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Automation in Agricultural and Biosystems Engineering

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

During the industrial revolution, agriculture saw a tremendous improvement in the way it was done. For the first time in the history of agriculture, steam and internal combustion engines were used to carry out laborious on-site farm activities, the first milling machines were built, and several other hitherto manually operated and tiresome operations were mechanized. Since then, however, just like in other fields, the industrial revolution has served as a turning point in the way things are done. Continuous research was carried out in a quest for more improvements and developments. Agricultural machinery has never seen as much improvement as it has in the technological age,

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which started around the mid-twentieth century. Transformations occurred in the way agricultural machines are being built, and one of the most significant transformations is the automation incorporated into machines such as harvesters, ploughing machines, and irrigation systems. Each of these machines has made their dedicated operations easier, faster, and more efficient, and with little human supervision. Traditional manual machines were also known to make work easier, faster, and more efficient, but not without the full supervision of man. Automation, however, ensures that work is carried out more efficiently by making machines work on their own accord, precisely and accurately, with very little or no human supervision. This research was carried out utilizing literature reviews on other earlier researches to show more clearly how agricultural machines have been automated in developed countries and to suggest how they can be emulated by a developing country like Nigeria. Nigeria, as a developing country blessed with resources, can rise and become the next great nation by fully harnessing the power of automation in agriculture.

Keywords: Automation; engines; machinery; agriculture; technology.

1. INTRODUCTION

1.1 Background of Study

Agricultural machinery, like any other machinery used in other fields, has gone through a series of developmental stages over the years. Since the beginning of time, man has always fought for survival and depended solely on his surroundings, mostly plants and animals. He used everything he could, to feed himself. Man, also cultivated plants and raised animals to sustain himself, as his only source of energy was himself. Shearer et al. [1] reported that man first discovered how to use animal power around 200 years ago, beginning with the growth of US agriculture. In conclusion also added, manpower is not sufficient for agricultural Activities. The result was that, on average, man produces about 0.1 HP (0.075 KW), which justifies the introduction of animal power, which is many orders of magnitude greater than that of man. Man harnessed the animal's power, combined with the development of a heat engine ten times more powerful than manpower. Man, today, has control over more than 600 horsepower (450 kW) of modern tractor power.

Farming and agriculture are critical to our day-to-day activities. The significance is as old as time itself. There are a lot of new techniques and technologies in place to improve the quantity and quality of farm produce. The use of transformative technologies like automation in agricultural machinery can make farming and agriculture become much more efficient and highly productive. Automation is the issuing of orders that involves setting tasks for the system, adjusting positioning factors, controlling energy input and output then comparing and analysing the information generated in the system to send out different signals and warnings. Automation of Agricultural machinery helps to save production time, increase the quantity of farm produce, increase economic benefits, improve preservation methods, and improves the quality of agricultural products. Some of the areas where automation has found its way include but are not limited to, weeding and planting, which uses robots to effectively carry out pre-planting and planting operations, harvesting, which uses sensors-inbuilt robots to visualize and harvest only the right crops, thereby increasing field yield, capacity, and field efficiency, irrigation, and remote supervision and control, which uses drone technology in aerial survey and supervision.

1.2 Problem Statement

The demand for food and bioenergy is increasing, and with the world population expected to exceed 9 billion by 2050, agricultural production would need to double. To achieve this goal by reducing the enormous pressure agriculture places on the environment, agricultural production efficiency is expected to increase by 25%, taking into account the limited resources of land, water, and manpower. As a result, the agricultural industry must move at a rapid pace to ensure that supply meets demand [2]. This will entail more intelligent machines performing agricultural tasks rather than mechanical machines that cannot function without full human supervision. To achieve this goal, technology such as automation, which consists of developing and deploying technologies to perform tasks with minimal human intervention, is required.

1.3 Aims and Objectives

The goal of this research is to improve existing knowledge and broaden horizons regarding agricultural machinery automation and the prospects for such automation.

