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Developments and Evolutions in Artificial Intelligence, Internet of Things, Quantum Computing, Robotics and Automation, and Voice Assistance/Natural Language Processing

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ABSTRACT

The landscape of technological innovation is rapidly evolving around the world, characterized by the convergence of diverse disciplines and paradigms. In this paper, I will critically examine the evolution, diffusion, acceptance, and uptake of five pivotal emerging technologies, which are, Artificial Intelligence (AI), Internet of Things (IoT), Quantum Computing, Robotics and Automation, and Voice Assistance/Natural Language Processing (NLP), with a particular focus on their application and impact within Africa context and beyond. Drawing from contemporary literature and case studies, the study explores theoretical frameworks underpinning technological diffusion, identifies current gaps and constraints, and proposes evidence-based recommendations for policy, research, and practice. The analysis demonstrates that while these technologies are increasingly integrated into critical sectors worldwide, significant challenges remain regarding scalability, interoperability, ethics, and contextual adaptation, especially in African settings. The paper concludes with a discussion on the future trajectory of these technologies, emphasizing the necessity for inclusive strategies to bridge persistent digital divides and maximize societal benefits.

Keywords: Developments, Evolutions, Artificial Intelligence, Internet of Things, Quantum Computing, Robotics, Automation, Voice Assistance, NLP

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1. INTRODUCTION

The Fourth Industrial Revolution marks a transformative epoch defined by the integration of digital, biological, and physical systems, with technologies such as Artificial Intelligence (AI), the Internet of Things (IoT), Quantum Computing, Robotics and Automation, and Voice

Assistance/Natural Language Processing (NLP) at its core (Uddin et al., 2021). These technologies are not only reshaping industries but also fundamentally altering human interaction, governance, and economic structures. The proliferation of smart devices, the rise of data-driven decision-making, and the emergence of quantum paradigms constitute a new frontier for innovation and societal advancement.

In Africa, the adoption and adaptation of these technologies present both unprecedented opportunities and formidable challenges. While the continent grapples with infrastructural deficits, regulatory complexities, and socio-economic disparities, it also showcases remarkable ingenuity and leapfrogging potential (Uddin et al., 2021). This paper seeks to provide a comprehensive analysis of these five technologies, examining their historical evolution, current state, theoretical underpinnings, practical applications, and the unique dynamics of their diffusion in Africa and globally.

2. LITERATURE REVIEW

Artificial Intelligence

AI's conceptual origins trace back to the mid-20th century, epitomized by Alan Turing's proposition of the Turing Test as a measure of machine intelligence (Rubens, 2014). Over the decades, AI has matured from symbolic reasoning and expert systems to data-driven approaches such as machine learning and deep learning. The influence of AI is evident in applications spanning healthcare diagnostics, financial analytics, autonomous vehicles, and smart home devices (Moin et al., 2022; Uddin et al., 2021).

