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Systematic Mapping of Literature in Machine Learning for Quantum Teleportation for Satellite Networks

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***Abstract*—Machine learning is a powerful tool for quantum teleportation, one of the expected pillars of a future quantum internet and quantum communication. Objective: to identify possible lacks and applications in the literature for the study of machine learning for quantum teleportation in a satellite network. Justification and motivation: machine learning is a widespread tool in quantum computing, however, the authors have not found any similar work that verifies its usefulness in teleportation. Conclusion: this work identified the main uses of machine learning in quantum teleportation, as well as the research gaps that exist in this theme.**

***Index Terms*—Machine learning, quantum teleportation, satellite network, photonic.**

I. Introduction

In the internet's future, the existence of a quantum internet ready for society is expected [1]. For that a quantum network becomes essential. Many architectures require the quantum teleport [2] for the transfer of information [3].

Neural networks, included within the larger area of Artificial Intelligence (AI), are useful for recognizing hidden patterns and correlations in raw data, grouping and classifying them, and, over time, learning and continually improving. Quantum neural networks are described as a block system with a specific input and output [4]. Quantum artificial neural networks (QuANNs) algorithms have the advantage of being able to react and adapt independently in a classical environment and in a quantum environment [5]. These neural structures are derived from human brain neurons [4]. The great opportunity for Machine Learning for quantum technologies is the learning of many lessons, often simple, to increase the efficiency of society [6] and not just do complex concepts that require many researchers in the field.

In long distances as presented at the research [7], the use of photonic technologies is more efficient in teleportation [8]. Quantum teleportation plays a fundamental role in continuing research as quantum communication, quantum computing and quantum network [8]. There is a quantum algorithmic model based on generative models, the Quantum Generative Model (QGM). It has been proven that this model can offer exponential improvement in representation capacity over a commonly used classical generative model [9].

Quantum teleportation is originally described in two levels of quantum systems called qubits [8]. The protocol considers two remote parties, referred as Alice and Bob, who share two qubits, *A* and *B*, prepared in a pure entangled state.

$$F = \langle\psi|\rho|\psi\rangle \quad (1)$$

Quality in quantum teleportation is commonly characterized by the fidelity F (Eq. 1) of the teleported state ρ with respect to the state $|\psi\rangle$.

The possibility of a network of satellites around the earth for a full-time quantum internet will require a high demand for quantum entanglements [10], consequently there will be a need for a high amount of quantum teleportation devices around the globe for the communication of the network. A quantum network on a global scale can be made by distributing a constellation of satellites, distributing entangled pairs of photons to stations on the earth's surface that use quantum memories for storage [11] [12] [13].

There are several technologies for quantum teleportation. For longer distances, the use of technologies with photonic qubits is the most suitable, when for low efficiency rates [8]. Photonic technologies that use the polarization method reach closer distances for use in satellites and, due to this factor, this will be the method primarily focused on in this article.

The goal of this article is to identify possible gaps and applications in the literature for the study of ML for quantum teleportation in a satellite network, using a Systematic Mapping of Literature (SML).

II. Systematic Mapping of Literature (SML)

To achieve the objective of this study, an MSL was conducted using the methodology proposed by Petersen *et al.* [14]. The SML was conducted as shown in Figure [1].

The following research question was asked *"What are the main applications of Machine Learning in teleportation?"*. The justification for selecting this research question is the interest of the research team involved at this work in identifying the uses of ML in quantum teleportation.

Two bases of scientific literature were identified as important to the subject and selected. The IEEExplore Digital Library by the Institute of Electrical and Electronics Engineers (IEEE) and the ACM Digital Library by the Association for Computing Machinery (ACM).

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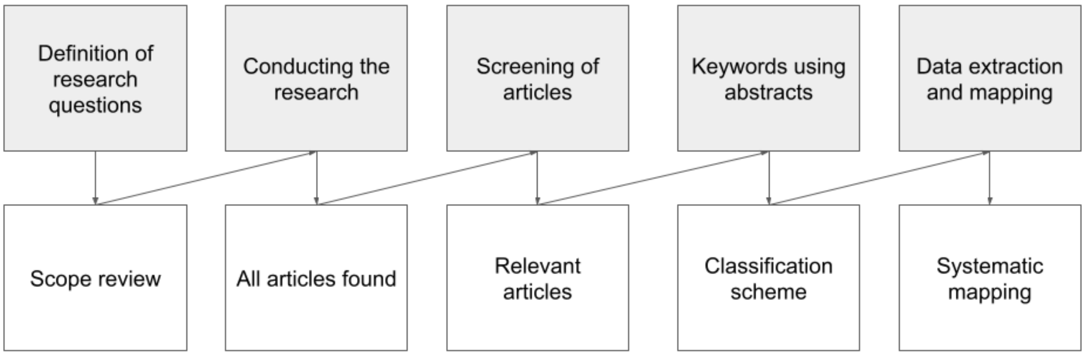

Figure 1: SML [14]

The articles searched to this research were from January 2011 to March 2021 with the following search keys for the research question: *Quantum* AND *Teleportation* AND *"Machine Learning"*.

After screening more than a hundred articles, a total of twenty-five articles were selected, of which twenty-four are from ACM and one is from IEEE. Of the total of twenty-five selected articles, six of them have a direct connection with this article and nineteen of them have a theoretical foundation. All of the twenty-five articles are showed at Table 1.

