



ABSTRACT

Harvesting of cowpea is one of the major operations in the cowpea production. It is carried out when the pods are fully matured and dried but these pods do not mature at the same time because of its staggered flowering period. Traditional handpicking of cowpea is still widely employed by most Nigerian cowpea farmers to harvest the rain fed cowpeas intermittently;

CONCEPTUAL DESIGN OF AN INTELLIGENT COWPEA (*Vigna unguiculata*) HARVESTING MACHINE

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INTRODUCTION

Cowpea (*Vigna unguiculata*) is the most important legume used for human consumption. It is one of the most important staple food crops in sub-Saharan Africa, especially in Nigeria (Tijjani et al., 2015). With protein content of 25%, cowpea/bean remains one of the cheapest sources of protein in the diet of many Nigerians, in addition to its several mineral and vitamin contents (IITA, 2014). It is also one of the most important economic crops in the tropics for the fact that all of its



while the late maturing cowpeas are left to dry completely and then harvested at once using cutlass or sickle. Manual harvesting continues to be one of the most time consuming and labour intensive, resulting in low efficiency and limited competitiveness. These however, pose significant obstacle to sustainable food security that only cutting-edge technologies such as agricultural robotics and computer vision can address. This work is aimed at Conceptual Design of an Intelligent Cowpea (*Vigna unguiculata*) Harvesting Machine using a Single Shot Detector (SSD) deep learning algorithm. In this work, multidisciplinary conceptual design methodology adopted, and consists of five different stages established towards intelligent cowpea harvesting machine. The first stage is determination of the engineering properties of the cowpea plant, pod panicles and dried pods relevant to the design of an intelligent cowpea harvester. This work, investigated and presented the overall framework and high-level ideas towards the development of an intelligent cowpea harvesting machine. The outcome of the study presented a feasible design concept as a prelude to solution of challenges confronting manual hand picking of non-uniformly maturing cowpea pods.

Keywords: Algorithm, Cowpea, Harvesting, Intelligent, Single Shot Detector

parts are useful for human consumption and for the provision of livestock feed.

Harvesting of cowpea is one of the major operations in the cowpea production. It is carried out when the pods are fully matured and dried but these pods do not mature at the same time because of it staggered flowering period (<https://agriculturenigeria.com>). An important consideration is the mechanism for harvesting of dry cowpeas. Cowpeas are still largely hand harvested when grown in small farms in Africa and Latin America. When grown on large farms, as in the United States, cowpeas are harvested mechanically, either via a two-step process or via direct harvest (Miklas *et al.*, 2022). Advances to improve the upright plant architecture of dry cowpeas during the last two decades have enhanced options for direct harvest (Uebersax *et al.*, 2022).

Traditional handpicking of cowpeas is still widely employed by most Nigerian cowpea farmers to harvest the rain fed cowpeas intermittently; while the late



maturing cowpeas are left to dry completely and then harvested at once using cutlass or sickle. Navas *et al.* (2021), stated that: in manual harvesting, humans use their hands to move different elements of plants, grasp the fruits and detach them, either directly or with the help of a tool; and that among the main tasks in agricultural processes, those that involve the manipulation of fruits and vegetables continue to be one of the most time consuming and labour intensive, resulting in low efficiency and limited competitiveness. These however, pose significant obstacle to sustainable food security that only cutting-edge technologies such as agricultural robotics and computer vision can address.

As stated in the study reported in Billingsley (2011), the proliferation and combination of low-cost computing power, and applications that target its use for entertainment has led to a readily available platform for analyzing vision signals in a variety of ways. Applications are many and various, but some of the most potentially significant ones are found in agriculture, for example the development of low-cost method for precision agriculture using arduino (Sundaresan and Priyadharshin, 2018)

This work is aimed at Conceptual Design of an Artificial Intelligence Based System for Selective Harvesting of Dried Cowpea (*Vigna unguiculata*) using a Single Shot Detector (SSD) deep learning algorithm.

LITERATURE REVIEW

Relevant theories associated with cowpea production including harvesting systems were reviewed; so also, basic concepts in Artificial Intelligence use in Agriculture, computer vision and deep learning algorithms for real time object detection. Similarly, reviews of the related research works were also carried out to identify research gaps as presented in Table.



