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MECHATRONICS IN AGRICULTURE FOR BUILDING A SUSTAINABLE ECONOMY IN AFRICA

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ABSTRACT

Integrating mechatronics into agriculture (Agritronics) offers a significant opportunity to promote sustainable economic growth in Africa. It intergates mechanical systems, electronics, and intelligent control to improves agricultural productivity, enhances resource use, and supports environmental sustainability. Its uses cover the entire agricultural value chain, including GPS-assisted land preparation, precision planting, automated post-harvest processing, and climate-resilient agricultural practices. Ag-IoT technology implementation platforms such as Arduino Uno, ESP32, and Raspberry Pi facilitates the scalable introduction of smart technologies for various agricultural settings, from smallholder farms to larger commercial operations. As Africa aims to secure food supply, minimize post-harvest losses, and explore new value chains, mechatronics plays a crucial role in the modernization of agriculture. Nonetheless, the effective adoption of these technologies relies on collaborative efforts among governments, educational institutions, private sector stakeholders, and rural communities. Targeted investments in infrastructure, technical education, innovation ecosystems, and supportive policies are vital to fully harness mechatronics to create a resilient and inclusive agricultural economy throughout the continent.



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I. INTRODUCTION

Agriculture is the main stake of the economy of African countries, with more than 60% of the population deriving their livelihoods from farming [1]. While Africa has immense agricultural potential, characterized by extensive uncultivated arable land, and adaptable youthful population, food security continues to pose a serious challenge. About 821 million individuals experience undernourishment globally, with Kenya, Nigeria, Mali, and other Sub-Saharan African countries having a significantly high level of food insecurity [2], [3]. The gap between agricultural potential and food security in Africa continues to widen due to persistent environmental challenges, such as erratic weather patterns, inadequate infrastructure, and obsolete farming techniques. This shortage of food production is often linked to poor farm practices, ineffective crop management, and outdated harvest and post-harvest systems. These limitations highlights the urgent need for the adoption of smart farming technologies, integrated food systems, efficient land use practices, and sustainable environmental management [4], [5]. Addressing these issues is crucial for boosting productivity, enhancing climate resilience, and ensuring long-term food security across the continent.

Agricultural mechanisation involves the use of tools, machinery, and equipment for soil tillage, crop cultivation, harvesting, storage, and processing. It offers a promising alternative to the traditional human and animal-powered methods. By integrating modern technologies such as satellite imagery, GPS, and geospatial information systems (GIS), into mechanised agriculture can further enhances efficiency, improves timelines, reduces drudgery, optimises farming techniques and ultimately boosts crop yields [4], [6].

Historically, agriculture began as a subsistence practice and has progressively evolved from the use of sticks, hand tools, and animal driven tillage and harvesting implements to the adoption of various innovative mechanical and mechatronics technology, as illustrated in Figure 1. The choice of appropriate technology is often determined by its capacity, cost, accuracy, and effectiveness [7].

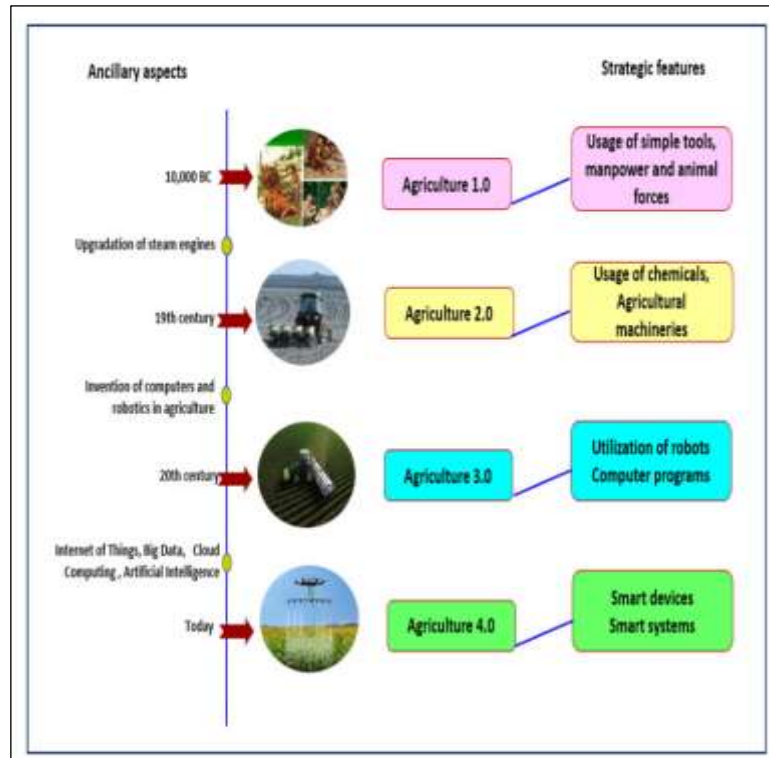


Figure 1: Agricultural evolution from subsistence to mechatronics technology.
Source: [8].

