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Applications of Robotics Technologies In The Agriculture Sector Worldwide: A Review

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Abstract: *The demand for food is rising due to the growing global population. A barrier to agricultural productivity has been the scarcity of cultivable land. However, research indicates that technology has increased agricultural output, particularly for fruits and vegetables, which are in high demand worldwide. Consequently, farming has produced more since robotics was introduced. Additionally, there has been a decrease in the amount of time and money spent on farming operations. As a result, this paper examines robotics' achievements in farming and also looks ahead to the field's use of robotics in agriculture. Robotics have been developed to improve harvesting; digital farm implementation and targeted precision site management are anticipated to increase productivity. This paper examines the benefits and drawbacks of using robotics in agriculture to perform tasks in a complicated, dynamic, and unpredictable environment. The reviewers' knowledge was expanded and different approaches to robot design and development were accessed through the use of secondary sources from online repositories. The primary goal of this work is to increase low-cost agricultural outputs and to compete with other farmers in fields where farmers may be considering eliminating labor positions to reduce costs and increase the quantity and quality of their products by proposing a robotic system for fruit harvesting in Uganda.*

Keywords: Robotics, Agriculture, sensors, Autonomous, Tractors, Geographical Position System, Unmanned Aerial Vehicle, Internet of Things.

1. Introduction

The agricultural sector is critical in the life and sustenance of man, and it has metamorphosed into an industry that cannot be overlooked (Ravi Nandan, 2020). Information from this sector has graduated from substance data to big data, leading to innovations and policy making. The agricultural industry not only provides food but also creates a platform for producing goods and services that transform into growth in the nation's Gross Domestic Product.

The exponential global population growth has been a cause of concern to policymakers and governments of countries, more to the prediction by United Nations has projected that there will be a total of nine billion individuals on Earth by the year 2050 (UN, 2019). Agricultural production is enhanced to increase and sustain food demand to curtail food scarcity. To achieve the required level of food sustainability, benchmarking the agricultural products supply chain with the consumption rate becomes necessary (Pablo Gonzalez-de-Santos, 2020). The cumulative technological inclination and climatic variations limit arable land globally. Hence, the agricultural production rate needs a 25% upsurge to achieve food sufficiency (*World Population Prospects 2019 Highlights*, n.d.).

With the advent of technology, productivity has been enhanced in several factors, such as medicine and business, to mention a few. Modernization of agriculture is moving from traditional practices to a technology-driven approach (Reshma Rajmane, 2020). Agricultural engagements have moved from a manual approach to mechanical and technology-driven ones. Increases in yield have been observed from every shift in practice, and consequently its incorporation of technology, including AI, big data, as well as the IoT, when adequately enhanced, will shoot up productivity (Pablo Gonzalez-de-Santos, 2020).

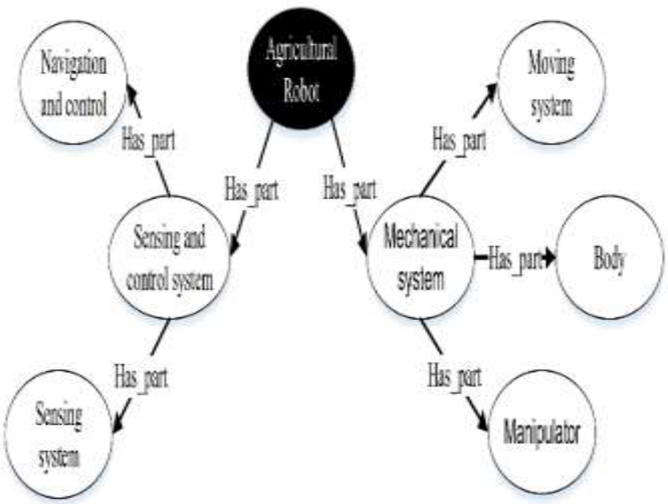
Farmers and agricultural Scientists face the production of food from small-scale land to meet the needs of the 9.8 billion population in 2050, which translates to feeding an additional 200,000 people per day. According to (Reshma Rajmane, 2020), Robotics which is part of Artificial Intelligence, has proven to be a solution enhancer in many fields, and integrating it into agriculture will be the same. Robots have been developed to enhance harvesting, and specified precision site management and digital farm implementation are expected to boost production.

