

Magnetic Field Prediction of PM Motor Based on The Improved Numerical U-net Neural Network with Output Linear Activation Function

Tong Ben¹, Wenguang Ke¹, Long Chen^{1,2}, Libing Jing¹, Yongjian Li³

¹College of Electrical Engineering and New Energy, China Three Gorges University, Yichang, 443002 China, bentong@ctgu.edu.cn

²Hubei Provincial Engineering Technology Research Center for Power Transmission Line, China Three Gorges University, Yichang, 443002 China, chenlong@ctgu.edu.cn

³State Key Laboratory of Intelligent Power Distribution Equipment and System, Hebei University of Technology 300130 Tianjin, China

To improve the computational efficiency of the magnetic field prediction of permanent magnet (PM) motors, an improved numerical U-net neural network model based on linear activation function is proposed in this paper. First, to address the pixel-level error and poor generalization under the pixel prediction of traditional U-net network, the output linear activation function is utilized to combine with the U-net network. And a two-dimensional array of magnetic field distributions is derived to achieve the numerical prediction. Secondly, a parallel convolutional layer is utilized to import two-channel inputs, representing the geometry and excitation dimensions, respectively. Finally, the magnetic field distribution of the motor under different excitations with different geometries and rotation angles are predicted. By comparing with the results of finite elements method (FEM), the improved numerical U-net neural network is 13 times more efficient in the range of peak motor excitation currents from 50 A to 250 A, and the average percentage error is within 4%.

Keywords: Deep Learning, Permanent Magnet Motors, Electromagnetic Fields, Digital Twins

I. INTRODUCTION

To improve the design efficiency, the magnetic field distribution should be predicted quickly and accurately. However, traditional computational methods suffer from high resource consumption and insufficient generalization capability. Deep learning is used to improve computational efficiency and image segmentation is used to construct relationships between geometry and cloud maps for pixel prediction. Supervised learning was used to predict the magnetic field distribution for different geometries and material cases [1]. The improved Linknet model proposed to predict the magnetic field for different motor structures [2]. However, the above methods are essentially pixel prediction rather than numerical computation and suffer from pixel-level errors and poor generalization.

To address the aforementioned problems, this paper proposes several innovations. Firstly, it introduces a linear activation function. Secondly, it modifies the network's output into a two-dimensional array specifically for numerical prediction. This transformation enhances the network's generalization capabilities. Furthermore, by adopting this approach, it significantly reduces the time required for magnetic field prediction. Taking a permanent magnet motor as an illustrative example, the paper verifies the proposed method's accuracy and speed by comparing it with finite element analysis.

II. IMPROVED NUMERICAL U-NET NETWORK MODEL

A. Pixel Image Replacement to 2D Array

The Dropout module is introduced to prevent overfitting, as shown in Fig. 1. The hollow convolution kernel is utilized to improve computational efficiency, and the output function is selected as a linear activation function.

To realize numerical computation, the output of the conventional U-net network from FEM derived magnetic field cloud map is replaced with a two-dimensional array of fixed raster size for numerical prediction, as shown in Fig. 2.

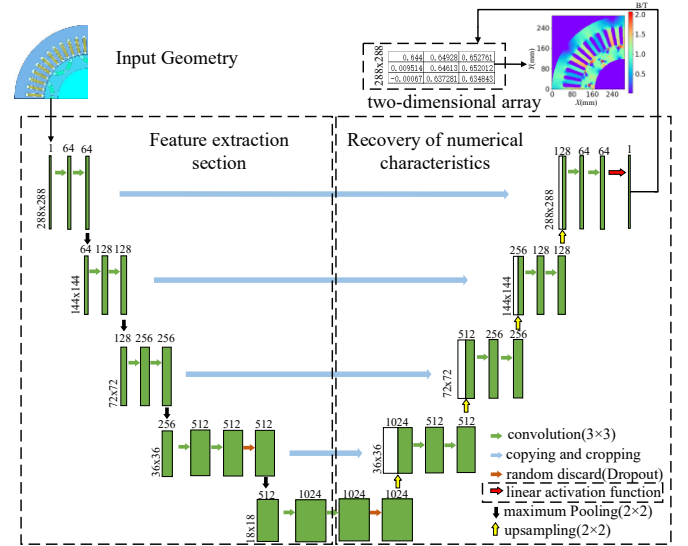


Fig. 1. Schematic diagram of the improved numerical U-net network

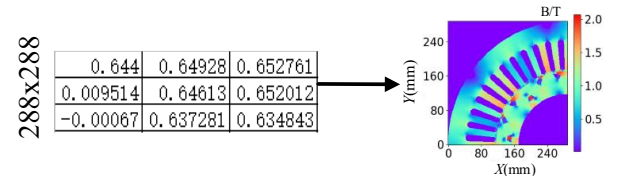


Fig. 2. 2D Array Replacement Pixel Image Map

B. Election Of Output Linear Activation Function

As the traditional U-net network is mostly used for pixel regression, the output layer activation function often selected the nonlinear functions, which lead to high resource consumption. To improve computing efficiency, linear function

is chosen as the activation function of the output layer to directly output continuous values, because the output is a two-dimensional array containing many values in the numerical prediction task.

The comparison of nonlinear and linear activation functions is shown in Fig.3. As shown, the output linear activation function can directly reflect the input-output relationship.

