Extracting of optical microcavity coupling properties assisted by coupled mode theory informed neural networks

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Abstract

Optical microcavity coupled systems have become an ideal platform for studying various physical mechanisms. Although complex coupled systems can be described by coupled mode theory (CMT), it is still a challenging task to directly extract the physical parameters in the high-order Hamiltonian from the spectra. In this paper, we propose the CMT-Informed Neural Network (CINN), which combines deep learning with physical prior knowledge to achieve efficient prediction of spectral and physical parameters in coupled mode equations. Compared to Visual Attention Network (VAN) and Multilayer Perceptron (MLP), the spectral prediction error of CINN is only 13% and 5.97% of that of VAN and MLP, respectively.

1 Introduction

- The traditional CMT fitting method has multiple solutions in the microcavity coupling system and needs to set the initial value. It will consume a lot of computing resources for the fitting of a large number of spectra.
- The black box nature of traditional machine learning methods makes them lack of interpretability, and the prediction results depend heavily on the training data process, and the generalization ability is not good.
- In this paper, we propose the CMT-Informed Neural Network to improve the prediction accuracy of the spectral line and physical parameters of the microcavity coupling system, and solves the problem of poor interpretability and weak generalization ability of the tradiotnal neural network model to a certain extent.

2 Physcial and network model

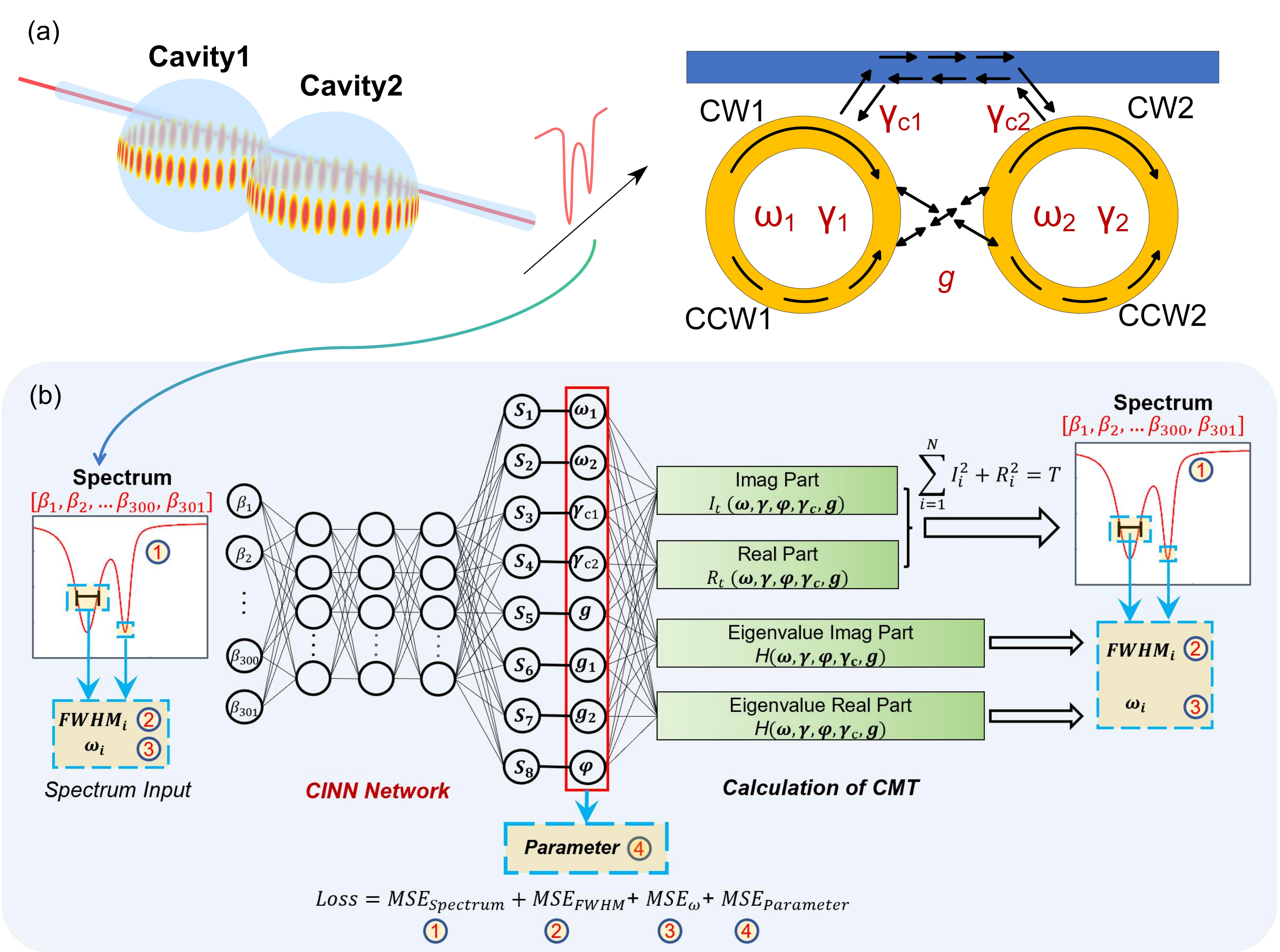

Figure 1. (a) Schematic diagram of the microcavity coupling model. (b) Schematic diagram of CINN model architecture, S1-S8: Sub Neural Network.

