KEYNOTE ADDRESS

Big Data Science and the Application of Digital Twins: Imperatives for Africa's Agriculture

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on the Occasion of the 2nd Faculty of Agriculture International Conference (Hybrid), Nnamdi Azikiwe University, Held at the University Auditorium, Awka Campus of the University from 12th to 14th March, 2024, during the Openning Ceremony Being Thursday 13th March, 2024.

INTRODUCTION

The present paper places its emphasis on the emerging but poorly understood concept of 'Big Data and Digital Twins'. The literature describes Digital Twins as digital models of actual physical systems interweaving solutions of complex systems analysis, decision support and technology integration[1]. In the Article ***Computers and Electronics in Agriculture***, *Pylianidis* describes Digital Twins as a digital or virtual representation of physical assets, products or services[2]. Digital Twins applications collect real-world data to create simulations through integrated models that are useful in providing decision support in the life cycle of a product or system or service[3]. The development and use of digital twins have been on the ascendency in the transformation agenda of many sectors of development including industry, service, and more recently the agricultural sectors[4]. Digital twins application provides different levels of control over physical units and helps to manage complex systems through the integration of a range of technologies. Lately, the agricultural sector and the food system have seen several technological improvements including the development and use of digital twins. In this presentation, I shall draw your attention to how digital twin technology has been utilized in different economic sectors including agricultural sector by emphasizing the benefits it brings to these sectors. I will further discuss the practical challenges limiting with the adoption and use of digital twin in the agri-food system. Before I end my presentation, I shall make propositions worth considering in our collective efforts to adopt and use of digital twin to transform the agri-food system.

APPLICATION OF DIGITAL TWIN IN SELECTED SECTORS

Research has shown that over the past few years, the use of digital twin has been increasing across several disciplines. The concept of digital twin was introduced in 2003[5] and since then, it has been applied in various

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5 M. Grieves, "Digital twin: manufacturing excellence through virtual factory replication," White paper, vol. 1, pp. 1–7, 2014.

fields. The manufacturing sector[6], the automotive sector[7], the energy sector[8], the healthcare sector[9], petrochemical[10] and the utility sector[11] have all benefited from the application of digital twin for addressing their respective difficulties. However, the application of digital twins application in agriculture is an emerging area[12]. This provides an opportunity for researchers and scientist to focus their lenses on its application in the agricultural sector. This is particularly so in Africa where efforts are being made to draw attention to the enormous contribution of digital twin can make towards the promotion and transformation of the agri-food system of Africa where millions are still food insecure and malnourished. The concept of digital twin in agriculture is described as consisting of a physical system which is interconnected to the virtual system to monitor and control farming (*crop, livestock, aquaculture*) process.

The emergence and increased use of digital twin application in the different sectors of several economies is attributed to many factors including the enhanced uptake of Internet of technologies th*at al*low for the monitoring of physical twin at high spatial resolutions in real-time, through both miniature devices and remote sensing. Digital twins have been useful for bringing together the physical and virtual spaces guaranteeing information continuity through the system lifecycle, system development and validation through simulation[13]. The integration of internet of things and data analysis has enabled data acquisition, simulations, and interaction between human and physical objects on the field[14]. Promoting technologies such as wireless communication technologies and cloud computing have also triggered the interactions between the physical and virtual space and have led to the increased application of digital twin in various economic sectors[15].

APPLICATION OF DIGITAL TWIN IN THE AGRICULTURAL SECTOR

The use of innovative technologies such as the internet of things (IoT), data analytics (DA), and artificial intelligence (AI) in the agriculture sector is aimed at addressing the issues of food security globally[16]. These technologies pave the way for smart agricultural practices with applications such as real-time monitoring, tracking, and tracing in the food cycle, precision agriculture, agricultural machinery, as well as greenhouse production of food crops.

