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An IoT Course Program to Foster the Adoption of IoT Driven Food and Agriculture in Sub-Saharan Africa (SSA)

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***Abstract*—The Internet of Things (IoT) technologies, together with other technological advances such as big data analytics, Artificial Intelligence (AI), automation, and unmanned electrical vehicles (e.g., self-driving vehicles and drones), are currently being used to transform the food and agriculture industry to increase yields significantly with minimal damage to the environment. These recent advances in Information and Communication Technologies and advances in biotechnology are driving the transition into the fourth agricultural revolution or agriculture 4.0. Some research studies on the adoption of IoT in the agriculture sector in Sub-Saharan Africa concluded that some of the reasons the rate of adoption of IoT in Africa is still very low are gaps in knowledge, skills, finance, and infrastructure. The knowledge and skills gaps are partly a result of an educational curriculum that is not up to date with current advances in the food and agricultural industry. To foster IoT adoption in the food and agriculture sectors and other sectors or industries in Sub-saharan Africa, we propose an IoT course program consisting of lectures and laboratory modules. The course is accompanied by textbooks, video lectures that are freely available on Edx, and remote online laboratories with the hardware resources hosted in some European countries but accessible through the Internet. These courses can also be adapted by vocational training schools, Higher Institutes, and universities in Sub-Saharan Africa or could be used by professionals and enthusiasts to improve their skills.**

***Index Terms*—Internet of Things (IOT), education, IoT driven food and agriculture, Sub-Saharan Africa (SSA)**

I. Introduction

Agriculture plays a major part in the economies of developing countries, especially those in Sub-Saharan Africa (SSA). It provides many jobs to a significant part of the working population in SSA as hundreds of millions of people are employed along the agricultural value chain from the food production, food supply chain, food processing, storage to the distribution (retail) stage. There has been a continuous increase in the demand for food in Africa resulting from the continuous increase in the population [1] and the growing middle-class [2]. Food accounts for roughly 40% of the consumption basket in SSA, and the increase in food prices is one of the driving forces behind the growing inflation in SSA [3]. The continuous increase in food prices in SSA is due to the inability of the food and agriculture sector in SSA to satisfy the growing demand as agricultural production in SSA has remained very low compared to the rest of the world [4] despite natural and human resources and potential found in this region. The agricultural production in SSA has lagged behind that of the rest of the due to insufficient skilled labour, poor transport infrastructure, storage facilities, food processing, market structures, and financial institutions [4], and energy infrastructure.

One of the ways to boost agricultural production in SSA is to improve or strengthen its research and educational institutions to provide solutions to the food and agriculture sector and offer quality training to students and practitioners (e.g., farmers, food processing professionals, retailers). The authors in [5] recommends that students and practitioners could be better equipped by developing agricultural education and training curriculum or programs that prepare them for the complex, interdisciplinary challenges that they will face when solving food and agricultural challenges in their environment. It is important to design an Interdisciplinary approach that combines electrical, electronics, control, and computer engineering disciplines with agriculture to train students that will be able to create startups in the food and agricultural sector in developing countries, especially those in Sub-Saharan Africa. It is also important to build strong food and agricultural technology research collaboration between researchers in SSA and those of other parts of the world to facilitate research and development and exchanges of experiences.

The Internet of Things (IoT) is a network of low-power computing devices (IoT devices) that are equipped with sensors to collect data from the physical environments and send it to a remote server (e.g., a fog computing or cloud computing server). The remote server performs some processing, and the results are either sent to the operator for decision-making or sent back to the low-power computing devices attached to an actuator capable of manipulating physical systems. IoT devices can be equipped with sensors (e.g., temperature, humidity, soil moisture, gas, light, and motion sensors) and cameras to periodically collect data and send it to data-analytic platforms to monitor parameters that affect crops and livestock. The data analytic or control platforms can send messages to the operator to make certain decisions and take actions to ensure favourable conditions for the crops and livestock, e.g., taking action to combat pests attacks, harvesting crops on time, or providing food and water to the animals. It can also send commands or instructions to the actuators to perform some actions, automating some of the routine work on the farm.

The Internet of Things (IoT) is remodelling agribusinesses by empowering agro entrepreneurs and farmers with a range of strategies and tools to deal with the challenges affecting the agro-industry [6]. The use of IoT in the field of agriculture is about the empowerment of farmers with automation technologies, decision tools, knowledge, and services to improve productivity, quality, and profit [7] in a sustainable way. The adoption of IoT in Africa is very slow, partly due to the reluctance to update the educational curriculums to meet up with recent technological and knowledge trends [8], [9], and the disconnection between the industry and academia.

