International Journal of Emerging Technology in Computer Science & Electronics (IJETCSE)
ISSN: 0976-1353 Volume 26 Issue 3 – APRIL 2019.

Quantum Intelligent Systems: A Review

Vedant Bahel[#1]
[#]*Student (BE), Department of Information Technology, G. H. Raisoni College of Engineeirng, Nagpur, India*

***Abstract*— Artificial Intelligence (AI) is a humongous field which is potentially solving tones of real-world computational problems. With increasing implementation, there has also been an improvement in algorithms of AI. It includes high scale data management and operations, which slows down the process due to memory and performance limitations. All these issues are resolved when an interdisciplinary field of AI with Quantum Computing is brought into the picture. This paper focuses on the potential applications of Quantum Computing in the field of Artificial Intelligence and Machine Learning with the aim of solving the performance issue and lack of computing power faced by current intelligent systems.**

Keywords* —*Quantum Computing, Artificial Intelligence, Quantum Neural Networks and Intelligent Systems.

I. INTRODUCTION

Quantum Mechanics is one of the biggest achievements of 20th CE, giving an answer to various modern physical theories. By time Quantum Mechanics could find a way to enter into computer sciences. Quantum Computing is the application of concepts of Quantum Mechanics to increase computing power over classic computers [1]. In a classic computer, the computational task is carried in form of bits which can take the value 0 or 1. Whereas, a quantum computer works on qubits. Qubits have some idiosyncratic quantum properties that mean a connected group of them can provide way more processing power than the same number of binary bits. One of those properties is known as superposition and another is called entanglement. Even qubit can take value 0 or 1. However, due to the quantum concept of superposition, a qubit can take multiple states simultaneously. Thus, a quantum computer can carry out power tasks with less computing power [2]. Quantum machines are also great for optimisation problems because they can crunch through a vast number of potential solutions extremely fast. These days, quantum computing has come up with many applications like optimisation of classifiers, circuit and software fault simulation, cyber security, computational chemistry, genetic programming etc. But one greater branch of application arises when concepts of quantum computing are applied to Artificial Intelligence and other advanced intelligent systems [3], [4].

Artificial Intelligence (AI) is the exhibition of human intelligence by a machine. It is made in use to solve large computational problems dealing with a large amount of data which cannot be solved by a human. Computer Intelligence is the ultimate goal of AI systems. Although, AI tries to solve the problems with intelligence which is similar to human intelligence but in a much faster way in comparison with traditional computing systems [5]. Depending upon the increasing trend in the implementation of AI applications, it is clear that Industries have known the importance of Intelligent systems. Today, most of the researches involve AI as one of the key concepts. AI has different algorithms that work differently and is chosen depending upon the type of data and problem. Example: Machine Learning, Computer Vision, Natural Language Processing, etc. Moreover, AI gives real-time analysis and decision-making power to the machine reducing the processing time [6]. That's the reason it is also being used in a technical, operational and computational field of study. The task of AI system includes application, implementation and self-correction. AI is already impacting the world economically, socially and politically and also improving the living conditions. Efficient energy usage paradigms, analysation of climate change, agriculture and irrigation practices, all of these can be monitored and recognised using AI systems. But there are certain drawbacks of current AI systems [7].

The author has tried to discuss the current drawbacks and their solution using Quantum concepts. This paper demonstrates the different applications which are the result of the fusion of Intelligent systems and concepts of Quantum computing.

II. QUANTUM INTELLIGENT SYSTEMS

With the aim to increase the computation power researchers tried to implement quantum concepts in machine learning, fuzzy systems, Neural Networks, Bayesian networks, etc. All these applications are explained in depth below:

A. Quantum in Machine Learning

Machine Learning is all about finding a pattern between the independent and dependent variables of the data. There are different types of Machine Learning problems, Supervised and Un-Supervised Machine Learning depending upon the type of data. But again, sometimes there are hardware and software challenges for the implementation of Machine Learning algorithms. The certain problem requires large training time, sometimes processing issue and other computational errors. Thus, quantum systems can help get over these issues and problems. It can increase the efficiency of Machine Learning systems as it is capable of drawing

patterns in data more proficiently and with lesser response time [8]. Machine Learning involves the classification of n-dimensional vectors. Classical system for solving such problems characteristically take time polynomial in the number of vectors and the dimension of the space.

