Original Research Paper

Development of an Arduino-Based Robotic Arm Yam Heap Maker

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Abstract: In this study, a prototype robotic arm yam heap-maker using Arduino was developed. Nigeria produces around 75% of global yam production which is widely consumed as staple foods in Africa and Asia and as raw materials for processing into other finished goods. The production of this economic commodity is largely crude and labor-intensive as such the need to adopt a modern approach to farming. The prototype was designed to perform heap-making activities in the cultivation process of yam and utilizes two Degrees of Freedom (2 DOF), it has an overall weight of 2.39 Kg, 350 mm length, 250 mm width, and 240 mm height. A systematic design method of the product design process was adopted in the prototype development. The heap maker was controlled remotely using an android phone. The trial experiments were performed on sandy, loamy, and clay soils. The average effective heap height and depth were best observed on loamy soil with 5 cm height and 7 cm depth.

Keywords: Arduino, Smart Agriculture, Robotic Arm, Yam Cultivation, Manipulator

Introduction

The production of yams in Africa accounts for around 92% of the global production of tubers, with Nigeria producing over 75% of that quota with an annual growth rate of 4.12%, a capacity of around 118 million tonnes in 2020, making Nigeria the largest producer of roots and tubers in the world (Knoema, 2022).

The top five regions of yam production in Nigeria are Taraba, Benue, Niger, Enugu, and Kaduna 2005 which accounted for about 50.55% of the total yam produced in Nigeria (Knoema, 2005). Yams (Dioscorea spp.) are one of the most widely consumed staple foods in Nigeria, as such the production of this commodity plays a key role in ensuring food security (Andres *et al.*, 2017). It contains essential proteins and micronutrients for human development, marketed as fresh produce, transformed into other value-added products based on the preferences of the consumer ranging from yam flour, starch, poultry, and livestock feed (Opara, 2003) in some regions, it is respected and plays a key socio-cultural role in most Africa such as new yam festival.

Yam cultivation takes around 8-11 months in Nigeria, yams are cultivated at the end of the rainy season while those intended for long-term storage are cultivated between December-January (Obidiegwu and Akpabio, 2017). The absence of improved technology in the cultivation process of yams further exacerbates the rate of spoilage through infestation, physiological damage during harvesting, and breakage of tubers due to the hardness of the soil, coupled with the labor-intensive nature of cultivation that could lead to injuries to farmers (Sanginga, 2015).

With the global increase in population, drastic measures are needed to ensure food sufficiency through the adoption of modern technologies to address the issues of agricultural productivity and ensure food security for all (Cariou *et al.*, 2009). Most African countries are threatened by food insecurity as a result of banditry, corruption, poor policies, and civil unrest have made this vision almost impossible, in Nigeria, most farmers had to abandon their farms during harvest because of the non-stop harassment and attacks by Boko haram terrorists, bandits and herders rendering the majority of the rural dwellers in abject poverty and shortening the supply of food to the markets (Ilesanmi and Odefadehan, 2022).

Farming practices in Nigeria are largely labor-intensive and subsistence, mechanization, and adoption of modern innovations are still under-utilized, postharvest losses account for almost 50% of the produce (Nurudeen *et al.*, 2020). The distinction between agriculture and other manufacturing sectors is that agricultural machines are seasonally used, for instance, planters and harvesters are needed only at the beginning and end of the farming season (Sistler, 1987). Having these robots perform agricultural tasks will require the use of sensors for visualization of the

environment, image acquisition and processing, navigation, and intelligent decision-making systems for effective and proper performance under certain and uncertain situations (Karkee, 2021).

The automation of agricultural operations and management of resources is receiving huge attention as the process has been found to effectively increase productivity through data generation and regeneration, reduced labor costs, boost generated revenue, reduce drudgery in farming practices, increase efficiency as well as using technology to predict future yield (Gollakota and Srinivas, 2011; Baby *et al.*, 2017). Robots for agricultural mechanization have been developed in several parts of the world with the USA, China, Japan, and Australia leading the global production of these able machines (Mahmud *et al.*, 2020; Borisov and Danilova, 2020). A robotic arm is a machine that performs useful services to humans through a programming language to function like the human arm and execute tasks semi or fully autonomous manner (Yusoff *et al.*, 2012).

