application examples. The training process is not affected by an increase or a decrease in the grid number. A parallel structure is adopted to solve the issue that learning will no longer be policy-based at some point, causing asynchronous training instability. In addition, we use a stepwise training method to avoid repeated exploration in designs with different frequencies. This work presents an AI model and design mindset for irregular structures, which is of great significance in promoting the development of filter devices.

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Data Availability The data generated and analysed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethical and informed consent for data used This article does not contain any studies with human participants or animals performed by any of the authors. Informed consent was obtained from all individual participants included in the study.

Conflicts of interest The authors declare that they have no conflict of interest.

References

1. Guo X, Zhu L, Wu W (2019) Design of complex weighted feeding network based on generalized coupled-resonator filter theory. IEEE Transactions on Microwave Theory and Techniques 67(11):4376–4385. https://doi.org/10.1109/TMTT.2019.2939238
2. Kishore S, Arora A, V. Phani Kumar K, et al (2021) Compact dual-band bandpass filter with high-passband isolation using coupled lines and open stub. Microwave and Optical Technology Letters 63(11):2710–2714. https://doi.org/10.1002/mop.32940
3. Chen W, Wu Y, Wang W (2020) Planar wideband high-selectivity impedance-transforming differential bandpass filter with deep common-mode suppression. IEEE Transactions on Circuits and Systems II-Express Briefs 67(10):1914–1918. https://doi.org/10.1109/TCSII.2019.2959814
4. Freno BA, Matula NR, Johnson WA (2021) Manufactured solutions for the method-of-moments implementation of the electric-field integral equation. Journal of Computational Physics 443. https://doi.org/10.1016/j.jcp.2021.110538
5. Olm M, Badia S, Martin AF (2019) On a general implementation of h- and p-adaptive curl-conforming finite elements. Advances in Engineering Software 132:74–91. https://doi.org/10.1016/j.advengsoft.2019.03.006
6. Jansson E, Thiringer T, Grunditz E (2020) Convergence of core losses in a permanent magnet machine, as function of mesh density distribution, a case-study using finite-element analysis. IEEE Transactions on Energy Conversion 35(3):1667–1675. https://doi.org/10.1109/TEC.2020.2982265
7. Luo HY, Shao W, Ding X et al (2022) Shape modeling of microstrip filters based on convolutional neural network. IEEE Microwave and Wireless Components Letters 32(9):1019–1022. https://doi.org/10.1109/LMWC.2022.3162414
8. Wu Y, Pan G, Lu D et al (2022) Artificial neural network for dimensionality reduction and its application to microwave filters inverse modeling. IEEE Transactions on Microwave Theory and Techniques 70(11):4683–4693. https://doi.org/10.1109/TMTT.2022.3161928
9. Zhao P, Wu K (2020) Homotopy optimization of microwave and millimeter-wave filters based on neural network model. IEEE Transactions on Microwave Theory and Techniques 68(4):1390–1400. https://doi.org/10.1109/tmtt.2019.2963639
10. Feng F, Na W, Jin J et al (2022) Artificial neural networks for microwave computer-aided design: The state of the art. IEEE Transactions on Microwave Theory and Techniques 70(11):4597–4619. https://doi.org/10.1109/TMTT.2022.3197751
11. Dai X, Yang Q, Du H et al (2021) Direct synthesis approach for designing high selectivity microstrip distributed bandpass filters combined with deep learning. AEU - International Journal of Electronics and Communications 131(153):499. https://doi.org/10.1016/j.aeue.2020.153499
12. Yahya SI, Rezaei A, Nouri L (2021) The use of artificial neural network to design and fabricate one of the most compact microstrip diplexers for broadband l-band and s-band wireless applications. Wireless Networks 27(1):663–676. https://doi.org/10.1007/s11276-020-02478-x
13. Salehi MR, Noori L, Abiri E (2016) Prediction of matching condition for a microstrip subsystem using artificial neural network and adaptive neuro-fuzzy inference system. International Journal of Electronics 103(11):1882–1893. https://doi.org/10.1080/00207217.2016.1138539
14. Na WC, Zhang QJ (2014) Automated knowledge-based neural network modeling for microwave applications. IEEE Microwave and Wireless Components Letters 24(7):499–501. https://doi.org/10.1109/LMWC.2014.2316251
15. Pinchuk P, Margot JL (2022) A machine learning-based direction-of-origin filter for the identification of radio frequency interference in the search for techno signatures. Astronomical Journal 163(2). https://doi.org/10.3847/1538-3881/ac426f
16. Singh P, Singh VK, Lala A, et al (2018) Design and analysis of microstrip antenna using multilayer feed-forward back-propagation neural network (MLPFFBP-ANN). In: Advances in Communication, Devices and Networking. Springer Singapore, pp 393–398, https://doi.org/10.1007/978-981-10-7901-6_43
17. Sharma K, Pandey GP (2021) Efficient modelling of compact microstrip antenna using machine learning. AEU - International Journal of Electronics and Communications 135(153):739. https://doi.org/10.1016/j.aeue.2021.153739
18. Ai MX, Xie YF, Tang ZH et al (2021) Deep learning feature-based setpoint generation and optimal control for flotation processes. Information Sciences 578:644–658. https://doi.org/10.1016/j.ins.2021.07.060
19. Shen CY, Gonzalez Y, Chen LY et al (2018) Intelligent parameter tuning in optimization-based iterative ct reconstruction via deep reinforcement learning. IEEE Transactions on Medical Imaging 37(6):1430–1439. https://doi.org/10.1109/Tmi.2018.2823679
20. Harandi MT, Nili Ahmadabadi M, Araabi BN (2009) Optimal local basis: A reinforcement learning approach for face recognition.