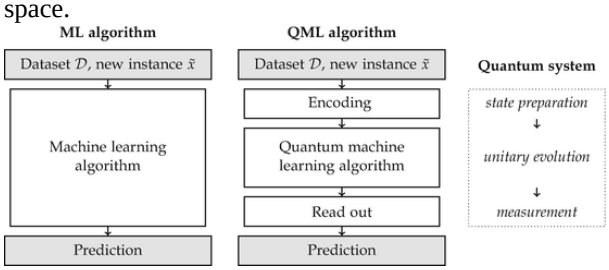

Fig. 1: Comparative block diagram of simple Machine Learning system and Quantum Machine Learning system [9].

Quantum computers are upright at deploying high-dimensional vectors in large tensor product spaces. Quantum machine learning can take log(t); where t is the tin processing both- the number of vectors and their dimension, thus providing an exponential speed-up over classical algorithms [10]. In [11], authors tried to implement an optimized binary classifier i.e. Support Vector Machine (SVM) on a Quantum Computer which ensured efficient performance of the model. Whereas in [12], authors implemented the machine learning to autonomously generate algorithms that can be used for adaptive feedback scheme for quantum measurement. In order to accelerate machine learning algorithm, researchers tried to implement Unsupervised ML algorithms over a small photonic quantum computer which gave them astonishing results [13].

B. Quantum Bayesian Network

Bayesian model is a probabilistic acyclic graphical model. Bayesian networks and graphical models are better suited for the classical system as they are much more natural than a list of conditional dependencies. Bayesian network is also used as a classifier and has high dominance in AI [14]. The concept of Bayesian network can be also implemented using quantum adiabatic algorithm [15]. A Quantum Bayesian Network is similar to the classical Bayesian network except that the real probability numbers are replaced by quantum probability amplitudes [16]. In [17], Bayesian networks and their accompanying graphical models are widely used for prediction and analysis across many disciplines. We will reformulate these in terms of linear maps. The mentioned reformulation will bring forth a natural extension, which can be shown to be equivalent to a standard textbook of quantum mechanics. Therefore, this extension will be termed quantum.

C. Quantum Concepts in Image Processing and Computer Vision

Principles of quantum physics prove that the computing power of a quantum machine is enormous compared to that of a classical machine. Encouraged by this idea many researchers tried to implement Quantum concepts in the field of Image processing. In [18], the author discovered a method for retrieving and storing geometrical shapes in the quantum mechanical system. The study aimed at enabling emergent quantum technology to be used in high impact scientific disciplines in which extensive use of image processing is made. Quantum algorithm can be also applied for image enhancement. Researchers in [19] aimed at the enhancement of medical images for classification purpose using quantum algorithms. Image processing is widely used for object recognition and tracking in every field especially the security industry. In [20], the author used the concept of Quantum Mechanics- Schrödinger's for mathematical segmentation of the model to increase the performance of such an object recognizing paradigms.

D. Quantum Fuzzy Logic System

Fuzzy logic system is a computation logic system that resembles human logic. It has application in numerous fields including Artificial Intelligence. Fuzzy systems can be implemented using Quantum concepts. In [21], the behaviors of the humanoid robot were programmed using binary circuits, fuzzy circuits and quantum circuits. Quantum systems can be also applied to develop certain aspects of information processing using fuzzy logic [22]. Quantum system reduces the number of calculations so as to calculate fuzzy numbers. Since the fuzzy numbers are encoded with the help of superposition of qubits [23].

E. Quantum in Intelligent Robotic System

Robotics and automation are the other advancing branches of AI systems. Robotics is a vast branch which is somehow linked to various other computational fields. Also, it has stepped in the world of quantum computers. Quantum-inspired computational intelligence is the solution for many robotic elements. Systems like Adaptive quantum mutation, Quantum logarithmic search, Quantum associative memory, etc. can be of utmost importance in the field of robotics [24], [25]. According to a study, this fusion of quantum concepts with robotics systems can reduce the complexity of the searching algorithm for robots. In [26], they implemented quantum reinforcement learning algorithm to impart intelligence in robots. With the implementation of Quantum measurement and amplitude amplification in Quantum Computation so researchers proved to be successful in designing a navigation system for robots. The concept proved to be more robust to the learning rates over traditional system [27], [28]. According to research, Grover's algorithm can help the intelligent robot learn faster and become more intelligent [29].