The objectives of the project are;

1. to show areas where agricultural machinery can be automated to enhance productivity
2. to see the importance and benefits of automating agricultural machinery
3. to understand how automating agricultural machinery works

1.4 Overview of Automation in Agriculture

Automation in agriculture contributes to many industrial advancements, helps farmers save time and money, and calls for high investment in this area of technology. Recently, various machines, like harvesters, irrigation systems, ploughing machines, and self-driving tractors, have been automated. As submitted by Walker et al. [3], investment in advanced agricultural technologies has increased by 80% annually since 2012, a great portion of which is majorly focused on automation, with a great interest existing in the new robotic technologies according to Tillett [4] and Oberti et al. [5]. Numerous elements of agriculture are already being silently transformed by robots and drones. Ranging from mobile robots used in fields and farms for harvesting to the ones used in the processing sections, agricultural activities are getting more efficient. According to Jakasania and Yadav [2], the installation of thousands of robotic milking parlours has already generated a $1.9 billion industry that is expected to grow to $8 billion by 2023. In dairy farms, mobile robots are even more common, automating activities like pushing and cleaning waste. Self-driving tractors with high incorporation of GPS technologies are also being manufactured. In actuality, over 300,000 tractors with automated transmissions were sold in 2016, with over 66,000 units sold annually by 2027 [2]. Interestingly, the use of robots is not limited to the already-developed countries; rather, farmers in developing countries show interest in using robots in their fields for taking care of simple but repetitive tasks such as plucking and picking fruits and maintaining the animals [2].

1.5 Limitations of Agricultural Machinery without Automation

There are many limitations associated with agricultural machinery without automation, which include increased quandaries, a power dilemma, and the obsolescence of machines. “Many agricultural producers use large machinery to reduce labour costs and improve operational timeliness. Pesticide application errors associated with larger equipment result in overapplication, reduced yield due to crop injury, and poor pest control. According to a recent study, manually operating a 24.8- m boom (5 control sections) resulted in an average over-application of 12.4% across a wide range of field shapes and sizes” [6]. Over-application increases with boom section width as operators try to control boom sections manually.

“Problems associated with off-rate application errors are also results of the use of larger equipment, as increased boom widths result in greater velocity, pressure, and height variations across the spray boom. Previous research has indicated that off-rate errors resulting from turning movements on a sprayer with a 24.8 m boom could affect between 3% and 23% of fields (of a variety of shapes and sizes) receiving an application rate beyond ±10% of the target rate” [6].

Speaking of the power dilemma, the trend has always been toward higher machinery when using equipment in the production of grain crops. To effectively utilize the power produced by the engine, the tractor must be adequately ballasted. To achieve the best possible performance and fuel efficiency, tyre inflation pressures are reduced to the bare minimum because of the soil-tyre interface. As stated by Scott et al., "The dilemma in Europe is that tractor manufacturers must work within the 3.0 and 3.5 m transport widths, thereby limiting tyre spacing and/or section widths."

More importantly, machine life and obsolescence pose a great limitation to non-automated agricultural machinery. Obsolescence is when the service of an object is no longer wanted, even though it may still be in good working order. In short, obsolescence occurs when newer technologies emerge, and then older technologies cease to be used. ASABE [7] lists the anticipated life of agricultural tractors at 10,000 horsepower. However, some diesel engine manufacturers boast of the development of million-mile engines. We can never fully utilize the capacity of machines produced by manufacturers because, with the rate at which new technologies are developed, older technologies become obsolete prior to the end of their physical life.

1.6 Area of Application of Automation in Agricultural Machinery

Research has proven that a number of agricultural machines and equipment have already experienced a substantial amount of automation and are moving from the usual automatic guidance of today to the fully autonomous field robots of tomorrow. Some of the areas of advancement include but are not limited to automatic vehicle guidance and steering system, automated harvesting, machinery coordination, machinery communication and data structures, and automated turn management [1].

Another area advancing swiftly is agricultural robotics with vision ability. In organic farming, for example, robotic tools with vision capabilities have been used successfully for a while. These tools aid in mechanical hoeing, follow crop rows, and detect weeds. These cutting-edge robotic tools' subsequent generation is currently beginning to be used commercially [2]. An example of this is the orchard intelligent weeder automation program design [8].

The domains of guidance and steering control have received appreciable improvement with the introduction of automation technologies into them. These systems use GPS-based navigation or technologies that position the vehicle in relation to the crop to precisely guide vehicles while requiring little driver input [9,10]. One of the main objectives of automatic guidance is the elimination of overlap during planting, spraying, fertilizing, and harvesting, which consequently reduces input costs and improves machine efficiency [11], Antille et al. [12]. And according to [13]," these systems have been available for about 20 years, although depending on the positioning technology being employed, varying degrees of positional precision have been recorded. Additionally, they vary in the degree of control, which can be anything from steering-wheel attachments for automatic control to fully integrated automatic control, as well as light-bar guidance for operator control [14,15].