The adoption of smart agriculture, smart food processing, and other agriculture 4.0 technologies can be fostered by developing interdisciplinary education and training programs that combine the Internet of things (IoT), Artificial Intelligence (AI), and Big Data Analytics (BDA). It will enable the training of food and agricultural engineers and farmers who will be creative, innovative, flexible, create new jobs, and develop sustainable food production methods based on the local context . IoT is gradually becoming a mainstream field of its own, and with its broad applications, it will be adopted as a study program in other disciplines or interdisciplinary study programs.

This paper proposes an IoT-driven food and agriculture program that educational institutions could adopt to prepare the researchers, students, practitioners, educational/training institutions, and agribusinesses for the fast-approaching fourth agricultural revolution (agriculture 4.0).

II. Some Challenges in Food and Agriculture Industry in Sub-Saharan Africa

The food and agriculture sector in SSA contributes significantly to the Gros Domestic Product (GDP) of the countries that constitute this region. However, it is puzzling that African countries, especially those in SSA, are still net importers of food and agricultural products, despite their vast agricultural potential [10]. It could be attributed to the challenges that the food and agricultural sectors in the region are facing. It is important to understand the challenges faced by the food and agriculture industry in Sub-Saharan Africa to apply IoT to address some of the challenges faced by Africa's food and agriculture industry. The authors in [8] discussed some of the challenges faced by farmers in SSA. Some of the major challenges faced by small scale farmers in Africa, that could be solved with the use of IoT as discussed in section III include:

- Climate fluctuation has led to extreme temperatures, increasing aridity, and unpredictable rainfall and has led to an increase in food insecurity as it is gradually disrupting the rainfed agricultural systems on which the majority of the population depends.
- Water management as the bi-seasonal climate cause farmers in Africa to depend on irrigation during the dry season, and desertification has caused more water scarcity requiring proper water management.
- Peste outbreaks, as the warm tropical climate offers a conducive environment for pests that damage crops and cause diseases to livestock.
- Theft of farm produce or livestock is also a serious challenge for farmers due to the continuous increase in unemployment.
- Crop/livestock monitoring is a challenge because it makes farming activities labour intensive, time and resource-consuming, and less profitable due to excessive losses.
- Insufficient storage facilities and poor storage methods often result in food wastage and revenue losses.
- Insufficient capital as most smallholder farmers cannot access loans from financial institutions, and there is little or no support from the governments.
- Very low market prices which are controlled by the intermediaries and sometimes cause farmers to become discouraged, e.g., the drop in the coffee and cocoa prices in the global market caused some farmers in Africa to abandon the cultivation, as there is very little domestic market due to little processing of this cash crop within the continent.
- Management of the products along the food supply chain to ensure traceability and preservation of the quality of the food.
- Mitigating the conflict between the animal farmers and crop farmers is the so-called farmer grazier conflict, which often leads to massive losses for crop farmers whose crops are often damaged by livestock.
- Difficulties to transport crops or livestock from the farms in rural areas to the markets in urban areas.
- Political conflict has displaced farmers and has paralysed the transportation system increasing the cost of running agribusinesses.
- Land fragmentation is a big problem because it makes it difficult to scale agricultural businesses and investments.
- Energy shortages result in long hours of blackouts and harm the businesses engaged in value addition throughout

the food and agricultural value chain. A lot of rural areas do not have access to the electricity grid.
- Food preservation and quality assurance
- Trust issues and low level of collaboration, coupled with the weak judicial system, make it difficult to create partnerships to establish large-scale agricultural ventures.
- Data collection and management challenges which makes it hard for farmers to make rational decisions and for policy makers to design and implement efficient policies.
- Counterproductive state intervention policies such as controlling of food prices and the banning of food exports which sometimes makes the cultivation of certain food products unprofitable.
- Insufficient agricultural research, agricultural education, and training institutions.

Some of the challenges discussed could be addressed by adapting the agricultural education and training programs to generate the needed skilled labour to address these challenges and develop efficient and sustainable technologies. Some of the challenges could be addressed through government policies, educational reforms, and improvements or reforms in the administrative and judiciary systems to enforce the rule of law to create a suitable environment for agribusiness and agro-training institutions to strive. The governments in SSA could also address some of these challenges by providing some public infrastructures such as good roads, a stable electricity grid, local markets, Information and Communication Technology (ICT) infrastructure, financial institutions, and regulatory agencies. Some smart agriculture or IoT Driven Agriculture (IDA) use case applications that have been proposed and developed by some researchers to address some of the challenges discussed above are presented in the next section below.

III. Some IoT driven food and agriculture use case applications

IoT-driven food and agriculture (IDFA) or IoT-based agriculture refers to using IoT technologies and applications together with information and communication technologies (ICT) and other technologies to address some food and agricultural challenges. The Internet of Things is the technological paradigm in which low-power sensor devices with internet connectivity are used to collect monitoring data from physical systems of objects. The collected data is sent to the edge, fog, or cloud platforms for data analytics. The data analytics results can be used to make decisions or control cyber-physical systems or objects. An illustration of a simplified model of IoT architecture is shown in figure 1.