There are several advantages digital twin provides to the agri-food sector. The use of digital twin helps actors along the agri-food system to better understand the operations and processes required in different agricultural activities. Actors are able to use the virtual systems of various applications of the digital twin to simulate the performance of various farm inputs and growth parameters. Actors in the sector can estimate how the different parameters affect growth processes and production within the sector. Digital twins models can be used to educate agricultural value chain actors on various aspect of the agri-food system. The virtual system can be used to train stakeholders for skills acquisition without embarking on actual farming on the field. One of the potential benefits of the digital twin to the agricultural sector is its ability to interact with the physical

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system using a virtual system, and this provides enormous opportunity for experts to provide technical support to farmers and other value chain actors remotely. Digital twins have the potential to transform agricultural practice in the developing world such as Africa, Asia, and South America as well as the Caribbeans. This is particularly true especially for rural dwellers in in these economies who are constantly exposed to a lot of risks such as drought, diseases, and other non-agricultural-related problems such as security[17].

I wish to state here that, despite the tremendous benefits digital twins provide to the agri-food system in Africa and other developing world, its application in the agriculture sector has been at a low level, and traditional practice and small-scale farming still dominate in these regions. Socioeconomic factors responsible for this observation include low literacy rate among farmers, lack of internet, the relatively high cost associated with such technologies, and non-adaptability of some of these technologies to the African terrain[18]. Regardless, governments in Africa are making tremendous efforts to promote the adoption and use of digital twin technologies across the continent as evident in the increased area under smart farming over the last five years[19]. However, there is still tremendous opportunity for the revolutionizing of the agricultural sector using the latest innovative technologies in irrigation, smart farming, livestock, preservation, equipment, and crop growth models, and ***I call upon*** scientists and researchers on the continent to take up this challenge.

Smart farming, irrigation, livestock farming, food preservation, equipment automation and crop growth model are few of the agricultural sub-sectors that can easily adopt digital twin for transformation and growth.

Smart Farming

Smart farming involves the use of modern technologies in various farming activities to reduce the amount of agricultural input while increasing efficiency and productivity[20]. The use of digital twin technology is intended to increase agricultural production with minimal use of farming inputs is a **necessary and sufficient condition** for the transformation of the food system. Several studies including[21] have demonstrated the ability for smart farming to estimate final production/output and resource consumption based on different parameters that govern agricultural activities. The literature has well documented the application of digital twin framework for the detection of crop diseases, monitoring of soil parameters and prescription of fertilizers around the world. In Nigeria for example, digital twins have been applied in tomato cultivation using sensor information from a physical greenhouse[22]. A similar approach has been recorded in the literature where digital twin has been used for future cultivation and production of orchard farms where the digital twin adaptively learnt the production system by querying it to automatically analyze specific outcomes under varying simulated environmental and orchard management parameters[23]. Another practical example is a novel digital twin for hydroponic farming which was achieved using wireless sensor networks to track the environmental condition and growth pattern of plants. The data collected was used to develop a forecasting model integrated into digital twin to serve as feedback to the farmer to aid decision management[24].

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Irrigation

Digital twin applications have enhanced the proactive management of irrigation systems through online predictions to mitigate the effect of environmental disturbances before there is an adverse effect on the yield and quality of crops produce. Toward building a digital farming environment, a cyber-physical system using digital twin technology can be developed for better management of resources such as water and fertilizer[25]. To further explore the opportunities in digital twin to help improve irrigation, the integration of digital twin with real-time data monitoring has helped to provide the virtual digital representation of soil, plant, and weather behavior to optimize water and fertilizer usage[26].

