Temperature Reconstruction in Turbulent Rayleigh-Bénard Convection Using Physics-Informed Neural Networks from Tomo-, Stereo-, and Mono-PIV Data

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Abstract

In Rayleigh-Bénard convection (RBC), temporally and spatially resolved velocity fields can be measured using techniques such as particle image velocimetry (PIV). However, temperature measurements with comparable resolution remain challenging or infeasible.
To address this limitation, we propose a framework for reconstructing temperature fields using only velocity data and thermal boundary conditions at the heated and cooled plates.
This approach uses physics-informed neural networks (PINNs), which utilize the governing equations of RBC (doi.org/10.1016/j.compfluid.2024.106419, doi.org/10.1016/j.icheatmasstransfer.2025.109284, doi.org/10.1016/j.jcp.2022.111022).

Here, we investigate the reconstruction performance for three different experimental measurement configurations with increasing levels of data sparsity: tomographic, stereoscopic, and monoscopic PIV.
For each configuration, we analyze the corresponding requirements and challenges for the PINN training.

Our results show that concentrating training points in the top and bottom thermal boundary layers, where temperature gradients are strongest, improves reconstruction accuracy in all cases.
As the available velocity information is reduced – for example, to a single measurement plane in stereoscopic PIV – the reconstruction task becomes more challenging.
Nevertheless, for moderate Rayleigh numbers (Ra=10), we achieve excellent agreement between the reconstructed and reference temperature fields, with coefficients of determination exceeding $R^2(T) > 0.99$ for the case of stereoscopic PIV.
Even when the out-of-plane velocity component is omitted, as in monoscopic PIV, the in-plane temperature fields can still be reconstructed accurately ($R^2(T)=0.95$).

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Our current work focuses on extending the methodology to higher Rayleigh numbers, where increased turbulent fluctuations and smaller flow scales pose additional challenges for the PINN-based reconstruction.
At the conference, we aim to present results for Rayleigh numbers up to Ra=10.