IoT is a promising technology with a high potential to modernise the agricultural sector, and research institutions, as well as enterprises, are working together to deliver more products to agricultural stakeholders [11]. Some technologies that enhance the use of IoT in agriculture include big data, artificial intelligence, fog computing, cloud computing, and low-power communication technologies. IDA techniques can increase the efficiency of agricultural systems, reduce production costs and ensure environmental sustainability.

Some of the challenges affecting the food and agriculture industry, which were discussed in section II above, can be addressed with IoT applications. Research and industrial communities have proposed several IoT applications to address agricultural challenges and boost productivity in the food and agriculture industry. Although challenges such as those discussed in section IV have slowed down the adoption rate, there is progress in using IoT in the food and agriculture sector. Figure 2 illustrates some of the IoT driven food and agriculture applications, which include:

- Smart irrigation system to automate the irrigation process [12].
- Smart Prevention maintenance [13] of Agro infrastructure.
- IoT based food supply chain management with blockchains [14]–[17].
- Smart detection of fire outbreaks in agro-fields, and agro-infrastructures [18], [19].
- Smart food processing [18].
- Pest management to detect and control pest outbreaks [20], [21].
- Smart crop monitoring to remove weeds, apply fertilizer or manure and on time [22], [23],
- IoT enabled planning and forecasting using monitoring and data analytics tool [7], [24], [25].
- Smart food storage monitoring to control the environment of storage facilities to mitigate food wastage [26].
- Smart food waste management [27].
- Smart food packaging [28]
- Theft detection to mitigate the loss of products and other assets through theft [29], [30],
- Precision agriculture using IoT to increase yield per acre significantly,
- unmanned electrical vehicles (e.g., drones and self-driving tractors) assisted farming
- Smart Greenhouse farming [31],
- Livestock monitoring and tracking, e.g., IoT based livestock tracking [32], [33]
- Smart Poultry [34]–[37], to monitor environmental variables in poultries and to automate some of the processes.

Many researchers have proposed a lot of IoT-driven agriculture use case applications, and in the section, we have outlined just a few. The authors in [38] discussed some IoT-based agriculture use case applications, which include the internet of arable farming, the internet of dairy farming, the internet of fruits, the internet of vegetables, and the internet of meat as part of the ”Internet of Food and Farm 2020” project aimed at boosting the competitiveness of the European agriculture on the global scale.

Adopting IoT in agriculture could become easier to speed up the transition into the fourth agricultural revolution, the so-called agriculture 4.0 if IoT is integrated as part of the agriculture education and training programs. Some research studies have demonstrated the practical applications of IoT in agriculture, as outlined above. However, the authors have not

