Hybrid quantum tensor networks for aeroelastic applications

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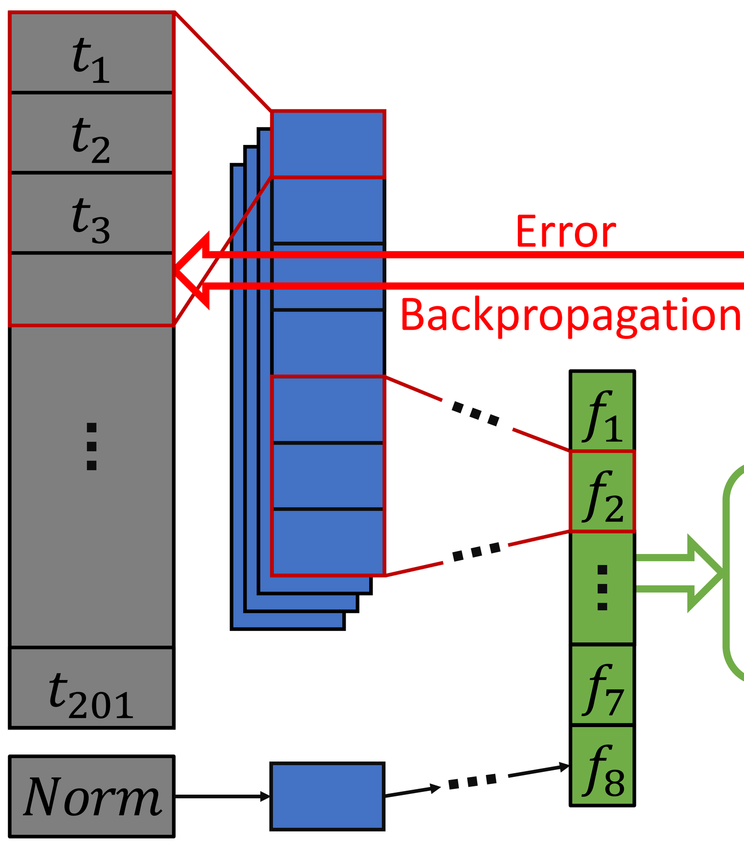
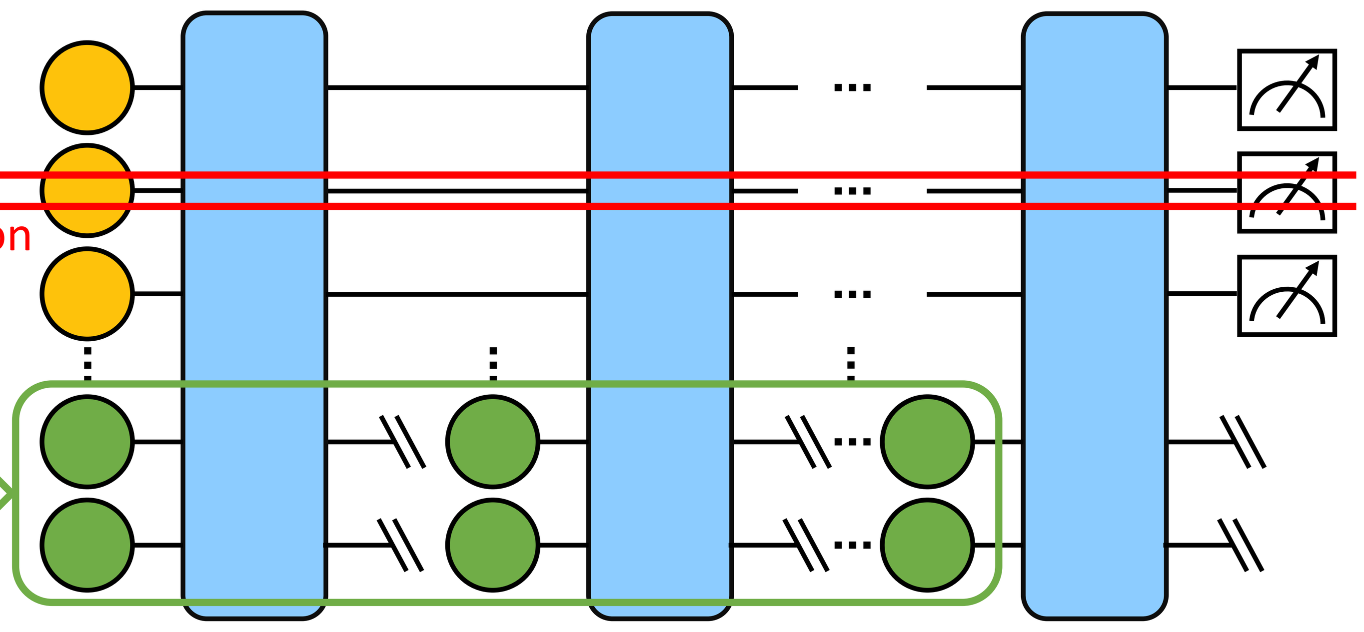
Hybrid Tensor network inspired algorithm