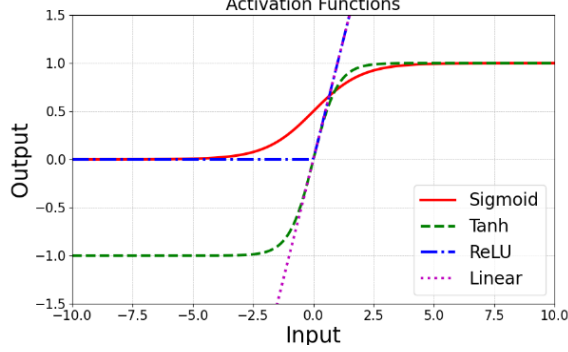


Fig.3. Graphs of common activation functions

III. FAST NUMERICAL PREDICTION OF MAGNETIC FIELD BASED ON U-NET NEURAL NETWORK

The magnetic field prediction of a PM motor based on the improved numerical U-net neural network is constructed, as shown in Fig. 4. First, the solution domain and optimization parameters are defined. And the data set is obtained based on the FEM results. Then, it is trained by the geometric-numerical data set under different angles, geometries and excitations to predict the numerical distribution of the magnetic field in the untrained case.

To improve the generalization of the prediction as well as the speed and accuracy of the magnetic field prediction. We firstly constructed a geometric-numerical dataset, which is combined with the traditional image segmentation to realize the numerical prediction at the same time. Secondly, we utilize the generalization and numerical characteristics of the network to achieve fast and accurate prediction of the magnetic field under unknown working conditions.

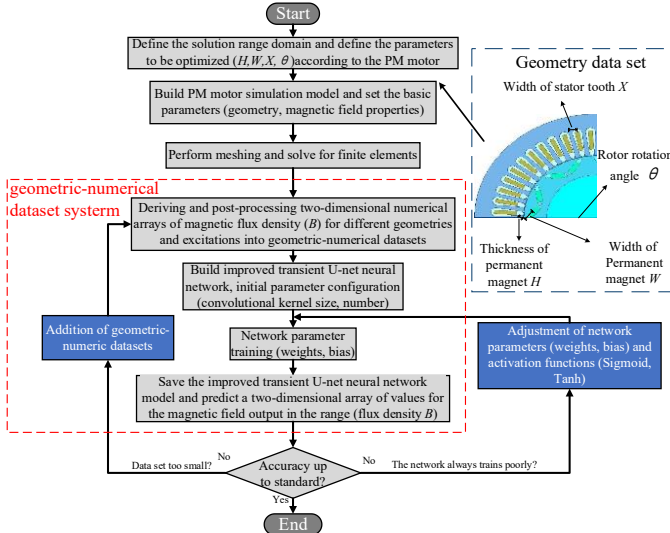


Fig. 4. Flowchart for Improving Fast Prediction for U-net Networks

IV. RESULT AND DISCUSSION

For the fast prediction of the motor magnetic field values for unknown excitation, rotation angle and geometry, the comparison results are shown in Fig. 4. It can be seen that most of the errors are concentrated in the stator teeth and the permanent magnet contour at peak winding currents of 125A, 175A, and 225A. While some of the error rates were 19%, most of them were less than 3%, and the average error rate calculated was less than 4%. Therefore the model can meet the accuracy requirements.

The computational efficiency of the improved model is shown in TABLE I. It can be seen that its computation time is reduced by more than 13 times, so the model can meet the requirement of rapidity.

TABLE I
CALCULATION EFFICIENCY COMPARISON TABLE

calculation method	finite element method	numerical U-net fast prediction method
6875 samples		
computation time	6h	0.4h

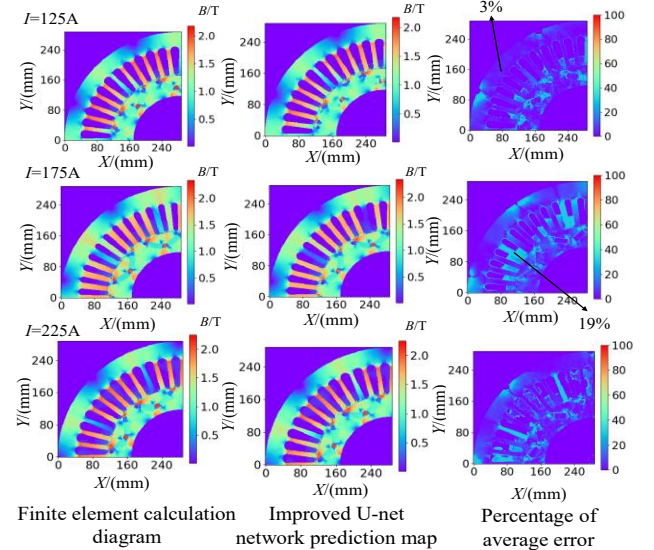


Fig. 5. Comparison of magnetic field prediction by finite element and improved U-net network

V. CONCLUSION

In this paper, a numerical U-network magnetic field prediction model based on output linear activation functions is proposed. By improving the output layer activation function and deriving a two-dimensional array of outputs for numerical prediction, the model can predict the numerical distribution of the magnetic field of a motor with different excitations, geometry and rotation angle. And the prediction time is reduced by 13 times than FEM for different excitations, and the average percentage errors are all within 4%.

REFERENCES

- [1] Khan A, Ghorbanian V, and Lowther D, "Deep Learning for Magnetic Field Estimation," IEEE Transactions on Magnetics, vol. 55, no. 6, pp. 1-4, 2019.
- [2] Jin L, Liu Y, Yang Q, et al, "Prediction Method of Motor Magnetic Field Based on Improved Linknet Model," COMPEL-The International Journal for Computation and Mathematics in Electrical and Electronic Engineering, vol. 42, no. 1, pp. 90-100, 2023.