Digital tools integration and sensor technologies have enhanced the design and development of agricultural robotics; independently guided farm machinery and tractors equipped with sensors operating in row crops and orchards have been developed. Manipulators and agricultural field robots have become a vital part of various aspects of digital farming with advances in control theory. Implementing these robots in digital farming shows interest in growth in automation and the evolution of high-tech industries in field activities that attract professional engineers, investors, and companies (Rekha Raja, 2019). With development mostly at the phase prototype, robots can now perform many operations, which involve crop scouting, weeds, and pest control, to mention but a few prototype successes.

This work reviews the successes and challenges of integrating robotics in agriculture for tasks within a complex, dynamic, and uncertain environment. The effect on agricultural output is based on different arrangements in plant size and shape, branches, stems, leaves, the color of the fruit, and texture.

1.1 Composition of Agricultural Robots

Robots are technologically driven artifacts that support operations and delivery of goods and services in a chosen sector of human endeavors. It has three main components, as identified by (Yuchen et al., 2021), and they are the mechanical, sensing, and control systems. This they demonstrated in the design of the agricultural robot shown in Figure 1



Robot Component TKG, Source: https://www.mdpi.com

In this review, this work adopted this as the main components of a robot hence will be limited to this component for discussion.

2.0 Materials and Methods

After the abstract review, 100 journal articles were selected for a proper review, of which 30 were seen to be very relevant to this work. This review used secondary sources from online repositories to enrich the authors' knowledge and access various approaches used in the design and development of robots. Two hundred articles related to this review were downloaded from various website databases such as Google, Science Direct, IEEE, ACM, and AACM.

The design approach was adopted to design a fruit pick robot adapted to the African environment, basically Uganda in East Africa. The design is expected to metamorphose into prototype development.

3.0 The Literature Survey

Numerous tech inventions have cropped up, and more are yet to be evidenced in agriculture. Due to the seemingly high implementation costs, many of these technologies haven't been utilized thoroughly in farming procedures (Reshma Rajmane, 2020), which has led to the introduction of a reliable, cheap method with less electric consumption. The urea spraying method employs robotic moving cars for data collection. An Internet of Things (IoT) functionality is applied for remote data communication.

The monitoring of logic gates, circuits, and computer chips rendered a principal methodology for systems deployment aimed at remote sensing and capturing. This modeling version yielded an elevated execution capability quadrotor with a brushless DC motor.

According to (Bera. Dutta, 2021), farmers have been performing different tasks on farms like planting, weeding, crop soil suitability prediction, yield prediction, and harvesting, all using the classical approach. Unlike the modern days where farm practices like harvesting are automated.

An unmanned aerial vehicle (UAV) was developed and coded in Arduino components via a network; this crewless aerial vehicle consisted of electromagnetic spectrum resolution and temperature cameras used in different climatic conditions (Pablo Gonzalez-de-Santos, 2020). The coding of the unmanned aerial vehicle was set such that the system automatically corrected errors arising from the feedback because data like the field images were captured regularly by sensors. Not only data capturing, but the system was also able to calculate the forces of acceleration and the gyroscope, which the remote operators used to be able to track the system remotely with the help of independent degrees of freedom that were provided by brushless motors, which enabled the system to move effeminately in different directions. (A Kulkarni et al., n.d, 2022).

Unmanned ground vehicle (UGV) exploits the weakness of UAVs by making ground measurements on farms (Amir Degani, 2021). Its strength lies in short-range or physical contact with the target. The crewless ground vehicle physically accesses the target location and takes samples for performing tests. On some occasions, an amalgamation of the two technologies (UAV and UGV) has yielded excellent results, for example, in crop disease detection, where the UAV renders a view of a suspected infected area. Algorithms like a dragonfly (DA) were employed to optimize robot movements using a bioinspired path channel to communicate amidst the UAV, and UGV was used on the robotic team (Lytridis et al., 2021).