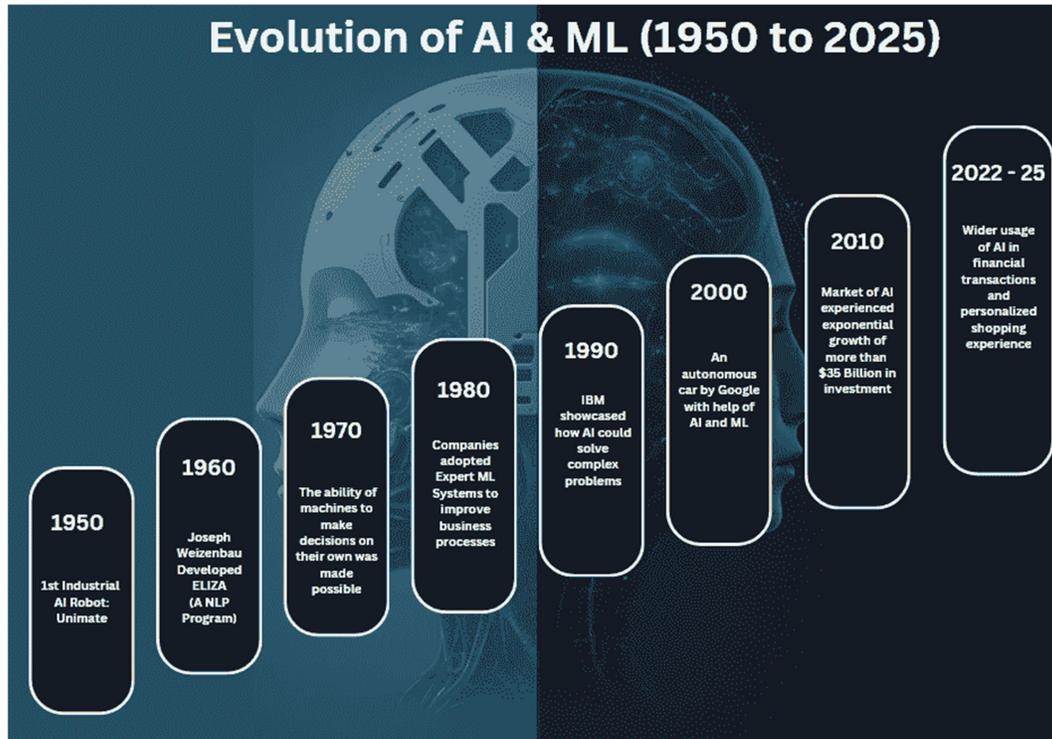


Fig 1: Evolution of Artificial Intelligence

Source: <https://www.netcomlearning.com/blog/the-future-of-ai-trends-every-c-level-executive-should-know>



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Uddin et al. (2021) highlight the integration of AI in daily life via smart devices, exemplified by their MirrorME system which is a low-cost AI-powered smart mirror that leverages facial recognition and voice input to deliver personalized information and services. Rubens (2014) discusses AI's evaluation via the Turing Test, underscoring the challenges of assessing intelligence in non-traditional devices within the IoT landscape.

Internet of Things

The IoT concept brings computation and connectivity to physical things, which makes it possible for data to be sent and received in real time and for smart automation (Fu & Ratnasamy, 2023). The development of cloud-edge architectures, improvements in wireless communication, and falling sensor costs all contribute to the growth of IoT. The swift development of IoT-enabled environments, ranging from smart buildings and cities to customized consumer electronics, as demonstrated by Uddin et al. (2021) and Fu & Ratnasamy (2023). However, as Fu and Ratnasamy (2023) explained, the promise for universal data access in IoT is hampered by organizational silos and interoperability concerns. To solve these issues, their concept for the "Internet of Data Apps" (IoDA) calls for a universal data access layer based on AI and established protocols.

Quantum Computing

Quantum Computing is also another paradigm shift in information processing, leveraging quantum mechanical phenomena such as superposition and entanglement to solve problems intractable for classical computers (Moin et al., 2022; Tangpanitanon, 2024). Landmark achievements, such as Google's demonstration of quantum supremacy have spurred global investments in quantum research and its integration with AI and IoT (Moin et al., 2022; Tangpanitanon, 2024). Quantum technologies are anticipated to revolutionize sectors like cryptography, optimization, and materials science, with emerging use cases in energy management and cyber-physical systems (Tangpanitanon, 2024; Moin et al., 2022).

Robotics and Automation

Robotics and Automation, closely intertwined with AI and IoT, are central to the operationalization of intelligent systems in manufacturing, healthcare, logistics, and service industries (Uddin et al., 2021). Robotics has evolved from rigid, pre-programmed machines to adaptive, AI-driven agents capable of perception, reasoning, and autonomous action. In the African context, robotics holds promise for addressing labor shortages, enhancing productivity, and supporting critical infrastructure.

Voice Assistance and Natural Language Processing

Voice Assistance and NLP technologies facilitate intuitive human-computer interaction, breaking barriers of literacy and accessibility (Uddin et al., 2021). Advances in deep learning and large language models, such as GPT, underpin the remarkable improvements in speech recognition, language understanding, and conversational AI (Fu & Ratnasamy, 2023). Voice-enabled applications are increasingly integrated into smart environments, offering personalized, context-aware services.

3. EVOLUTION, DIFFUSION, ACCEPTANCE, AND UPTAKE OF THESE TECHNOLOGIES

Global Trends

The adoption of AI, IoT, Quantum Computing, Robotics, and Voice Assistance/NLP reflects broader global trends toward digital transformation and automation. Major economies have institutionalized national strategies, invested heavily in research and education, and



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established regulatory frameworks to foster innovation and mitigate risks (Moin et al., 2022; Tangpanitanon, 2024).

The “democratization” of access to cloud-based quantum computers and AI services by leading providers (Amazon, Microsoft, IBM, Google) has lowered entry barriers and accelerated experimentation (Tangpanitanon, 2024). The rapid growth of intelligent devices and data-centric platforms has established a basis for the large-scale integration of these technologies (Uddin et al., 2021; Fu & Ratnasamy, 2023)

African Context

In Africa, the diffusion and uptake of emerging technologies are shaped by unique socio-economic, infrastructural, and regulatory dynamics. While challenges such as limited broadband penetration, energy deficits, and skills gaps persist, there is growing evidence of adaptive innovation and advancement. Uddin et al. (2021) emphasize the increasing use of IoT and AI in African urban centers, with applications spanning smart agriculture, health monitoring, and security. The deployment of smart mirrors with facial recognition and voice input demonstrates localized innovation attuned to contextual needs and resource constraints. Quantum Computing, though in nascent stages, is attracting strategic attention in African research institutions, with pilot projects exploring its potential in energy management and cryptography (Tangpanitanon, 2024). Robotics initiatives, often driven by universities and start-ups, are addressing challenges in manufacturing, logistics, and health services. Voice Assistance and NLP are particularly significant in Africa, where linguistic diversity and varying literacy levels necessitate accessible interfaces. The integration of voice-driven services in mobile health, education, and banking is reducing barriers and enhancing inclusivity.

