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Comparison of PINN-SAMI3 and EKF data assimilation methods for Ionospheric Prediction

Jiayu Ma(1)(2), Yuhong Liu (1)(2), Haiyang Fu*(1)(2)
(1) School of Information Science and Engineering, Fudan University, Shanghai, China, e-mail: haiyang_fu@fudan.edu.cn
(2) Key Laboratory for Information Science of Electromagnetic Waves (MoE), Fudan University, Shanghai, 7 China

The objective of this study is to explore the feasibility of using PINN, the new data assimilation method, for ionospheric modeling. We propose a novel ionospheric inversion model, Physics-Informed Neural Network based on fully physical models SAMI3 (PINN-SAMI3) [1]. The model incorporates the governing equations of the ionospheric physical model SAMI3[2] in the magnetic dipole coordinate system into the neural network to reconstruct the temporal-spatial distribution of ionospheric plasma parameters. The simulation results show that if sparse ion densities with noise are used as training data, it is possible to retrieve ionospheric electron densities, ion velocities and ion temperatures, respectively. The PINN-SAMI3 framework (Figure1a)) has better results than the traditional data assimilation method, the Extended Kalman filter (EKF) method (Figure1b)). The framework will contribute to advance the future space weather prediction capability with artificial intelligence (AI).

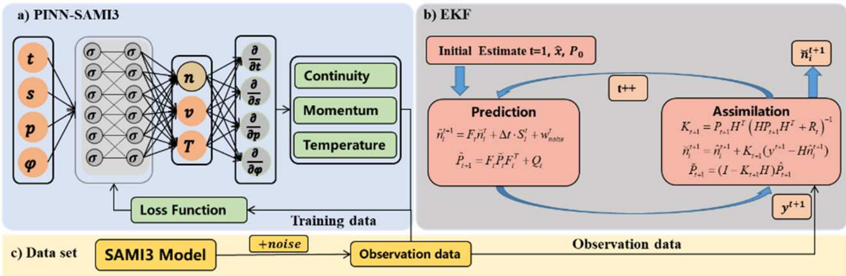

Figure 1. Ionospheric parameter inversion framework. The whole module includes a) PINN-SAMI3 (Physics Informed Neural Network based on SAMI3) architecture, b) Extended Kalman Filter (EKF), c) Observations generated by the SAMI3 model.

Table 1 Comparison of advantages and disadvantages of PINN-SAMI3 method and EKF method.

	PINN-SAMI3	EKF-SAMI3
Advantages	Higher accuracy and smoother results on complex physical models in small noise data	High computational efficiency
Disadvantages	For complex, large-scale problems, longer training time may be required.	The linear or Gaussian assumptions limit its accuracy on complex physical systems

Comparison of PINN-SAMI3 and EKF is shown in Table 1[3]. PINN-SAMI3 method could achieve similar or even better accuracy than traditional EKF under the condition of small noise data, while it will require a long training time. Due to the need for linearization when dealing with complex physical systems, EKF method is difficult to achieve good results in inverting high-dimensional problems such as ion density in SAMI3 models. The PINN-SAMI3 method outperforms the traditional EKF approach in conditions of less noise for offering enhanced accuracy and superior handling of complex nonlinear problems without the need for linearization or reliance on Gaussian noise assumptions. Future endeavors will contemplate the integration of multisource observational data into the neural network training process, aiming to substantially enhance the model's real-time performance capabilities.

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3. Du Y , Wang M , Zaki T A .State estimation in minimal turbulent channel flow: A comparative study of 4DVar and PINN[J].International journal of heat and fluid flow, 2023.