The uses of these smart machines in agriculture are diverse, ranging from perception, manipulation and decision-making processes with the aid of sensors, devices and mechanisms, artificial intelligence, and cloud-computing all coupled together to perform tasks of seeding, harvesting/picking, plowing, weed control, pruning, spraying, sorting and packing, temperature regulation, milking, feeding, slaughtering and many more with the use of right technology (Ghafar *et al.,* 2021; Seyyedhasani *et al.,* 2020; Xue *et al.,* 2017).

The essence of this study was to develop a prototype robotic arm yam heap maker and perform experimental processes on sandy, loam, and clay soils.

Materials and Methods

Description of the Prototype System

The robotic arm has a total of 4 axes which are the base, the shoulder, elbow, and gripper pitch. It was designed based on the systematic design method, it is a product design process that classifies processes into phases; problem definition, alternatives, function structure, forming phase, concept generation, and prototype development (Bakker *et al.,* 2010). The outcome of the systematic design phases led to the development of the chart shown in Fig. 1. which translates the function structure, concept generation, and prototype development. The problem definition phase explores the objectives of the design that are of variable or fixed requirements for the design, also, it entails the functions of the robot. In this case, the functions were amongst other things to navigate through the field make heaps at the desired spacing and path.
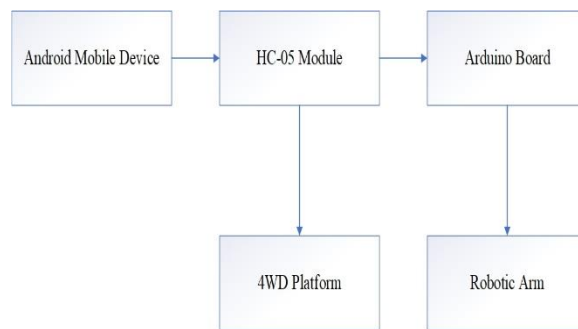

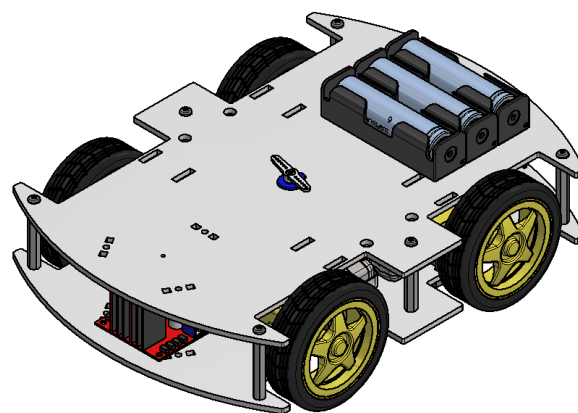**Fig. 1:** Block diagram of the robotic arm heap maker

Fig. 2: Showed 4-wheel drive base and battery array designed using solid works©
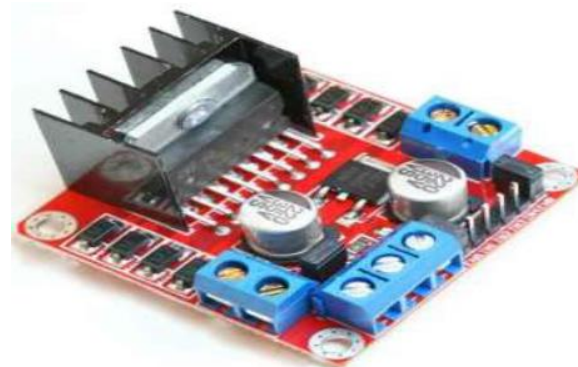

Fig. 3: Geared DC motor

Fig. 4: Dual Channel H-Bridge motor driver module (L298N)

Then, these functions are grouped to form a function structure, in this phase, the ideas of how the robotic arm will perform tasks were developed and several alternative solutions as well were drafted such as how will the movement of the robotic arm be, depth and height of yam heaps, heap spacing, energy required, etc. These functions and their alternative solutions were carefully selected and culminated into the developed prototype.

Figure 1 displayed block diagram of the mobile robotic arm yam heap maker, the android mobile device is used for connection and control of the mobile robotic arm, Hc-05 module is the Bluetooth module connected to the Arduino board and mounted on the 4-wheel drive platform which serves as the means for communication between the operator, the robot and holds firmly the robotic arm and its components. The Arduino board is the microprocessor that executes and translates the operator's commands into useful tasks through the robotic arm which houses the end effector. Figure 2 showed the 4-wheel drive base, battery array, and used for mounting the end effector, robotic arm, links and joints, microcontroller, Bluetooth module, L293d motor drive, and the electric circuit.

