Review Article

Status and Scope of Automated Coconut Harvester in India: A Review

Abstract

Coconut plays a substantial role in the Indian economy. South Indian states, namely Kerala, Karnataka, Tamil Nadu, and Andhra Pradesh are the leading producers accounting for more than 90% of the total coconut produced in the country. The traditional/conventional process of coconut harvesting includes climbing on the tree and cutting the coconut bunches with a cutter, which involves high risk. Climbing on a coconut tree is the main risk factor and it is life-threatening. The present review paper presents the status and future research need for automated coconut harvesting machines in India. This paper also focuses on the basic components of the automated coconut harvesting machine, as well as the advantages and disadvantages of each component are critically analyzed based on its findings, future research needs are proposed in order to meet all the fundamental aspects of autonomous coconut harvesting machines.

Keywords: Automation, Coconut, harvester, India, agriculture robot.

Introduction

India is a major producer of coconuts, which contribute 72% of the world's total production. In India, Kerala, Karnataka, Tamil Nadu and Andhra Pradesh produces 89% of coconut production and 90% of coconut area. Coconuts are versatile crops used for a variety of purposes but in India, almost 70% of the coconut is used for edible purposes. Coconut trees are productive throughout the year. However, the yield may vary from season to season. A normal-bearing coconut palm usually produces one harvestable bunch on monthly basis. The number of bunches harvested per palm annually reaches about 14 from tall and 16 from dwarf trees. A bunch of coconuts from each tree has 5 to 15 nuts. Coconuts are harvested every month from a coconut palm. On average, 10-45 nuts are collected from each coconut tree at various maturity stages during every harvest cycle. Asian and Pacific Coconut Community (APCC) had recommended about 45-day harvest cycles for successive coconut harvests to yield a good number of mature nuts with high copra and oil recovery.[1]

Completely ripe and dry nuts stored for making ball copra. The average yield of coconut is 80 - 100 nuts/palm/year depending on the variety. The yield of dwarf varieties, tall varieties, and hybrids are 70 - 80, 80 - 100, and 100 - 130 nuts/palm/year, respectively. Bunches should be harvested and brought down by using ropes to prevent damage to seed nuts/tender coconuts.[2]

Coconuts are usually harvested by climbing the tree using a rope ring around the foot or ankle of the climber or by using a ladder. After reaching the top, the climber taps the nut in the lowermost bunch with its harvesting knife to ensure its maturity. If the user is satisfied, the climber cuts the bunch at the base of the stalk when it drops down to the ground. In addition to cleaning the crown, the climber removes dry leaves, sheaths, and spathes. In some regions, including the West Coast, where coconut leaves are used for thatching houses, the lowermost leaves are also cut at harvest time. The cutting down of green leaves is considered undesirable as it affects the yield of trees to some extent.

Presently three harvesting methods/techniques i.e. climbing, power tiller operated ladder, and climbing cycle/equipment are used for coconut harvesting. The advantage and disadvantages of different harvesting methods are shown in Table 1.

Table 1— Harvesting methods/techniques

S. No.	Harvesting method	Advantages	Disadvantage	References
1.	Manual harvesting	Minimum requirement of equipment	Climbing high trees is risky, skill is required, time-consuming and involves drudgery	Manual-operated
2.	a. Manual-operated mechanical harvesting aid for climbing	A person after small training can harvest the coconut, reducing human drudgery	A person is required for the climbing tree, take time and involves drudgery	4,5
	b. Manual operated powered mechanical harvesting aid for climbing	A person after training can harvest the coconut, the time required is less, reduces human drudgery	A person is required for climbing, machine costs more than a mechanical tool to climbing	6
3.	Remote-controlled coconut harvester	A person after training can harvest the coconut, reducing to human drudgery	The device is still under development, perfection is required, time-consuming, higher cost of equipment, identifying mature coconut and cutting particular coconut is difficult	7-27, 29

Numerous research studies on automated coconut tree climbing and harvesting machines have already been done and published, which is emphasized in the above papers. This review focuses on the pros and the cons of existing technologies related to the automated coconut harvesting machine. In addition, future work is also proposed based on the shortcomings in existing technologies and the need for further development.