Table 1: Related Research

Author	Title of the Study	Findings	Gap
Ojomo et al. (2010)	Development and Performance Evaluation of a Cowpea Harvester	Large tractor (fuel) dependent cowpea harvester	Lack of precision capabilities for selective harvesting
Saito et al. (2013)	Development of a Robot for Combined Harvesting of Beans	Relatively large size, high tech sensor technology based, robotic beans combine harvester.	Non handy, non vision based and non selective
Shen & Hassan (2015)	Design and Development of Colour Sorting Robot	new approach for continuous recognition and sorting of objects into desired location using low cost technology	Colour sensitive only, there is need for shape recognition
Eizentals (2016).	Picking System for Automatic Harvesting of Sweet Pepper	High tech picking system for automatic harvesting of sweet pepper	There is need for adaptation to small cowpea farms
Abdulkarim et al. (2016)	Design of Mini Combine Harvester.	mini harvester for multi crops with relatively uniform maturity	Lack of automation
Cai, et al. (2020)	Fruit Image Recognition and Classification Method Based on Improved Single Shot Multi-box Detector	an improved SSD (Single Shot Multi-Box Detector) to classify apple, persimmon, nectarine and pear was proposed and evaluated	Algorithm not tested for real time objects recognition
Ruparelia et al. (2022)	Real-Time Tomato Detection, Classification, and Counting System Using Deep Learning and Embedded Systems.	real-time testing of the models deployment of the detection model on an embedded platform in a real field	embedded platform does not incorporate mechanism for automatic harvesting



MATERIALS AND METHODS

Materials

Two kinds of materials were considered; biological material such as complete cowpea plants, cowpeas pods and the pod panicle, and construction materials such as mild steel sheets, angular iron bars, flat bars, rubber, plastics, and fabrics. The objective of material selection is to minimize cost as well as selecting the appropriate material to be used for each component considering engineering factors such as strength and machinability; as well as the environmental factors or service conditions of the components so that they will perform properly with high degree of reliability.

Method

The method adopted for this conceptual design is multidisciplinary in nature, and consists of five different stages established towards intelligent cowpea harvesting machine. The first stage is determination of the engineering properties of the cowpea plant, pod panicles and dried pods relevant to the design of an intelligent cowpea harvester. The second stage is the mechanical design analysis and development of an intelligent electro-mechanical device that would integrate an AI model using an SSD algorithm on an onboard computer to achieve selective harvesting of dried cowpea pods. The third stage is development of an embedded computer vision system that detects and recognizes dried cowpea pods. Therefore, an AI based algorithm using SSD (single shot detector) to achieve real time detection and selective harvesting of dried cowpea pods is suggested. The fourth stage is integrating the AI system, fabrication and assembly of the intelligent cowpea harvesting machine. Fifth stage is the performance evaluation of the developed intelligent cowpea harvesting machine in an on-farm environment. The flow diagram for the adopted methodology is presented in Figure 1.

