Leveraging Artificial Intelligence and Quantum Machine Learning for economic growth in Africa

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Abstract. Artificial Intelligence (AI) and Quantum Machine Learning (QML) have become the most promising significant tools for addressing the challenges of the Fourth Industrial Revolution (4IR). Besides its use in understanding physical and complex systems, these tools have demonstrated unmatched potential applications in numerous research disciplines and sectors such as banking, finance, social networks, cybersecurity, and health. Most importantly, recently, they have played a critical role in addressing challenges related to the Covid-19 pandemic. While these developments are remarkable, Africa has been lagging. Therefore, this paper aims to identify opportunities behind the challenges of implementing AI and MLA in addressing this technology gap, especially in earlier sectors, and fully participate in the 4IR. While the quantumness presents various opportunities, especially for industries and stakeholders, we examine which intelligent tools can address these challenges. Thus, this will allow the proper application of these techniques to solve Africa's long-standing problems.

1. Introduction

Artificial Intelligence (AI) has driven development in technology in many societies and economies of developing countries to enforce sustainable human development. AI has been defined as the "science and engineering of making intelligent computer systems" to enhance learning and decision making for solving problems [1]. Many countries have benefited from applications of AI, which provided faster performance and efficiency in conducting tasks better than humans. At present, AI systems can understand human expressions, recognise images, predict traffic, and many others. It has aided technological innovation as digitalised data continued to grow, and thus many economies depended on its applications in order to expand the digital revolution that addresses challenges of the Fourth Industrial Revolution (4IR) [2]. Quantum machine learning (QML) is an emerging field encompassing systems learning without being programmed or modified. As data grows massively, better computing storage and performance are required to achieve accurate results faster. Therefore, QML enhances systems through superposition and entanglement tools to solve complex systems and perform operations on large data. It has also been successful in optimising classical machine learning algorithms [3].

Such applications of AI and QML are transparent across sectors such as banking, finance, social networks, cybersecurity, and health and are currently addressing the Covid-19 pandemic, as discussed in this paper. Since AI and QML are the elementary technology of the 4IR, various developing countries have been committed to developing their competencies. AI and QML have

both aimed at sustaining human development in many countries; however, there is a wide variation between developing countries and Africa in applying these tools. Africa has been falling behind with visions of accessing these 4IR tools due to some challenges; among them is poor growth of human capital, which leads to poor productivity as per Amankwah-Amoah [4]. On the other hand, these tools can bring industrialisation opportunities that have considerable potential to improve the economies in Africa so it could be more efficient and competitive in its industrial processes. As Africa leans towards the acquisition of these tools, it will address various challenges which impact the implementation of the 4IR, which are necessary for technological progress in order to achieve a successful transformation in the sectors as mentioned earlier [5].

Against this background, we explore ways in which Africa can benefit from the Fourth Industrial Revolution to solve some challenges, bringing some development in some countries in the various stated sectors. We show how AI and QML can impact these sectors to close the technological gap between Africa and other developed countries. Moreover, we demonstrate how these tools can impact these various sectors. Therefore, we organise this work according to the following. First, section 2 examines the impact of AI and QML in developing countries' economies, especially its relevance in Africa. Second, in section 3, we identify opportunities available for the continuous development of economies in Africa. Third, in section 4, we demonstrate the advantage of the quantumness (i.e., the condition of being quantum in nature), especially in performing high-end tasks faster and efficiently then; finally, in section 5, we conclude.

2. Impact of AI and QML in economies of developing countries

AI has been successful in various developing countries at performing different tasks that assist people. Nowadays, many intelligent assistant software can understand human behaviour based on a pattern from data collected by that software. Various industries use this data to give better comfort of using the software to their customers, thus driving the economies. QML, on the other hand, utilises superposition and entanglement to give a better computational performance and is expected to revolutionise the future. Since it has successfully optimised classical machine learning algorithms to solve complex systems, it will also escalate the development of AI-based systems. This is on account of qubits being able to occupy two simultaneous states $|0\rangle$ and $|1\rangle$ at once. Thus QML suffices up to the task of solving computationally-intensive operations. QML has shown its unmatched potential by solving algebraic computational problems such as the problem of factoring large integers using Shor's algorithm, which improves computational speed and data storage over a range of computer systems [6]. Moreover, the advance of AI and ML have resulted in the need to pay more attention to the provision of privacy to the data being analyzed [7, 8].

