Physics-Informed Decomposition Techniques for Vibration and Flow Analysis

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Introduction

Experimentation and data collection are crucial for engineering and research projects. Despite their importance, noise and outliers find their way into most datasets regardless of the focus of the project. This poster looks at applying various methods to de-noise data, while attempting to maintain valuable information and even uncover previously unresolved features. The methods explored are the Singular Value Decomposition (SVD), PRANK, and Robust Principal Component Analysis (RPCA). These methods will be applied to a camera-based cantilever beam modal analysis and to particle image velocimetry (PIV) of bluff bodies.

Objectives

The objectives of this research project are to:

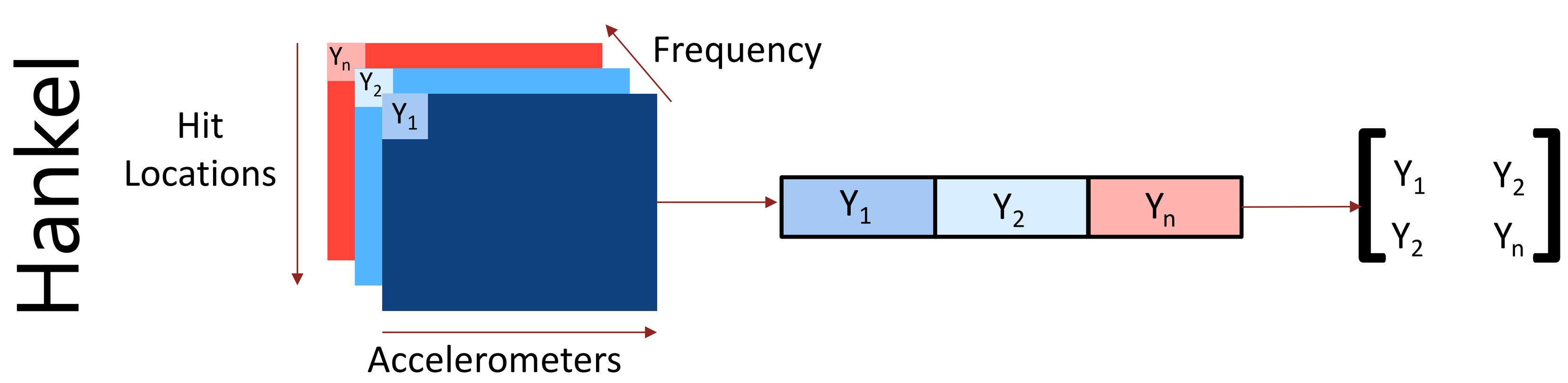
- validate results of de-noise data while ensuring the high energy modes of the system are minimally altered
- the new hybrid PRANK method
- understand the limitations of SVD, PRANK, and RPCA in regards to truncating and cleaning data