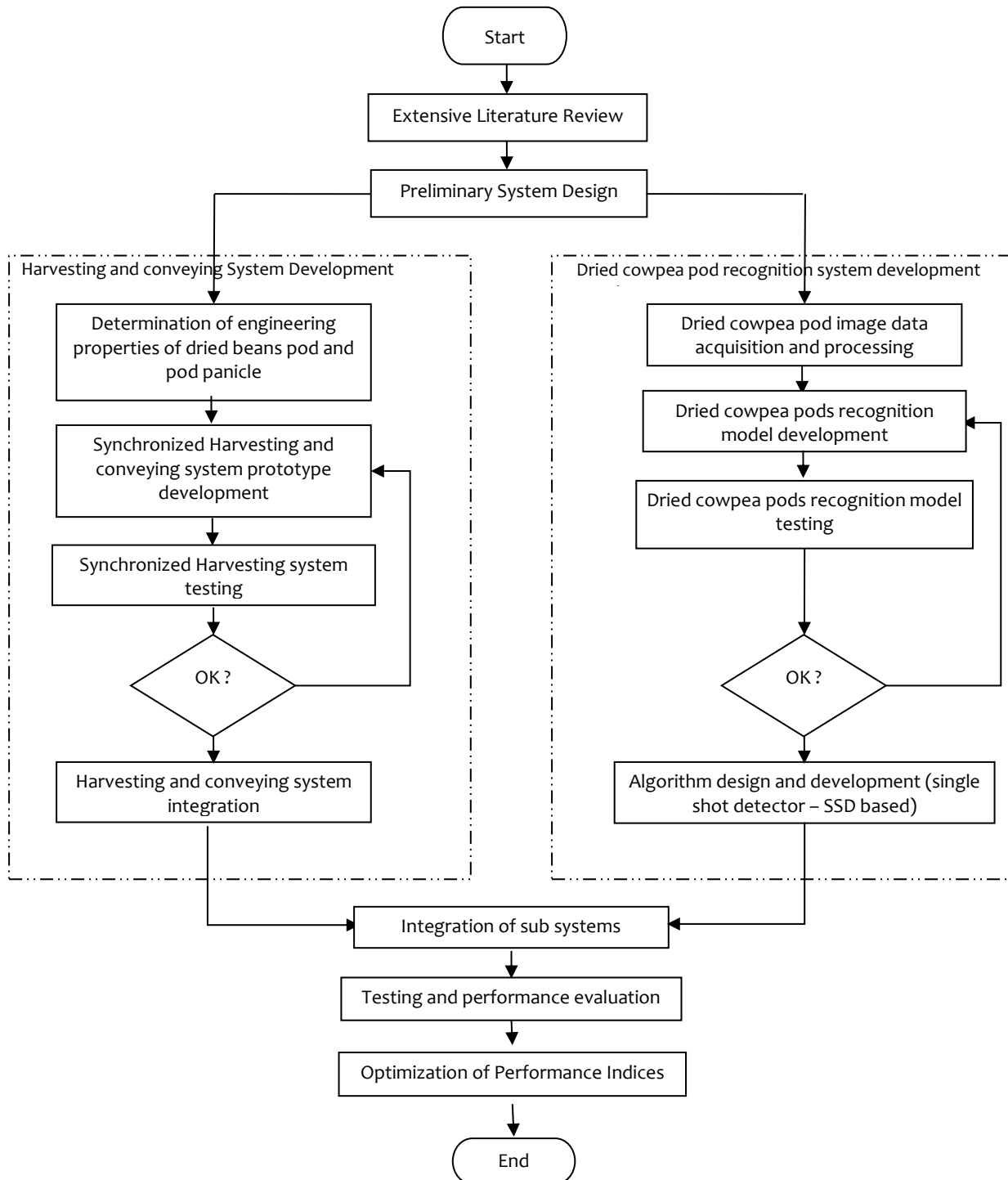


Figure 1: Methodology of the Study Towards Intelligent Cowpea Harvesting Machine



Conceptual Framework

The concept of object sensing and identification (image processing and image analysis) is the core of computer vision systems. Computer vision systems (CVS) emulate human vision in order to gather information from an object without requiring a physical interaction with it (Sandoval *et al.*, 2018). A typical computer vision system is part of the conceptualized intelligent cowpea harvesting machine and consist of the following components:

- *Camera*: System has one digital camera that record colour, monochrome, or wide-spectrum images. Just like consumer cameras, the optics/lenses attached deliver a specific field of view and available light.
- *Image Processor*: A computer program to process images, detect, measure, compare etc.
- *Trigger*: This component makes sure that specific action takes place in response to something the camera sees. A synchronizing sensor for part detection to trigger image acquisition and processing and some form of actuators to sort, route or reject defective parts.
- *Cables*: Input/output hardware (e.g., digital I/O) or communication links to report results and to automatically reject components.

Engineering Properties of Cowpeas Plant, Panicle and Pod

Engineering properties of the selected white cowpeas (*Vigna unguiculata*) plant are of great importance in the design of the machine for the automated harvesting of the matured cowpeas pods. Therefore, the properties such as height, size, shape, colour at maturity; and shearing strength of the cowpea panicle was taken into consideration.

