Hybrid Classical and Quantum Deep Learning Models for Medical Image Classification

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Abstract

Quantum machines enhance the capabilities of classical counterparts across various domains, notably in addressing real-world challenges. The classification of brain MR images for tumor detection is a crucial diagnostic process in the analysis of brain images. Traditional approaches, such as classical machine learning techniques and conventional deep learning structures like convolutional neural networks, are frequently employed for image classification. However, as the network size increases, training these models becomes increasingly arduous. Quantum algorithms offer advantages by optimizing the performance of classical algorithms through the incorporation of the intrinsic properties of quantum bits. In this paper, we proposed a hybrid classical and quantum convolutional neural network for Alzheimer's disease (AD) classification. The proposed model was further validated on the brain tumor classification task. The fundamental concept involves encoding data into quantum states, facilitating quicker information extraction, and subsequently utilizing this information to discern the data class. The proposed model results underscore the reliability and robustness and demonstrated by optimal performance accuracies across various datasets, the proposed model substantiates its efficacy in detecting and classifying AD disease and brain tumors.

Keywords: Quantum machine learning, Deep learning, Classification, Alzheimer's disease, Brain Tumour, Hybrid Quantum technique in medical imaging.

1. Introduction

Alzheimer's disease (AD) is the most common reason of dementia worldwide [1]. Dementia belongs to assess abnormal changes in the brain and commonly interrupts the communication between the brain cells [1]. Disrupted communication between cells can lead to impairments in an individual's cognitive functions, including memory loss, emotional regulation, reasoning and decision-making, behavior, and language proficiency [1]. In recent years, substantial progress has been achieved in the advancement of cerebrospinal fluid (CSF) biomarkers [2] and cutting-edge imaging techniques like amyloid and tau positron emission tomography (PET) [2]. Although there have been significant advancements, numerous emerging diagnostic and treatment approaches are still primarily confined to research settings. As a result, the primary means of diagnosis before death continues to rely on traditional clinical evaluation, neuropsychological testing [10] and magnetic resonance imaging (MRI) [11]. Mild cognitive impairment (MCI), which serves as an early precursor to dementia, can also represent a subtle initial manifestation of Alzheimer's disease (AD). Diagnosing MCI as an early sign of AD demands a high level of clinical expertise from skilled specialists. Alzheimer's disease (AD) is a neurological disorder that can be detected through brain imaging, and numerous studies have concentrated on using machine learning or deep learning methods to classify AD based on brain images [3].

Recently, various studies proposed deep learning models for AD classifications [3], [4]. They proposed traditional deep learning classification models, in this study we investigate a hybrid model based on classical deep learning and quantum machine learning. Recently Quantum machine learning research has gained success in the medical community.

Few studies proposed quantum machine learning for brain tumor classification [5]. We have proposed hybrid deep learning and quantum layers for the classification of AD and compared the performance with state-of-the-art methods using a hybrid proposed approach. We proposed first-time hybrid classical deep learning and quantum machine learning models for AD classification. We have compared performance using the brain tumor dataset using our proposed technique.

2. Methodology

Our proposed approach combines a classical network with a quantum network to harness the strengths of both worlds, creating a model that can effectively identify AD abnormalities using MRI analysis. The architecture primarily emphasizes the utilization of classical algorithms for enhanced detection, thereby expediting the diagnosis and treatment processes. The substructure integrated into constructing a quantum layer aims to transform classical data points into quantum states, facilitating faster information extraction and improving the efficiency of feature detection and pattern recognition.

The Convolutional Neural Network (CNN) is a widely employed architecture for a range of processing tasks, such as image recognition, segmentation, and classification [6], [7], [8], [9], [10], [11], [12]. It is composed of three basic layers: Convolution, pooling, and fully connected layers. The convolution and pooling layers are involved in feature extraction from input images, while the fully connected layer extracts features to the output, facilitating classification based on the identified features. A typical CNN structure comprises multiple blocks that integrate convolution, pooling, and fully connected layers. We have proposed three blocks of conv layers. Each block consisted of 2D Conv, 2D MaxPool, and 2D Normalization layers [13], [14], [15]. We have used one fully connected (FC) layer and one hybrid quantum layer for AD and brain tumor classification. The structure of the proposed model is shown in Figure 1.