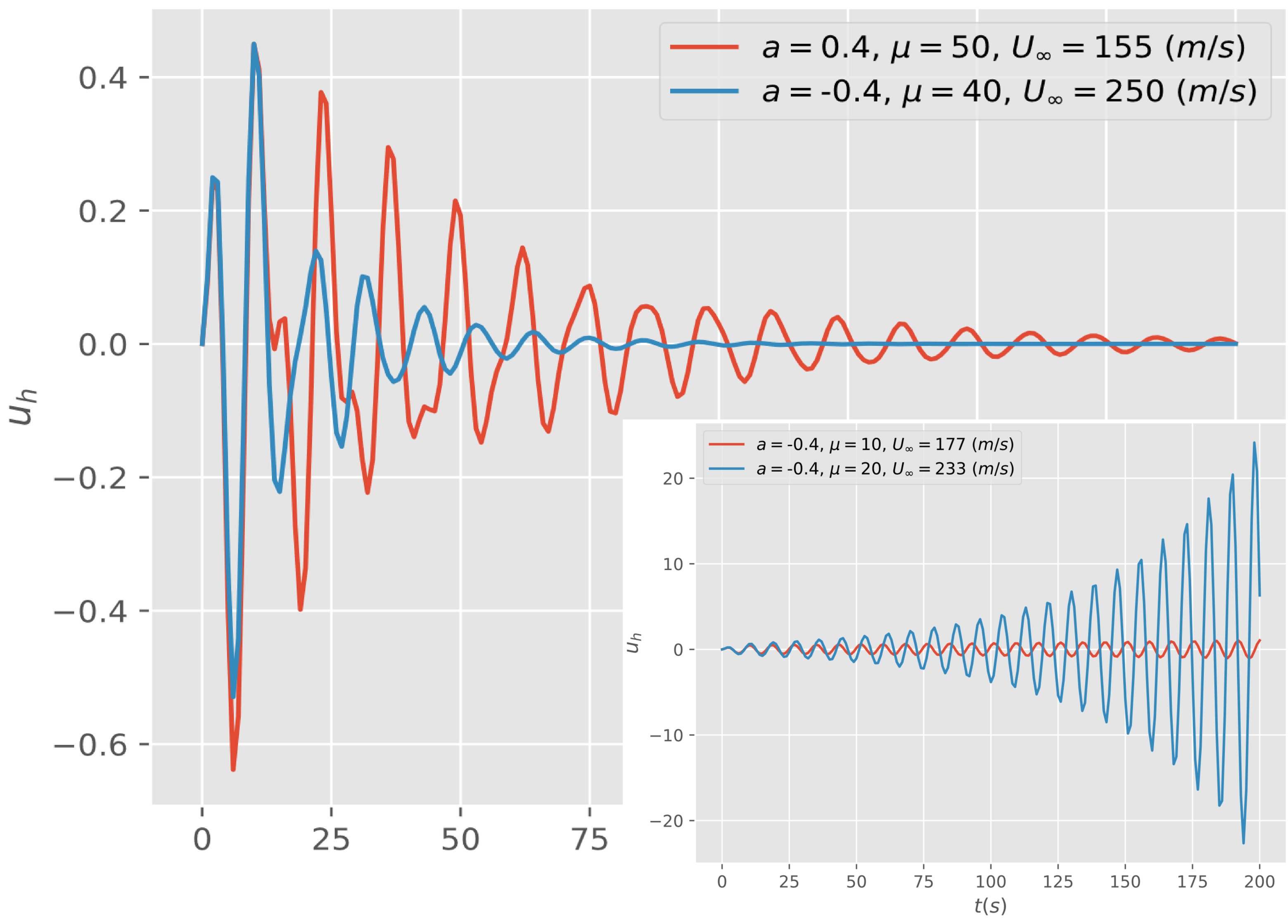
We investigated the prospect of using hybrid quantum tensor network based algorithms for aeroelastic problems. Quantum tensor networks for Machine Learning can be realized by Variational Quantum Circuits using a tensor network inspired internal gate structure [1].



