Master thesis/ Student research project

Design of electrical machines with invertible neural networks

The design and optimization of electrical machines, e.g., for electric vehicles, is of great importance to ensure the competitiveness of the developed drive system. Usually, a rough design is carried out first with regard to the torque, speed or power requirements of the machine. In a second, more comprehensive design step, several goals are optimized simultaneously. These include, e.g., higher efficiency, lower manufacturing cost or a smaller construction volume. These objectives conflict with each other, i.e., all objectives can never be met equally and a compromise must be found. Furthermore, this procedure is very time consuming due to the finite element analysis (FEA), which must be repeated again after one parameter has changed.

(a) Simulation library PYLEECAN

(b) Exemplary sketch of a PMSM with interior magnets.

In this work, the simulation library PYLEECAN is to be used to develop an FEA model of a permanent magnet synchronous machine (PMSM) within Python, which is used for a precise analysis of the magnetic behavior of the machine. Subsequently, target parameters will be defined and the geometry parameters of the machine are identified and heuristically modified within a simulation study. With this created data set an invertible neural network (INN) [1] should be developed to generate multiple motor geometries within one shot, circumventing the conventional method that would include long and cost-intensive fine tuning.

Key research questions:

- How big is the computational effort to generate the data set considering geometrical constraints leading to feasible machine designs?
- Is it possible to include further objectives (losses, mass, cost, ...) or even necessary to produce invertible geometry-to-objective mappings?

Necessary requirements:

- Finished course work on electrical machine and power electronic fundamentals
- First experience or interest in machine learning
- Interest in programming with Python

WP 1: Literature research **[3 weeks]**
Scanning the scientific literature for relevant publications and patents related to machine design with INNs and FEA for electric drives and related fields is the first step. Also, getting familiar with PYLEECAN is part of this WP. Relevant work will be stored in a literature review software (e.g., JabRef) and summarized in the thesis.

WP 2: Model development **[6 weeks]**
First, a suitable machine model must be developed with the utilization of the PYLEECAN library. This library already contains some machines, however, their suitability must be checked regarding the geometry complexity. Also, finding geometry constraint functions to limit the model scope to feasible designs is part of this WP.

WP 3: Data set generation **[3 weeks]**
In this WP, a data set must be generated with the developed FEA machine model. Therefore, the geometry parameters should be uniformly distributed in within the data space to cover all possible designs, including architectures with low performance. Simplification of the task by reducing the number of changeable variables is advised, e.g., by fixing the rotational speed over all simulated machines.

WP 4: Neural network design **[4 weeks]**
The first step is to design the neural network model, which has to be directly in the INN structure. One design parameter is the distribution of the latent variables, for which a solution should be found. The training is performed in forward direction and evaluated based on the training loss value.

WP 5: Inverting the network **[3 weeks]**
In this WP, the neural network must be inverted. All estimated geometry parameters should lead to feasible machine designs. Secondary objectives may then be applied to narrow down the geometry.

WP 6: Validation **[2 weeks]**
The estimated geometry parameters must be validated to assess the performance of the INN. Therefore, the estimated geometry parameters should be utilized to analyze the corresponding machine via PYLEECAN. Thus, the FEA simulation has to be started again to compare the demanded torque that was fed into the INN, and the simulated torque from the FEA simulation.

WP 7: Documentation **[4 weeks]**
All work packages should be reported in a structured way within the thesis. A LaTeX template should be used for this purpose: `https://github.com/IAS-Uni-Siegen/thesis_latex_template`. Writing instructions can be found within the provided template source files. Based on the previous empirical findings, conclusions should be drawn, and future research directions should be outlined.

Gantt chart

The planned timetable is shown in the Gantt diagram below.

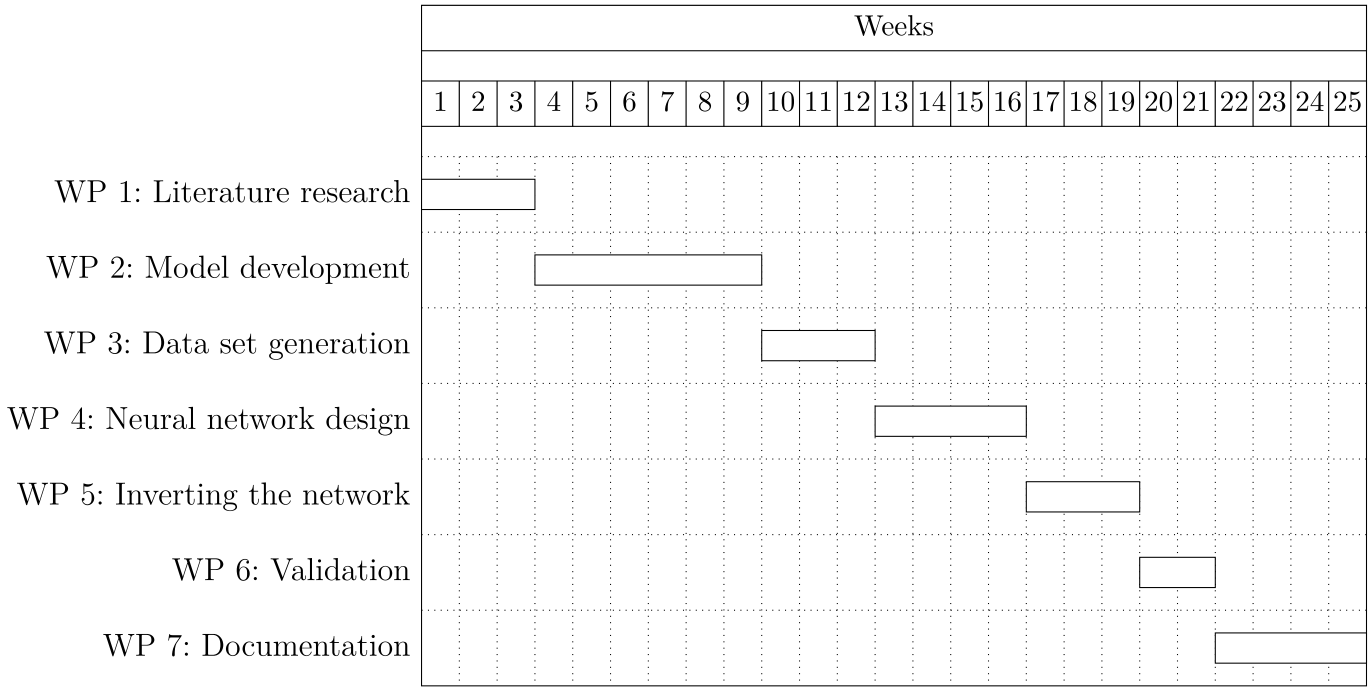

Figure 2: Gantt chart for the thesis.

References

[1] L. Ardizzone, J. Kruse, S. Wirkert, D. Rahner, E. W. Pellegrini, R. S. Klessen, L. Maier-Hein, C. Rother, and U. Köthe, "Analyzing inverse problems with invertible neural networks," *arXiv preprint arXiv:1808.04730*, 2018.