Inaccordency (Rajmane et al., 2020) highlighted the new idea being used in Israel, where robotic swarms are being used in agriculture to gather data in actual time on the farms, and then remotely share the recorded data to the cloud's capabilities, such that data can be analyzed, and automatic reports were generated, expressed in moisture content, nutrients deficiency which helped farmers understand the status and health of the plants hence improving production at the end of the day.

Robotics in the Agricultural field

Agricultural robots have elevated farmers' production yields in different ways. For example, Drones to tractors are automated, then robotic arms (Abhijit Khadatkar, 2022). This shows technological application advancement in a way that is innovative and creative; for instance, robotics applied in numerous agricultural fields sectors like the milking section, which uses the Merlin Robot milker, orange harvester, and weeders, but milk bot is the number one large-scale use of a robot in farming today, and that has brought about by their non-requirement and efficiency to move because it can complete a given task repetitively while in a single place (Ravi Nandan, 2020). What is more, such robots that work repetitively, like the milking robot, accomplish roles given to them to a consistent and particular standard.

The Agricultural sector is being transformed by Robotics technology in numerous aspects, with no exception of the Agrochemicals business since Ultra-precision Agriculture is enabled by autonomous and intelligent robots, potentially changing the agrochemicals business nature. Furthermore, with that, we shall therefore see a Robotics adapted combination to a specific task and use of the modern tractors because the most well-known issue is that many modern robotic systems, for instance, can't be resilient enough to withstand actual-world circumstances for example, muddy areas, rainy areas, low and high-temperature zones, and the most manipulators have not equipped to deal with glass houses humidity (Chimmani et al., 2019).

3.1 Successful Applications of Robots in Agriculture

In the agricultural sector worldwide, farm routine automation through the use of tractors and robots not only saves execution time but also guarantees efficiency to a certain extent. The worries of shortage in agricultural farm labor, aging skilled farm workers, and high employee costs, among others, are in the modern era being waived and substituted by systems with remotely operated mechanisms for monitoring plant growth. A detailed exploration of the agro-bots is as follows;-

Inspection

This is a farm plant monitoring procedure for specific conditions that may affect high yielding. In agriculture, pests and diseases are the major contributors to poor produce hence seasonal loss to the farmers. The divergent weather, soil temperatures, prolonged drought, and disease emergencies need total/frequent farm inspection. Traditionally, farmers would manually use their open eyes to detect any oddities in plants to carry out an inspection; however, as these farmers get older, their sight lowers, which makes it hard for them to do the inspection using their human vision during the inspection processes. Computer programs embedded in hardware like cameras operate and scan plants to detect disease infection and yield prediction more effectively than humans. (Bera & Dutta, 2021,)

Spraying

Spraying is the standard method of applying agricultural pesticides to crops; fertilizers are applied using a spraying pump in a delicate thin mist to treat plant disease and manage plant growth (Abhijit Khadatkar, 2022). This spraying pump technique has uneven spatial distribution, especially during development at the early stages. Hence, to minimize pest control costs and use of chemicals in any agricultural operation, the introduction of selective spraying, which was a highly automated equipment or mobile robot that was able to apply pesticide only where and when it was needed on a specifically selected crop (Rajmane et al., 2020).

Harvesting

Harvesting is picking ready mature yields from a plant in a garden, where the yields or products are sorted and then sold to customers or consumers in the marketplaces. This process involves collecting fruits or vegetables, which are stored for further processing or directly sold to consumers, and this process needs detailed observation with respective procedures, which is also said to be time-consuming and labor-intensive. Therefore, numerous robotic innovations have been conducted in past years to ease harvesting in crops like strawberries, apples, tomatoes, and heavyweight crops, where these robotics innovations are determined to target the location of the natural fruit to be harvested using the different vision schemes like computer vision and neural networks which can solve a specific problem of targeting accurately which is like human eye or superior when compared to the human works during harvesting without affecting the quality, (Mahmud et al., 2020).

Seed Mapping

The technique of passively recording each seed's precise location before planting it in the ground is known as "seed mapping." When a seed drops, infrared light is cut by the RTK GPS stocked to the robot/seeder and put beneath the seed a chute. This causes the data logger to activate and record the seeder's position and orientation, which is used to determine the seed's actual position in the soil using a kinematics model (Sweety Dutta, 2019).