Agricultural Era 1.0, is the first era of human involvement with farming, initially focused on basic animal husbandry and subsistence food production for human survival. Often referred to as the era of ancient or traditional agriculture, this time depended largely on human labor and primitive instruments, including wooden ploughs, sickles, and hoes. Agriculture depended solely on indigenous knowledge passed down over centuries with restricted access to mechanization and other technology inputs. Food production was consequently confined, and agricultural output was only adequate to fulfill immediate demands for subsistence with no extra for storage [9].

The 19th century introduced Agricultural Era 2.0, highlighted by the emergence of steam engines and mechanical agricultural equipment, coupled greater reliance on synthetic chemicals such as fertilizers and insecticides. While these improvements contributed to huge gains in production, they also created serious environmental concerns, including soil deterioration and pollution [10]. The 20th century witnessed the rise of Agricultural Era 3.0, defined by the advent of robots, programmable technology, and precision agricultural practices. This era focused on tackling environmental and resource concerns by pushing technology like precision irrigation, optimum chemical usage, and targeted pest management, all aimed at boosting sustainability while maintaining high yields [11]. Currently, the agriculture industry is undergoing a transformational period known as agriculture Era 4.0, fuelled by modern technologies such the Internet of Things (IoT), big data analytics, artificial intelligence (AI), cloud computing, and remote sensing [12]. These technologies equip farmers and stakeholders with real-time information on crop health, soil conditions, weather patterns, and resource use, thereby enhancing production efficiency, lowering water and energy use, and reducing the environmental imprint of farming activities.

The obvious shift in global agriculture practices, with advanced nations increasingly switching from relying on human and animal power, to embracing mechanical power and sophisticated mechatronic systems, has considerably enhanced food production. However, many less-developed nations, especially in Africa, are experiencing a concerning reverse, with farm practices still depending on human labor due to restricted access to automation and advanced agricultural equipment. For instance, just 21.99% of farms in African nations employ mechanical equipment, a striking contrast to around 78.60% in Asia [13]. Despite the transformative potential of Agricultural 4.0, its use and benefits remain unevenly distributed across all the continents and countries. African agriculture is yet to fully harness the potentials of digital and precision technologies due to persistent infrastructural limitations, economic constraints, and weak research and technology development strategies.

These challenges hinder the adoption and scaling of smart agricultural innovations, thereby limiting productivity growth and the continent's ability to achieve sustainable food security. Unlocking the full potential of mechatronics in African agriculture involves concerted efforts to extend access to mechanization, encourage knowledge transfer, construct solid digital infrastructure, and conduct capacity-building programmes suited to the climate requirements of African regions and the financial capacity of smallholder farmers. Such activities are vital for narrowing the technology gap and helping farmers to embrace modern tools and systems successfully. By tackling these crucial areas, African agriculture may better align with global trends, boost productivity, and use emerging technology to alter its production systems and sustainability results for the future [8]. Mechatronics in agriculture is a cutting-edge field that combines mechanical systems, electronic components, and intelligent computer control to enhance farm operations and promote sustainable

practices [14], [15]. It enhances real-time crop health monitoring, irrigation management, waste reduction, and precision farming, boosting agricultural resilience and production in places confronting environmental and resource restrictions [16]. The advent of the fourth industrial revolution has further accelerated technological innovation in agriculture through the confluence of artificial intelligence (AI), Internet of Things (IoT), robotics, drones, big data analytics, automation, blockchain, nanotechnology, and cloud computing. These technologies are crucial to the development of intelligent farming systems, facilitating data-driven choices, improved process automation, and real-time monitoring of critical agricultural variables such as soil quality, crop development, and water consumption. The technological shift is driven by the integration of smart sensors, and embedded control systems, into mechanised agricultural platforms to permit accurate and responsive farm management [17], [18]. For instance, IoT-enabled technology allows for continuous monitoring of farming activities, therefore facilitating informed decision-making that enhances productivity, conserves natural resources, and decreases environmental damage. These improvements are especially important in Africa, where the use of mechatronic technology would potentially solve critical concerns linked to inefficient land management, low food yields, and susceptibility to climate change.