The geared DC motor (Fig. 3.) converts rotational motion to linear motion, while the gear heads reduce the speed with a subsequent increase in torque, the battery array comprises three lithium polymer ion (LiPo) batteries with a combined output of 6,000 mAh to power the 4-wheel drive base (4000 mAh) and the robotic arm (2000 mAh).

The motor driver (Fig. 4.) is a dual channel H-bridge motor driver module (L298N) with a voltage tolerance between 5-35V. Arduino UNO R3 (Fig. 5) has a powerful microcontroller that provides solutions to embedded wireless control applications. Bluetooth module (HC-05) provides a seamless wireless connection between the microcontroller and the android mobile device.

Material Selection

The materials selected for the construction of the robotic arm were considered based on cost-effectiveness, strength, availability, and machinability. The robotic arm was constructed using Perspex sheet; a lightweight thermoplastic material with a tensile strength of around 69 MPa, and flexural strength of 117 MPa (Roehm, 2022). The end effector (cutting discs) used for making yam heaps were constructed from aluminum sheets; aluminum was selected because of its lightweight and resistance to corrosion. Microcontrollers, Geared DC motors, motor drivers, and wheels were purchased from the online market.

Results and Discussion

Components Composition of the Robotic Arm Yam Heap Maker

The image from Fig. 6 showcased an exploded view of the robotic arm yam heap maker and its constituent

elements as highlighted in Table 1, the table summarized the description of each element that constitute the robotic arm yam, heap maker. Figure 7 and 8 displayed the robotic arm and cutting discs, a fully assembled robotic arm as designed using SolidWorks© software and the developed prototype.

Android Control App

Bluetooth module was used in controlling the robotic arm yam heap maker, codes were developed using the Arduino Sketch app and then downloaded to the Arduino UNO R3 microcontroller. For communication between the mobile phone and the robotic arm yam heap maker, a Bluetooth connection was established. Then commands were executed from the mobile phone (Prabhakar *et al.*, 2021). Figure 9 and 10 presented a preview of how connections were established to enable seamless communication.

Performance Tests

The performance of the robotic yam heap maker was tested on three different soils; sandy, loam, and clay soils. It was observed that the soil with the highest depth of cut was the loam soil with an average depth of 7 cm and heap height of 5 cm which was higher than the clay soil and sandy soil with 5, 3 cm depth of cut, and heap height of 3 and 5cm respectively. The variations in heap height could be the result of soil texture and moisture content as reported by other researchers (Phogat *et al.*, 2015). Figure 11a, b, and c: Showcased the images of the heaps produced on different soils. From Fig. 11a it can be observed that the heaps are loose and not properly formed as a result of the lack of cohesion of sandy soil particles, while Fig. 11b showed that the particles are bonded together but not as required due to the nature of clay soils (Mamedov *et al.*, 2015).
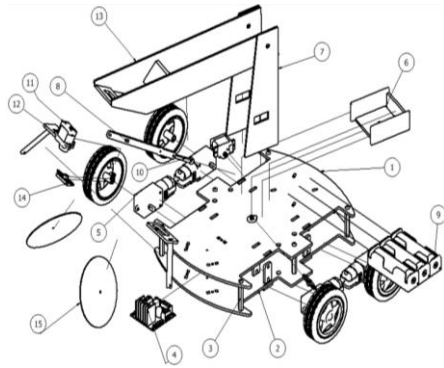

Fig. 5: Arduino microcontroller

Fig. 6: Exploded view of the Robotic arm yam heap maker designed using solid works©
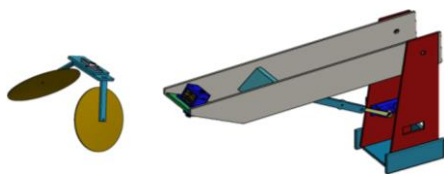

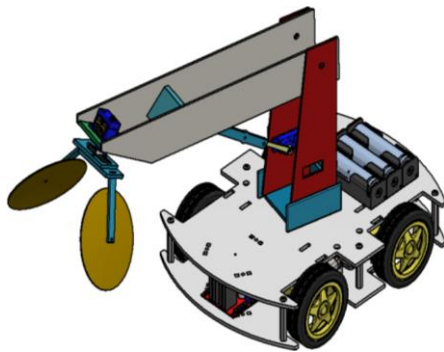**Fig. 7:** Robotic arm and cutting discs designed using solid works©