“One leading company in the manufacture of machines with these systems is John Deere. With its AutoTrac product, which makes use of NavCom's StarFire GNSS (Global Navigation Satellite System) navigation system, John Deere provides guidance and steering control. The StarFire system provides a variety of positioning accuracies that can be chosen dependent on the application and is compatible with local RTK (real-time kinematic), which permits 2.5-cm positioning precision, or satellite-broadcast correction information” [14,15].

It should however be noted that these machines still require some amounts of human interactions, although very minimal, and hence more efficient compared to the traditional machinery that requires full interaction and total supervision. Different navigation issues must be considered in light of the likelihood that numerous completely autonomous vehicles may operate in a single agricultural field in the future [16].

Another aspect of agriculture that has experienced the touch of automation is harvesting. This particular activity done traditionally is prone to low efficiency, however, the introduction of automated harvesting is one turning point in the way it’s done. The harvesting operation is gradually transitioning from the traditional ways of harvesting using crude equipment or agricultural implements where enormous losses are recorded to the automated harvesting systems, with higher precision and hence efficiency. One of the most important advancements in harvesting technology over the past 20 years has been the use of yield monitors 1]. These technologies are continually improved to give information about moisture content and yield of crops during harvest operation and to accurately provide information to pre-processing units.

These systems have incorporated vision-enabled facilities to detect the quality and ripeness of crops and to separate diseased crops from healthy ones. One way overall harvest efficiency can be improved is by increasing the quantity of healthy and quality grains harvested while reducing grain loss 1]. With these automated harvesters, harvesting operations increase in efficiency. Some manufacturers also incorporated automated guidance systems and steering systems into their machines to enable them to move through stalks. John Deere and New Holland are two of the leading producers of automated harvesters [1].

"Precision Agriculture-Based technology is another important area where agriculture has been greatly improved. The precision agriculture technology system has been refined using information technology to support crop science, agronomy, soil science, plant protection, resource and environmental science, intelligent equipment and automatic monitoring, decision support, etc. The system creates a crop yield distribution map, a crop management database and growth and development simulation model, a crop management assistant decision system, and a crop management prescription map using agricultural machinery intelligent equipment technology" [8].

1.7 Some Evolving Automation Technologies

To fully achieve automated agricultural machinery, new technologies are essentially needed to be put in place. Some of these new technologies include but are not limited to wireless communications, positioning systems, ground knowledge of data structures and algorithms, with their applications, and automated guidance.

Wireless communications stand at the heart of modern automation systems, in contrast, wired ones require both high costs of resources and maintenance. The capability to transfer data wirelessly can help monitor the working statuses of agricultural machinery and allow the reallocation of tasks dynamically in the event of malfunctions. As stated by Scott et al. [17] "For large-scale high-tech agricultural operations, establishing vehicle-to-vehicle and vehicle-to-office communication is becoming imperative to manage the logistics of the tasks and to ensure the safety of the machines working in the field. Cell GSM, Wi-Fi, WLAN and Wireless stand-alone modems are typically used for vehicle-to-vehicle and vehicle-to-office communications".

An essential aspect of automation is sensing. Sensing technology is achieved with sensors. It entails accurately and promptly discovering signals. The use of space-based positioning systems is an effective sensing technology that is used in the machine automation field. As stated by Scott et.al "Advancements in sensing, communication and control technologies coupled with Global Navigation Satellite Systems (GNSS) and Geographical Information Systems (GIS) are aiding the progression of agricultural machines from the simple, mechanical machines of yesterday to the intelligent, autonomous vehicles of the future. The benefits of GPS, specifically in the agricultural industry, have been well documented as they have progressed from point location mapping (soil sampling or yield monitoring) to real-time equipment control (auto-steer or map-based automatic section control)" [18].

Data structures are also an important technology needed to be put in place in order to achieve automation in agricultural machinery. It involves the transfer from the farm office to agricultural machinery on the field and back to the farm office. The need to reconcile data is driven by map-based applications. Farm managers have data transfer needs that range from moving prescription maps from the farm office to agricultural machinery and then returning field operations verification files along with sensor data for summarizing crop health and performance to the farm office. Prescription maps direct where and how the inputs will be applied to crop production systems.