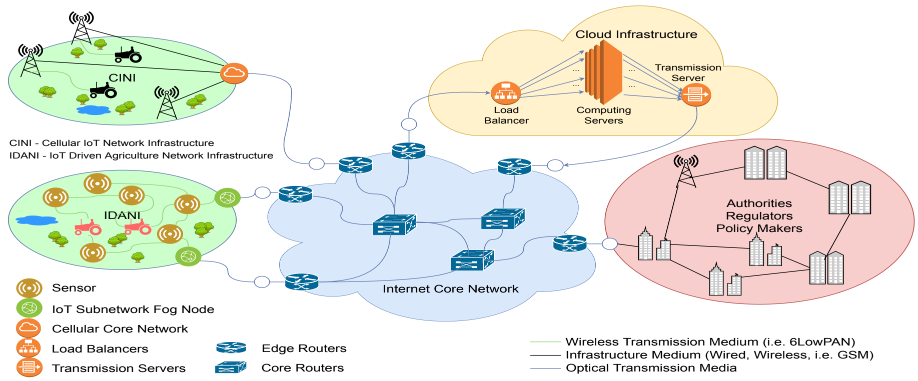

Fig. 1. An illustration of a simplified model of IoT architecture

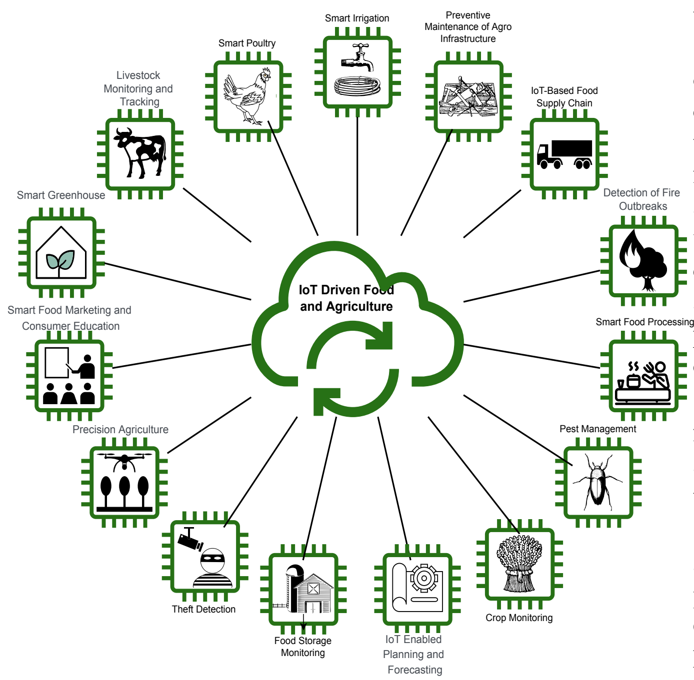

Fig. 2. Some IoT applications in the food and agriculture industry

seen any studies that have analysed the effectiveness of IoT in agriculture. There are still some technical challenges to the implementation and effective adoption of IoT, as discussed in [7], [9], [39].

IV. Courses of the Proposed IoT Driven Agriculture Program

In this section, we present a list of courses and a possible study program that could be designed to train the workforce that is well equipped with the appropriate knowledge and skills on industry 4.0 and agriculture 4.0 technologies. The objective of such a program should be to equip students with the skills required to apply IoT-driven food and agriculture solutions for efficient and sustainable food production. An IoT education program can be developed by adapting courses from other disciplines such as electrical engineering, electronics, telecommunications, robotics, automatic control, and computer science. Therefore, an IoT-driven agriculture program can be developed by adapting courses from disciplines such as electrical engineering, electronics, telecommunications, robotics, automatic control, and computer science with core courses from food and agriculture disciplines. Few courses from economics and management disciplines could be added to equip students with entrepreneurial and management skills. Some of the IoT courses we have included in our proposed program are from a survey of IoT courses offered by 12 universities (see [40], pp. 6) In developing core IoT course A list of some of these courses is shown in table I

This programme includes 3,5 years (7 semesters). The following proposal covers the yearly breakdown of the courses, as a semester-by-semester approach would be too detailed at this stage.

Year 1 (2 semesters) General subjects (common course for all students) Mathematics for Science and Engineering (Analysis, Linear algebra), Physics for engineering and agriculture, Chemistry and biochemistry, Introduction to agriculture and husbandry, Basics of botany, Basics of animal anatomy, Basics of bioinformatics Digital Design and Logic Circuits, Computer Programming basic (Pascal / Java / C#), Fundamentals of Electronics and measurements, Network Fundamentals

Year 2 (2 semesters) Starting from year 2, students must choose the software path (SW) or hardware path (HW). Every student should choose at least two modules per year from another path.

General subjects (for all students): Agrometeorology, Soil science, Microbiology of soils and plants, Animal physiology and organic nutrition, Basics of plant biochemistry and physiology, Probability calculus, Computer Architecture, Computer Programming - advanced (C, C++), Digital electronics

Software development (compulsory for SW students, options of choice for HW students): Database management, Computer Architecture, Communication and Information Theory, Computer networking, Digital modelling and simulation

Hardware engineering for IoT (compulsory for HW students, options of choice for SW students): Analogue Electronics, Electronic measurements, Theory of Signals, Design

TABLE I
LIST OF COURSES THAT COULD BE ADAPTED FOR AN IOT DRIVEN AGRICULTURE EDUCATION PROGRAM

Foundational Courses	**IoT Core Courses**	**Food and agricultural Core Courses**	**Economic and Management Courses**
Introduction to programing	Computer architecture	Agronomy	Engineering management
Advanced mathematics	Embedded operating systems	Animal/livestock production	Operations Research
Discrete mathemtics	Embedded systems	soil science	Basic Economics
Linear Algebra	Sensors and Actuators for IoT	water and environmental management	Entrepreneurship
Physics	Microntrollers for IoT	Peste and disease control	Agribusiness
Chemistry	Microprocessors for IoT	Environmental protection	Marketing
Research methods	Programming of IoT devices	Introduction to agriculture and husbandry	International Business
Introduction to IoT	Networking and Protocols	Introduction to Botany	Project management
Digital electronics	Mobile Communication	Crop production	Financial education
Analog electronics	Low power access networks for IoT	Sustainable food production systems	Food supply chain management
Power electronics	Databases	Agroecology	Food and agriculture law and Regulation
Signals and systems	Data structures and analysis	Food safety and hygiene	
Digital signal processing	IoT cloud computing	Animal physiology and nutrition	
Control engineering	Machine Learning	Value addition and processing of plant products	
Communication Principle	Artificial Intelligence for IoT application	Food storage Systems	
Circuit Analysis	Edge Computing	Introduction to plant biochemistry and physiology	
Computer aided design	Security of the Internet of Things	Smart and precision farming	
Operating systems	UAVs (e.g., Drones) in smart farming	Smart Food Supply chains and logistics	
Web and mobile app development	IoT application system design		
...	...	...	...

of Digital Systems, Automation Control Engineering, Systems modelling and design, Basics of cyber-physical systems

Year 3 (2 semesters) Students must continue the previously chosen path. Every student should choose at least four modules per year from another path or a collection of optional subjects.

