Quantum technology: A potential tool for development in Africa

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Abstract.
The first quantum revolution started in the early 1900s and was characterized by the exploration of physics at the sub-atomic level. This was followed by a second revolution around the 1970s, which witnessed the application of quantum physics to develop quantum technology. Currently, quantum technology is gaining traction in most parts of the world. However, besides having a history of innovation in quantum physics, Africa has fallen behind in each quantum revolution. Therefore, this paper highlights challenges relating to quantum technologies and points to the opportunities that quantum technologies present to close the gap and drive economic growth and development in Africa. The latter can be achieved through capacitation and the democratization of quantum technology knowledge. This initiative will, in turn, ensure that Africa is adequately represented in the second quantum revolution. Finally, in this paper, we introduce a new development framework, namely quantum technology for development (QT4D), and explore how Africa could deploy this framework to advance the adoption and use of quantum technology and become part of mainstream computing landscape. This will allow Africa to apply these technologies in space communications, finance, drug development, and material science, thus solving some everyday challenges and opening new opportunities for industries leading to economic growth and development.

1. Introduction

Quantum technology is poised to revolutionize the technological world. In essence, quantum technology makes use of quantum-mechanical concepts and principles in order to process information [1, 2, 3]. The field of quantum technology has various sub-fields. These sub-fields include quantum communication, quantum cryptography, quantum computing, quantum sensing, and quantum imaging.

The advent of quantum technology can be traced back to the $1970s$ [1, 4]. Since its inception in the $1970s$, quantum technology has gained some traction across the globe. However, Africa is still lagging behind in the adoption of quantum technology [5]. In this paper, we discuss the opportunities and challenges related to the adoption of quantum technology in Africa. Furthermore, this paper proposes and explores a new quantum technology framework, namely the Quantum Technology for Development ($QT4D$) framework.

The remainder of this paper is structured as follows. The next section provides the background information on quantum technology and the development theory. This is then followed by Section 3, which outlines the quantum technology initiatives in Africa. Additionally, this section highlights the opportunities and challenges facing Africa in the adoption of quantum technology. Furthermore, Section 4 outlines the Quantum Technology for Development framework that is proposed in this paper. The $QT4D$ framework proposed in this paper can serve as a handy tool towards providing an assistance in the closing of the quantum technology adoption gap, especially in Africa and other low-resource regions of the worlds. Finally, Section 5 concludes this paper.

2. Background Information

2.1. Quantum Technology

Quantum technology is also referred to as the second Quantum Revolution [6, 7]. It uses the laws of quantum physics in order to enable information processing in a manner that offers some advantages over the conventional, non-quantum information processing paradigm. Therefore, it is envisaged that quantum technology should offer some advantage over the current non-quantum technology. Quantum concepts that enable quantum technology to offer advantages over its conventional counterpart include entanglement, superposition, interference, tunneling, and no-cloning Theorem [1, 7].

Analogous to the conventional information processing paradigm; which uses a binary digit (bit) as a unit of information, quantum technology uses a quantum bit (qubit) as a unit of information [1, 2]. Unlike a bit, which can only exist in either state 0 or state 1, a qubit can exist in superposition of both states. Mathematically, a qubit is represented as [1]:

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle, \tag{1}$$

where α and β, which are referred to as probability amplitudes, satisfy the condition [1]:

$$|\alpha|^2 + |\beta|^2 = 1. \tag{2}$$

2.2. Theory of Development

In essence, development is associated with a positive change in the society [8, 9]. That is, the objective of development is to implement technical and/or economic interventions that are intended to bring about a positive change in a society [10]. This positive change can either be physical, social, environmental, or economic.

The positive change can be brought about in a way that is sustainable; that is, without irreversibly depleting resources. In such a case, the development is referred to as the sustainable development [9, 11]. The United Nations (UN) has been responsible for developing and overseeing the implementation of the seventeen Sustainable Development Goals (SDGs) for the duration of fifteen years; from 2015 to 2030. These SDGs are pictorially depicted in Figure 1.

Technology can be used as a tool to drive a positive change in a society. The use of technological tools in development is referred to as Technology for Development ($Tech4Dev$). Different technological tools can be used to address various developmental challenges. Examples of these tools include Information and Communication Technology for Development ($ICT4D$) [12, 13] and Artificial Intelligence for Development ($AI4D$) [14].

