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Ghost Image Reconstruction with Classical and Quantum Convolutional Neural Networks

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Image reconstruction is a critical problem in industry, especially in certain areas of Optics, such as the Ghost Imaging experiment, [1], [2]. The experiment has many beneficial practical applications such as live cell imaging or remote sensing. The key leverage here lies with its non-local imaging procedure. This allows one to view a quantum image without collapsing its state. The experimental approach requires twice the number of measurements as opposed to a classical image, due to the real and complex part of the quantum image. Thus, requires ≈ 2N 2 measurements to reconstruct a N × N image, [3]. The experimental procedure has challenges in the speed and fidelity of reconstruction. Commonly used classical reconstruction methods are effective but can be computationally intensive or struggle to leverage the inherent patterns in natural images.

We have designed a Classical and Quantum algorithm to overcome this intensive computational task. The method we present reconstructs low-sampled images measured from the Ghost Imaging experiment, using a Classical and Quantum Convolutional Neural Network (CNN), [4]. Low-sampled images have a linear representation using the Hadamard transform, where a number of coefficients of the linear decomposition are unknown. The CNN's take the low-sampled coefficients as inputs and reconstructs the complete set of coefficients. Instead of directly processing pixel-domain images, our method focuses on reconstructing missing coefficients in the Hadamard transform domain.
The Quantum CNN model architecture adapts the principles of a Classic U-Net Convolutional Neural Network. With the use of Variational Circuits, we will apply the convolutional and pooling layers. Due to quantum properties such as quantum superposition and quantum entanglement, the model may be able to exploit more intrinsic patterns and correlation within the Hadamard coefficient space. We have simulated the Quantum CNN, and seems to show possible improvement in reconstruction speed and higher fidelity rates, as compared to its classical counterpart of similar size.
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This paper will detail the proposed Classical annd Quantum CNN architecture, the encoding scheme for Hadamard coefficients into quantum states, the variational quantum layers for feature extraction and upsampling, and the classical optimization loop. We will present simulation results on the MNIST data set, and real experimental results from the Wits Structured Light Lab. Demonstrating the CNN's ability to reconstruct full Hadamard coefficient sets from various levels of undersampling, followed by inverse Convolutional Neural Network to generate high-fidelity pixel-domain images. The findings highlight the potential of quantum machine learning to significantly advance computational imaging techniques like Ghost Imaging, paving the way for faster, more accurate, and quantum-enhanced imaging solutions.

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