Weed mapping

The method of documenting a weed's position, density, or plant matter, as well as the species it is using machine vision to detect weeds automatically is known as weed mapping; with this kind of technology, numerous studies were performed that have Discrimination techniques and Classification techniques. According to the study, we presume the best autonomous weed mapping alternative to be manual weed mapping; this implies that farmers utilizing a handheld GPS device, manually map and record weeds in the gardens, and some in developing countries do manual weeding with their hands after seeing weed out and competing with the crops (Reddy et al., 2016,).

The future of robots in the Agriculture sector

Robotics technology has manifested itself in most operations involving crop production, poultry farm hatching technology, and animal spraying as a treatment measure, among others (Reshma Rajmane, 2020). In general, call it agricultural processes automation, focusing on Cost of production reductions, consequently raising dividends for precision farmers.

These technologies, and more yet to be evidenced, are not just for the sake, but instead waging human force time for other activities on the farm, thereby automating mostly the repeatedly to be performed operations, most hectic operations for example, food distribution for birds in a poultry farm, egg collection, and packing. If birds' drinking water levels are known and programmed in embedded technology, call it a robot; why cannot they monitor such and refill after mixing with treatment medicines according to the application prescription? If a robot is designated for such, then without fault or favor, this job will be executed efficiently and repeatedly as scheduled.

Poultry birds' health monitoring

Imagine if, on a poultry farm, a robot is responsible for monitoring a bird's feeding patterns, moving patterns, and physical status to spot which bird needs immediate isolation from others and treatment. Such not only protects the other birds from contracting but also reduces the human workforce of monitoring many birds, thus to say in thousands, and treating diseases at early and manageable stages. (Neethirajan, 2022)

Wi-Fi-soil moisture sensor

Moisture sensors that can communicate using wireless technology to farm owners the slight change in the water composed in soil. Alerts to the irrigation systems can be a smart idea if generated and sent on a specific portion of land, and action against such is done in a regulated/required quantity to maintain that specific level as optimum for our crops. (Yu L M, 2021)

One of the most recommended and perhaps crucial approaches in agriculture is understanding the soil texture and the plants and establishing the chances or factors that favor such growth. In Africa and other continents, after several years of cultivation, the land loses soil fertility, but this is plant or crop-specific. For example, some plants need land that has been abandoned for some years so that it gains that soil nutrient over time.

On the other hand, due to time and costs of production like securing land, crop production scientists devised a mechanism that, when embraced, fertilizers boost the soil fertility hence continuous usage for cultivation. Moreover, some of these fertilizers can be manually produced by farmers from plant remains and other materials in the garden hence fewer side effects, as seen that at times imported fertilizers turn out to affect plants in case of a slight miss application fault.

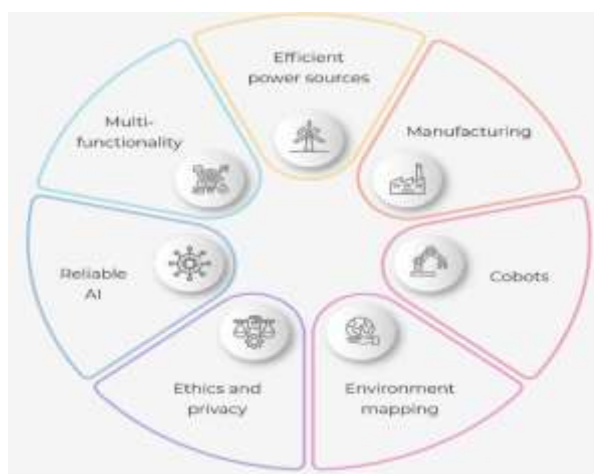
Crop-specific soil suitability mapping

An expected wave of robotic technology and Geographical Information systems will implement soil sampling and give recommendations of suitable crops, monitor changes in soil condition, and trigger alerts for rectification of such so that the crops can get as optimum growth conditions as needed for high yield returns. Robotic technology with geographical Information system functionalities will not only ease human farm monitoring but also establish the most important conditions at which plant or crop (El Behairy, et al., 2022).