3. Quantum Technology Initiatives in Africa: Opportunities and Challenges

As stated earlier in this paper, Africa is lagging behind in the adoption of quantum technology. However, some African countries have already started some initiatives geared towards the adoption of this technology. For instance, South Africa has already drafted a quantum technology framework document [5]. Furthermore, South Africa has various research groups that work on quantum technology [5]. Egypt and Tunisia also have research groups working on quantum technology, and Rwanda is pursuing quantum technology research through the

Figure 1. The seventeen UN Sustainable Development Goals The picture courtesy of https://www.un.org/sustainabledevelopment/news/communications-material.

AIMS (African Institute of Mathematical Sciences)-based "Quantum Leap Africa" initiative. AIMS is an institute that is responsible for the promotion of mathematical sciences in Africa. through its "Quantum Leap Africa" initiative, AIMS intends to promote data analytics, machine intelligence, smart systems, and quantum technology in Africa[1].

Another approach that is being used in Africa to fast-track the adoption of quantum technology is by partnering with the international organizations. For instance, the University of Witwatersrand has partnered with IBM in order to pursue quantum computing research [2]. Through this partnership, researchers who are based at any member of the African Research Universities Alliance (ARUA) can have access to the IBM quantum computing facilities through the University of Witwatersrand.

Furthermore, through citizen-led initiatives, some African countries have partnered with an international organization called QWORLD[3] in order to promote quantum computing in their respective countries. QWORLD is an organization that has the objective of promoting quantum technology across the globe. The African countries that have partnered with QWORLD are: Tunisia, Egypt, Morocco, and Zimbabwe.

Another international organization that African countries have partnered with (through citizen-led initiatives) is OneQuantum[4]. OneQuantum is an organization that brings together quantum technology researchers and enthusiasts world-wide. So far, the African countries that have partnered with OneQuantum are South Africa and Kenya.

[1] https://quantumleapafrica.org
[2] https://research.ibm.com/blog/south-africa-quantum-ready
[3] https://qworld.net/
[4] https://onequantum.org/

3.1. Challenges Facing the Adoption of Quantum Technology in Africa
The key challenge facing the adoption of quantum technology in Africa is the availability of funds. To date, virtually all African countries spend less than 1% of their Gross Domestic Product (GDP) on research and development [15]. This lack of funding in turn leads to the second challenge, namely the 'brain drain' [16, 17]. African countries lose their quantum technology researchers to the countries that are relatively more resourced. As a consequence of 'brain drain', African countries are left with another challenge, namely the dearth of quantum technology skills-base.

Another challenge facing the adoption of quantum technology in Africa is the lack of intra-continental collaboration. This lack of collaboration then leads to the uneven access to quantum technology resources; with the African countries which are relatively well-off having access to such resources while the relatively low-resourced do not. Finally, like most STEM (Science, Technology, Engineering, and Mathematics) fields; where gender disparity is a challenge [18], the field of quantum technology in Africa is still male-dominated.

3.2. Quantum Technology Opportunities in Africa
Although Africa has a wealth of natural resources [19], this wealth does not equally translate to developed economies in Africa. In this regard, quantum technology can be used to spur both technological and economic developments in Africa. Potential applications of quantum technology in Africa are [5, 19]:

- quantum machine learning;
- quantum chemistry;
- quantum finance; and
- quantum metrology.

4. Quantum Technology for Development ($QT4D$) Framework
The $QT4D$ framework is intended to guide the adoption of quantum technology so as to address the developmental challenges. In Africa, the framework can be used to ensure that when it comes to quantum technology, no-one is left behind.

The pictorial representation of the Quantum Technology for Development framework is shown in Figure 2.This framework can be summarized as follows. First, the developmental challenge that affects the society is identified. Then the identified problem is probed in order to assess whether it is amenable to the quantum solution. If the problem is amenable to the quantum solution, it is further probed in order to ascertain if the potential solution is sustainable. Finally, the societal impact of the potential quantum-driven solution is assessed. If the potential solution has a potential have an impact to the society, then such as quantum approach (which is referred to as 'quantum solution' in the figure) could be explored.

Based on the sustainability theory of development, the potential use-cases for the Quantum Technology for Development are provided in Table 1.