F. Quantum Neural Network

When we speak of AI systems, there are various algorithms to approach a problem. One such algorithm is Artificial Neural Network (ANN). ANN is the intelligent modelling of artificial neurons inspired from human brain functioning. It is the imitation of human brain structure and information processing to strengthen machine intelligence. The human brain consists of billions of neurons. Each neuron is connected with thousands of other neurons, and

receive information from them through dendrites. This information is then stored in the human brain in such a manner it can be distributed and information can be extracted from the memory by processing it parallelly when required. Thus, the human brain is made up of many parallel processors. Similar to the arrangement of human brain neuron is the placement of artificial neuron in multi-layer ANN. Each neuron is connected to other neurons with certain coefficients. During training, information is distributed to these connection points so that the network is learned [30]. Depending upon different factors like output channel, network architecture, hyper-parameters, etc. the training of ANN may consume a lot of time since it requires a lot of computing power. Example: A 4 convolutional layer neural network with 100K+ training size may take up to 5 days for training. To eradicate this issue with ANN, there comes Quantum Neural Networks (QNN). QNN is considered to be the next step for the evolution of neurocomputing system. In traditional Neural Networks, many patterns are stored in a single network whereas since QNN can take multiple values at once due to superposition it may be able to store multiple patterns in multiple networks at once [31].In QNN, the input vector in the first layer is encoded into quantum states. In [32], researchers tried implementing QNN for speech recognition. In this case, QNN models the fusion of neural modelling and fuzzy systems. According to their experiment, this algorithm helped in reducing error by 15% over the backpropagation network.

Advantages of QNN over ANN and classicial AI Systems:

- higher memory capacity [33];
- higher performance for a lower number of hidden neurons [35];
- Lesser training time [34];
- elimination of catastrophic forgetting due to the absence of pattern interference [34];
- complex problems solved with just a single layer of a neural network [34];
- higher stability and reliability [35]
- Faster processing speed [36]

Thus, QNN has the ability to increase the potential of the system with greater extent.

III. Conclusion

The future of the world will all be in the hands of AI and robotics. And to Quantum system is the best way to increase the efficiency of these robotics system. This paper delivered the implementation of Quantum, concepts in various fields like Machine Learning, Neural Networks, Computer vision, Image Processing, Fuzzy System, Bayesian Network, etc. And this implementation is indeed helping the existing system to improve it performance. But still it has not been seen in practical implementation. But is expected to arrive soon as the need for computational advancements is increasing day by day and will be at peak soon.

Acknowledgment

I thank Mr. Atharva Peshkar (G. H. Raisoni College of Engineering) for helping me out with the content of the paper and supporting me throughout the work.

Refrences

[1] Ying, M. (2010). Quantum computation, quantum theory and AI. *Artificial Intelligence*, *174*(2), 162-176.

[2] Steane, A. (1998). Quantum computing. *Reports on Progress in Physics*, *61*(2), 117.

[3] Spector, L., Barnum, H., Bernstein, H. J., & Swamy, N. (1999). Quantum computing applications of genetic programming. *Advances in genetic programming*, *3*, 135-160.

[4] Ambainis, A. (2003). Quantum walks and their algorithmic applications. *International Journal of Quantum Information*, *1*(04), 507-518.

[5] Kumar, Koushal, and Gour Sundar Mitra Thakur. "Advanced applications of neural networks and artificial intelligence: Areview." *IJ Information Technology and Computer Science* 6 (2012): 57-68.

[6] Mohaghegh, S. D. (2005, April 1). Recent Developments in Application of Artificial Intelligence in Petroleum Engineering. Society of Petroleum Engineers. doi:10.2118/89033-JPT

[7] Pawlak, Zdzislaw. "AI and intelligent industrial applications: the rough set perspective." *Cybernetics & Systems* 31.3 (2000): 227-252.

[8] Biamonte, J., Wittek, P., Pancotti, N., Rebentrost, P., Wiebe, N., & Lloyd, S. (2017). Quantum machine learning. *Nature*, *549*(7671), 195.

[9] Schuld M., Petruccione F. (2017) Quantum Machine Learning. In: Sammut C., Webb G.I. (eds) Encyclopedia of Machine Learning and Data Mining. Springer, Boston, MA

[10] Lloyd, S., Mohseni, M., & Rebentrost, P. (2013). Quantum algorithms for supervised and unsupervised machine learning. *arXiv preprint arXiv:1307.0411*.

[11] Rebentrost, Patrick, Masoud Mohseni, and Seth Lloyd. "Quantum support vector machine for big data classification." *Physical review letters* 113.13 (2014): 130503.

[12] Hentschel, Alexander, and Barry C. Sanders. "Machine learning for precise quantum measurement." *Physical review letters* 104.6 (2010): 063603.