The 4IR promotes the implementation of AI and QML for efficient industrialization. However, Africa has fallen behind in technological development, and the challenges are poor human development which involves poverty, youth unemployment, poor health, and education. Another motive for Africa being undeveloped is due to lack of technical education across various countries, thus stagnating the economies [9]. Nevertheless, AI and QML can increase opportunities offered by technology to transform Africa and bring innovative ideas over numerous sectors. These tools can enable Africa to close the technological gap with developed countries and encourage economic growth. Failing to exploit the opportunities of 4IR will consequently urge additional risks on African stakeholders, with no attempts to find new innovative ideas for digital growth. This will additionally weaken global competitiveness as Africa risk falling behind.

3. Opportunities available for continuous development of economies in Africa

3.1. Banking & Finance

AI and QML are significant in interacting with people such that they acquire data to perform cognitive activities such as learning, understanding, and giving feedback on the best course of action. As such, they enhance software capabilities, and due to this, many software nowadays can automate some banking processes that involve customer accounting, making payments, or cash handling. Therefore, customers could enjoy faster services at the comfort of staying home instead of forming long queues at banks. Customers can also benefit from using straightforward assistant services from their devices to make financial plans, whereby the software analyze their behavior and best interests for better well-planned and cost-effective actions [10].

QML can be used in communication to manage information and insist on better encryption methods. For example, through quantum key distribution (QKD), an untrusted party is prevented from eavesdropping on the information shared by, in context Alice (client) and Bob (server) [11]. Thus this demonstrates the capability of cryptographic algorithms securing data from attack or leaking, which will be a successful application in banking and finance [12]. Furthermore, since AI and QML can fluently analyze data and give accurate results through algorithms, it can help to forecast risks in loans which can improve the long-term growth of industries [13], thus developing the economy.

3.2. Social networks

These tools have demonstrated the ability to drive the economy through social networking primarily, as Africa can acquire needed skills to understand its customer trends, offer preferred product or service (through recommendation systems) [14], based on the data accumulated. This will help industries to effectively manage resources through citizen participation, thus promoting the market growth. Nowadays, the same knowledge and technology are used in popular software, such as LinkedIn and Facebook, to suggest preferable connections and serve users with specific posts of interest in their feed. QML can also create a secure network by merging with the Internet of Things (IoT) and Blockchain [15], which will improve efficiency in systems that contain large data and also provide reliable data protection schemes. Distribution of marketing content will also be faster and monitored easily across most social media platforms, with shortened links and some auto-scheduled shares. Industries in Africa could also use these technologies to recognize emerging customer trademarks and keep track of social mentions to identify approaches for better social media promotions [16].

3.3. Cybersecurity

AI can be used in the 4IR to strengthen cybersecurity in Africa by detecting data breaches to remove unwanted data or malware from systems being developed to lower the cyber-attack. This is done through analyzing patterns from input data and recognizing unusual patterns of behavior. These could enable quality protection through QML in systems or accessories when using artificial neural networks and data mining techniques such as classification, clustering and regression-to- to ultimately give better security services [17]. Through QML, it could be relatively easy and faster to determine how vulnerable or exposed the system is, guided by how the pattern behaves to recognize the infiltration points. This will therefore alert authorities much sooner to protect sensitive data from being swindled from their computers [18]. Nowadays, AI provides more intelligent biometric authentication systems such as face or voice recognition and fingerprint scanning across various devices. As a result, authentication is improved; for example, in voice recognition, tone, accent, and pitch are analyzed much faster, and biometric systems can identify unique voice impressions accurately [19]. According to Perdomo-Ortiz *et al.* (2018), QML will assist in storage and performance challenges, wherever systems contain large data, and also build systems that will transform current security initiatives, such as quantum

sensors, quantum radars, and location detection, which cannot be interfered with easily [20]. Furthermore, since these systems also use communication systems, they will be secured through quantum encryption.

