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Continuous-Variable Deep Quantum Neural Networks for Flexible Learning of Structured Classical Information

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Abstract. Quantum computation using optical modes has been well-established in its ability to construct deep neural networks. These networks have been shown to be flexible both architecturally as well as in terms of the type of data being processed. We leverage this property of the Continuous-Variable (CV) model to construct stacked single mode networks that are shown to learn structured classical information, while placing no restrictions on the size of the network, and at the same time maintaining it's complexity. The hallmark of the CV model is its ability to forge non-linear functions using a set of gates that allows it to remain completely unitary. The proposed model exemplifies that the appropriate photonic hardware can be integrated with present day optical communication systems to meet our information processing requirements. In this paper, using the Strawberry Fields software library on the MNIST dataset of hand-written digits, we demonstrate the adaptability of the network to learn classical information in a multitude of machine learning tasks to very large fidelities.

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1 Introduction

Neural networks enjoy widespread success both in academia and the industry, with a plethora of applications ranging from solving simple classification problems to information security and processing. The review article by Pal and Pal [1] on image segmentation

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predicted that neural networks would have a multitude of applications even in the field of image processing. One of the most representative models – the Deep Convolutional Neural Network, has been widely used in diverse areas from time-dependent signal processing to computer vision. However, despite these plethora of applications, the dramatic increase in the computational cost has been deemed as a bottleneck in the functionality of these networks. Quantum computing, however, seems to provide a viable alternative to satisfy our growing demand for computational power and efficiency.

The advent of quantum technologies has resulted in what is being referred to as quantum-enhanced machine learning where we expect a speed-up either by employing genuine quantum effects, or by classical machine learning to improve quantum processes. A hybrid classical-quantum system achieves this speed-up by outsourcing computationally difficult subroutines to the integrated quantum device – specifically the quadratures of light in a quantum optical system. The KLM protocol [2], proposes that quantum computing can be achieved solely using linear-optic tools, single photon sources, photodetectors and ancilla resources. In the following paper, we demonstrate the use of the Continuous-Variable (CV) model to flexibly learn structured data without restrictions on the format of the data, while proposing a method to realize the same experimentally via parameter-dependent gates.

Information systems have always had the need for components that would effectively be able to handle a multitude of signals and could easily be integrated in existing networks. The following work introduces such an element that we show to be adaptable to our signal processing requirements by means of numerical experiments with some of the most fundamental applications of deep learning networks on the platform of image processing – namely image classification, image reconstruction and image enhancement. The versatility of the kind of information being learnt is illustrated in these cases with the architecture modified to suit to specifics of the data. Note that while an image could be considered as a two-dimensional signal, there is no feature of the network that confines it to learn such data – higher dimensional tensors and time-dependent signals can be learnt equally well with the appropriate datasets, by simply stacking the proposed layers one after the other. Furthermore, we propose an experimental model that is commercially feasible and can be assimilated into modern optical communication systems.

This paper is organized as follows: In section 2, be provide a brief theoretical background to the CV model as well introduce the construction for the experimental implementation of our network. We then demonstrate the results of our numerical simulations for fundamental applications in image processing. Finally, after a discussion of the merits of the model, we conclude with the applications and future scope in this field.

2 Continuous-variable single mode quantum layer

2.1 Operating principles of the quantum layer

The widely accepted model of the qubit based quantum computer has proven to be ill-suited to tackle continuous-valued problems [3]. Fortunately, the CV model [4] proposes