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PHYSICS-INFORMED NEURAL NETWORK–BASED PARAMETER ESTIMATION FOR INVERSE PROBLEMS OF CAPILLARY FLOW IN POROUS MEDIA

Gabriel S. Gerlero[a,b,+] **and Pablo A. Kler**[a,c]

[a]*Centro de Investigación de Métodos Computacionales (CIMEC, UNL–CONICET), Colectora RN 168 km 472, S3000GLN Santa Fe, Argentina, https://cimec.conicet.gov.ar*

[b]*Universidad Nacional de Rafaela, Bv. Roca 989, S2300KCJ Rafaela, Santa Fe, Argentina, https://www.unraf.edu.ar*

[+]*ggerlero@cimec.unl.edu.ar*

[c]*Departamento de Ingeniería en Sistemas de Información, FRSF-UTN, Lavaisse 610, S3004EWB Santa Fe, Argentina, https://www.frsf.utn.edu.ar*

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Abstract.

Inverse problems in capillary flow through porous media are central to applications ranging from groundwater hydrology to paper-based microfluidics. These problems typically involve estimating unknown model and physical parameters from limited or noisy data, making them challenging to solve accurately. In this work, we introduce a physics-informed neural network (PINN) model for parameter estimation in capillary flow systems governed by the horizontal Richards' equation. By incorporating the governing physics directly into the neural network's loss function, our approach yields solutions that are consistent with both experimental data and the underlying physical principles. Our implementation leverages the JAX ecosystem for high-performance computation, and builds on our custom Fronts packages, which are tailored for modeling and solving capillary front propagation problems. This integration allows for efficient training and seamless incorporation of experimental data to validate our model. We demonstrate the effectiveness of the method through case studies in paper-based microfluidics, highlighting its ability to accurately recover flow parameters without relying on iterative trial-and-error approaches, and demanding considerably lower computation costs. This work illustrates the power of combining physics-based modeling with modern machine learning techniques and showcases JAX as a robust platform for solving real-world inverse problems in porous media flow.

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