Livestock Farming

The integration of digital twin technology into livestock farming is still evolving, but it has the tendency to improve on the real-time monitoring and control of the behaviors, physiological, and environmental parameters surrounding the animals using different types of sensors, camera, microphone, and detector27. Using the data collected from the animal's ecosystem and condition such as body temperatures, humidity, it is highly possible to formulate a control strategy for the management of the barn, pen, or housing of the animals. Similarly, the use of digital twin technologies through real-time video capture of images can facilitate early-stage disease detection when there is an anomaly from the usual behavior of farm animals. This has shown to prevent further spread of the diseases among the herd28. In countries in Africa such as Nigeria, Sudan, Ghana, and Burkina Faso, cattle farmers and headers are faced with a lot of challenges ranging from cattle rustling, cattle theft, and uncontrolled grazing. Digital twin offers a promising solution to these issues, as effective sensor-based monitoring and tracking of livestock movement with grazing advice can be achieved to address some of the issues faced by livestock farmers29.

Crop Growth Model

The use of crop growth models is a promising strategy for simulation of crop performance. The increasing use of data-driven predictive modelling of weather and soil moisture predictions can be enhanced through digital twin to simulate crop response to water deficit as well as control of irrigation30. Crop water simulation models such as AQUACROP, regression, artificial intelligence, and other mechanistic models which provide predictions on crop development, weather, and environmental factors such as soil moisture content, can be implemented efficiently on a digital twin framework to guide farmers on the management of their farmers. The feasibility of digital twin to monitor nitrogen cycle between growth models and soil models is also being studies to limit losses and to minimize Nitrogen use by the plant31. There is the need for farmers and researchers, especially in Africa to put into use some of these crop growth models to be able to simulate and validate crop cultivation performance in terms of yield and required agricultural inputs.

Food Processing and Preservation

Food waste and high post-harvest losses continue to be a bane in many African countries, and their contribution to food insecurity, poverty and malnutrition cannot be underestimated. Preservation of agricultural produce helps to reduce waste and spoilage due to bacterial, fungi and other microorganisms or chemical changes. The lack of adequate preservation results in post-harvest food loss and poses as a major factor of high cost of food and food insecurity, especially for seasonal produce which is common in Africa. Traditional methods of food preservation such as smoking, salting, fermentation, roasting, canning or

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bottling, and refrigeration are still largely practiced in many countries in Africa and around the developing world32. It is estimated that approximately 50% of perishable farm produce, including fruits, vegetables, roots, and tubers, and approximately 30% of food grains, such as maize, millet, and rice, are lost after harvest or before reaching the market in West African countries due to a lack of modern preservation facilities33. Digital twins can be applied in better preservation methods such as solar drying to predict the appropriate time to halt drying to avoid under-drying or over-drying. In digital twin, a virtual system can be integrated with the physical system of a solar dryer to capture relevant kinetics of heat and mass transfer processes inside and around the product34.

Agricultural Robotics and Equipment Automation

In the area of industrial automation and agricultural robotics, full digitization of production equipment can leverage on the internet of things technologies to achieve the interconnection of equipment's in digital twin configuration. The data of production process are transferred to the cloud server where an artificial intelligence processing can be equipment or farming controllers, the production activities will not be on hold as it was in many cases.

Agricultural Business

Digital twin can be applied in agricultural businesses to simulate, plan and analyze farming process towards sustainability. Risk analysis can be carried out by forecasting models to minimize external risks from uncontrollable factors such as weather or drought. Farmers can simulate profitability by minimizing cost and decreasing time to market their agricultural products. In addition, methods to determine the per-land area yield and soil management can be simulated to maximize profitability.

MAIN CHALLENGES TO THE APPLICATION OF DIGITAL TWINS

Notwithstanding the obvious benefits of digital twin in transforming the agri-food system, its development and adoption are challenged, especially in Africa, and I seek to discuss some of these challenges in the African context.

Inadequate Human Capacity and Expertise

The development and deployment of digital twin begins with the design which involves the collaboration of researchers from different fields. Skills and expertise such as data scientist, engineering, agricultural scientist, animal scientist, developers and programmers, business analyst are required for a successful implementation of digital twin. Though available on the continent, the number of scientists and researchers with these skills and expertise are limited in Africa. With low number of scientists in Africa (*250 researchers per million people)*[35] on the continent, it is imperative that more scientists are trained in these areas of expertise by various governments to take advantage of the benefits digital twin provides to the agricultural sector. The ability to coordinate between different departments, research organizations and ministries where this expertise reside can pose a challenge for the development and operationalization of the technology in Africa.