The increasing corpus of literature shows the transformational potential of mechatronics in agricultural development. As seen in Figure 2, a systematic examination of scholarly articles linked to mechatronics, mechanisation, and precision agriculture from the Web of Science database reveals a considerable rise between 2017 and 2021, showing increased academic and business interest. The peak in citation rates during 2021 shows the usefulness of these technologies in tackling modern agricultural concerns. Although citation rates have fallen significantly in succeeding years, this pattern may indicate a change from conceptual research to the actual application of mechatronic breakthroughs in the field. The expanding research focus on agritrionics reflects its potential to greatly increase agricultural efficiency, reinforce food systems, and assist climate-resilient farming in Africa. This research contributes to existing conversation by studying the growth of mechatronic technologies and their essential role in altering agricultural systems toward a more sustainable and productive future.

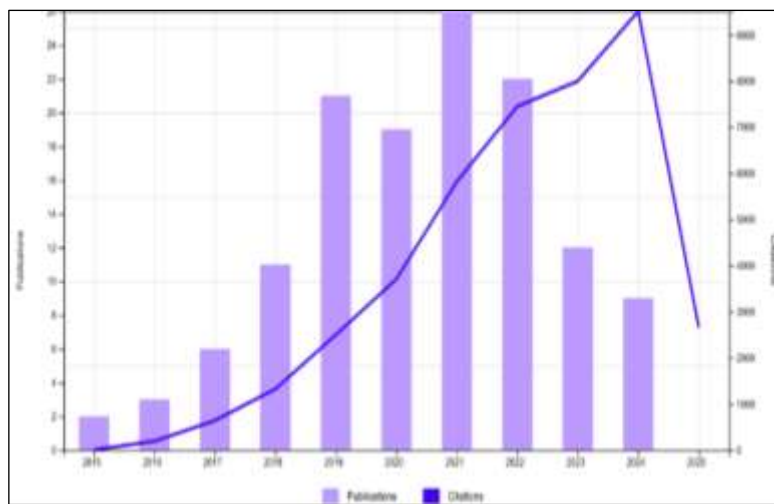


Figure 2: Trends in scholarly output and citations highlighting increasing interest in mechatronics for sustainable agriculture in Africa. Source: Authors, (2025).

II. MECHATRONICS APPLICATION IN AGRICULTURE

Mechatronics is revolutionising agricultural practices by integrating robotics, automation, sensors, and artificial intelligence to optimize farming practices. These innovations play a major role in increasing agricultural productivity and promoting resources and environmental sustainability [19], [20]. The following is an overview of key innovations in mechatronics and their benefits:

II.1 AGRICULTURAL INTERNET OF THINGS (Ag-IoT)

Internet of things (IoT) has transformed many industries in the last twenty years, with the synchronisation of sensor technology, wireless communication, data analytics, and cloud computing to enhance the collection, processing, and utilisation of agricultural data within Ag-IoT systems. It has been progressively used to monitor essential agricultural characteristics, such as crop health, soil and climatic conditions in real-time. Some of the instruments include soil moisture monitors, temperature sensors, and weather stations [21], [22]. This provides vital data, which is then analysed to facilitate decision-making in irrigation, pest management, and nutrient optimisation [8], [23]. The data-orientated methodology enhances resource utilisation, increases production, and sustainable practices. Researchers are developing innovative methods and equipment using sensors to monitor and communicate crop information at various growth stages, utilising various communication devices and machinery.

This section thoroughly discusses Ag-IoT sensors and its compatible data processing platforms:

Ag-IoT sensors: These sensors are crucial in Ag-IoT systems as they convert physical signals into digital signals, measuring crop, soil, and microclimate parameters, including temperature, light intensity, accelerometers, and soil moisture [24]. Sensors such as photoelectric, electromagnetics, conductivity, and ultrasound, as shown in Figure 3 are widely used to smart agriculture to estimate critical parameters like soil texture, nutrient levels, vegetation, humidity, vapour, air, and temperature. Remote sensing technologies can also be deployed to detect types and varieties of crop, pest and weed infections, and soil, plant, and climatic conditions across different landscapes [25].



Figure 3: Agricultural Internet of Things.
Source: [26]

These environmental and agronomic parameters are continually monitored using sensor-based systems for optimal plant health. Data is captured with the sensor and transmitted to the microcontrollers which trigger action when thresholds are exceeded for the optimal crop requirement. Table 1 presents field parameters, sensor variables, device and application of agricultural IoT use in monitoring crop parameters.