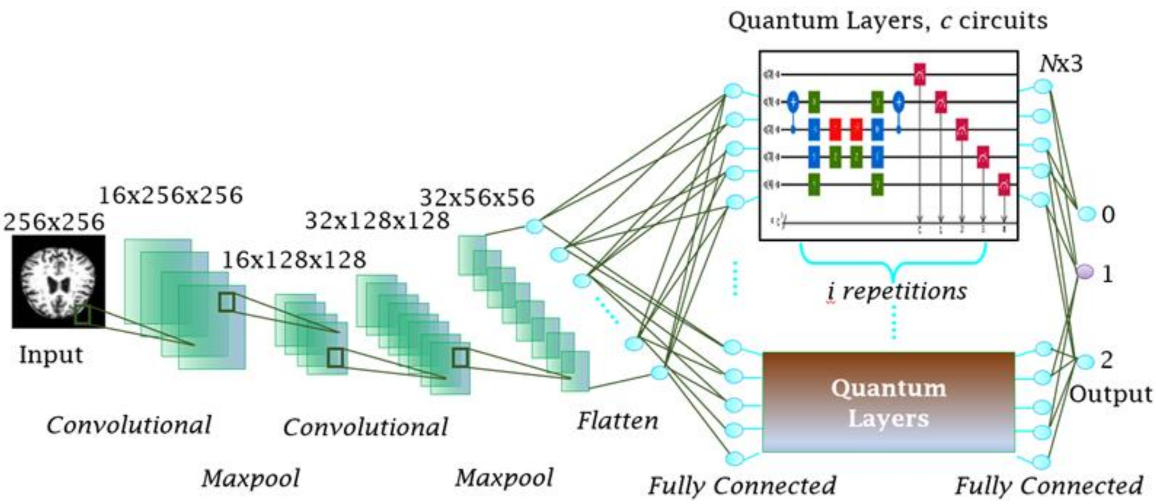

Fig. 1 The structure of the proposed classical and Quantum deep learning network.

3. Quantum Layers

Quantum supremacy manifests when solving intricate problems more effectively than traditional classical methods [5]. Quantum mechanics provides the fundamental framework for the operation of quantum machines. In a quantum computer, the fundamental unit of information processing is a quantum bit, or qubit, akin to the role played by classical bits in conventional computers. A standard quantum computer utilizes the unique features of a quantum bit, primarily superposition and quantum entanglement, to process data and information. Unlike a classical bit, a qubit's superposition property enables it to simultaneously exist in multiple states, including zero and one. In essence, qubits can be described as state vectors within Hilbert space. The hybrid layer has been proposed with classical deep learning models for AD classification and further compared on the brain tumor classification dataset.

Figure 2 shows the complete block architecture of the quantum layers.