Inadequate Infrastructure

The operation of digital twins' technology especially in the agricultural sector requires basic infrastructure such as constant electricity, access to reliable internet, water availability and equipped laboratories for research purposes. The lack of these facilities in many parts of Africa pose a challenge to the deployment of the technology. Several models of digital twin have been developed for agricultural production in other parts of the world[36]. While these models can be adopted for digital twin in Africa there is the need for enhancement

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or modification of such models to suit the natural, climatic, environmental, soil, pest, and diseases as well as the socioeconomic conditions of the continent.

Difficulty in Accessing Big Data

With the large amount of data generated and analyzed in digital twins' systems, big data algorithms and the internet of things technology are powerful allies that can provide support to a great extent to successful digital twins implementations[37], but these are generally unavailable in Africa. Also, the development and deployment of digital twins rely on the availability of accurate and quality data especially geospatial data. Data acquisition problems especially in sub-Saharan Africa has been detected. One of the major data acquisition problems in Sub-Saharan Africa includes instrumental errors due to lack of modern equipment for data capture and observer errors which arise from the limitation of human expertise. especially error in the reading data.

High Cost of Implementation

High costs of implementation due to the increased cost of sensors and computational resources needed pose another challenge to the implementation of the technology in Africa[38]. Due to the expensiveness of digital twin implementations, their accessibility is limited by the accessibility of such resources, which is often poor in developing countries[39]. The increase in the cost of sensors needed comes with an added complexity regarding data connectivity and processing poses a challenge. This challenge also poses a limitation for practitioners to pilot the technology for full-scale deployment.

Low Predictive Power of Digital Twin

Digital Twins are also expected to offer predictions of the future world for better planning and preparations towards eventualities against the agri-food system. However, digital twin that extrapolate knowledge based on data from the past into the future may fail to take into consideration relevant modifications that may come about in environmental conditions, social and economic behaviour, market structures, laws and institutions or governments[40]. Such changes may undermine the relevance of the future that is presented by the digital twin technology. For example, data of the past may fail to predict disruptive events like the Russia-Ukraine conflict, or environmental disasters such as excessive rain that causes floods, or extreme drought conditions. While the digital twin is said to represent reality, reality may change faster than it is able to anticipate, given that it is based on data from the past.

RECOMMENDATIONS

The application and tremendous benefits of digital twin technology to the transformation of the agri-food system especially in Africa has been discussed. The challenges that militate against the application of the technology to take advantage of its benefits have also been discussed in this presentation. *May I take* this opportunity to make the following suggestions as my recommendations to enhance the development and application of digital technology in the agri-food system in Africa.

Pilot Digital Twin

Piloting the technology is needed to develop models such as fertilizer models, crop growth models, irrigation models, preservation models, etc. for various agricultural practices. This will ensure generating interest in the application of the technology through the showcasing of the enormous benefits digital twin to the agri-food sector[41]. Governments on the African continent are urged to develop fertilizers to suit different soil types in the various countries. Digital Twin models can be developed and piloted for the application of fertilizers that are suitable for the different soil and crops such as rice, maize and sorghum. The soil test meter has been

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used to determine the values of soil parameters such as pH, organic carbon, and sodium levels in Africa[42]. The production of various crops in Africa can be digitized to analyze growth and farm input parameters, and the data generated from these analyses can be converted into models for simulation purposes[43]. Research in preservation models can be piloted to digitize the traditional methods and adopt modernized methods used in developed countries. Several preservation models for perishable crops can be developed using DT to address the current challenges of farmers in many parts of Africa[44]. Several livestock farming systems such as fish, poultry, snail, pig, snail, cattle, goat, and rabbit farming require models that consider food formulation, weather condition, diseases, and market. Automated physical systems can be deployed for monitoring fishponds and interconnected to the digital twin platform, and the data such as feeds, medication, rate of growth and production acquired can be used for modelling of fish production in various parts of the continent[45].