Table 1: Agricultural - IoT for Monitoring Crop Parameters.

Field Parameter	Sensor Variable	Sensor Device	Applications in Literature
Thermal	Heat flux, thermal conductivity	Thermocouples, RTDs, and Thermistors	Impact of Climate Change on Agricultural Ecosystem [27], [28].
Soil Moisture and Humidity	Moisture content Resistance, Conductivity, and Permittivity	Frequency Domain Reflectometry, and Gypsum Block Sensors	Applied in irrigation scheduling, drought stress detection, and water use efficiency studies [29].
Light Intensity	Wavelength of light, Area receiving light, and Quantum	Illuminance sensor, imaging sensors, and thermal imaging camera	Optical Performance of Winter Wheat under Different Irrigation Conditions [30], [31].
Insect wing beat sound	Sound frequency spectrum (wingbeat)	Microphone (electret or MEMS mic) array	Real-time pest monitoring via acoustic classification (e.g. fruit flies); reduces pesticide use [32]
Soil penetration resistance	Tillage force (penetration)	Penetrometer with load cell (hand-held or automated robot probe)	Penetrometer with load cell (hand-held or automated robot probe) [33]
Soil nutrients (pH, EC, NPK)	pH, electrical conductivity (EC)	Soil pH probe (electrode), EC probe	Fertilizer management and nutrient optimization to improve yield [34]
Ambient temperature & humidity	Air temperature (°C), relative humidity (%)	Digital sensor (DHT22, BME280, SHT3x)	Climate monitoring for frost/disease forecasting; greenhouse climate control [8]
Rainfall/precipitation	Rain amount (mm)	Tipping bucket rain gauge (analog)	Irrigation scheduling and drainage management based on rainfall data [35]
Wind speed	Wind velocity (m/s)	Anemometer (cup or ultrasonic)	Adjust spraying/ dusting operations; protect crops (e.g. windbreak activation) [36]

Source: Authors, (2025).

II.2 COMPATIBLE AG-IOT DATA PROCESSING PLATFORMS

The effective implementation use of Ag-IoT technology depends on the compatibility of sensors with IoT platforms capable of seamless data acquisition, processing, and communication. Identification and choice of suitable platform is vital in ensuring accurate measurements of key field parameters and support real-time responsiveness. These platforms play significant roles in customising Ag-IoT devices to suit diverse agronomic and climatic patterns in Africa. Figure 4 show the flowchart of remote sensing and satellites images methods in smart farming, while the processing platform is discussed as follows:

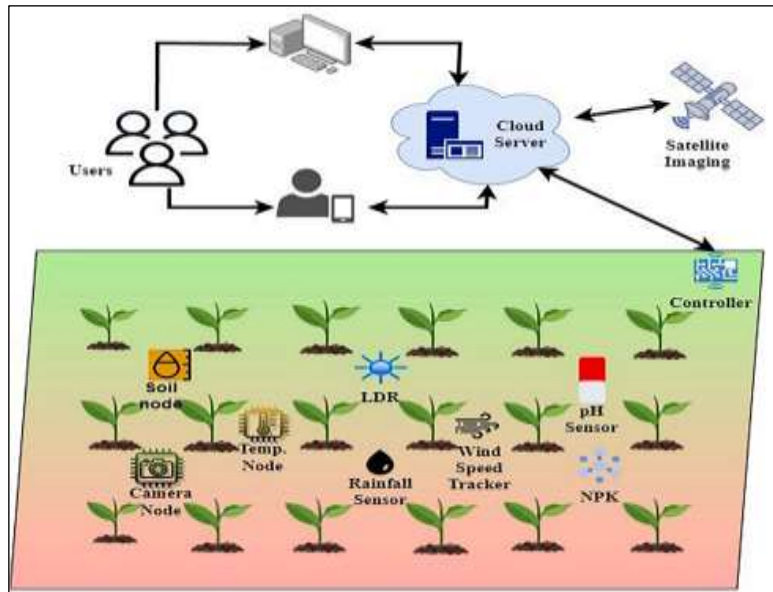


Figure 4: Flowchart of remote sensing and satellites images methods in smart farming.