Automated Coconut Harvesting Machines in India

In India, various types of robots have been developed for the harvesting of coconuts. These robots can be divided into three categories as shown in Table 2. The developed remote-controlled automated coconut harvesting machines are not complete solutions for coconut harvesting and a large extent of manual intervention is required. This development of remote-controlled harvesters inspire to development of an automated coconut harvester. However, no literature has been reported on autonomous coconut harvester robots with no/minimum manual intervention. A drone-based solution for coconut harvester is desired in the future.[27]

Table 2 — Types of coconut harvesting machine/robots

S. No.	Harvesting method	Advantages	Disadvantage	Development stage	References
1	Remote-controlled coconut harvesting machine	Man does not need to climb the tree	A skilled person is required to operate the harvester	Prototypes developed	9,20-22,24,25-27, 29
2	Autonomous	No human intervention is	A costly and	Not available	NA

	harvesting machine	required	complicated design		
3	Drone base coconut harvester (semi-automatic/automatic)	One person required/ semi-automatic	Costly and complicated design, low battery life	Not available	27

A number of developments have been done on automated coconut harvesting machines with different shapes of body structures, tree gripper mechanisms, tree climbing, and descending mechanisms, vision systems, bunch cutting mechanisms, robotic arms, wireless remote control mechanisms, electronic controller components, circuitry, and other accessories. The prototype and design of some automated coconut harvesting machines and components are shown in Fig. 1.

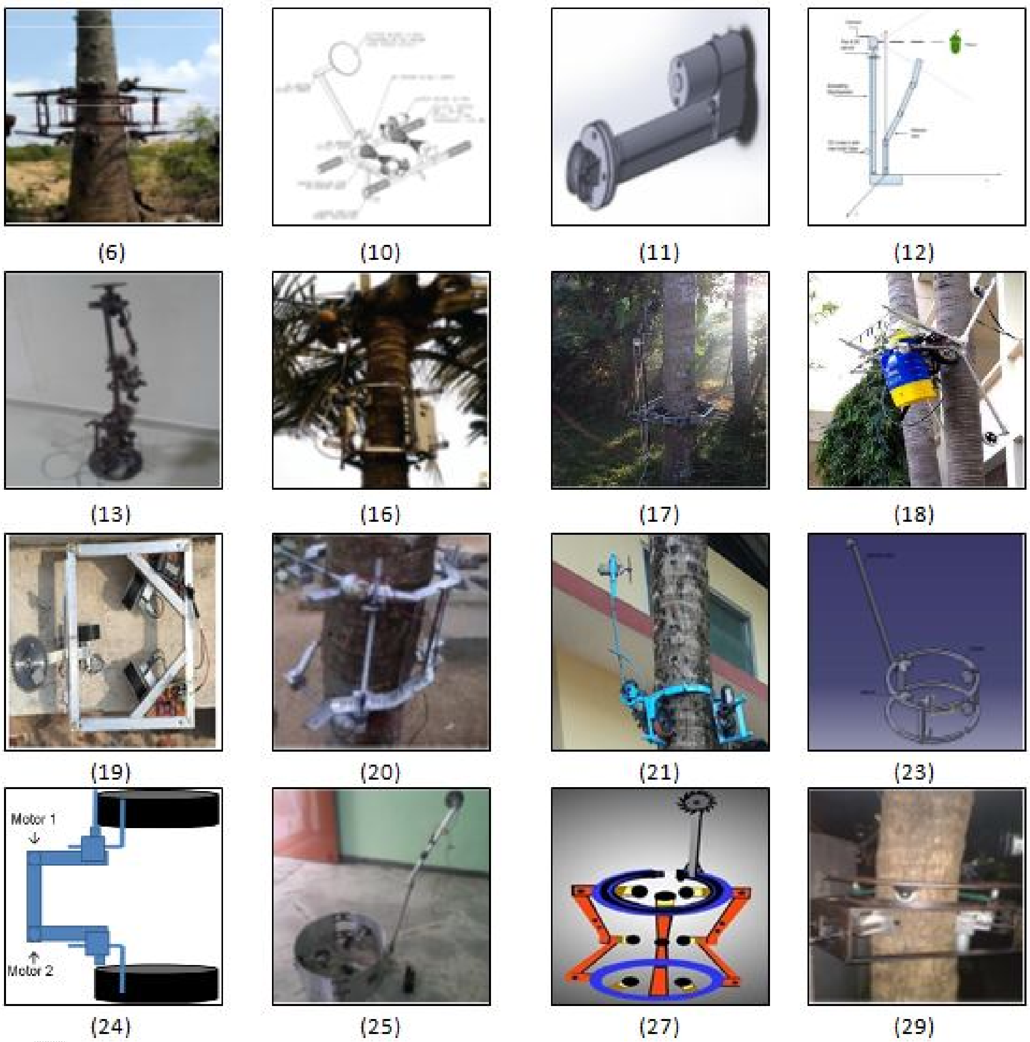

Fig. 1 — Different models of automated coconut harvesting machines

Components of Automated Coconut Harvesting Machines

A robot behaves stable only if different components of the robot function synchronously with the controller unit. The study of each component is very crucial before starting the development of such advanced robots. The identified primary components to build a robot for coconut harvesting are shown in Table 3.