An attempt to coordinate data transfer has been proposed and adopted by Macy [19] and is termed the Field Operations Data Model (FODM). FODM is based on three components: a description of field operation, a framework, and a general machine model. Field operations are described using one of four models: whole-field, product-centric, operations-centric, or precision agriculture. The FODM framework is object-based, which includes resources (people, machines, products, and domains) and operation regions (space and time). Data logged to summarize field operations can either be infrequently changing data (ICD) or frequently changing data (FCD).

To automate agricultural machines like tractors and other mobile engines, automated guidance must be incorporated. As stated by Scott et al. Two basic types of automated guidance systems are typically used today by producers. The first system consists of a steering actuator that is mounted to the tractor's steering wheel. The second system is integrated into the tractor's steering system and utilizes a control valve to actuate the hydraulic steering cylinder directly. The overall accuracy of these systems relies heavily on the type of GPS technology used (RTK GPS provides the highest accuracy) as well as proper installation and setup.

1.8 Some Agricultural Machinery that has been Automated

Over the years, quite a number of agricultural machineries have been automated and are still undergoing automation.

Countries like the US, Spain, Portugal and many other countries are already making use of automated harvesting robots to harvest fruits from the farm. The harvest robots mainly use RGB-D cameras to detect and locate fruits based on colour. Yoshida et al. [20] 2018 automated a dual-arm fruit harvesting robot. The harvesting robot was equipped with two robot arms to increase work efficiency. The upper robot arm (UR5) harvests the fruit on the upper side of the tree, while the lower robot arm (UR3) harvests the fruit on the lower side. It was designed to approach many of the target fruits by specific colour designated for fruit maturity, robot arm's operating range and fruit tree standards was also a consideration.

Automated Irrigation Systems have also been developed. It is the use of a device to operate irrigation structures, so that the change of flow of water can occur in the absence of the irrigator. Sensors are used to determine when the automated irrigation system needs to be turned on. A variety of factors are also taken into consideration when determining when the automated irrigation system needs to be switched on- the amount of moisture in the soil is a major factor used to determine the threshold of switching on the automated Irrigation system. Uroromu et al. [21], 2019 designed "an automated Irrigation system. The automated irrigation system automatically and continuously measures the moisture level in the soil using a monitoring unit that comprises several sensors, an Arduino Mega, XBee Shield, and XBee Pro Module. It also measures the temperature and humidity. Each valve in the irrigation pipeline is fitted with a control unit consisting of an Arduino Mega, XBee Shield, XBee Pro Module and a Relay to electrically control its power supply using the Arduino Mega. The water pump at the water source is also fitted with a control unit. When the moisture level drops below a certain threshold, the system sends a wireless message to the water pump and the pipeline valves of the irrigation system". "Once these valves receive the message, the power supply to the water pump and valves is altered to activate the pump and open the valves, causing water to flow through the system and water the soil in that particular region. When the moisture level rises above a certain level, the system sends a wireless message to the water pump and the pipeline valves in the irrigation system, altering the power supply to the pump and the valves to close them, causing water to stop flowing through the system and the pump to stop allowing water from the water source to flow into the irrigation pipelines and into the soil in that particular region. The automated irrigation system can be applied to a single land section requiring irrigation or to multiple land sections with differing irrigation requirements. While the system is to be used primarily for land irrigation, it can also be used for automated watering of livestock, and cooling of plants and livestock [21]

There are also upcoming machines that will perform the function of ploughing agricultural lands. This will reduce drudgery and increase yield on a very large scale. Sensors are used to manoeuvre robots in the field. Four post sensors are used to define the territory, and this robot senses the track length and pitch for movement from line to line. The robot moves on to different ground contours and performs digging and ploughing.

There are also developments in tractorization, self-driving tractors that not only steers themselves but also do not need a human operator have been developed. A self-driving tractor is an autonomous farm vehicle that delivers a high tractive effort at slow speeds for tillage and other agricultural tasks [22,18]. John Deere has developed a self-driving tractor that can be controlled with a phone. The tractor steers itself and doesn't need a driver to operate it. This machine is to help farmers with precision agriculture and thus, making life easier.