Source: [8]

- **Thermal and Climate Sensors:** Microcontrollers like Arduino Uno, ESP32, and Raspberry Pi are used for temperature, humidity, wind speed, and rainfall data acquisition because of their capabilities for both analogue and digital inputs, low energy usage, and compatibility with DHT22, BME280, tipping bucket rain gauges, and anemometers. These platforms are essential for temperature and humidity measurements, which are critical for effective greenhouse management and early disease identification [37].
- **Soil Moisture and Nutrient Monitoring:** Arduino Mega and NodeMCU ESP8266 are commonly used to connect with capacitive and resistive soil moisture sensors for measuring conductivity, pH, and fertiliser level, along with ion-selective nutrient probes. These microcontrollers provide ample analogue pins and Wi-Fi capabilities for the real-time transmission of soil health information, facilitating precise fertilisation and irrigation practices [38], [39].
- **Light Intensity and Optical Sensing:** High-data multispectral imaging and chlorophyll assessments are done using Raspberry Pi and Jetson Nano. They offer the necessary processing capabilities for executing image analysis algorithms and can be combined with high-resolution cameras to monitor plant health and identify diseases [40].
- **Acoustic Sensing:** MEMS microphones are used for pest monitoring acoustic-related applications like wingbeat detection. ESP32, Raspberry Pi Pico, and Raspberry Pi Zero W are the preferred support platforms because they support real-time sound processing and wireless communication while maintaining low power consumption [41].
- **Mechanical Sensing:** Soil penetration and load cell indices with soil compaction or grain weight are heavy-duty field measurements managed by platforms such as Arduino Uno with HX711 amplifier modules. These systems are dependable and robust for amplifying analogue signals and capturing real-time data from mechanical sensors [42].
- **Integrated Systems and Automation:** Some extensive smart farming applications required both sensing and actuation; this kind of technology needs platforms like ESP32 and BeagleBone Black. They provide flexibility with GPIOs, support PWM, and come equipped with wireless modules. These are used to control actuators (like irrigation valves, sprayers, and fans) based on input from environmental sensors [43].

III. APPLICATIONS OF MECHATRONICS FOR SUSTAINABLE AGRICULTURAL ECONOMY

The application of mechatronics in agriculture has given leverage for technology-driven crop production. These facilitate a resilient approach during farm survey, land preparation, crop management, harvest, and post-harvest processing stages by enabling automation and data-driven crop tillage, cultivation, harvest, and processing [44].

- **Smart land preparation:** Smart devices and sensors can be installed on GPS-guided tractors, seeders, and sprayers. Equipping farm machinery with AG-IoT sensors helps mitigate the effect of climate change while improving energy efficiency, reducing greenhouse gas emissions, and preserving soil health [45].
Combining these advanced technological solutions with context-specific agronomic practices will reduce operational delays and input wastage. These systems will also boost output per hectare, making farms more profitable and reducing dependency on imports [44].
- **Post-Harvest Efficiency and Value Addition:** Food security and value addition for sustainable farming depend heavily on agro-processing, which transforms agricultural inputs into consumable or intermediate items. However, the industry confronts continuing issues such as labour shortages, uneven product quality, and inefficiencies associated with old processing techniques.
To address these constraints, robotics and mechatronics have emerged as transformational solutions. These technologies automate essential procedures, improve accuracy, and save operating expenses. Innovations like automated dryers, sorters, and packing systems

not only eliminate post-harvest losses but also greatly increase product quality and uniformity. The integration of mechatronic systems into agro-processing creates new prospects for local value addition, agro-industrial growth, and improved export competitiveness [46].

- **Resource optimisation:** Smart irrigation, precision fertiliser applications, and climate-responsive greenhouses employ sensors and actuators for administering inputs depending on real-time crop demands. This focused method optimises production per unit of input, consistent with the key principles of sustainable intensification. In particular, vertical farming is predicted to witness a boom in automation, spurred by developments in technology.

The integration of automation and artificial intelligence (AI) in vertical farming systems boosts efficiency, assures constant plant development, and promotes predictable harvests. This technology-driven strategy not only decreases the danger of human mistakes but also dramatically lowers labour expenses compared to conventional farming techniques, making it a viable model for future agricultural output [47].

- **Climate resilience:** Mechatronic systems are crucial for improving agricultural adaptability to fluctuations in climate. By consistently tracking weather, soil, and crop conditions, these technologies facilitate prompt and flexible reactions to environmental changes. Automated systems can issue early alerts for drought conditions, pest invasions, and soil decline, aiding proactive decision-making. Climate change, marked by long-term alterations in global weather patterns such as rising temperatures, severe weather occurrences, and changing rainfall patterns, results from both human actions like greenhouse gas emissions and natural phenomena.