Table 3 — Primary components/features of automated coconut harvesting machines

S. No.	Components/Features	Definition/Details
1	Mainframe	It is the main structure on which all other components of automated coconut harvesting machines are mounted.
2	Tree gripper mechanism	It describes the mechanism used to adjust the variant tree trunk diameter while climbing the coconut tree.
3	Tree climbing and descending mechanism	It is the mechanism by which the robot climbs the coconut tree employing mechanical and electronic components.
4	Vision mechanisms	Vision unit used in robot to identify the coconut bunches while harvesting.
5	Bunch cutting mechanism	Cutter is driven by high-speed motors to harvest the coconuts.
6	Coordination between camera and cutter	This mechanism is used in the robotic controller to handle the robotic arm for cutting the coconut bunches utilizing the vision unit.
7	Robotic arms	This describes the structural design of robotic arms.
8	Controller Unit	This acts as the brain of the robots.
9	Remote Control and Communications protocol	Robotic operations can be driven manually by using remote controller modules from the ground.

Each component of the automated coconut harvesting machine plays a vital role in its optimal performance. Automated coconut harvesting machines use a variety of components, each of which has its own advantages and limitations. The automated coconut harvesting machine developed in India has been discussed in a different section with special reference to its functional components.

Main Frame

The mainframe of the automated coconut harvesting machine is a structure on which all other components are mounted. The structural design of the main frame is very crucial to build a stable robot. There are mainly four types of mainframes i.e. circular, hexagonal, rectangular, and "Y" shapes. The circular and hexagonal-shaped frame was mostly preferred in automated coconut harvesting machines developed to date. The details of different types of frames mentioned in the literature are described in Table 4 and Fig. 1.

Table 4 — Different types of frames used in coconut tree climbing robot

S. no.	Frame type	Advantages	Disadvantage	References
1	Circular frame			
	a. Single circular frame	Simple design and less weight	Less stability	9,21
	b. Double circular frame interlinked with vertical bars	More stable than a single frame	Complex design, increased weight	15,23
	c. Double circular frame interlinked with one joint segments	More stable	Complex design, increased weight, slow movement	26

2	Hexagonal frame			
	a. Single hexagonal frame	Simple design and less weight, better grip than the circular frame	Less stable	10,17,27
	b. Double hexagonal frame interlinked with a pair of pistons and threaded rod-nut arrangement	More stability than a single frame	Complex design and increased weight	20
	c. Double hexagonal frame interlinked with an extendable and bendable continuum body made up of 2 bendable parts.	More stability or most stable	Complex design, increased weight, slow movement speed	24
3	Rectangular frame	Simple design and less weight	Less stability	19
4	Two "Y" shaped frames interlinked with four horizontal bars (at three endpoints, one pivot point)	More stability can carry additional payload	Complex design, slow movement speed	18

The main frames with two circular/rectangle/hexagonal rings connected by links are more stable than a single frame. However, the hexagonal frame gives more mounting options without additional changes in structure.

Tree Gripper Mechanism

The diameter of the coconut tree varies with the height of the tree.[26] Without a proper gripping mechanism, a robot can't climb up and may slip while climbing down. The dynamic adjustment in grip at variant trunk diameter is achieved by means of a tree gripper mechanism while climbing up and down on the tree. The tree gripper helps the robot to hold the tree properly at different heights of the tree. A spring-loaded suspension system and tyres are usually used for gripping coconut trees. During climbing, tyres make it easier for the climber to move smoothly over the bark. Spring tension varies according to the tree's diameter and generates a required force on the wheels to hold the tree properly. Additionally, the linear actuators and current sensor in combination with a closed-loop system framework are proposed for holding the tree by adapting to the variations in the tree trunk girth.[11,20] The current sensor develops current based on the load on the wheel and accordingly, the linear actuators act and apply force to hold the body to the coconut tree trunk. The increase in the number of wheels can increase stability by improving gripping action. More wheels give more stability but at the same time, it increases the weight and cost of the machine. Some of these gripper systems are shown in Fig. 1. Summary of the different types of gripper mechanisms used in automated coconut harvesting machines is given in Table 5.