[13] Cai, X-D., et al. "Entanglement-based machine learning on a quantum computer." *Physical review letters* 114.11 (2015): 110504.

[14] Friedman, N., Geiger, D. & Goldszmidt, M. Machine Learning (1997) 29: 131. https://doi.org/10.1023/A:1007465528199

[15] O'Gorman, B., Babbush, R., Perdomo-Ortiz, A. et al. Eur. Phys. J. Spec. Top. (2015) 224: 163. https://doi.org/10.1140/epjst/e2015-02349-9.

[16] Moreira, Catarina, and Andreas Wichert. "Quantum-like bayesian networks for modeling decision making." *Frontiers in psychology* 7 (2016): 11.

[17] Pejic, Michael. "Quantum Bayesian networks with application to games displaying Parrondo's paradox." *arXiv preprint arXiv:1503.08868* (2015).

[18] Venegas-Andraca, Salvador E., and J. L. Ball. "Processing images in entangled quantum systems." *Quantum Information Processing* 9.1 (2010): 1-11.

[19] Fu, Xiaowei, et al. "A new quantum edge detection algorithm for medical images." *MIPPR 2009: Medical Imaging, Parallel Processing of Images, and Optimization Techniques*. Vol. 7497. International Society for Optics and Photonics, 2009.

[20] Aytekin, Çağlar, Serkan Kiranyaz, and Moncef Gabbouj. "Quantum mechanics in computer vision: automatic object extraction." *2013 IEEE International Conference on Image Processing*. IEEE, 2013.

[21] Raghuvanshi, Arushi, and Marek Perkowski. "Fuzzy quantum circuits to model emotional behaviors of humanoid robots." *IEEE Congress on Evolutionary Computation*. IEEE, 2010.

[22] Domenech, G. & Freytes, H. Int J Theor Phys (2006) 45: 228. https://doi.org/10.1007/s10773-005-9019-6

[23] Gandhi Deepak, Banthia Raja "*Quantum Computers & Fuzzy Logic*"

[24] Manju, A. & Nigam, M.J. Artif Intell Rev (2014) 42: 79. https://doi.org/10.1007/s10462-012-9330-6

[25] Zhou W, Zhou C, Huang Y, Wang Y (2005) Analysis of gene expression data: application of quantum-inspired evolutionary algorithm to minimum sum-of-squares clustering. In: Ślęzak D (eds) Proceedings of 10th international conference on rough sets, fuzzy sets, data mining, and granular computing, LNAI, vol 3642. Springer, Berlin, pp 383–391

[26] Dong, Daoyi, et al. "Quantum Robot: Structure, Algorithms and Applications." *Robotica*, vol. 24, no. 4, 2006, pp. 513–521., doi:10.1017/S0263574705002596.

[27] D. Dong, C. Chen, H. Li, "Reinforcement strategy using quantum amplitude amplification for robot learning", *Proc. 26th Chinese Control Conf.*, pp. 571-575, 2007, vol. 6.

[28] Dong, Daoyi, et al. "Robust quantum-inspired reinforcement learning for robot navigation." *IEEE/ASME transactions on mechatronics* 17.1 (2012): 86-97.

[29] Dao-Yi, Dong, et al. "Quantum mechanics helps in learning for more intelligent robots." *Chinese Physics Letters* 23.7 (2006): 1691.

[30] Kröse, B., Krose, B., van der Smagt, P., & Smagt, P. (1993). An introduction to neural networks.

[31] Ezhov A.A., Ventura D. (2000) Quantum Neural Networks. In: Kasabov N. (eds) Future Directions for Intelligent Systems and Information Sciences. Studies in Fuzziness and Soft Computing, vol 45. Physica, Heidelberg

[32] Li, Fei, Shengmei Zhao, and Baoyu Zheng. "Quantum neural network in speech recognition." *6th International Conference on Signal Processing, 2002.*. Vol. 2. IEEE, 2002.

[33] Ventura, D. and Martinez, T. (1998) Quantum associative memory with exponential capacity, Proceedings of the International Joint Conference on Neural Networks, pp.509-513.

[34] Menneer, T. and Narayanan, A. (1995) Quantum-inspired neural networks. Technical report R329, Department of Computer Science, University of Exeter, UK

[35] Cutting, D.(1999) Would quantum neural networks be subject to the decidability constraints of the Church-Turing thesis? Neural Network World, N.1-2, pp.163-168

[36] Behrman, E.C., Steck, J.E., and Skinner, S.R. (1999) A spatial quantum neural computer., Proceedings of the International Joint Conference on Neural Networks, to appear.