It has a profound effect on ecosystems, biodiversity, public health, and economic stability. The interaction between agriculture and climate change is mutually influential: agriculture not only contributes to climate change but is also significantly affected by its consequences. Incorporating climate-smart technologies such as mechatronics is vital for developing a more sustainable and robust agricultural framework [48].

- **Crop Pest and Disease Management:** Mechatronic solutions in agriculture, especially with the integration of the Internet of Things, provide a more sustainable and accurate method for managing pests and diseases. The Food and Agriculture Organisation estimated global crop yield lost at about 20 – 40% per year. Although pesticides and agrochemicals have been used to tackle food loss, they pose significant risks to human and animal health and contribute to environmental degradation [49]. IoT devices installed on agricultural robots, wireless sensor networks, and drones have improved the detection and control of crop pests and pathogens. They depend on image detection and processing.

Remote sensing imagery and in-field sensors continuously gather essential data, including indicators of plant health and pest occurrences, through real-time monitoring, modelling, and forecasting of diseases throughout the growing season. These technologies surpass conventional pest management approaches in terms of both accuracy and effectiveness. Moreover, automated traps enabled by IoT are designed to capture, count, and identify various insect species. The collected data is then sent to cloud-based platforms for thorough analysis. Recent progress in robotics has resulted in the creation of agricultural robots that are fitted with multispectral imaging sensors and precision spraying nozzles. Within IoT management frameworks, these robots can effectively identify and tackle pest infestations, thereby reducing the need for harmful agrochemicals and lessening ecological impact [8], [50].

- **Yield Monitoring and Forecasting:** Yield monitoring systems deliver immediate insights on crop yield, moisture levels, and quality elements vital for sustainable agricultural strategies. Mechatronics systems for monitoring crop output provide real-time information on essential parameters for forecasting crop maturity, quality, moisture content, and crop yield, as illustrated in Figure 5. Yield forecasting aids farmers in strategic planning, resource allocation, and market preparation by predicting crop quality under various environmental conditions, thereby enhancing crop quality. Evaluating crop maturity by examining factors like fruit size and colouration is crucial for identifying the best time to harvest.

Precise forecasting of harvest windows leads to enhanced crop quality, increased production, and contributes to market regulation efforts. Having up-to-date information on the ideal harvest period helps farmers enhance their profitability and minimise losses after harvest. Contemporary yield monitors, when integrated into harvesting equipment and linked to mobile apps, showcase real-time harvest data and automatically relay information to cloud-based systems for analysis. Satellite remote sensing technologies are utilised to estimate crop yields over large agricultural areas. In the case of fruit crops, high-resolution RGB satellite images are employed to evaluate traits such as fruit size and colour, supporting predictions of maturation stages, harvest timing, and market readiness [51]. These optical sensors are essential for tracking physiological changes in fruits, like shrinkage during drying, thus aiding in quality control and enhancing post-harvest processing efficiency [8].

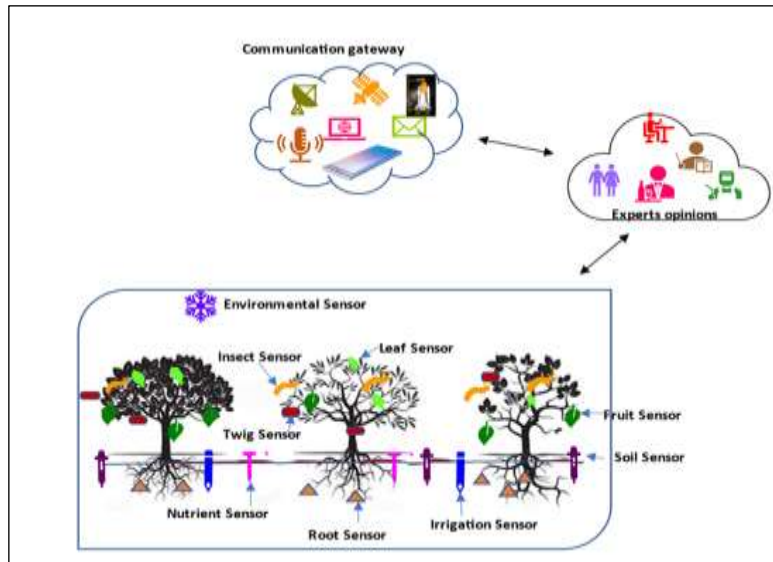


Figure 5: An Internet-of-Things-based network for smart farming.
Source: [8]