RESULTS AND DISCUSSION

Description of the Conceptualized Intelligent Cowpea Harvesting Machine

The framework for the proposed intelligent cowpea harvesting machine was built around the concept of electronic control of mechanical system using an embedded computer vision technique. Electronic components used for the development of the system are onboard computing device (Raspberry Pi 5), Smart Camera module (pi camera), DC solenoid electromagnetic plunger, LEDs, 2way relay module, switch button and the power supply; while the mechanical



components to include: header (cowpea plant alignment) unit, pods alignment unit, electromagnetic actuated pod harvesting/picking fingers, ground wheels, belt conveyor, transmission system, chassis and pods holding bin. The device is electrically powered by an on-board solar electricity system. An overview of the conceptual framework of the study is presented in Figure 2.

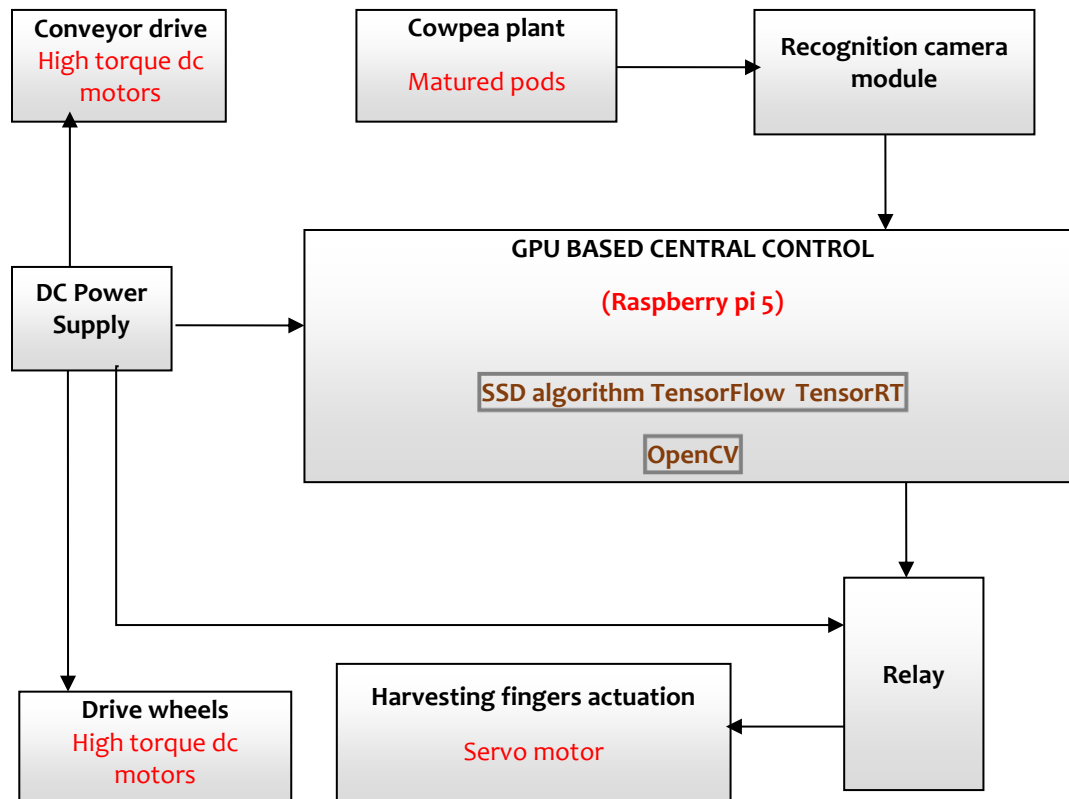


Figure 2: Block Diagram of the Conceptualized Intelligent Cowpea Harvester

Components Parts of the Conceptual Intelligent Cowpea Harvesting Machine

The intelligent cowpeas harvesting is made up of the following key components:

Header Unit

This is primarily the cowpeas plant aligning head which gathers and guides the standing plants towards pods aligning unit. The header adopts a conical shape and is located at the fore front of the machine.