Classical dimensionality reduction



Example of a Qubit efficient tensor network inspired quantum circuit. The green circles represent elements of the feature vector. Adapted from [1]



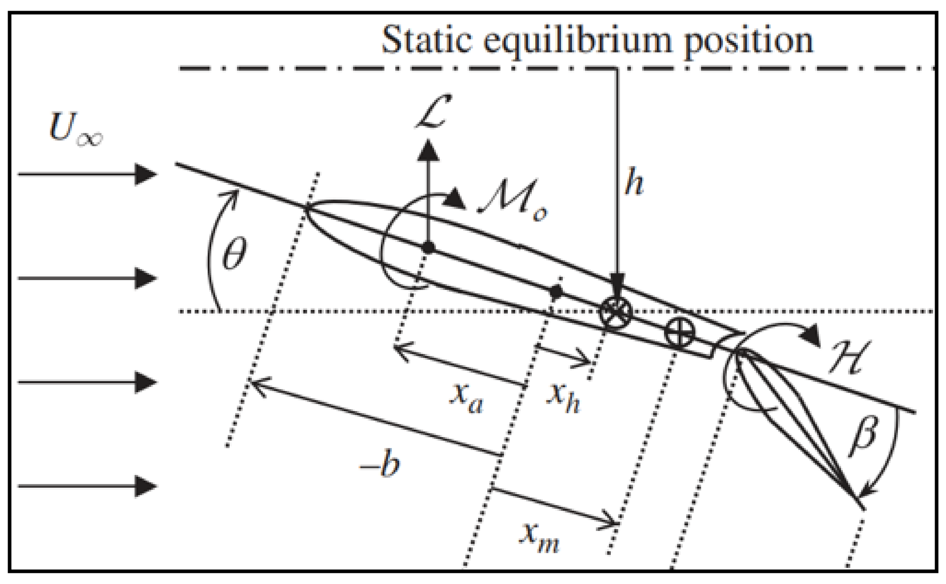
Representative time histories: with stable (top) or unstable (bottom) aeroelastic response for non-zero initial conditions.

Use Case

Typical aeroelastic section of a wing with three degrees of freedom: heave h, pitch θ around the elastic axis and aileron rotation β.

Simulation dataset for constant aeroelastic parameters up to :

- a: the nondimensional distance between midchord and elastic axis
- μ: the mass ratio
- U_∞: the airspeed



Simplified aeroelastic configuration. Adapted from [2]

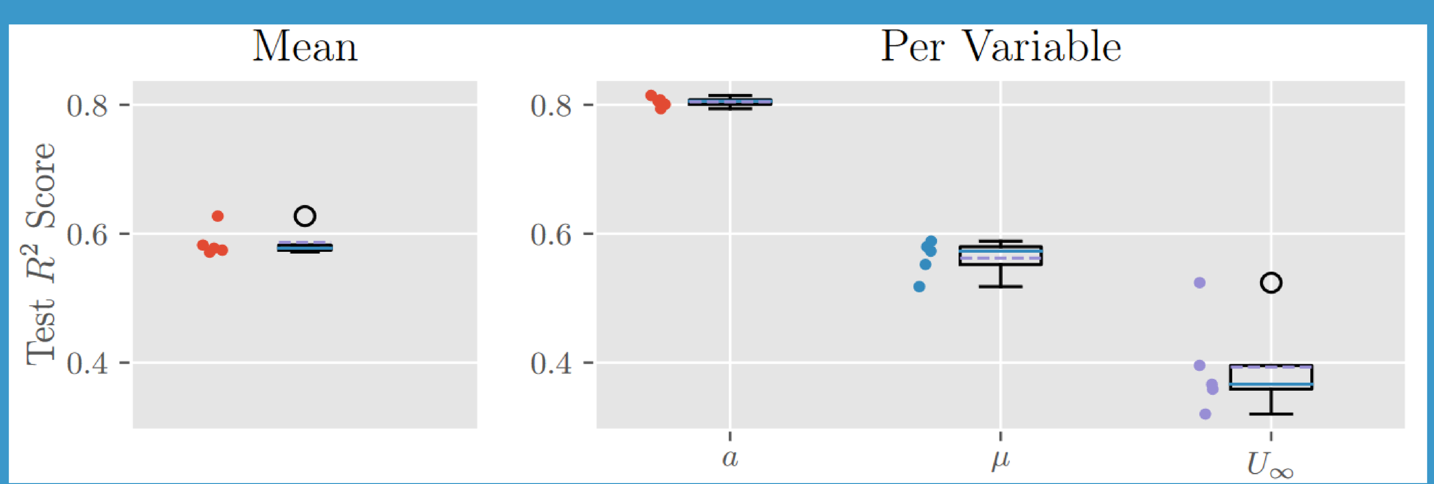
Training was done on ~7000 examples using 5-fold cross validation. And testing was carried out on ~2000 examples.

