

- Section 2.2: You refer to Figure 2 before Figure 1. Please swap the figures.

Thanks for that notice. It was actually correct in latex, though the formatting process swapped them.

- Section 2.2: Are you using one particular blade for this study or is it generalised? Please explain this better.

Added:
"We will be performing the analysis on the DemoBlade of the SmartBlades2 project (SmartBlades2, 2016-2020)."

- Line 111: With "In contrast to the simplified visualisation" do you mean the one used in the previous study?

I have to admit, that it isa bit confusing. No, the figure shows a coarse mesh, however, in the anaylsis a more refined mesh is applied. I have adapted the sentence to:
"In contrast to this simplified visualisation in Fig 1…"

- Line 118: Why "five equidistant nodes"?

Added:
"The number of spline nodes can be chosen arbitrary; however, a high number increases the computational costs (more updating parameters) and can lead to collinear behavior if the nodes are to near, whereas a low number reduces the flexibility to adapt to short distance changes. For this study the number where chosen based on experience as a trade-off between computational costs and a sufficient approximation of a global parameter variation."

- Line 163: "which does not necessarily improve the updating performance, but reduce the performance." This is a bit confusing. Does the second "performance" refer to the computational performance?

Oh, this is really confusing. Yes, it is the computational performance. This sentence was changed to:
"This repeated information does not necessarily improve the updating results, but reduce the computational performance."

3. INN ARCHITECTURE

- Lines 179-184: I would make the two colours in Fig. 4 more clear - it's hard to see them and differentiate between them.

We have changed the color and the thickness of the lines, to make it more clear.

- Line 190-198: can you give non-cINN-experts an idea of what the consequences of the flattening process are? I find myself not able to understand the effect of this on the results and it would be nice if you helped me out here (and others).

There are no effects on the results, it is just about how the data is processed in the network:
"A consequence is, that the sub-networks cannot make use of convolutional layers, but have to include feed-forward layers. However, this will not have any significant impact on the result. As mentioned before, the conditions and input features are stacked in the sub-networks, which thus need a similar spacial shape. Consequently, the conditional network has to flatten the shape to a vector for each output, in order to agree with the input shape in the sub-networks."

- Line 201: Please explain the table structure briefly. Remind us what the different clusters are.

"As previously explained the conditional network processes the conditions c and has 5 outputs at different stages of the processing. Each of this outputs is fed into a cluster of 3 CCs. the configuration for each cluster and the corresponding hyperparameters for the conditional network, cINN and sub-networks is summarized in Table 3."

4. MODEL UPDATING

- Line 244: Please quantify this, i.e. instead of "most of the values hit the ground truth." write something like "x% of the values are within x% of the ground truth"

"However, the overall posterior prediction in this example is very good, as approx. 70\% of the predictions are within a range of $\pm\,0.05$ (standardized scale) of the ground truth."

- Line 249: You write "Thus, the ideal case would correlate to an exact line with a slope m = 1." (also with the intercept = 0?) - R^2 is not a measure of how close m is to one, but of how close the points are to the regression line y = mx + c (isn't it???). Please clarify this discrepancy and forgive me if I'm wrong.

You are right. This has to be mentioned. However, the slope accuracy (to 1) and the R^2 value correlate in general for these results. This would only differ significantly if a systematic error appears in the predictions. For this publication the slope m was added as additional information in Figure 9 and is now discussed briefly in the text:
"Approximately 70% of the selected features reach a very satisfying linear correlation with $R^2>0.9$, while showing a slope m of approx. 0.9 or higher. For the rest of the discussion we will be sticking with the R^2-value for the accuracy, as the slope accuracy correlates with the R^2-value."

- Line 327: why 5%?

This is arbitrary chosen on behalf of a maximum measurement error. For example, in the SmartBlades 2 Project the errors estimated for the strain gauges or the accelerometers were below 5%.

- Line 331: Please quantify the statement "most of the input features are predicted as accurate as with a clean output." (i.e. what do you mean by "most" and "as accurate"?)

We hope this satisfies your concerns:
"As visually confirmed in Fig. A1 the other features do not show a wider spread (orange) than the original values (blue) and therefore do not suffer from any accuracy loss."

- Lines 377-378: Quantify these two statements too!

"Again, all mean values are close to 1 (90% with MAC≥0.995), so an overall excellent updating performance can be stated. Single predictions lead to worse results, as depicted by the minimum value (4.3% of all have a MAC≤0.98), especially for the higher order modes, though the MAC value of less than 0.8 is only obtained for the 10th eigenmode of the free-free configuration."

- Line 386: "The counteracting intrinsic model ambiguities cancel each other out". Could you explain this a bit more please?

"The counteracting intrinsic model ambiguities discussed in Sec. 4.2 cancel each other out, i.e., the overall shell laminate properties are correctly predicted, although the individual stiffness or density of the layers (Biax90 and Triax) are not predicted accurately. So the cINN still correctly captures the global model behavior with respect to mass and stiffness distribution."

- Line 390: Quantify this!

"The overall cINN updating performance is strikingly good, with on average 90% of the mode shapes showing a MAC≥0.995."

- Line 396: It would be better to first mention this when introducing Sobol above (I already mentioned that you should expain why you chose the method), and then refer to it here.

This is already mentioned in Sec. 2.2:
"SALib uses the quasi-random sampling with low-discrepancy sequences technique from Saltelli et al. (2008) for the sensitivity analysis. To compute the Sobol index, the algorithms require a variation of each input feature individually for each of the n samples, which results in a total sample size of ntotal (dim(x) + 2) = 79,360 to compute the 1st order Sobol indices."

CONCLUSIONS

- Lines 471-475: Please say something about how realistic the assumptions were. You say that it should now be applied to a real life application. This means you think that the assumptions you made in this work will impact the results. How and why?

We hope that the following rephrasing and additions make it clear, what are the limitations and what still should be targeted in future research:
"The cINN proved to be extremely capable of performing an efficient model updating with a larger parameter space. The physical model complexity in form of a Tymoshenko finite element beam is already at the state of the art level applied in industry. However, to ensure that the cINN learns the complete inverted physical model, it is important that all possibly relevant parameters have to be varied, so that the cINN is trained for all circumstances of variations for the model updating. Therefore, ongoing and future investigations should bring this method to a real life application, where the parameter space will span more relevant aspects of blade manufacturing deviations, such as e.g., adhesive joints."

Technical corrections

Thank you for your technical corrections, which were all considered in the revision.