General subjects (for all students): Cropping systems, Plant breeding and seed materials, Weeds and weed management, Biotechnological methods in environmental protection, Basic of Economics, Hardware/software co-design

Software development (compulsory for SW students, options of choice for HW students): : Operating Systems, Software engineering (Complexity and optimization), Principles of Digital signal processing, LAN & Internet Protocols, Web and Mobile Application Design

Hardware engineering for IoT (compulsory for HW students, options of choice for SW students): Power electronics, Physics of semiconductors, Design of Computer Systems, Mechatronics, Time-critical systems

Year 4 (1 semester) Every student should choose at least three modules from another path or a collection of optional subjects.

General subjects (for all students): Renewable energy sources and energy storage systems, Information management & security, Entrepreneurship, Agrobusiness, Project management, Diploma project

Hardware engineering for IoT: Mobile Communications Systems,

Software development: Cloud and Distributed Computer Systems,

Optional courses for students of Yr 3 & 4, HW and SW (examples): Machine learning, Computer Vision and Image analysis, Unmanned vehicles and simulation of autonomous systems, Advanced system modelling, Weather and climate modelling, Research methods, Theory and practice of electromagnetic waves, Organic agriculture and biotechnology, Organization of organic farms.

The courses and the program presented above is still a proposal and an attempt to stimulate a discussion among educators and researchers in the educational, food and agricultural science and engineering, electrical and electronic engineering, and computer science and engineering on ways to develop an educational and training program to respond to the need of skilled labour for agriculture 4.0. Agricultural education and training institutions could fine-tune these courses to meet their learners' training objectives and background. The learning approach should consist of: lectures, laboratory modules, projects internships/apprenticeships, field trips, workshops, research collaboration.

V. THE IOT COURSES DEVELOPED WITHIN THE IOT-OPEN EU PROJECT

The authors developed an IoT program that provides introductory material for bachelors students and advanced material for masters students. It was under the IoT-OPEN EU project funded by the European Union. The course consists of video lectures and a remote laboratory where the learners can access the hardware resources deployed in some European countries online. A course book accompanies the course [41] and a

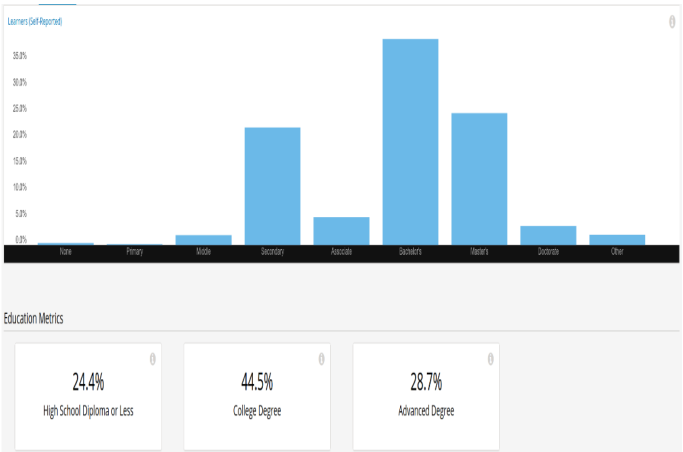

Fig. 3. Distribution of the level of educational level of the learners of our IoT program (theory and remote laboratories) hosted on EDx

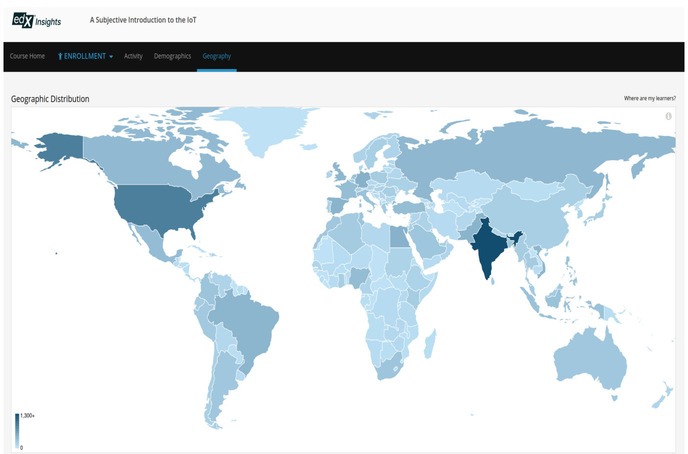

Fig. 4. Geographic distribution of the learners of our IoT program hosted on EDx

program outline [42]. The courses are hosted on the Edx platform [43]. Details on the design and implementation of the program are presented in [44].