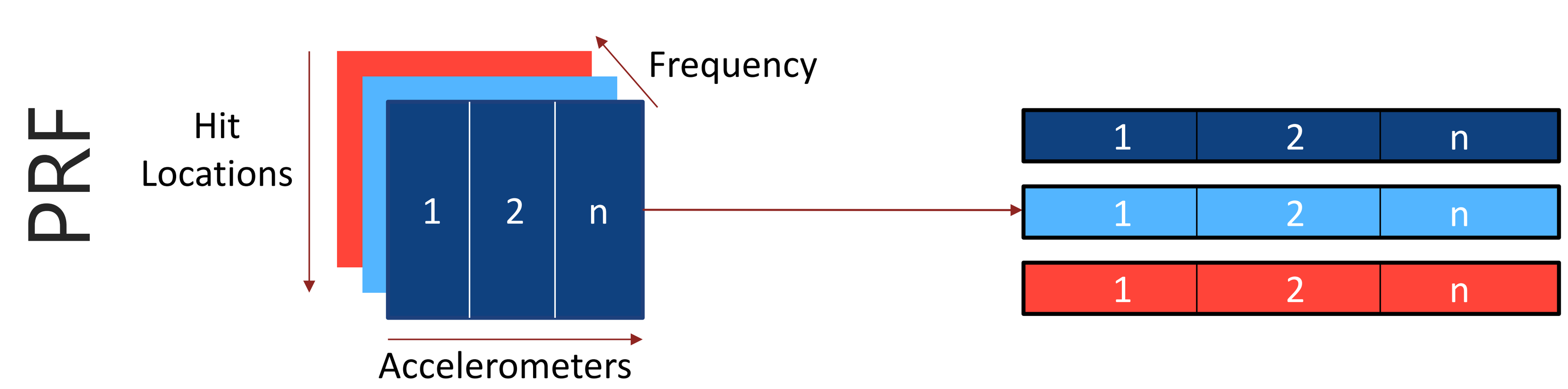
Methodology

Singular **V**alue **D**ecomposition decomposes a matrix into its singular vectors (U), its singular values (Σ), and its right singular vectors (V). The singular values illustrate the impact each singular vectors has on the system.

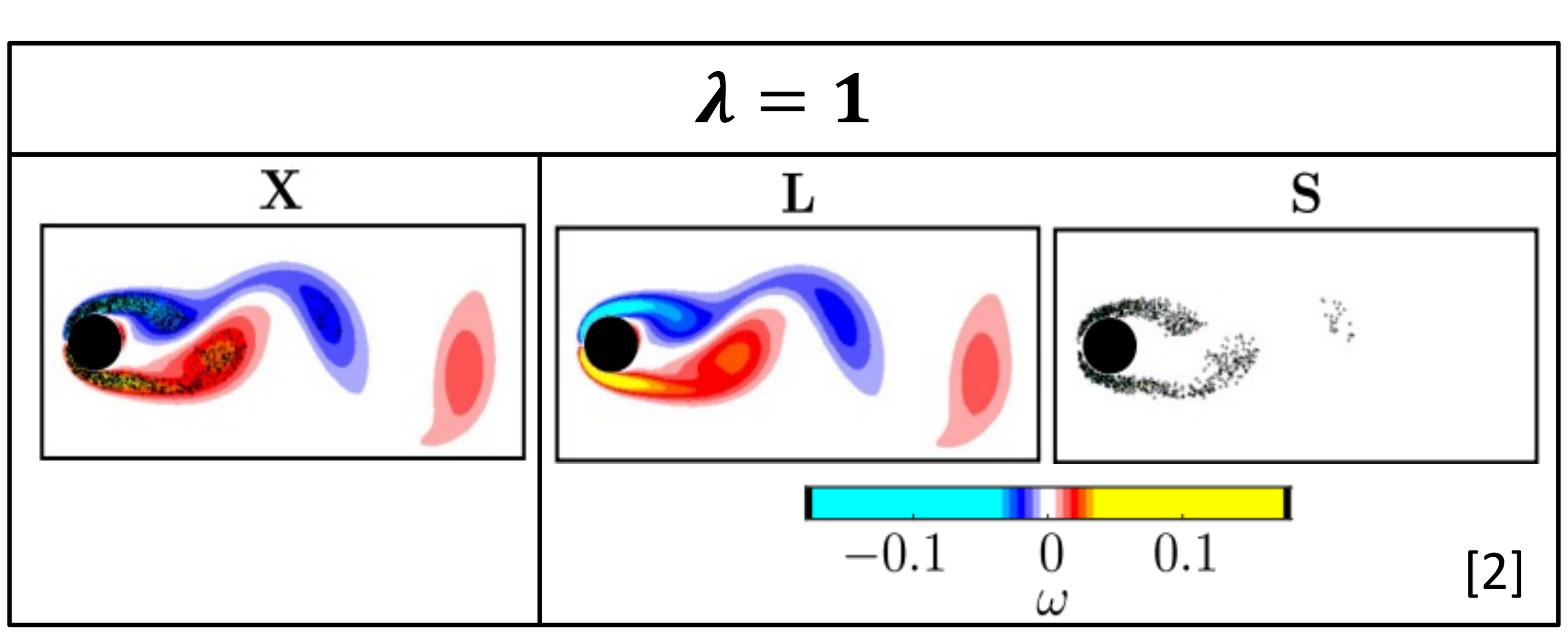
$$[\,X\,] = [\,\hat{U}\,][\,\hat{\Sigma}\,][\,V^*\,]$$