The two microcavities can either transmit energy through a waveguide or exchange energy directly. The Hamiltonian of the coupled system is:

$$H=\begin{bmatrix} \omega_1 - i(\gamma_{c1}+\gamma_1)/2 & g_1 & 0 & g \\ g_1 & \omega_1 - i(\gamma_{c1}+\gamma_1)/2 & g & -i\sqrt{\gamma_{c1}\gamma_{c2}}e^{i\varphi} \\ -i\sqrt{\gamma_{c1}\gamma_{c2}}e^{i\varphi} & g & \omega_2 - i(\gamma_{c2}+\gamma_2)/2 & g_2 \\ g & 0 & g_2 & \omega_2 - i(\gamma_{c2}+\gamma_2)/2 \end{bmatrix}$$

ω_1 and ω_2 denote the intrinsic resonant wavelengths of the two microcavities, respectively. $\gamma_1(\gamma_2)$ and $\gamma_{c1}(\gamma_{c2})$ represent the intrinsic loss of the first (second) microcavity and the coupling efficiency between the first (second) microcavity and the waveguide, respectively. $g_1(g_2)$ represents the coupling coefficient between CW and CCW of the first (second) microcavity. Parameter g and φ is the couple strength and transmission phase between two microcavities.

3 Results and discussion

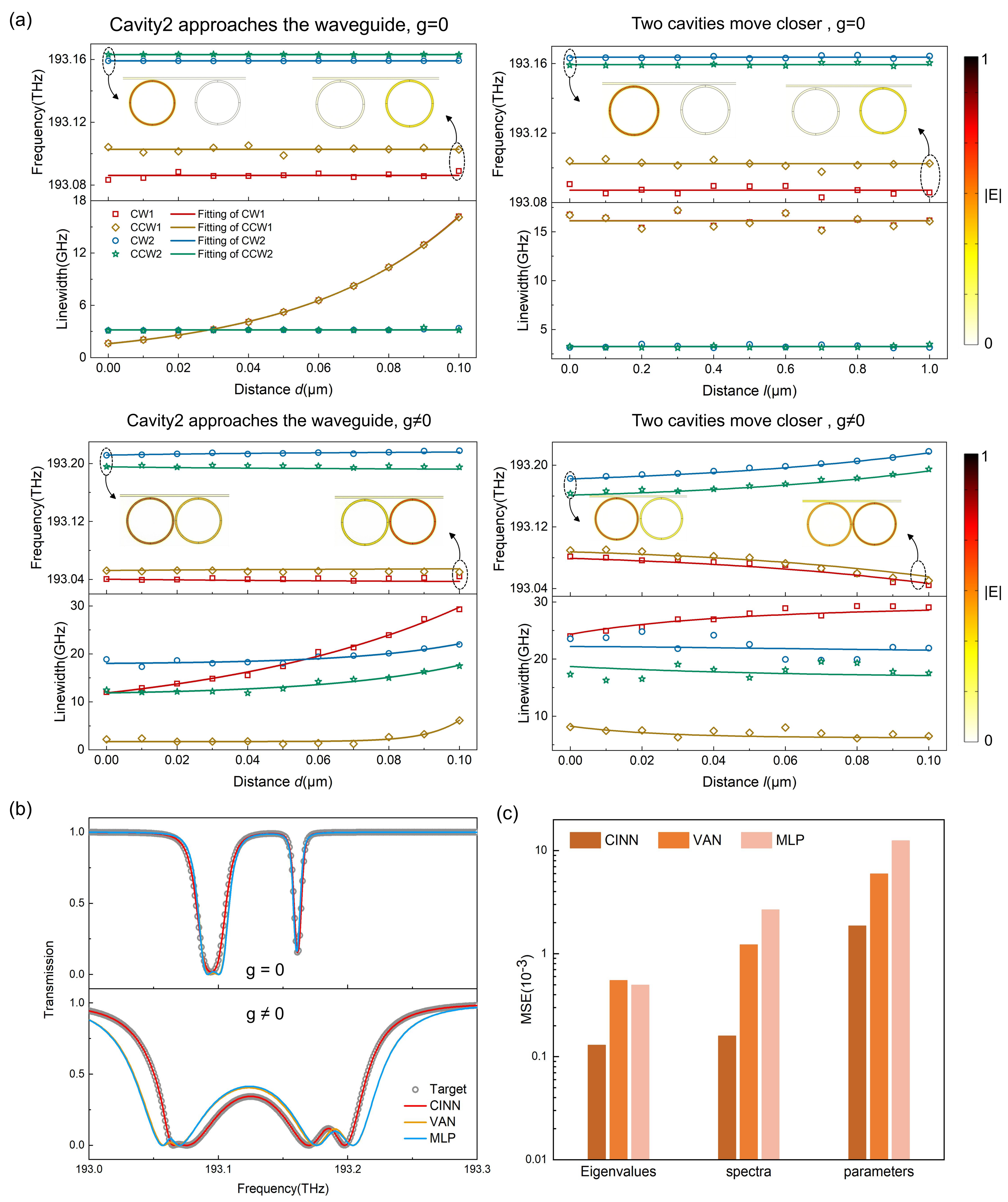

Figure 2. (a) Prediction evolution of the eigenvalues of the coupled system with two microcavities. The inset shows the electric field distribution at the corresponding position. (b) Comparison of the predicted spectral line results of three respective models CINN, VAN, and MLP under g=0 and g≠0. (c) Comparison of the three respective models in predicting physical parameter errors, transmission spectrum errors, and eigenvalue errors across the entire test set.

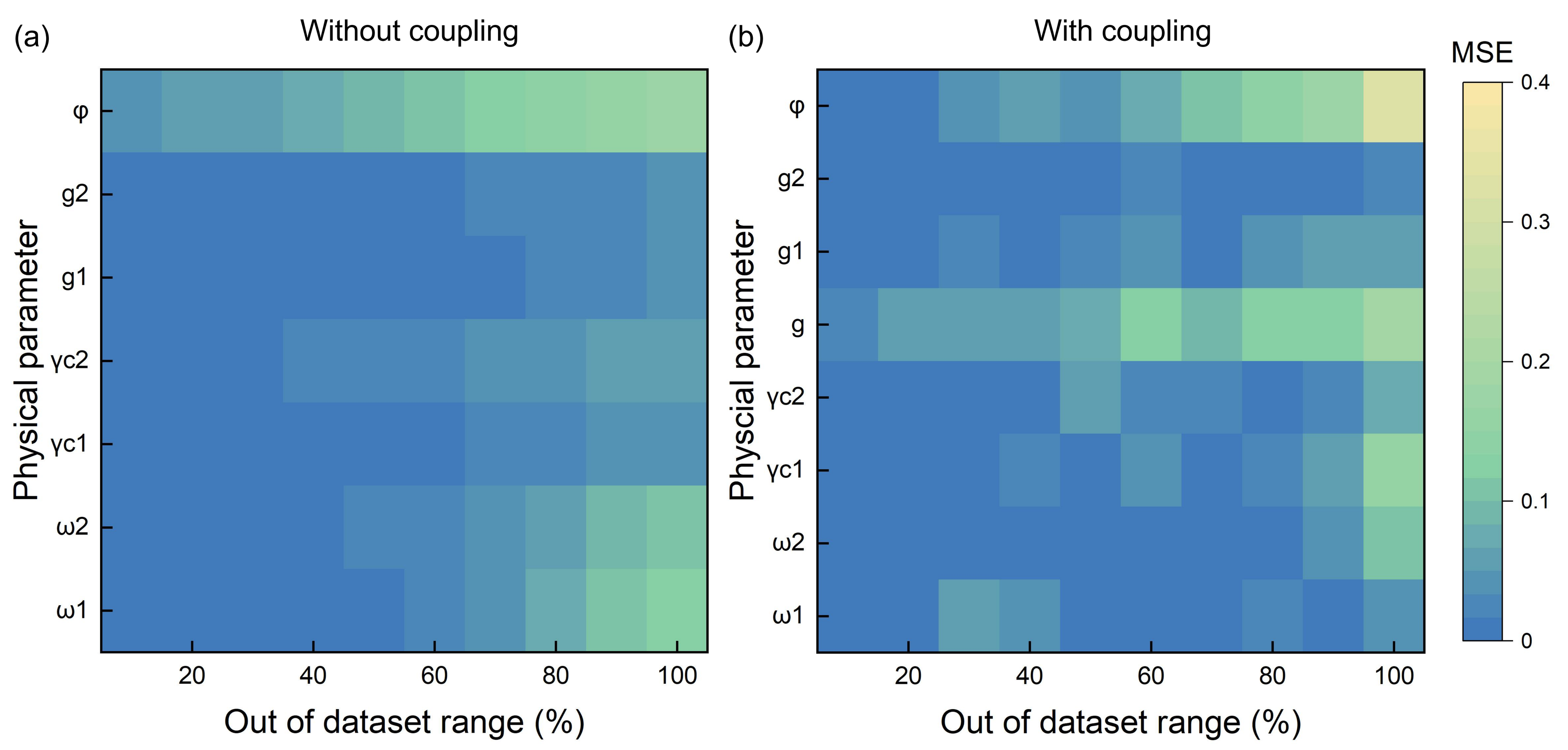

Figure 3. Integrated prediction error for different parameters outside the percentage range of the dataset in (a) without coupling and (b) with coupling. Out of dataset range's percentage is defined as the ratio of the physical parameter exceeds the dataset range to the corresponding range interval of the dataset.