3.2 Challenges of robot integration into agriculture

Joshi, 2020 identified seven key challenging issues in building a robot, and this is diagrammatically illustrated in Figure 2.

Source: Joshi, 2020



Manufacturing procedures

Robots' mechanical component has not progressed compared to the other components. They are still being developed using gears, motors, and actuators. Currently, computer vision and machine learning technologies are being used to solve the mapping problem. These technologies work best in controlled environments, though they are not infallible. the main component of movement and functionality. Hence the procedures have yet to see changes, and the Cost of these materials is high depending on the developing environment. Even though robots created with conventional methods of production are very prone to malfunctioning because they have a lot of moving, stiff parts. Pleasant automation can be used to develop robots and overcome this challenge.

Enhancing Human-Robot Cooperation

Better use of robots can occur when they are built to collaborate with humans. Developing robots that understand emotions, behavior, and the behaviors of humans has been a challenge; hence, this has affected the development of successfully implemented robots in different sectors of human endeavors. Hence, there is a need to develop robots that will understand and feel what humans feel as regards the work environment. In combating this challenge, there is a need for advanced artificial intelligence in the area of the Natural Language Process, to mention a few.

Creating better power sources

Intelligent machines still use antiquated methods for producing and storing power. Robotic batteries typically have a short lifespan and are dangerous. Robots are still powered by antiquated technologies like lithium-ion and nickel-metal hydride. As a result, new energy sources with high safety standards capable of authority robots for a longer amount of time must be developed.

Environment mapping

Another challenge faced by developer robots is navigating around an environment without obstruction. It is still impossible for robots to avoid obstructions in their path. The smallest changes necessitate relearning and environment adaptation, even for robots that have been trained to comprehend their surroundings. Currently, computer vision and machine learning technologies are being used to solve the mapping problem. These technologies work best in controlled environments, though they are not infallible.

Reducing threats to confidentiality and safety

Security, ethics, and privacy are always being questioned with any technology. Robot malfunctions may result from reprogramming or altering the data that was used to train the robots. Similarly, fraudsters may be able to access and use the data a robot collects over its lifetime, including images, videos, and spot information for nefarious ends. Privacy, safety, and ethical concerns still present difficulties. Furthermore, ownership of the robot's data is unclear. Whether the end user, robot maker, or software provider is the data proprietor is still up for debate. Furthermore, it is unclear what portion of the data belongs to which party and for what purposes.

Creating dependable Artificial Intelligence

The use of AI and ML technologies are typically used to program robots, but even with these developments, robots can only be partially trusted. To begin with, a vast amount of data is needed to instruct robots to perform tasks. Even so, since the robots are typically trained in controlled environments, there is no guarantee that they will function as intended. Sometimes, real-world environments are difficult for robots to understand and respond appropriately to.

Creating Automated Machines with Multiple Functions

One task can be completed by robots effectively. Nevertheless, a single robot is not able to carry out several tasks as effectively or efficiently. To reduce costs and boost productivity, firms must use multitasking robots in light of the growing competition. In a manufacturing setting, robots must communicate with people, things, as well as surroundings while also identifying them.

3.3 Other Challenges

Challenges have been identified during the cause of designing a fruit-picking robot in an African environment. These challenges are itemized as

i. High Cost of developing materials
ii. Inadequate technological advancement and infrastructure
iii. Importation of technological skill that affects ethics, privacy, and security
iv. Non-existence of policy supporting the design and development of robotic artifacts
v. Knowledge divide between Academia and implementing industries

4.0 The proposed prototype design of ground fruit picking robot Robotic prototype design

The design will be done using the unified modeling language; the prototype operation was diagrammatically represented as a design block, Flowchart, and use case diagram.

Block Diagram

The block diagram shows the different components of the robot prototype and how they interact with each other. This is shown in Figure 3. Tasks will be performed based on the communication between the microcontroller and other components. The microcontroller holds a set of instructions that controls all the peripherals connected to the expansion hub as motors. This is achieved when the battery powers the microcontroller, and then the microcontroller powers the expansion hub and peripherals; the system will now be in a position to receive instructions from the operator through the driver hub. In addition, when the operator initiates the instructions, which will be passed through the microcontroller up to motors for operation actions, it answers the specific objective of designing a robotic prototype for fruit harvesting.