Table 5 — Different tree gripper mechanisms used in coconut tree climbing and harvesting robots

S. No.	Tree gripper mechanism	Advantages	Disadvantage	References
1	3-wheeler system and springs	Lesser stability than a higher wheel system, low cost	Simpler design than a higher number of wheels	9,19, 21,27
2	4-wheeler system and springs	Lesser stability than a	Simpler design than	20,23

		higher wheel system	a higher number of wheels	
3	6-wheeler system and springs	Increase stability	Complex design, more weight, higher cost	15
4	9-wheeler system and springs	Increase stability	Complex design, more weight, higher cost	26
5	10-wheeler system	Increase stability	Complex design, more weight, higher cost	29
6	Linear actuator and current sensor are utilized for developing a holding setup that adapts to the variations in the tree trunk.	Increase stability	Complex design, more weight	11, 20

Generally, spring-loaded wheels pressed against the tree trunk are used as a tree gripping mechanism. In this type of gripping system, the wheel is pressed at a high presser at bottom of the tree due to the higher tree trunk diameter whereas the pressure sensor-based actuator for the tree gripping mechanism exerts the same amount of pressure throughout the length of the tree with varying trunk diameter on the tree for smooth climbing and less chance of failure of gripping at thin top stems.

Tree Climbing and Descending Mechanism

The robot climbs the tree on a wheel driven by DC motors. The motors can rotate clockwise and anticlockwise direction for climbing up and down from the tree. The automated coconut harvesting machines usually climb by means of three types of motion namely continuous, discrete, and serpentine.[23] The automated coconut harvesting machines mainly use continuous motion because of less energy consumption and faster speed. Robots with discrete motion consist of two parts of frames interlinked with one mechanical arrangement. The first part is locked on a certain place of the trunk and the other part moves while climbing.[20,22,24] The application of serpentine motion had not been reported in any literature on automated machines for coconut harvesting. Some of these mechanisms are shown in Fig. 1. The advantage and disadvantages of the different systems are shown in Table 6.

Table 6 — Tree climbing and descending mechanism of coconut tree automated coconut harvesting machine

S. No.	Tree climbing and descending mechanism	Advantages	Disadvantage	References
1	Frame driven by motors (continue motion)	Less energy consumption, high speed	Achieving the stability of the robot is a major challenge.	9, 15, 17-19, 23, 26, 27, 29
2	Upper frame moves whereas the lower frame remains stationary and vice versa (discrete motion)	More stable than continuous motion.	High energy consumption. Slow speed.	20, 22, 24

Climbing up and down harvesting machines is mostly driven by DC motors for faster climbing. However, harvesting machines with double interlinked frames are more stable on the tree but it takes much time to reach the top of the tree.

Vision Unit

Machine vision technology can identify and track objects in the image through digital image processing techniques. The camera attached to the robot captures images of coconut bunches on the coconut tree. The automated harvesting of coconut is done by using different algorithms for detection and determining the coordinates of the coconut bunch. The robotic arm is then moved toward the coconut bunch using the determined coordinates. As per the literature, USB and wireless cameras were used in the robots as shown in Table 7.

Table 7 — Types of the camera mounted on the robot

S. no.	Camera Mount	Advantages	Disadvantage	References
1	No camera mounted-operated by human vision	-	Depending upon expert manpower, the decision will be difficult for a tall tree	20-26
2	USB/ Wireless camera	USB/ Wireless camera is helpful for on-board processing	The image needs to transfer to the processing unit.	9, 13, 15-17, 27, 29

Harvesting machines without a camera are operated manually by human experts from the ground. But, machines equipped with a camera work on an automated machine by taking real-time decisions during coconut harvesting. An automated harvester machine has an on-board intelligence to identify coconut on a tree by means of digital image processing technology and an intelligent decision support system.[12,16,17] The coordinates of the identified coconuts are used by the microcontroller to guide the robotic arm while harvesting.[13] But, the semi-automated machine is controlled from the ground by an expert person, and the harvesting operation is performed manually by visualizing the live stream of the camera feed on the monitor on the ground station. Zigbee wireless protocol and sensors are used for wireless transmissions of live feed between the ground station and the harvesting machines.[9,21] Advantages and disadvantages of different harvesting mechanisms are discussed in Table 8.