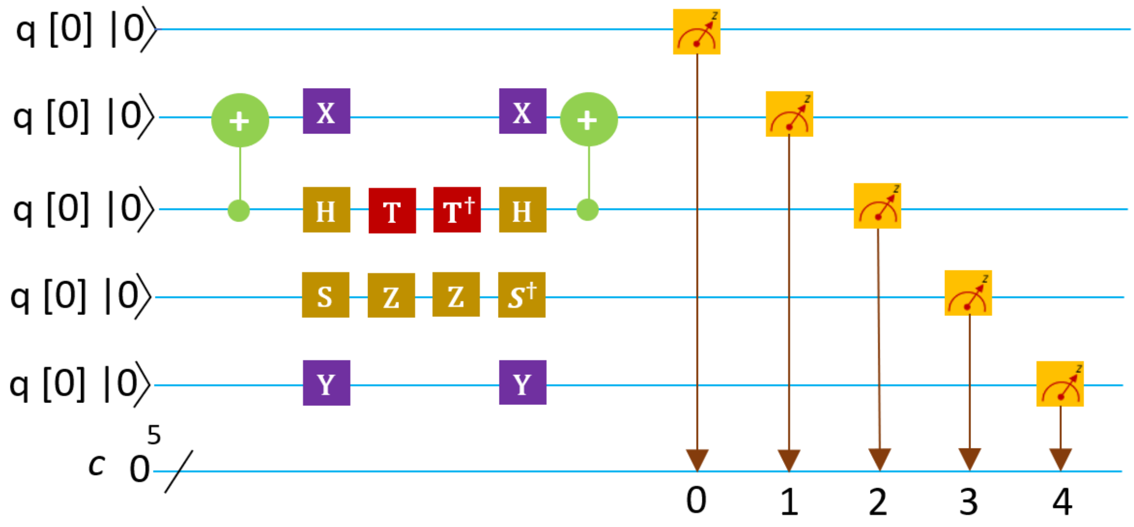

Fig. 2 Block of the quantum layer.

4. Dataset

We have used an Alzheimer's Disease Neuroimaging Initiative (ADNI) dataset, consisting of 1,821 participants based on magnetic resonance imaging (MRI) scans. After rigorous inclusion criteria were applied, the dataset comprised a total of 8,916 participants. Subjects were labeled according to the clinical diagnoses provided by the ADNI study cohort. For any subjects with documented dementia and a primary diagnosis of Alzheimer's disease dementia, an AD label was assigned regardless of the presence of additional dementing comorbidities. We compared the performance of our proposed method using a brain tumor dataset. All algorithms undergo training and performance validation using the Kaggle Brain Tumor MRI dataset. The Kaggle Brain dataset comprises 7,023 human brain MRI scan images in DICOM format, categorized into four distinct classes, namely glioma, meningioma, no tumor, and pituitary [5].

5. Results and Discussion

In this study, a series of tests have been performed to assess the benefits of employing quantum circuits in AD disease and brain cancer classification. These tests specifically compared the performance of a traditional CNN with quantum circuits used for feature extraction, with a focus on highlighting the advantages of quantum circuits. The proposed approach with Quantum layers produced comparable performance using both datasets as shown in Table 1.

Table 1 Classification performance of brain tumor using classical and quantum deep learning models

Methods	**Accuracy**	**precision**	**recall**	**F1-score**
A. Pashaei et al. [16]	93.68	--	--	--
Classical CNN	94.33	95.07	94.33	94.98
Classical and Quantum CNN	95.33	96.34	95.88	94.23

Table 2 The Alzheimer classification using classical and quantum deep learning models.

Methods	Accuracy	precision	recall	F1-score
Di Wang et al. [17]	87.25	--	--	--
Classical CNN	88.33	88.90	89.90	90.39
Classical and Quantum CNN	89.56	90.87	91.63	91.22

Table 2 shows the performance of the proposed model using classical and hybrid deep learning models. The quantum-based hybrid deep learning model produced optimal performance on brain tumor and AD disease classification tasks.

Furthermore, the results found have the capacity of the hybrid quantum model to enhance the efficiency of medical image classification and diagnosis. However, additional research is necessary to evaluate its performance in classifying different types of data. This research offers valuable insights into the benefits of integrating quantum circuitry into CNN models for the analysis of medical images, opening possibilities for quantum-enhanced machine learning within this field.

6. Conclusion

The proposed study introduces an efficient Hybrid Quantum deep learning model for the classification and diagnosis of AD disease and Kaggle brain tumors medical image datasets. The proposed model attains a comparable performance accuracy as compared to the conventional CNN's performance. The validation accuracy results provide additional evidence of this superior performance. Future research efforts will be directed towards assessing the resilience of hybrid quantum-based models against adversarial attacks. The research on quantum with classical deep learning models will continue to enrich the body of knowledge in quantum computing and its potential applications in medical imaging research, ultimately driving progress in precise diagnosis and enhanced patient care.

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Authors Introduction

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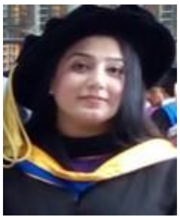

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