3.4. Health

Digital technology will play a significant role in making cost-effective algorithms to diagnose patients effectively by learning from past cases or reports to enhance clinical decisions. This technology can also monitor multiple patients at the same time through medical algorithms. These algorithms can also offer self-service to patients with health-related inquiries and thus save time, effort, and most importantly, lives [21]. Moreover, AI machines are capable of analyzing data from past surgeries recorded, and they could be more precise at detecting illnesses and even discover some new surgical procedures, which could improve the health facilities in Africa. Finally, in battling current medical concerns, AI and QML can track the spread of Covid-19 by effectively evaluating existing data to make predictions on infection rates across countries [22]; this provides viable information and meaningful future guidance across Africa.

4. Simulation of Grover's algorithm

Grover's algorithm enables one to find a specific element of interest within an unordered set of elements, with probability greater than $\frac{1}{2}$. Quadratic speedup needs to optimize classical algorithms. However, its applications can be considered in various and broad disciplines. We simulate Grover's search algorithm, with several items as $N = 2000$ for two input qubits. The amplitude is obtained as:

$$\begin{aligned} &\sin\theta = \frac{1}{\sqrt{N}} = \frac{1}{2} \\ &\text{where } \theta = \sin^{-1}(\frac{1}{2}) = \frac{\pi}{6} \end{aligned} \tag{1}$$

with the probability of $\frac{1}{4}$.

If we consider the element $'\mathbf{0}, \mathbf{1}'$ to be part of the database we wish to perform a search on, then it would be an input register $|x\rangle = |01\rangle$. Then we reference the winner item as $|k\rangle$; therefore, oracle U_f will act as follows:

$$\begin{aligned} &U_f|k\rangle = \frac{1}{2}(|00\rangle - |01\rangle + |10\rangle + |11\rangle), \\ &\text{or} \\ &U_f = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \end{aligned} \tag{2}$$

and it will distinguish the element 01 from the rest of the other elements.

The winner item is obtained following the condition:

$$f(x) = \begin{cases} 1 & x = k \\ 0 & \text{otherwise} \end{cases} \tag{3}$$

for all $N = 2000$ items.

The input qubits and target qubits are then passed through a Toffoli gate (using a conditional

NOT gate) as a control to flip the amplitude of the winner state, which ensures it is converted to 1s. Next, the conditional phase flips are obtained using a combination of CNOT, X and H gates. The final step is to restore the winner state to 1, and therefore obtain the results.

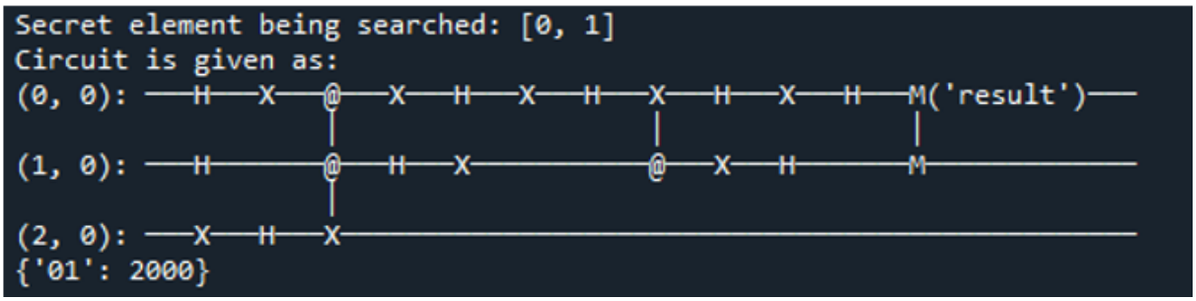

Figure 1: Results after performing the Grover's algorithm search

From Figure 1, Grover's algorithm is thus significant in optimizing classical machine learning algorithms to perform high-end tasks faster and efficiently. This shows how much QML and AI can enhance some daily computational tasks; this makes it powerful in the applications mentioned above. Furthermore, since 'big data' is the most concerning challenge, especially in the classical computing era, QML can thus increase chances of acquiring more excellent computational performance, speedups and ultimately provide many secure networks against cyber attacks. Therefore, all this knowledge can improve the standard of technology for the 4IR implementation in Africa, hence contributing to the growth of economies.

5. Conclusion

We have evaluated and illustrated how AI and QML can become powerful tools in implementing the 4IR and how these tools can address some significant challenges that prohibit full industrialization. The significance of these tools has proven effective in sectors such as banking, finance, social networks, cybersecurity, and health. Hence, it is significant that these technologies contribute to closing the gap in the mentioned sectors between Africa and other developed countries.

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