5. Conclusion
In this paper, we have explored the quantum technology initiatives in Africa. Additionally, we have discussed the challenges facing the adoption of quantum technology in Africa, and the potential technological and economic development benefits that the adoption of quantum technology can bring to Africa. Furthermore, we have introduced the Quantum Technology for Development framework. The Quantum Technology for Development framework is intended to guide the adoption of quantum technology in order to address the developmental challenges. This framework can be deployed in Africa, in order to address the developmental challenges in

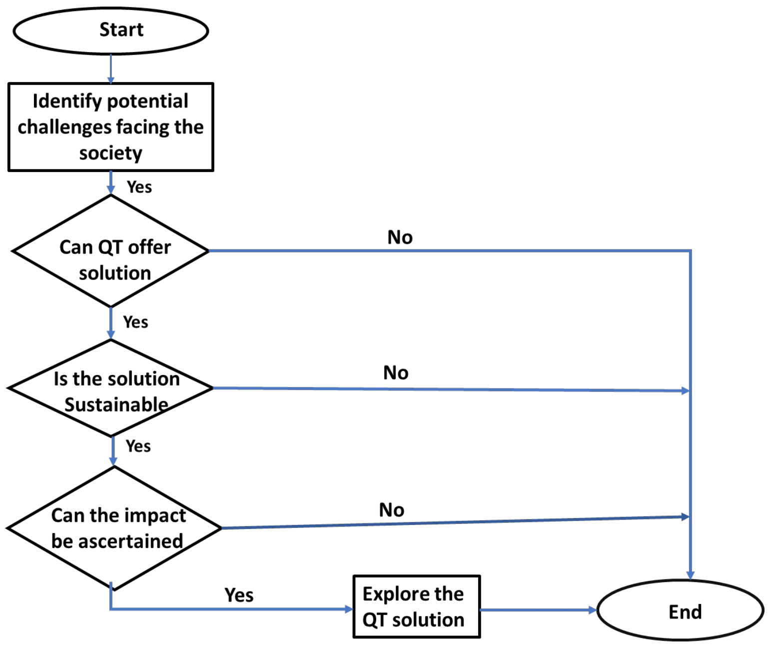

Figure 2. A pictorial representation of the Quantum Technology for Development Framework.

the continent. Future work will focus on the adoption by individual African states of the QT4D framework proposed in this paper.

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Table 1. The *QT4D* Potential Use Cases.

Mhlambululi Mafu is grateful for the support he received from his colleagues in the Department of Physics and Astronomy, at the Botswana International University of Science and Technology. Makhamisa Senekane acknowledges the support he received from the Institute for Intelligent Systems at the University of Johannesburg, and the National Institute for Theoretical and Computational Science.

SDG	**Potential use case**
*SDG*1	Data analysis using quantum computers.
*SDG*2	Quantum machine learning to predict climate-resistant crops.
	Quantum computers for analysis of big data for land use, agricultural drought, *etc.*.
	Quantum sensing for imagery.
	Quantum machine learning for yield forecasting.
*SDG*3	Quantum computers for health big data analytics.
	Quantum cryptography for health data protection.
	Quantum machine learning for drug discovery.
*SDG*4	Quantum machine learning to identify at-risk students.
	Equitable QT training (skills development).
*SDG*5	Inclusive and equitable representation in QT.
	Female-friendly QT environment.
*SDG*6	Quantum sensing to identify water sources.
	Quantum dots to test water quality.
*SDG*7	Quantum machine learning for energy forecasting.
*SDG*8	Intensive QT up-skilling.
*SDG*9	Innovation in QT.
	QT industrialization and entrepreneurship for inclusive job creation.
	Fair and equitable access to QT infrastructure.
*SDG*10	Inclusive access to QT tools.
*SDG*11	Quantum computers for big data analytics.
*SDG*12	Quantum computers for big data analytics.
*SDG*13	Quantum computers for climate modeling.
	Quantum machine learning for forecasting extreme weather event.
*SDG*14	Quantum computers for big data analytics.
*SDG*15	Quantum computers for big data analytics.
*SDG*16	Quantum cryptography to combat cyber-terrorism.
*SDG*17	Strategic partnerships for equitable access to QT resources; ensuring that no-one is left behind.

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