Frameworks Applicable to Evolution, Diffusion, Acceptance, and Uptake

A robust understanding of technological evolution and diffusion is critical to explaining the heterogeneous patterns of adoption observed globally and within Africa. Several theoretical frameworks provide analytical lenses:

Rogers’ Diffusion of Innovations Theory

Rogers’ (1962) model remains foundational, positing that the spread of innovation is influenced by factors such as relative advantage, compatibility, complexity, trialability, and observability. The adoption curve, which are innovators, early adopters, early majority, late majority, and laggards, maps the temporal dynamics of uptake. In the African context, the perceived relative advantage of leapfrogging (e.g., skipping landlines for mobile telephony) has often accelerated adoption of digital technologies.

Technology Acceptance Model (TAM)

The TAM framework emphasizes perceived usefulness and perceived ease of use as primary determinants of user acceptance. For AI, IoT, and voice interfaces, usability, trust, and cultural fit are critical (Uddin et al., 2021). In environments with low digital literacy, intuitive interfaces, such as voice assistance, greatly enhance acceptance.

Socio-Technical Systems Theory

Socio-technical systems theory highlights the interplay between technological artifacts and social structures. The successful deployment of robotics, automation, and AI-driven systems depends not only on technical sophistication but also on organizational readiness, regulatory support, and user engagement (Moin et al., 2022; Uddin et al., 2021).



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Model-Driven Engineering (MDE) for Quantum AI

Moin et al. (2022) propose extending Model-Driven Engineering (MDE) to Quantum AI, facilitating abstraction, automation, and interoperability in the development of complex, heterogeneous systems. MDE provides a framework for bridging the gap between high-level models and diverse hardware/software platforms, which is particularly salient in the context of quantum-classical hybrid environments.

Universal Data Access and Interoperability Models

Fu & Ratnasamy (2023) introduce the concept of the Internet of Data Apps (IoDA), emphasizing the need for universal data access, interoperability, and seamless integration across devices and domains. This framework is particularly relevant to the IoT and AI ecosystems, where interoperability and data silos remain significant barriers.

4. USEFULNESS AND LIMITATIONS OF THESE TECHNOLOGIES IN AFRICA AND BEYOND

Artificial Intelligence

Usefulness: AI's transformative potential is evident across sectors, such as, enabling predictive analytics, personalization, automation, and decision support (Uddin et al., 2021; Moin et al., 2022). In Africa, AI-powered systems support agricultural productivity, disease surveillance, and financial inclusion.

Limitations: Challenges include limited access to high-quality data, computational resources, skilled personnel, and contextually relevant datasets (Uddin et al., 2021). Ethical concerns, such as bias, transparency, and accountability are exacerbated by the lack of robust regulatory frameworks.

Internet of Things

Usefulness: IoT facilitates real-time monitoring, automation, and optimization in domains such as smart cities, energy, health, and logistics (Uddin et al., 2021; Fu & Ratnasamy, 2023). The MirrorME system exemplifies the integration of IoT with AI for personalized, secure services.

Limitations: Interoperability, data privacy, and security remain major obstacles (Fu & Ratnasamy, 2023). In Africa, infrastructural constraints (e.g., unreliable power, limited connectivity) hinder large-scale deployment. Data silos and lack of standardized protocols further impede universal data access.

Quantum Computing

Usefulness: Quantum Computing promises exponential speedups for problems in optimization, cryptography, and machine learning (Moin et al., 2022; Tangpanitanon, 2024). Pilot applications in energy management, such as optimal placement of distributed energy resources and efficient power flow, are emerging (Tangpanitanon, 2024).

Limitations: Quantum hardware remains in early stages, there is no experimental demonstration that exists for real-world quantum advantage in practical problems (Tangpanitanon, 2024). Integration with classical systems, skills shortages, and high costs limit accessibility, especially in resource-constrained settings.

Robotics and Automation

Usefulness: Robotics and automation enhance productivity, reduce human error, and enable new forms of service delivery. In Africa, robotics can compensate for skilled labor shortages and support critical infrastructure (Uddin et al., 2021).

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Limitations: High capital costs, maintenance challenges, and limited local expertise constrain adoption. Cultural and labor market considerations also impact acceptance and adaptation.