Pods Alignment Unit

As the machine moves forward, the condensed cowpeas plants move into pods alignment units, which is made to bring the cowpea pods within the range of the pi camera for accurate detection. Pod alignment unit is made of a specially finished metallic round bar inclined at an angle of 300 from the horizontal plane in order to allow for alignment of pods across varying locations in the plant (Eizentals, 2016).

Vision Module

The vision module employs techniques of computer vision to identify a matured or group of matured cowpeas pods by virtue of their shape and colorations as they pass through pod alignment unit. The vision module is of low-cost alternative system, comprising of an open-source development System on a Chip (Raspberry pi 5), Raspberry pi compatible smart cameras (csi camera) and interconnecting cables and is controlled by a trained artificial neural network in form of a Single Shot multi box (SSD) deep learning model as suggested in Shen and Hassan (2015). The designed vision system is attached to the fabricated harvester with the camera positioned along pod alignment unit to face aligned pods. When the switch button is pushed to start the system, the smart camera starts taking real-time images of the aligned cowpea plants and ignore them as soon as it discovers there are no pods attached. Once the camera sees a matured and dried cowpea pod or group of pods it will draw bounding boxes around them and signal the relay which in turn energizes the electromagnetic solenoid plunger actuating the picking fingers thereby harvesting only the dried cowpea pods.

Picking/Cutting Mechanism

The picking/cutting mechanism is the part of the intelligent harvesting machine that is responsible for the selective harvest of the cowpea pods. This is made up of electromagnetic plunger and picking fingers/claws. When ripped cowpeas pods are detected by the vision system, the relay connects electromagnetic element of the plunger to the battery bank to energize it; the energized plunger instantaneously closes the picking fingers on the panicle of detected pods, and there by plucking them. The picking claws is spring loaded and formed with sharpened interior edges to ensure effective picking.



Electrical System

This is the unit used for providing power for the vision module, electromagnetic plunger of the picking claws and for the high torque dc motor drives. The power source for the electrical system of the machine is onboard solar power system, comprising of solar photo voltaic cells (solar panels), fuse disconnects, charge controller, cables, switches and battery bank. Solar panels serve purpose of charging the battery.

Power Transmission Unit

This unit comprises mainly of chain drives. The chain drives are connected to link the dc motor drives with wheels to provide traction; and to also transmit power to drive harvested pods collecting conveyors.

Traction Device (Wheels)

These are in rubberized form, in a pair and are to be carefully sized to serve the purpose of transportation. Wheels will receive power from a high torque, low speed dc motors through chain drives (Ibrahim et al., 2019).

Chassis

This is a framework of the developed cowpea harvester upon which other component units are secured. It also determines the physical outlook of the machine.

CONCLUSION

Every innovative engineering design and development begins with iterative process of conceptual design which is a crucial step in the engineering process, as it lays the groundwork for developing a successful and functional product. This work, investigated and presented the overall framework and high-level ideas towards the development of an intelligent cowpea harvesting machine. The outcome of the study presented a feasible design simple concept as a prelude to solution of challenges confronting manual hand picking of non-uniformly maturing cowpea pods. The outcome also highlighted a comprehensive agricultural engineering design methodology that integrate AI functionality, outlining key design steps which if implemented would results to development of



a functional intelligent cowpea harvesting machine. Possible failure points in object detection and mechanical failures are due to environmental challenges such as dust, lighting conditions and uncertain soil conditions.

Recommendations

Therefore, it is highly recommended that:

- i. In an attempt to translate this concept to a full design, attention be paid to determination of relevant engineering properties of the cowpea plant; material specifications be based on local availability, this way cost effectiveness of the design can be achieved; and every detail of the design methodology be adhered to following standard practices and by using known mathematical relationships.
- ii. The developed and trained SSD algorithm be simulated, evaluated and optimized using performance metrics such as mean average precision (mAP) and response time.
- iii. Extensive performance evaluation be conducted on the eventually developed intelligent cowpea harvesting machine using performance indices such as harvesting, colour discrimination and pods handling efficiencies.
- iv. Future scopes are to address those identified potential technical limitations and propose mitigation strategies.

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