Works	*Source*
Wang (2016) [18]	ACM
Celeffi, Cacciapuoti & Biachi (2018) [19]	ACM
Barthe *et al.* (2019) [20]	ACM
Andreev & Lazarova (2020) [17]	ACM
Jia *et al.* (2019) [15]	ACM
Jia *et al.* (2019) [21]	ACM
Mykhailova & Svore (2020) [22]	ACM
Kozlowski *et al.* (2020) [23]	ACM
Chakrabarti *et al.* (2013) [24]	ACM
West & Leskovec (2012) [25]	ACM
Bozzo-Rey & R. Loredo (2018) [26]	ACM
Owyed *et al.* (2019) [27]	ACM
Gera, Juliano & Schmitt (2017) [28]	ACM
Cornet, Fang & Wang (2021) [16]	ACM
POPL (2017) [29]	ACM
Devitt (2016) [30]	ACM
Goldreich (2019) [31]	ACM
Buccio (2019) [32]	ACM
Dahlberg *et al.* (2019) [33]	ACM
Leung *et al.* (2018) [34]	ACM
Britt & Humble (2017) [35]	ACM
Malaney *et al.* (2019) [36]	ACM
Choi & Van Metter (2011) [37]	ACM
Spector (2011) [38]	ACM
Angara, Stege & MacLean (2020) [39]	IEEE

Table 1: Works

III. Discussion and Results

During the SML, the authors sought to identify in the available literature the possible answers to the research question: *What are the main applications of Machine Learning in teleportation?*

The combination of quantum mechanics and machine learning achieved important results in areas such as quantum key agreement (QKA), quantum secure direct communication (QSDC) and quantum teleportation and remote state preparation (QT&RSP) [15].

In response to the research question, the authors identified five applications as the most used of ML in quantum teleportation:

1) Quantum error correction [15];
2) Algorithmic Execution Speed [16];
3) Quantum Entanglement [17];
4) Grover's Algorithm [17];
5) Quantum Walks [17].

The main applicability of ML in teleportation is the first and second item on the list, quantum error correction (QEC), helping to increase the accuracy of the fidelity F (Eq. 1), and the algorithmic execution speed. The error hypothesis increases when a physical transformation is implemented imperfectly or when a particle is transferred over a long distance, like the case with satellites [16].

In the field of artificial intelligence applications, recent attempts are aimed at building a sophisticated architecture that allows scalability of algorithms through quantum entanglement [17]. A quantum-based machine learning algorithm, which employs quantum entanglement and quantum teleportation phenomena, uses links between elements and makes use of fast communication between the functional modules. To build a quantum-based neural network, some initial definitions are necessary, making it possible to make an equivalence association between terms from quantum theory and neural networks, as shown in Table 1.

Quantum Theory	*Neural Networks*
Wave Function	Neuron
Superposition (Coherence)	Connection Weights
Measurement (Decoherence)	Evolution for Attractor
Entanglement	Learning Rule
Unit Transformation	Activation Function

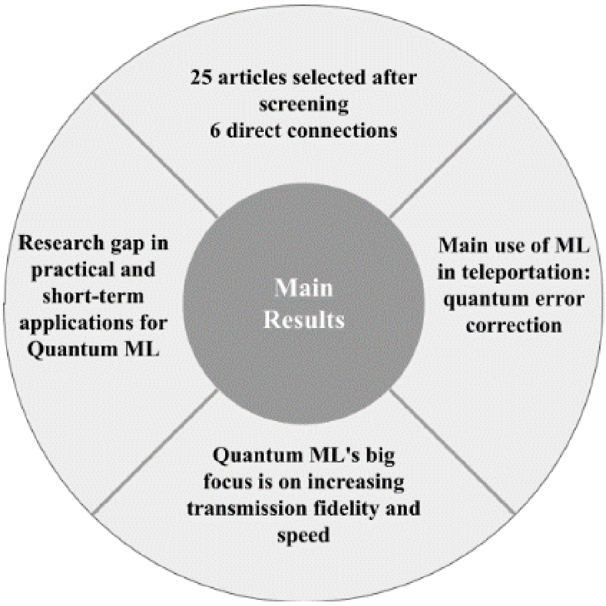

Figure 2: Main Results

Table 2: Quantum Theory and Neural Networks

In addition to ML applications in entanglement, the research [17] also identified some applications to support quantum teleportation processes, such as:

1) Grover's Algorithm: used for unstructured search that finds with high probability a single input to a black box function that produces a certain output value; and
2) Quantum walks: is the transition of entangled states of a given quantum object. ML assists in your analysis.

The main MSL results are shown in Figure 2. The demonstrated focus of quantum ML in the IEEE and ACM bases is primarily related to quantum error correction in order to increase fidelity and speed in the execution of algorithmic processes.

The papers that support directly the main results of this research are the [15], [16], [17], [21], [23] and [28]. Summarizing these papers, they show results and support the idea of the speed-up of the algorithm's execution in quantum neural networks, utilizing the phenomena of quantum entanglement and quantum teleportation. The approach of the paper [17] is not only for the category of photonic teleportation.

IV. Conclusion

The objective of this research was to identify possible gaps and applications in the literature for the study of machine learning for quantum teleportation in a satellite network, obtaining the answer to the research question, through an SML. SML focused on discovering the main applications of ML in quantum teleportation. The SML results showed that the great application of Quantum ML is a function of the improved fidelity *F*, equation 1, and some applications in quantum error correction. It was noted the lack of researches focusing on other processes that go beyond algorithmic or performance improvement of the model in which ML was implemented.

As future works, it is expected:

1) Evaluate new applications of quantum ML in satellite networks and how they could be leveraged and used. Examples of interest to the authors of this work involve the use in fire detection systems and prediction of natural occurrences; and
2) Expand MSL for a second research question of interest: *"What are the main problems for teleportation with photonic technologies?"*.

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