Fig. 3 shows the distribution of the educational level of the learners. It can be seen that 24.4% of learners have at most a high school diploma. Since IoT is becoming part of our daily lives and is gradually penetrating into other sectors of the economy, it could be taught at the secondary or high school level. The rest of the participants possess at least a bachelor's degree. The geographic distribution of the learners is shown in Fig. 4, which shows that majority of the participants are from North America, India and Pakistan. There is a negligible number of participants in SSA.

IoT-related emerging technologies such as unmanned electrical vehicles (e.g., drones and self-driving tractors) are transforming the agriculture industry. Unmanned aerial vehicles (UAVs) or drones can be used to inspect large farms and then take appropriate actions. UAVs can also be used to spray farms. Figure 5 shows our collaborators at Agro Best

Fig. 5. Our collaborators at Agro Best Cameroon, training farmers on the use of drones for crop monitoring and protection in Foumbot, Cameroon

Cameroon training farmers on using drones to inspect corn fields and to spray farms with herbicides. Agricultural students or practitioners should learn how to design, assemble or choose appropriate UAVs that suit their specific needs. They also need to learn how to fly drones for their intended purposes. We recently developed courses on Unmanned Electrical Vehicles and Simulation of Autonomous System, and more materials on these courses can be found in [45]. The course is also accompanied by a textbook that we recently published in [46].

VI. Conclusion

The food and agriculture industry in SSA can be enhanced by developing current, interdisciplinary and integrated education and training programs that can equip students and practitioners with the relevant knowledge and skills. To prepare the researchers, students, practitioners, educational/training institutions, and the agribusinesses in this region to be ready for the transition into the fourth agricultural revolution (agriculture 4.0), we have proposed an IoT driven food and agriculture program educational institutions could adopt in this region.

References

[1] U. N. E. C. for Africa, "The demographic profile of african countries," Addis Ababa, 2016. [Online]. Available: https://repository.uneca.org/handle/10855/2317.org, accesed on Feb. 4, 2022

[2] A. D. B. Group, "Africas middle class triples to more than 310m over past 30 years due to economic growth and rising job culture, reports afdb," 2011. [Online]. Available: https://www.afdb.org/fr/news-and-events/africas-middle-class-triples-to-more-than-310m-over-past-30-years-due-to-economic-growth-and-rising-job-culture-reports-afdb-7986, accesed on Feb. 4, 2022

[3] S. M. Choi, "Food inflation in sub-saharan africa," 2021. [Online]. Available: https://blogs.imf.org/bloggers/seung-mo-choi/, accesed on Feb. 4, 2022

[4] V. Bjornlund, H. Bjornlund, and A. F. V. Rooyen, "Why agricultural production in sub-saharan africa remains low compared to the rest of the world – a historical perspective," *International Journal of Water Resources Development*, pp. 1–35, 2020.

[5] D. A. Cletzer, R. Rudd, D. Westfall-Rudd, and T. A. Drape, "Agricultural education and training in sub-saharan africa: A three-step approach to aet institution building," *nternational Journal of Education*, vol. 8, no. 2, pp. 73–87, 2016.

[6] M. Naresh and P. Munaswamy, "Smart agriculture system using iot technology," *International Journal of Recent Technology and Engineering (IJRTE)*, vol. 7, no. 5, pp. 73–87, 2019.

[7] O. Elijah, T. A. Rahman, I. Orikumhi, C. Y. Leow, and N. Hindia, "An overview of internet of things (iot) and data analytics in agriculture: Benefits and challenges," *IEEE Internet of Things Journal*, vol. 5, no. 5, pp. 3758–3773, 2018.

[8] G. S. Kuaban, P. Czekalski, E. L. Molua, and K. Grochla, "An architectural framework proposal for iot driven agriculture," in *Proceedings of the 2019 International Conference on Computer Networks (CN 2019)*, P. G. et al., Ed. Springer Nature Switzerland AG, 2019, pp. 8–33,.

[9] N. P. Jellason, E. J. Z. Robinson, and C. C. Ogbaga, "Agriculture 4.0: Is sub-saharan africa ready?" *Applied Sciences*, vol. 11, no. 5750, pp. 1–11, 2021.

[10] M. A. Rakotoarisoa, M. Iafrate, and M. Paschali, "Why has africa become a net food importer: Explaining africa agricultural and food trade deficit," 2011. [Online]. Available: https://www.fao.org, accesed on Feb. 4, 2022

[11] A. Tzounis, N. Katsoulas, T. Bartzanas, and C. Kittas, "Internet of things in agriculture, recent advances and future challenges," *Biosystems Engineering*, vol. 164, pp. 31–48, 2017.