IV. CHALLENGES TO ADOPTING MECHATRONICS IN AFRICAN AGRICULTURE

Despite the exciting potential of mechatronic in agriculture (agritronics), many obstacles, including cost and accessibility, infrastructure deficit, skill gaps, and policy and regulatory weaknesses, hinder their widespread implementation in Africa:

- The high initial cost needed for mechatronic equipment such as automated harvesters, irrigation systems, and climate-control devices remains a key obstacle, especially for smallholder farmers who dominate Africa's agricultural landscape. Limited access to finance and funding methods worsens this difficulty [52].
- The shortage of dependable infrastructure, including internet access, energy, and remote road networks, inhibits the implementation and maintenance of smart agricultural systems. In many locations, fundamental infrastructure is either inadequate or altogether nonexistent, hindering the functioning of precision systems [53].
- There is a lack of trained professionals, including engineers, technicians, and agricultural extension workers, who can operate, maintain, and promote the usage of mechatronic systems. This absence of human capital lowers the efficacy and sustainability of technological adoption [53], [54].
- Weak institutional frameworks, limited government investment in agricultural innovation, and the lack of enabling regulations hold down the implementation of mechatronics. Inadequate standards, regulatory backing, and incorporation into national development objectives further impede growth [55].

V. ADVANCING MECHATRONICS DEVELOPMENT IN AFRICA

Africa possesses significant agricultural potential that remains largely untapped, with Nigeria using less than half of 73 million hectares of cultivable land. The continent holds 60% of the world's arable land, yet it is a net importer of food, with 220 million people suffering from undernutrition. Enhancing local engineering and technical skills is essential since agriculture accounts for 24% of Nigeria's GDP [52]. Modern agricultural practices depend on sophisticated mechatronic systems, which highlights the need for local training initiatives to emphasise practical engineering abilities for sustainably revolutionising agriculture and decreasing reliance on foreign technology [14].

V.1 HUMAN RESOURCE DEVELOPMENT

The development of mechatronics in Africa necessitates a strong human resource base, especially in robotics. The continent's large youth demographic and various engineering institutions must be equipped to create mechatronic products. This goal can be accomplished by incorporating agriculture-related modules into educational programmes, like designing farming equipment, to enhance food production without relying on imports. The National Centre for Agricultural Mechanisation (NCAM) in Nigeria not only designs local farming machinery but also conducts training sessions for engineers and farmers [52]. These organisational strategies guarantee that research meets the requirements of farmers and that advancements can transition from laboratories to practical applications in the field by:

- Update engineering programmes to emphasise mechatronic applications within the agricultural sector,
- Broaden the availability of hands-on workshops and internships across the country for apprentices in automation and sensor systems,
- Foster partnerships between the fields of engineering, agriculture, and data science,
- Equip agricultural extension workers with foundational technology skills to support a digitally savvy farming community, and
- Utilise expertise from diaspora professionals and international universities to access the latest developments.

V.2 ACADEMIC AND RESEARCH INSTITUTIONAL SUPPORT

Advancements in mechatronics within Africa necessitate robust institutional backing and well-defined research priorities. It is essential for governments and educational institutions to establish specialised research facilities aimed at addressing agricultural issues. The National Agricultural Technology and Innovation Policy (NATIP) for the years 2022-2027 in Nigeria emphasises the use of knowledge, technology, and innovation to enhance production. Organisations like NCAM, National biotechnology research and development agency (NBRDA), and universities can spearhead research and development focused on adaptive machinery and precision farming technologies [56]. Their research must:

- Concentrate on smart technology solutions tailored for both arable and cash crops,
- Emphasize investigations into sustainable mechanisation and innovations using local materials,
- Leverage intelligent systems, such as robotics, to address issues like rainfall variability and drought conditions.
- Encourage platforms for collaboration to share results and modify technologies accordingly, and
- Boost research and development funding to facilitate the creation of prototypes and conduct field trials.

V.3 DIGITAL INFRASTRUCTURE AND TECHNOLOGY INTERGRATION

Nigeria is encouraging the integration of mechatronics in farming through improvements in its infrastructure and the dissemination of technology. The nation has supported the FAO's Digital Village Initiative, which promotes the establishment of a National Integrated Digital Agriculture Platform that connects farms, markets, research, and extension services. This platform has the capability to compile weather forecasts, soil information, and market pricing, thereby enabling precision agriculture for smallholder farmers [57]. Rural agricultural development strategy should include:

- Investing in broadband and mobile access along with IoT sensors for agriculture in rural areas,
- Digitising the register of farmers and mapping agricultural land for data-driven decision-making in farming,
- Creating local prototyping hubs to foster engineering solutions within communities,
- Encouraging the use of renewable energy via solar-powered agricultural robots,
- Providing funding for demonstration projects to test the deployment of mechatronic tools, and
- Enhancing infrastructure to ensure the fast and equitable spread of technologies in rural regions.

