Complex-Valued Convolutional Neural Networks for Disease Detection Utilizing Digital Holographic Wavefronts

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Abstract

Phase carries crucial morphological and compositional information and is central to many optical imaging modalities. Digital holographic microscopy (DHM), interferometric technique, captures the complex object field of a specimen, containing both phase and amplitude. Conventional deep learning (DL) networks process complex data as paired real channels, neglecting intrinsic phase–amplitude coupling. In this reported work, we introduce complex-valued convolutional neural networks (CV-CNNs) for binary classification of normal and cancerous cervical cells using the DHM complex object field. Four CV-CNN variants (ModReLU, CReLU, Cardioid, zReLU) were evaluated via five-fold cross-validation against an equivalent real-valued CNN (RV-CNN). The ModReLU CV-CNN achieved the highest performance (Accuracy = 0.89 ± 0.03, F1 = 0.89 ± 0.04, Precision = 0.89 ± 0.04, Recall = 0.89 ± 0.05, AUC = 0.96 ± 0.02), demonstrating that phase-aware complex convolution significantly enhances the classification performance. By eliminating phase unwrapping, it also reduces associated computational cost and ambiguity. The methodology is also applicable to other phase-sensitive imaging modalities.

Keywords: Digital Holography, Phase Imaging, Disease Diagnosis, Deep Learning, Complex-valued Neural Networks, Complex Activation Function, Image Processing

1 INTRODUCTION

The phase of a signal carries much valuable information compared to the amplitude alone [1–3]. Its importance has been addressed in many research domains, such as magnetic resonance imaging (MRI) reconstruction [4, 5], radar signals [6], seismic imaging [7, 8], audio signals [9] or classification studies [10, 11]. Phase information is fundamentally important for nearly transparent, unstained biological cells, as conventional intensity-based microscopy techniques commonly used in bioscience laboratories and pathology clinics rely on dyes for contrast enhancement, an approach that can alter the natural state of cells. The phase component of light is modified by variations in optical path length and refractive index, which correspond to the cellular morphology and subcellular composition of the specimen, thereby providing three-dimensional structural information. In contrast, traditional intensity-based imaging systems measure only light absorption (2D information), and lack in inherent capability to