[12] C. K. Sahu and P. Behera, "A low cost smart irrigation control system," in *Proceedings of the 2015 2nd International Conference on Electronics and Communication Systems (ICECS)*. IEEE, 2015, pp. 1146–1152.

[13] M. W. Hoffmann, S. Wildermuth, R. Gitzel, A. Boyaci, J. Gebhardt, H. Kaul, I. Amihai, B. Forg, M. Suriyah, T. Leibfried, V. Stich, J. Hicking, M. Bremer, L. Kaminski, D. Beverungen, P. zur Heiden, and T. Tornede, "Integration of novel sensors and machine learning for predictive maintenance in medium voltage switchgear to enable the energy and mobility revolutions," *Sensors*, vol. 20, no. 2099, pp. 1–24, 2020.

[14] S. A. Bhat, N.-F. Huang, I. B. Sofi, and M. Sultan, "Agriculture-food supply chain management based on blockchain and iot: A narrative on enterprise blockchain interoperability," *Agriculture*, vol. 12, no. 40, pp. 1–25, 2022.

[15] D. M. Vistro, M. S. Farooq, A. U. Rehman, and H. Sultan, "Applications and challenges of blockchain with iot in food supply chain management system: A review," in *Proceedings of the Proceedings of the 3rd International Conference on Integrated Intelligent Computing Communication & Security (ICIIC 2021)*, ser. Atlantis Highlights in Computer Sciences, vol. 4. Atlantis Press, 2021, pp. 596–605.

[16] A. Iftekhar, X. Cui, M. Hassan, and W. Afzal, "Application of blockchain and internet of things to ensure tamper-proof data availability for food safety," *Journal of Food Quality*, vol. 2020, pp. 1–14, 2020.

[17] S. Awan, S. Ahmed, F. Ullah, A. Nawaz, A. Khan, M. I. Uddin, A. Alharbi, W. Alosaimi, and H. Alyami, "Iot with blockchain: A futuristic approach in agriculture and food supply chain," *Wireless Communications and Mobile Computing*, vol. 2021, pp. 1–14, 2021.

[18] C. Maraveas, D. Loukatos, T. Bartzanas, and K. G. Arvanitis, "Applications of artificial intelligence in fire safety of agricultural structures," *Applied Science*, vol. 11, no. 16, pp. 1–20, 2021.

[19] A. Lal and P. P, "Fire detection and prevention in agriculture field using iot," *Journal of Xi'an University of Architecture & Technology*, vol. 12, no. 4, pp. 3708–3719, 2020.

[20] A. Chougule, V. K. Jha, and D. Mukhopadhyay, "Using iot for integrated pest management," in *Proceedings of the 2016 International Conference on Internet of Things and Applications (IOTA)*. IEEE, 2016, pp. 17–22.

[21] D. Gao, Q. Sun, B. Hu, and S. Zhang, "A framework for agricultural pest and disease monitoring based on internet-of-things and unmanned aerial vehicles," *Sensors*, vol. 20, no. 1487, pp. 1–20, 2020.

[22] A. Rehman, T. Saba, M. Kashif, S. M. Fati, S. A. Bahaj, and H. Chaudhry, "A revisit of internet of things technologies for monitoring and control strategies in smart agriculture," *Agronomy*, vol. 12, no. 127, pp. 1–21, 2022.

[23] M. I, K. Ashokumar, and N. J, "Field monitoring and automation using iot in agriculture domain," *Procedia Computer Science*, vol. 93, pp. 931–939, 2016.

[24] V. Kadya and K. P. Karani, "An implementation of iot and data analytics in smart agricultural system – a systematic literature review," *International Journal of Management, Technology, and Social Sciences (IJMTS)*, vol. 6, no. 1, pp. 41–70, 2021.

[25] R. Akhter and S. A. Sof, "Precision agriculture using iot data analytics and machine learning," *Journal of King Saud University –Computer and Information Sciences*, pp. 1–17, 2021.

[26] S. PrasadNayak, S. ChampatiRai, and B. Sahoo, *SAW: A real-time surveillance system at an agricultural warehouse using IoT*. Elsevier, 2022.

[27] S. Gull, I. S. Bajwa, W. Anwar, and R. Rashid, "Smart enose food waste management system," *Journal of Sensors*, vol. 2021, pp. 1–13, 2021.

[28] E. Drago, R. Campardelli, M. Pettinato, and P. Perego, "Innovations in smart packaging concepts for food: An extensive review," *Foods*, vol. 9, no. 1628, pp. 1–42, 2020.