V.4 GOVERNMENT POLICY FRAMEWORK

The Nigerian National Integrated Digital Agriculture Platform (NATIP) seeks to enhance mechatronics by incorporating it into agricultural and industrial strategies. This initiative prioritizes mechanization and the adoption of technology as key national objectives, connecting technological advancement with food security and the creation of jobs. The African Union's Agenda 2063 also highlights the importance of food security and promotes investment in technology. It is essential for national governments to align their policies in science, technology, and agriculture, with NATIP 2022-2027 acting as a guiding framework [53]. Regional frameworks in Africa should promote the use of robotics and automation in agricultural practices and make regulatory support for Agri-Machinery by;

- Developing standards and certification for agri-machinery,
- Simplifying import regulations for local industries,
- Providing quality standards for homegrown machines,
- Reforming of extension services to include technology advisory,
- Revitalizing extension networks for smart agriculture adoption, and
- Monitoring and evaluating for data-driven governance.

V.5 PUBLIC PRIVATE SECTOR FUNDING MECHANISMS

The innovation and scaling in agri-mechatronics are being spearheaded by the public private sector, including startups, cooperatives, and investors. In Nigeria, a wave of new agritech startups is emerging to tackle on-farm issues, with companies like ThriveAgric and Releaf utilizing digital platforms and affordable machinery for financing and processing [58]. Nevertheless, funding presents a significant hurdle, as African agritech startups raised only about US\$65 million in 2024, which is considerably less than the capital directed toward fintech [59]. This underscores the necessity for targeted financial support and investment incentives in agri-mechatronics, and commercialization of locally-developed mechatronic solutions by;

- Promoting a dynamic private sector and ensuring access to financial resources,
- Supporting investment initiatives and incentives through venture capital, grants, public-private partnerships, and tax benefits,
- Providing startup support through agritech hubs and accelerator programs,
- Establishing market connections by collaborating with farmer cooperatives and large agribusiness entities,
- Rallying impact investments and donor contributions around agricultural transformation objectives,
- Leveraging funds like USAID's Feed the Future and AfDB's Nigeria Incentive-based Risk Sharing System for Agricultural Lending, and
- Employing blended finance strategies to address early-stage risks in robotics innovation.

VI. CONCLUSIONS

Mechatronics offers a transformative opportunity for improving agriculture and promoting a sustainable economy in Africa. By combining mechanical systems with electronic components and smart control technologies, it enhances productivity, optimizes the use of resources, and reduces post-harvest losses. From precision land preparation that utilizes GPS-guided machinery to sophisticated agro-processing and climate-resilient farming systems, mechatronics supports every step of the agricultural value chain. The flexibility of Ag-IoT platforms like Arduino Uno, ESP32, and Raspberry Pi provides scalable and cost-effective solutions for various farming situations, including those utilized by resource-constrained smallholders.

The widespread adoption of mechatronics in Africa faces challenges such as high initial costs, inadequate infrastructure, skills gaps, and weaknesses in policy and regulation. To tackle these challenges, Africa must enhance local expertise and technical skills, particularly in robotics, by developing human resources, supporting academic and research institutions, improving digital infrastructure and technology integration, and creating favorable government policies. Nigeria is implementing initiatives aimed at equipping local farmers with mechatronic solutions to increase food production without reliance on imports. The policy framework should align with NATIP 2022-2027, and regional strategies should promote the incorporation of robotics and automation in agricultural practices. Additionally, funding from both public and private sectors, including venture capital, grants, and partnerships, is being leveraged to encourage the advancement of agri-mechatronics.

VII. AUTHOR'S CONTRIBUTION

Conceptualization: Thomas Adedayo Ayorinde.

Methodology: Thomas Adedayo Ayorinde.

Investigation: Thomas Adedayo Ayorinde.

Discussion of results: Thomas Adedayo Ayorinde.

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Writing – Review and Editing: Tamba Jamiru and Peet F LE Roux.

Resources: Tamba Jamiru and Peet F LE Roux

Supervision: Tamba Jamiru and Peet F LE Roux.

Approval of the final text: Thomas Adedayo Ayorinde

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Data Availability: 'The raw/processed Data required to produce these findings cannot be shared at this time due to technical and time limitations'.

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