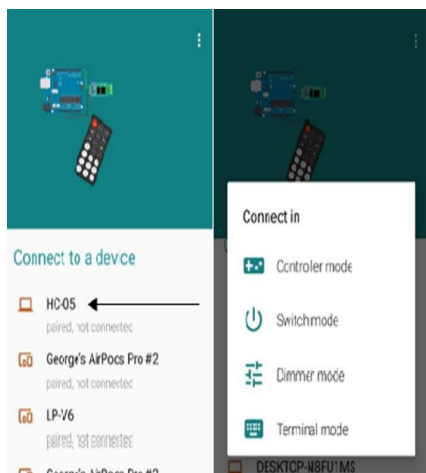**Fig. 8:** Fully assembled robot designed using Solid works©

Fig. 9: Bluetooth Connection between the mobile and the robotic arm yam heap maker
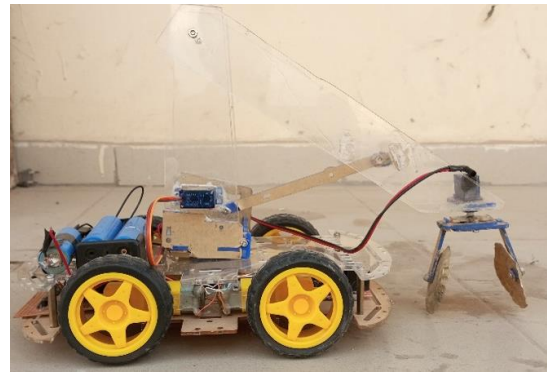

Fig. 10: Developed prototype of the robotic arm heap maker

Fig. 11a: Sample of heaps produced on sandy soil

Fig. 11b: Sample of heaps produced on clay soil

Fig. 11c: Sample of heap produced on loamy soil

Table 1: List of components of the robotic arm yam heap maker

S/N	QTY	Description
1	1	Chassis
3	6	ECU M3x35.IGS studs
4	1	L298N Motor driver
5	4	Reduction Drive
6	1	Robotic arm base
7	2	Shoulder
8	2	Push rod
9	1	Battery tray
11	1	End effector motor
12	2	End effector frame
13	1	Elbow joint
14	2	heaper base
15	2	end effector disc blades

Although the initial cost of obtaining a robot for farming practices is expensive but offers an economic advantage on the long run through saving a lot of money on manual labor, increasing work efficiency and profitability, Researchs on the economics of robotics are scarce but James (Lowenberg-DeBoer *et al.*, 2020) was able to conduct a review on the economics of robotics and automation in field crop production which realized that adoption of robotics in agriculture have economic advantages for farmers, unions, and societies to engage in commercialization of these robots depending on the market size, farming structure and as well as safety which will boost return on investments, increased data generation and agricultural policy.

Conclusion

A 2-degrees of freedom robotic arm yam heap maker was developed using Arduino. The prototype consists of chassis, end effector, frames, motors, and disc blades integrated on a 4-wheel drive base and controlled using Bluetooth through a mobile device. The Robot had a length of 350 mm, width of 250 mm, a height of 240 mm, and a total weight of 2.39 Kg. The prototype was able to achieve the following requirements; being able to perform heaps at desired locations, being able to move around along the desired paths, and experimental tests were conducted on three types of soils (sandy, loam, and clay) the robotic arm had better performance on loamy soils. The objectives of the study were met by the robot, however, the following were observed as areas for further research; Reevaluate the cutting discs to have adjustable blade angles, establish the prototype on a bigger scale, and adoption of higher degrees of freedom for the robotic arm to aid in adequate positioning of the end effector.

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Author's Contributions

Agbese Raphael: Hardware installation, experimental analysis, and programming.

Dagwa Ishaya Musa: Research methodology, supervision, proofreading, and organization of the study.

Nurudeen Abdulhakeem Hassan: Supervision, drafting of the manuscript, and proofreading.

Adekunle Josuah: Experimental analysis and programming.

Ethics

This is an original work and contain unpublished materials. The Authors declare no ethical issues regarding the publication of this manuscript.

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