Data-Driven Method for Real-Time Prediction of Fatigue Failure Under Stochastic Loading

Maor Farid
Massachusetts Institute of Technology, Cambridge, MA 02139, USA
Technion – Israel Institute of Technology, Haifa 3200003, Israel

Abstract. In the current work, a data-driven approach is suggested for both offline and real-time prediction of the time to failure (TTF) of mechanical components subjected to statistically steady-state stochastic loadings. An uncertainty quantification (UQ) is obtained based on the performance of the model on a test-set. The suggested method paves the way towards a predictive system, which is based on real-time measured signals. This method can be used as a basis for operational and safety instructions and to serve as a life-saving system.

Introduction

Fatigue failure refers to the malfunctioning of a mechanical component due to oscillatory loading below its ultimate tensile strength. Fatigue damage is cumulative over time and can take place at unexpected timing, leading to hazardous consequences. Fatigue is one of the main reasons for mechanical failure in aerospace and offshore structures, and machine components. Despite the major motivation, the existing methods for damage estimation, such as rainflow cycle counting and Miner's rule, do not predict the TTF and the corresponding PDF based on real-time measurements under stochastic loading. Moreover, disagreements between theoretical and experimental results were reported extensively in the literature [1].

Results and discussion

The current paper utilizes fully connected artificial neural networks (FC-ANNs) [2, 3] for real-time prediction of the TTF for a given mechanical component that is subjected to statistically steady-state stochastic forcing and characterized using a corresponding features vector. The ANN is trained over a dataset that can be taken from experiments, analytical models, or numerical simulations. In addition to TTF prediction, a Gaussian process regression (GPR) model is trained over the test-set of the data and quantifies the uncertainty for any predicted TTF value. To capture the underlying relations between the TTF τ, the material dimensionless parameters of the forced system, i.e. the fatigue strength A, the fatigue exponent b, and the ultimate tensile strength σ_{uts}) and the characteristics of the measured signal (mean S_m and the 90^{th} percentile amplitude S_p, the ANN is trained on a data-set of $N = 1500$ recorded signals. Each example, contains the features and the resulting TTF [4]. The input parameters are generated from a uniform distribution over the parameter ranges shown in Table 1. The phases ϕ are generated from a uniform distribution as well, $\phi \sim \mathcal{U}[0, 2\pi]$. The signals can be generated from any given PSD. As one can see in Fig. 1, there is a good agreement between ground truth (GT) and predicted results, both for offline and real-time analysis.

A	b	σ_{uts}	S_m	S_p
$1200 - 1500$	$-0.2 - -0.15$	$500 - 1000$	$0 - 250$	$120.67 - 142.1$

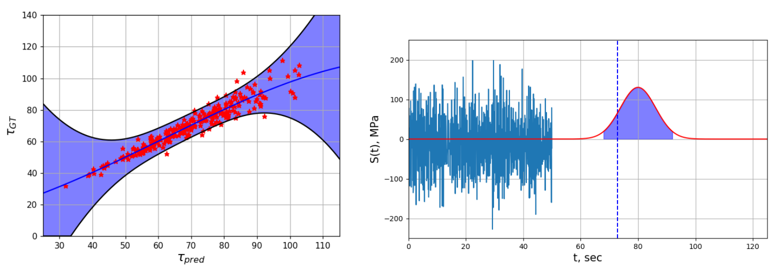

Figure 1: a) Prediction of the trained model on the test-set X^{test} (red points), regression curve (blue line), confidence region generated by GPR model with $\gamma = 1.96$ standard deviations (blue shade) and confidence boundaries (black lines); b) demonstration of real-time TTF prediction, the measured loading signal (solid blue), GT TTF τ_{GT} (dashed blue), predicted TTF τ_{pred} (dashed red), and confidence interval (purple shade).

References

[1] A Antoniou, M Vespermann, Florian Sayer, and Alexander Krimmer. Life prediction analysis of thick adhesive bond lines under variable amplitude fatigue loading. In *18th European Conference on Composite Materials (ECCM18)*, 2018.

[2] Anastasios P Vassilopoulos, Efstratios F Georgopoulos, and Vasileios Dionysopoulos. Artificial neural networks in spectrum fatigue life prediction of composite materials. *International Journal of Fatigue*, 29(1):20–29, 2007.

[3] JF Durodola, N Li, S Ramachandra, and AN Thite. A pattern recognition artificial neural network method for random fatigue loading life prediction. *International Journal of Fatigue*, 99:55–67, 2017.

[4] Herbert J Sutherland. On the fatigue analysis of wind turbines. Technical report, Sandia National Labs., Albuquerque, NM (US); Sandia National Labs, 1999.