Create Digital Twins Agriculture Platform

One of the most important constraints concerns the limited interoperability and lack of openness of different technical systems, thus limiting the choices farmers can make between suppliers of new technologies[46]. There is the need for increased research into the development and deployment of a digital twin platform for the agricultural sector and the entire food system. An enhanced interoperability would allow for increased data sharing and the resulting knowledge generation[47]. Improved and inclusive information flows and management within and among the targeted agricultural sectors based on transparent and fair data governance practices. Another main constraint is the lack of information on the effectiveness of new technologies which slows down their up-take[48]. Digital Twin could be deployed as an online platform to address this challenge faced by farmers and other value chain actors. Models which are developed from pilot projects be integrated into a digital twin platform for use by food system value chain actors in Africa[49].

Facilitate Research Collaborations

Applying participatory design methodologies in digital development projects can help develop more user-centered innovation[50]. There is enormous opportunity in the agriculture sector for collaboration among local researchers from the academia, research institutes and industry inn Africa. There are several research funds for developing countries that can be targeted towards international research collaboration for the deployment of digital twin in agriculture[51]. Examples of research funds are the Canada Fund for Local Initiatives (CFLI)[52] which is targeted for high-impact projects in developing countries, and Kirkhouse Trust targeted at legume research. I entreat scientists and researchers on the continent to take advantage of these opportunities to learn from their counterparts through collaborative drive to broaden their knowledge, skills, and expertise in the field of digital twin.

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Create Enabling Policy Environment

Realizing the vision of digital transformation for Africa requires appropriate policies and an enabling environment with critical policy reforms to the foundation pillars and critical sectors to drive digital transformation. Collaborative regulatory measures and tools are the new frontier for regulators and policy makers as they work towards maximizing the opportunities afforded by digital transformation across industries[53]. Recognizing the potential of emerging technologies and the impact that policy and regulatory frameworks can have on their success, countries and their regulators should encourage a regulatory paradigm that pushes frontiers and enables digital transformation[54]. Policy support for the application of digital twins is needed to improve efficiency, equity, and environmental sustainability of the African food system. Public policy and regulatory frameworks need to be up-to-date, flexible, incentive-based and market-driven to support digital transformation across sectors and across the continent regions[55]. Policies to support general agricultural financing including public financing digital twins is relevant for this course. The private sector could be leveraged as a good sources of financing technological advancement and application in the agri-food system. Sources of private finance for digitalizing the food system are growing on the continent and includes farmers' own-savings, local and international banks, microfinance institutions, and private sector foundations as well as agricultural investment funds. Actions such as harmonization of policy frameworks, integration of e-services *at al*l levels of economic sectors, strengthening collaboration between African institutions and building digital infrastructure have been identified to promote the application of digital twins in the food system of the continent[56].

CONCLUSION

The concept of digital twins and its application in different sectors of development as well as the agricultural and food system sectors have been presented in this paper. Several applications of digital twins including smart farming, livestock, food preservation, agricultural robotics and equipment automation, crop growth models, agriculture, and food processing, and have been identified and discussed in this presentation. The benefits and challenges of digital twins in the Africa context have also been presented. The steps towards the adoption of digital twins in Africa have also been presented. It is my strongest view that digital twins' applications offer an opportunity to transform the agriculture sector and food systems of Africa. To take full advantage of these opportunities, adequate infrastructure needs to be made available for the successful deployment of digital twin in Africa. Governments need to show commitment by creating the enabling environment in terms of policies and investment to enhance the involvement of the private sector in promoting the use and adoption of digital twins. There is an urgent need to train scientists to develop their expertise in digital twins and their application to take advantage of the benefits the technology brings towards the transformation of the agri-food sector.

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