Voice Assistance and NLP

Usefulness: Voice Assistance and NLP democratize access to digital services, particularly for populations with low literacy or disabilities (Uddin et al., 2021; Fu & Ratnasamy, 2023). In Africa, voice-enabled applications in local languages have expanded the reach of health, education, and financial services.

Limitations: Accurate language models require large, diverse datasets, which are often unavailable for African languages. Issues of privacy, accent variation, and contextual understanding persist. Furthermore, infrastructural limitations affect the reliability of voice-based services.

5. RECOMMENDATIONS FOR POLICY, RESEARCH, AND PRACTICE

Policy Recommendations

- **Develop Inclusive Regulatory Frameworks:** Policymakers should establish adaptive, forward-looking regulations that encourage innovation while addressing ethical, security, and privacy concerns and biases, especially in AI and IoT (Uddin et al., 2021; Fu & Ratnasamy, 2023).
- **Promote Standardization and Interoperability:** Adopt and develop open standards to facilitate interoperability across devices, platforms, and data domains, building on models such as IoDA (Fu & Ratnasamy, 2023).
- **Invest in Digital Infrastructure:** Prioritize investments in broadband, energy, and computing infrastructure to support large-scale deployment of IoT, AI, and quantum technologies, particularly in underserved regions (Uddin et al., 2021).

Research Recommendations

- **Contextualize AI and NLP Models:** Foster research into culturally and linguistically relevant AI and NLP models, with a focus on underrepresented languages and social contexts (Uddin et al., 2021; Fu & Ratnasamy, 2023).
- **Advance Quantum-Classical Hybrid Systems:** Support interdisciplinary research on the integration of quantum and classical computing, leveraging Model-Driven Engineering to abstract complexity and facilitate adoption (Moin et al., 2022; Tangpanitanon, 2024).
- **Address Data Gaps and Ethics:** Encourage research into data governance, ethical AI, and bias mitigation such as the “soap dispenser racist”, ensuring equitable and accountable technology deployment (Futurism, 2017)[video].

Practice Recommendations

- **Capacity Building and Skills Development:** Implement targeted training programs to build local expertise in AI, IoT, robotics, quantum computing, and NLP, fostering inclusive participation in the digital economy (Uddin et al., 2021; Tangpanitanon, 2024).
- **Foster Public-Private Partnerships:** Leverage partnerships between governments, industry, and academia to co-develop and pilot innovative solutions, with mechanisms for knowledge transfer and scaling.
- **User-Centric Design:** Prioritize co-design with end-users, ensuring that technologies are accessible, intuitive, and responsive to local needs and constraints (Uddin et al., 2021).

6. FUTURE DIRECTIONS

Looking ahead, several trends and imperatives are likely to shape the trajectory of emerging technologies:

- **Integration of AI and Quantum Computing:** The fusion of AI with Quantum Computing (Quantum AI) will unlock new paradigms of problem-solving, particularly as hardware matures and hybrid systems become operational (Moin et al., 2022).
- **Universal Data Access and Interoperability:** The evolution toward universal data access, as envisioned in the IoDA framework, will be critical for maximizing the value of IoT and AI, breaking down silos, and enabling real-time, bi-directional data flows (Fu & Ratnasamy, 2023).
- **Ethical and Responsible AI:** As AI systems become more pervasive, ensuring transparency, accountability, and fairness will be paramount. Multistakeholder collaboration will be essential for developing robust ethical frameworks.
- **Localization and Inclusivity:** Future research and development must prioritize the needs of diverse populations, particularly in Africa, by supporting local languages, cultures, and socio-economic realities.
- **Sustainable Innovation:** Environmental sustainability should be integrated into the design and deployment of emerging technologies, leveraging AI and IoT for energy efficiency, resource optimization, and climate resilience (Tangpanitanon, 2024).

7. CONCLUDING REMARKS

The convergence of Artificial Intelligence, Internet of Things, Quantum Computing, Robotics and Automation, and Voice Assistance/NLP constitutes the backbone of the Fourth Industrial Revolution. These technologies are reshaping economies, societies, and individual lives, offering unprecedented opportunities for innovation, efficiency, and inclusion. However, realizing their full potential, particularly in Africa context, requires deliberate strategies to overcome infrastructural, educational, regulatory, and cultural barriers.

This paper has synthesized insights from contemporary literature, highlighting both progress and persistent gaps. The African experience demonstrates the importance of contextual adaptation, leapfrogging, and inclusive design. As the global landscape evolves, stakeholders must prioritize interoperability, ethics, and capacity building to ensure that technological progress translates into sustainable and equitable development. In conclusion, the journey toward an inclusive, intelligent, and interconnected future hinges on our collective ability to harness the power of emerging technologies while conscientiously addressing the attendant risks and challenges. Africa, with its dynamism and ingenuity, stands poised to play a pivotal role in shaping this future.

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