1.9 Potential Risks and Challenges that May Arise from Automating Agricultural Machinery in Nigeria

There are quite a number of potential risks and challenges that may arise from the automation of agricultural machines. Recent studies from other industries imply that automation may increase demand for higher-paying jobs requiring secondary education, where people have a comparative advantage over machines (such as data management and analysis), but decrease demand for work that entails repetitive labour e.g., planting and harvesting [23,24]. The total number of people employed in agriculture declines as nations modernize, but between 300 and 500 million waged workers still rely on farm work [25]. The percentage of the workforce employed in agriculture is still high in several nations, such as Burundi (86%), Somalia (80%), Malawi (76%), Chad (75%), Niger (73%), and Uganda (72%), and is frequently associated with high rates of illiteracy, poverty, and gender inequality. Reduced direct labour requirements per unit of production in these nations run the risk of fostering new disparities or escalating old ones. Because of this, agricultural automation may be politically undesirable and impractical in various situations. A number of variables, including the ability to create new, more desirable occupations or other suitable employment opportunities outside the agriculture industry, will ultimately determine the influence on labour and salaries. Whether scale effects, in which farmers increase the size of their production and their income, surpass substitution effects, in which labour is driven out of the industry, will also be a determining factor. But, with the correct rules, laws, and regulations, agricultural automation may open up economic opportunities, promote respectable employment that pays a liveable wage, and encourage reasonable wages.

Moreso, some types of agricultural automation, particularly those that rely on large, heavy machinery, raise concerns that, if improperly managed, they could endanger environmental sustainability and resilience by causing deforestation, farmland monoculture, biodiversity loss, land degradation, soil compaction and erosion, salinity build-up, and broken drainage systems [26]. Even though these worries must be addressed seriously, many of them can be prevented or reduced with the right laws and policies. Moreover, some recent developments in automation machinery and equipment, particularly some equipment that uses AI, can undo some of the damaging environmental effects of earlier automation gear. Agricultural automation's possible benefits, drawbacks, and effects will all depend on the particular technology employed, how it was created, how well it suited local conditions, and how effectively it was adapted to local reality. Also, the mix of appropriate technologies that are likely to be adopted depends on the degree of socioeconomic growth as well as institutional and political limitations. As a result, both the good and negative impacts of agricultural automation depend greatly on the environment. Before recommending specific automation solutions, it is crucial to determine whether the environmental, social, and political circumstances are suitable for each nation or region. Certain automation technologies may need to be modified because they are not appropriate for all situations.

More importantly, there is a high cost associated with purchasing and maintaining automated machines. The high poverty rate of average Nigerian farmers is tagged as a major challenge to the adoption of model automated technologies. In fact, most farmers in Nigeria are yet to fully appreciate or adopt more sophisticated manual machines. Hence, the very high purchase and maintenance costs make it very difficult for automation in agricultural equipment to be adopted.

Apart from that, a lack of preparation for expansion is an important challenge that may arise for automating agricultural machinery. The machinery that is installed in an automated production cell determines how effective it will be. You will quickly run out of space if you are not dedicated to expanding your operations, increasing productivity, or increasing efficiency by adding more machines. It's critically important that all of the machines, people, and software in a production facility can effectively connect with the automation equipment. When it's time to scale up, you'll save time if you have a plan in place for making sure all of your tools are interconnected.

Lastly, there are several applications for machine vision, but it's crucial to pick the best tool for the task at hand. Machine vision may be overkill in situations where other forms of automation would suffice, yet failing to apply this technology may prevent you from recognizing opportunities or finding solutions.

2. CONCLUSION

The field of agriculture automation is expanding. With the research technologies currently accessible, a completely new mechanization system might be developed to assist the farming system based on small intelligent machines depending on the specific farm operation. In the case of a completely automated crop-row guiding, a number of technologies have been created and are being employed as building blocks- accelerometers, GNSS, and fiber-optic gyro sensors are a few examples of tools that have been used to determine position and direction, the steering angle being measured by rotary encoders, the clutch and brake positions being monitored by proximity sensors. An origin-to-destination path also enhanced using geometrical data structures etc. Bechar and Vigneault [27]; Almeida Bessa et al. [28].

Yet, in a developing nation like Nigeria, where such reports are rare or non-existent, there hasn't been much advancement in the automation of agricultural activities. The difficulties experienced are severe. that among other issues, the lack of technological know-how, poverty, and a lack of data and information are some of the main barriers preventing Nigeria from adopting highly automated agricultural technology. Due to comparisons with other industrialized nations in terms of agricultural mechanization, the disparity is obvious going by reports from this paper as in the case of Nigeria [29].

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COMPETING INTEREST

Authors have declared that no competing interests exist.

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