[29] S. S. Rajawat, S. Som, and A. Rana, "Iot based theft detection using raspberry pi," in *Proceedings of the 2020 8th International Conference on Reliability, Infocom Technologies and Optimization (Trends and Future Directions) (ICRITO)*. IEEE, 2020, pp. 829–834.

[30] H. Safa, S. P. N., V. G. P. S., S. Vishnupriya, and T. Boobalan, "Iot based theft premption and security system," *International Journal of Innovative Research in Science, Engineering and Technology*, vol. 5, no. 3, pp. 4312–4317, 2016.

[31] R. K. Kodali, V. Jain, and S. Karagwal, "Iot based smart greenhouse," in *Proceedings of the 2016 IEEE Region 10 Humanitarian Technology Conference (R10-HTC)*. IEEE, 2016, pp. 1–6.

[32] M. O. Ojo, I. Viola, M. Baratta, and S. Giordano, "Practical experiences of a smart livestock location monitoring system leveraging gnss, lorawan and cloud services," *Sensors*, vol. 22, no. 273, pp. 1–25, 2022.

[33] R.-S. Biljana, C.-B. Dijana, S. Gerhard, and M. Reza, "Real-time internet of things architecture for wireless livestock tracking," *Telfor Journal*, vol. 10, no. 2, pp. 74–79, 2018.

[34] K. S. Goud and A. Sudharson, "Internet based smart poultry farm," *Indian Journal of Science and Technology*, vol. 8, no. 19, pp. 1–5, 2015.

[35] R. B. Mahale and S. S. Sonavane, "Smart poultry farm monitoring using iot and wireless sensor networks," *International Journal of Advanced Research in Computer Science*, vol. 7, no. 3, pp. 187–190, 2016.

[36] P. Rajkumar, A.Kathiresan, M. Moulishankkar, N. Prabhakaran, and S.Vignesh, "Smart poultry farming," *International Journal of Current Trends in Engineering & Research (IJCTER)*, vol. 3, no. 3, pp. 17–24, 2017.

[37] G. A. Choukidar and N. Dawande, "Smart poultry farm automation and monitoring system," in *Proceedings of the 2017 International Conference on Computing, Communication, Control and Automation (ICCUBEA)*. IEEE, 2017, pp. 1–5.

[38] R. Tomasi, F. Rizzo, and D. Conzon, "The iof2020 use case architectures and overview of the related iot systems," 2011. [Online]. Available: www.iof2020.eu, accesed on Feb. 4, 2022

[39] V. K. Quy, N. V. Hau, D. V. Anh, N. M. Quy, N. T. Ban, S. Lanza, G. Randazzo, and A. Muzirafuti, "Iot-enabled smart agriculture: Architecture, applications, and challenges," *Applied Sciences*, vol. 12, no. 5750, pp. 1–19, 2022.

[40] B. Du, W. Huangfu, R. Zhou, and H. Ning, "Undergraduate university education in internet of things engineering in china: A survey," *Applied Sciences*, vol. 11, no. 202, pp. 1–18, 2021.

[41] A. Kapitonov, D. Dobriborsci, I. Pantiukhin, V. Chernov, R. Sell, R. Puks, M. Kingsepp, A. Nikitenko, K. Berkolds, A. Vagale, R. Rumba, P. Czekalski, K. Tokarz, O. Antemijczuk, R. Sell, S. Distefano, R. Dautov, R. D. Pietro, and A. L. Minnolo, 2020. [Online]. Available: http://iot-open.eu/io1/, accesed on Feb. 7, 2022

[42] ——, ""introduction to the iot" coursebook," 2020. [Online]. Available: http://iot-open.eu/io1/, accesed on Feb. 4, 2022

[43] ——, "Iprofessional certificate in iot: from hardware to practice," 2020. [Online]. Available: https://www.edx.org/professional-certificate/itmox-iot-from-hardware-to-practice?, accesed on Feb. 4, 2022

[44] K. Tokarz, P. Czekalski, G. Drabik, J. Paduch, S. Distefano, R. D. Pietro, G. Merlino, C. Scaffidi, and R. Sell, "Internet of things network infrastructure for the educational purpose," in *Proceedings of the2020 IEEE Frontiers in Education Conference (FIE)*. IEEE, 2020, pp. 1–9.

[45] R. Sell, T. Kalm, M. Malayjerdi, I. Sell, A. Nikitenko, A. Ziravedska, K. Berkolds, K. Vitols, P. Czekalski, . Tokarz, O. Antemijczuk, and G. K. Suila, "Erasmus+: A digital package for autonomous systems and self-driving vehicles - autonomian," 2021. [Online]. Available: https://robolabor.ee/et/content/12-autonomian, accesed on Feb. 4, 2022

[46] ——. RTU Press, 2021. [Online]. Available: https://robolabor.ee/et/content/12-autonomian, accesed on Feb. 4, 2022