PRANK [1] is a hybrid method to remove noise and outliers by organizing 3D data into a 2D flattened principal response function (**PR**F) matrix. The singular vectors from PRF Matrix are then rearranged into a H**ANK**el Matrix to be truncated using a rank-selecting algorithm.

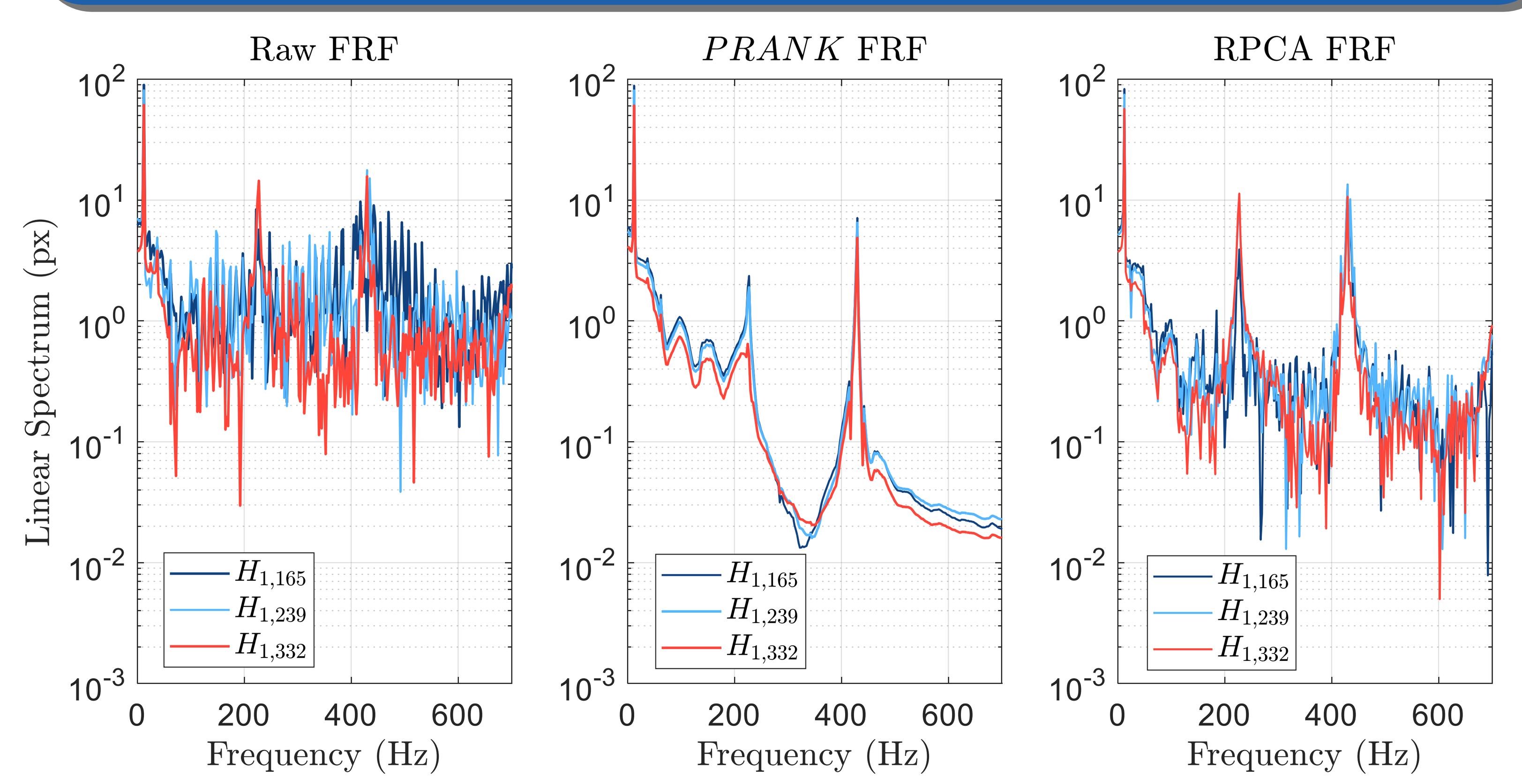


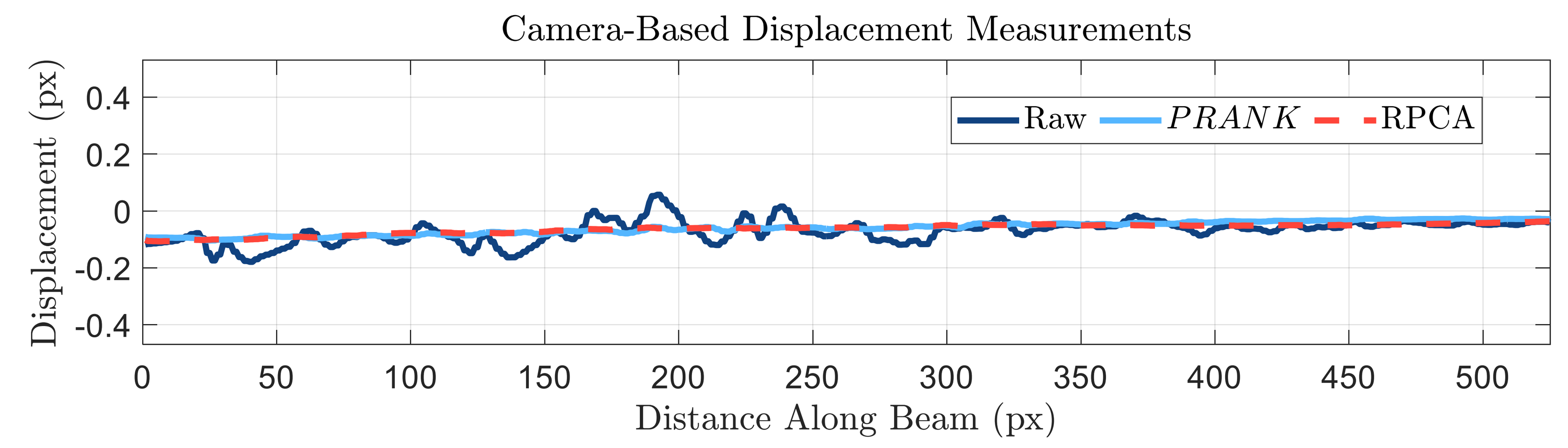


Robust **P**rincipal **C**omponent **A**nalysis [2] is a regularized implementation of SVD where the impact of outliers on the data reduction is minimized.