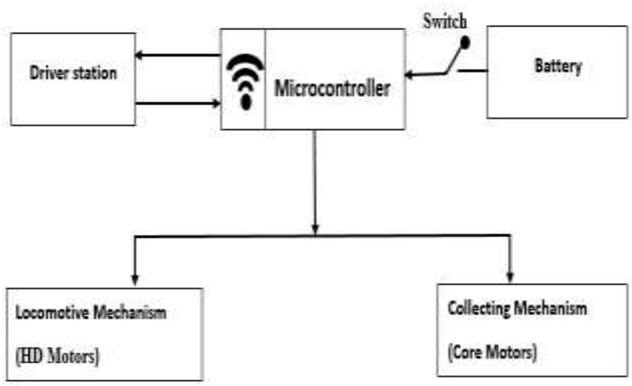


Figure 3: Design block for the proposed robotic system

Microcontroller

This is the brain and heart of the developed supervised robot because it is the one that bridges the communication between all the components mounted on the robot. In other words, it is responsible for transmitting the signal for the tasks to be executed. More to that is the one that holds the program that is coded based on the user requirement, and running an Android operating system gives it the flexibility to control mini robots and advanced robots, and also easy to update while the robot is in the field.

Drive Station

This compact mobile computing device was designed for interfacing or passing instructions from the operator to the microcontroller such that activities or tasks are performed. It features the Android operating system that is incorporated with dual-band Wi-Fi for easy signal transmission during operation. This capability attracted me to use it so the prototype can run smoothly during operation.

Battery

The battery to be used in this system has a 12v rechargeable battery, which powers the microcontroller, and then the microcontroller powers the system. During the development of this prototype, several batteries were studied, but this type of battery challenged all batteries in the category of lithium batteries because it takes a short time to get full charging when it is being charged. Furthermore, it takes a long to get out of charge. This was not only the fact that was considered during development but also the lightweight, which makes it easy to be mounted on the system.

Switch

This component is mounted between the battery and the Microcontroller so that the power supply can be easily controlled during the robot's operation.

HD Motors

HD motors will be used in developing this system for the robot's movements. These motors have a high-speed ratio compared to core hex motors, which is why in this system, they are used for the robot's locomotion from one place to another. These cables run from the expansion hub, one for power supply and another for signal receiving from the expansion hub during task execution.

Core Motors

This type of motor will be used as the robot's end effector since they have a low speed compared to HD motors. They also have two cables running from the expansion hub, one for power supply and another for signal receiving from the expansion hub while collecting fruits from the ground.

4.9 Proposed prototype development

This review proposes a prototype development that will be based on a Field-Oriented Control Algorithm. Embracing the usage of the Field-Oriented Control Algorithm (FOC Algorithm) to ensure the smooth running of motors (A. Srivastava, 2021), surgical tubbing, and corrugated plastic sheets will differentiate the prototype from the existing prototypes. Existing ones used convolution neural networks, computer vision, and machine learning, which were used to control the voltage needed by the motors to generate the required torque for each motor used in the system. Another essential component that will create a difference between the proposed robotic prototype and those that have been developed before is the use of Omni wheels in this development. Omni wheels are wheels that can move in all forward, backward, left, and right directions, making it easy for the prototype to turn fast compared to other wheels.

CONCLUSION

This review tries to further improve the knowledge of using agricultural robots; instead of farmers using the traditional methods of farming, they can now be able to know more benefits of using robots in agriculture, most especially in developing countries because recently, a notable amount of research and development has been carried out on the use of robots and automation technologies (satellite agriculture) to replace traditional farming, particularly in places of high food production. The main objective of robots in agriculture is to boost agricultural outputs at a low cost and challenge the competition in the fields of operations, where farmers reconsider the reduction of labor jobs to lower production costs and improve product quality and quantity.

References

A Kulkarni, A., Dhanush, P., Chetan, B. S., Gowda, C. S. T., & Shrivastava, P. K. (n.d.). Applications of Automation and Robotics in Agriculture Industries; A Review. *Materials Science and Engineering*, *748*(1).