Tasks

Regression

Predict the aeroelastic parameters (a, μ, U_∞) for each time history.

- We used the expectation values of three Qubits to approximate the target vectors.

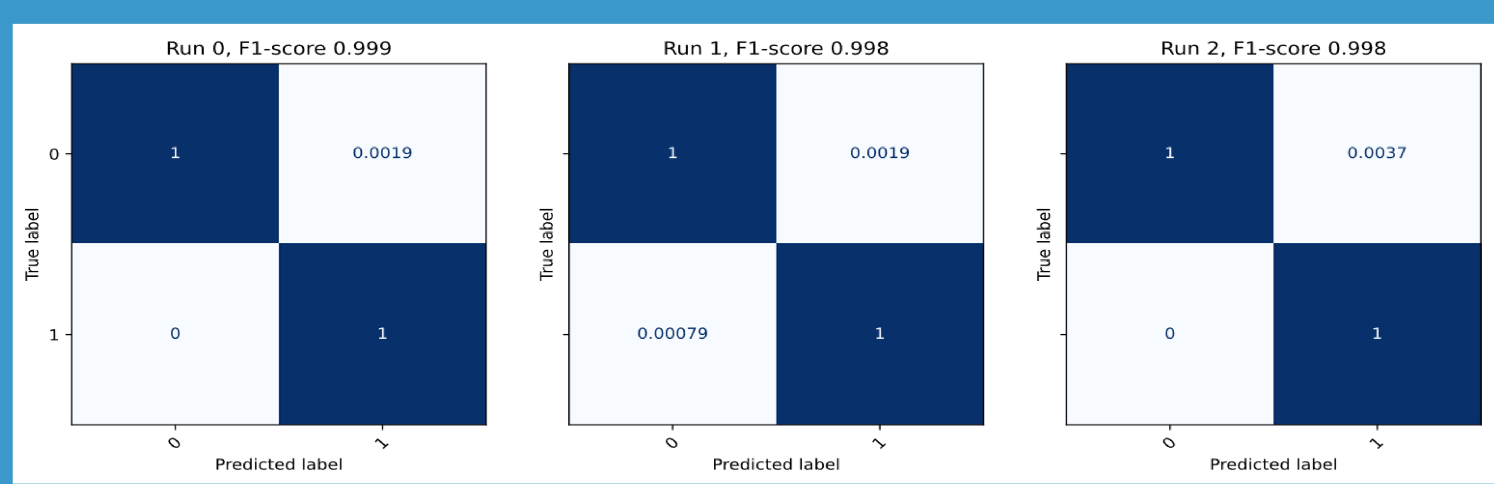


The univariate regression of a with 9 distinct values could be solved. The more complex multivariate regression including μ with 5 and U_∞ with 201 distinct values, could not be completely solved.

Classification

Provide the binary stability classification for each time history.

- We used the expectation value of a Qubit as the class probability.



Could be solved perfectly, although we observed that the results were very susceptible to random weight initialization.

Conclusion

We found that hybrid quantum tensor network based algorithms can be successfully applied to aeroelastic problems. Nevertheless, the appropriate choice of hyperparameters is still a challenge.

Outlook

We will investigate the impact of using classical tensor networks for the data dimensionality reduction. An ablation study will be performed to understand what each component contributes to the solution of the task.

[1] Rieser Hans-Martin, Köster Frank and Raulf Arne Peter (2023). Tensor networks for quantum machine learning. Proc. R. Soc. A.479:20230218.

[2] Tewari, A. (2015). Aeroservoelasticity. In Control Engineering. Springer New York

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