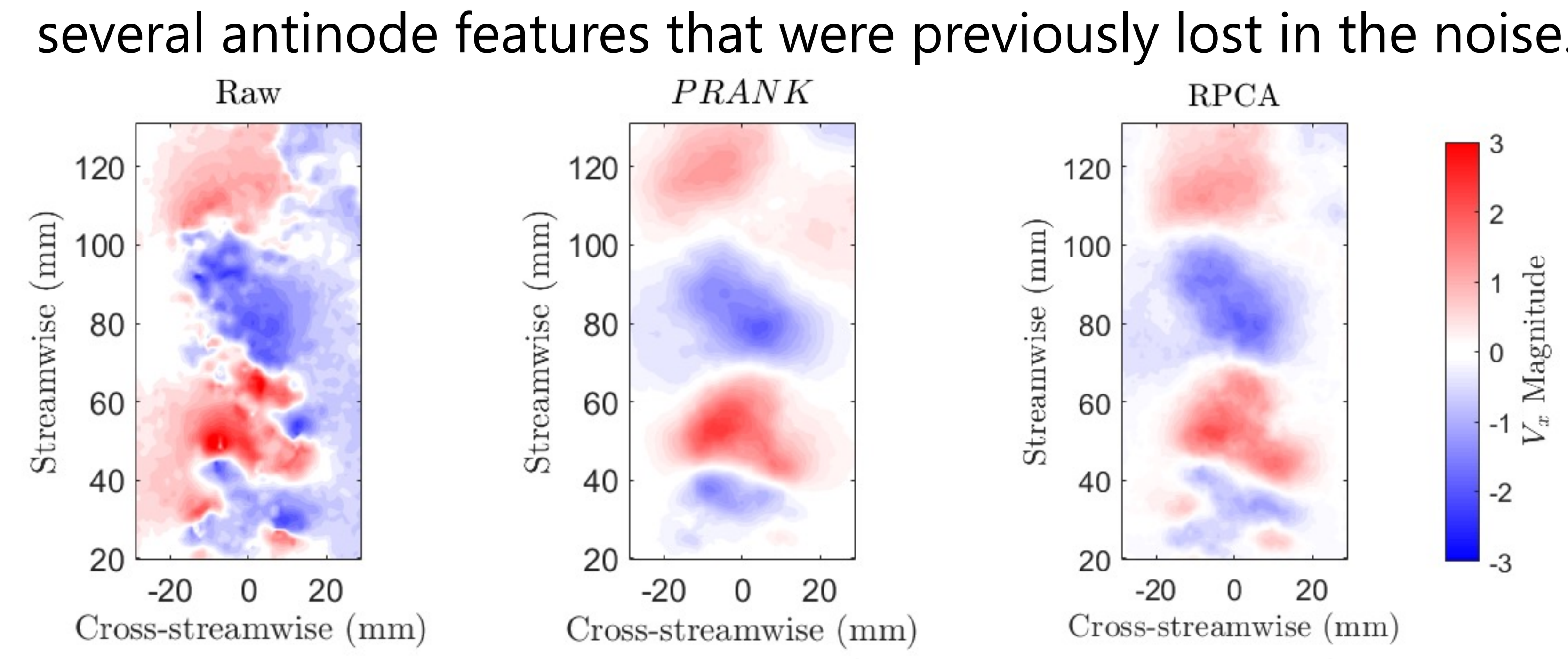


Results and Analysis





PRANK does exceptional in resolving the Frequency Response Functions (FRFs). PRANK and RPCA modes occur at the frequencies seen in the raw data; furthermore, PRANK resolves several antinode features that were previously lost in the noise.



The PRANK and RPCA plots identify several regions of positive and negative velocity, which were not as well defined in the raw plot. The PRANK methodology results in a lower ordered velocity reconstruction than RPCA.

Conclusions

PRANK and RPCA both use SVD in clever ways to manipulate data in a desirable manner; however, both techniques leave a lot to be desired. PRANK, reduces the noise and outliers significantly, but struggles with maintaining information such as amplitudes. RPCA, on the other hand, seems to resolve outliers well, but struggles more with the de-noising objective. These results are also dependent on truncation choice, herein done with the e15 algorithm. While this algorithm works well for data that is stored in a Short-Fat matrix, it is undefined for a Tall-Skinny matrix. A future objective, could be to determine a more robust algorithm for better informed decomposition.

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References

[1] Trainotti, F., S. B. Klaassen, T. Bregar, and D. J. Rixen (2022) "A singular value based filtering strategy for noise reduction on measured response data," in 41st Int. Mod. Anal. Conf., Unpublished, pp. 1–4.
[2] Scherl, Isabel, et al. "Robust principal component analysis for modal decomposition of corrupt fluid flows." *Physical Review Fluids*, vol. 5, no. 5, 28 May 2020, https://doi.org/10.1103/physrevfluids.5.054401.
[3] Brunton, Steven Lee, and José Nathan Kutz. *Data-Driven Science and Engineering: Machine Learning, Dynamical Systems and Control*. Cambridge University Press, 2021.