Bera, A., & Dutta, D. (2021). Application of Robotics in Modern Agriculture. *Just multidisciplinary agriculture e-newsletter*, *Vol.1*(Issue-11, JULY 2021), 6.

Chimmani, V., J, H., P, V., & Anand S, S. (2019). Use of Robotics in Agricultural Field and Its Applications: Short Commentary. *Advances in Robotics*. DOI: 10.4172/2168-9695.1000190

Lytridis, C., Kaburlasos, V. G., Pachidis, T., Manios, M., Vrochidou, E., Kalampokas, T., & Chatzistamatis, S. (2021). An Overview of Cooperative Robotics in Agriculture. *Agronomy*, 23. https://doi.org/10.3390/agronomy11091818

Mahmud, M. S. A., Abidin, M. S. Z., Emmanuel, A. A., & Hasan, H. S. (2020). Robotics and Automation in Agriculture: Present and Future Applications. *Applications of Modelling and Simulation*, *VOL 4*, 11.

Rajmane, R., Gitay, N., Yadav, A., Patil, Y., & Sonawane, A. (2020). Precision Agriculture and Robotics. *International Journal of Engineering Research & Technology*, *Vol. 9*(Issue 01, January-2020), 6.

Reddy, N. V., Reddy, A.V.V. V., Pranavadithya, S., & Kumar, J.J. (2016). A Critical Review on Agricultural Robots. *International Journal of Mechanical Engineering and Technology*, *Volume 7*(Issue 4), p. 7.

World Population Prospects (2019). Highlights. (n.d.). Population Division |. Retrieved May 7, 2022, from https://population.un.org/wpp/publications/files/wpp2019_highlights.pdf

Sweety Dutta, Udit Shanker, Sulekha Katiyar, Venktesh Singh, Mohd. Nayab Zafar, J. C. Mohanta. (2019). Development and Fabrication of an Autonomous Seed-Sowing Robot.

Neethirajan, S. Automated Tracking Systems for the Assessment of Farmed Poultry. Animals 2022, 12,232. https://doi.org/10.3390/ani12030232

Yu L M, Gao W L, Shamshiri R R, Tao S, Ren Y Z, Zhang Y J, Su G L. Review of research progress on soil moisture sensor technology. Int J Agric & Biol Eng, 2021; 14(4): 32–42.

El Behairy, R.A.; El Baroudy, A.A.; Ibrahim, M.M.; Mohamed, E.S.; Kucher, D.E.; Shokr, M.S. Assessment of Soil Capability and Crop Suitability Using Integrated Multivariate and GIS Approaches toward Agricultural Sustainability. Land 2022, 11, 1027. https://www.mdpi.com/2073-445X/11/7/1027

Christine M. Walsh-Kelly MD (2015). Flow Chart/Process Flow Diagram. http://www.ihi.org/education/IHIOpenSchool/resources/Pages/BobLloydWhiteboard.aspx#FC

Srivastava, R. Padgil, A. Gupta, A. Lohia, N. P. Nair, "Model-Based Sensored Field Oriented Control Implementation for Permanent Magnet Synchronous Motor," 2021 International Symposium of Asian Control Association on Intelligent Robotics and Industrial Automation (IRIA), Goa, India, 2021, pp. 337-344, doi: 10.1109/IRIA53009.2021.9588787

Abhijit Khadatkar, C. M. (2022). Application of robotics in changing the future of agriculture. Journal of Eco-friendly Agriculture, 48-51.

Amir Degani. (2021). Aerial and Ground Vehicle Collaboration in Agricultural Applications. The American Foundation for Basic Research.

Pablo Gonzalez-de-Santos, R. F. (2020). Field Robots for Intelligent Farms- Inhering Features from Industry. agronomy.

Ravi Nandan, L. S. (2020). Swarm robotics for agriculture. International Research Journal of Engineering and Technology (IRJET).

Rekha Raja, D. C. (2019). Crop signaling: A novel crop recognition technique. ScienceDirect, 279-291.

Reshma Rajmane, N. G. (2020). Precision Agriculture and Robotics. International Journal of Engineering Research & Technology (IJERT), 17-22.