Table 8 — Harvesting mechanism used in automated coconut harvester

S. no.	Harvesting Mechanisms	Advantages	Disadvantage	References
1	Manual	No camera and onboard processing are required.	Expert manpower is required.	20-26
2	Semi-Automated	Live feed from the camera is used.	Expert manpower is required.	9, 15, 27, 29
3	Automated	On-board image processing and intelligent decision support model for identification of coconut and coordinates, intelligent navigation of the robotic arm	Required a high configuration of SoCs to execute the algorithms.	13, 16, 17

Algorithms reported in the literature for the automated detection of coconut and its buches are shown in Table 9. Coconut bunches were identified by supervised machine learning algorithms using K-means clustering and the SVM classifier is used.[12] The applicability of the image processing and particle swarm optimization (PSO) method to find the position of the coconut is described.[16] The use of the steady-state genetic algorithm to detect the coconut and harvest it by using an extendable arm equipped with a cutter is reported/claimed.[17]

Table 9 — Algorithms reported for the detection of coconut in the image

S. no.	Algorithms	Advantages	Disadvantage	References
1	K-means clustering + SVM classifier	Coconut bunches automatically get identified using machine learning algorithms.	Training of the machine learning module with an improper data set may create erroneous behaviour.	12
2	Particle swarm optimization algorithm	Coconuts are automatically detected using the PSO algorithm.	The accuracy rate of coconut detection in the cluttered background is reported to be 80%.	16
3	The steady-state genetic algorithm	The position of the coconut is detected using a steady-state genetic algorithm	-	17

It is desired to develop an autonomous harvesting machine where the vision unit plays an important role. An autonomous harvesting machine must be equipped with a camera and built-in intelligence for detecting the coconut in real time on the tree and performing the harvesting operation without any manual intervention.

Robotic Arm

The robotic arm is the most important part of the main actuator of a robot on which the effectiveness/efficiency of the harvesting robot depends. A robotic arm is equipped with a camera and cutter for detecting and harvesting the coconut. Based on the reported literature, the arm designs can be divided into two main classes i.e. robotic arms without a circular mounting ring and with a circular mounting ring (Table 10). For the correct positioning of the arm for cutting of coconut bunch either the main frame needs to rotate on the tree or the arm needs to rotate 360 degrees by using a mechanism. The robotic arms without a circular mounting ring have less flexibility as it is unable to rotate around the trunk of the tree. Whereas, the arm mounted on a circular ring has more flexibility in comparison to the first type of mechanism. These robotic arms are further classified into different sub-categories based on their degree of freedom (DOF). The increases in DOF increase the flexibility of the robotic arm which simultaneously results in more complexity. Some of the robotic arms are shown in Fig. 1.

Table 10 — Different robotic arms used in coconut harvester robots

S. No.	Robotic arm rotation	No. of Robotic arm	Details	Advantages	Disadvantage	References

1	Robotic arm without a mounting on a circular ring	One robotic arm	Robotic arm with 2 DOF	Movement of the arm around the tree trunk, less complexity	Provide less flexibility than a higher DOF arm	24
			Robotic arm with 3 DOF	Movement of the arm around the tree trunk, less complexity	Power consumption may be high due to the four servo motors. Increase complexity for automatic handling.	9,20
			Robotic arm with 4 DOF	Provide more flexibility.	Increases weight, high complexity to handle.	14
			No degree of freedom /360deg movement to the arm	Movement of the arm around the tree trunk, less complexity	Provide less flexibility than a higher DOF arm	17,21
		Two robotic arms	One for plucking and another for cutting	It can hold the bunch with one arm and another for cutting	High complexity to handle. Increase in Weight.	22
2	With circular ring base for movement of the arm around the tree	One robotic arm	The 1st ring is a hollow track that is made for the cutter arm to follow in a revolutionary path around the trunk of the tree**.**	The robotic arm can move around the trunk.	Higher complexity.	26,27

The previous study shows that a 3-DOF arm with two linkages is more useful for harvesting coconut bunch. The movement of the robotic arm around the tree (360 degrees) will give the automated system more flexibility to cut the coconut branch.

Bunch/Coconut Bunch Cutting Mechanism

Most of the literature has reported the rotor blade as the cutter driven by a high-speed DC motor.[9, 17,20,21,27] The rotor blade is attached to the robotic arm. Generally, the base of the robotic arm is static but a 360-degree rotating robotic arm with a cutter that can rotate in all directions for the coconut harvesting operation was reported.[15] Whereas, two robotic arms, one to pluck the required coconut and another to cut the bunch of coconuts.[22] Usually, circular cutting discs were used for cutting coconut bunch stems. It is a cheap and easy tool.

Coordination between Camera and Cutter

Coordination between the camera and the cutter is a very crucial action for automated coconut harvesting machines. The robotic arm with the cutter is placed at the exact position with respect to the coconut bunch for harvesting coconut from the tree (Table 11). After properly positioning the arm with a cutter on the stem of the coconut bunch, a high-speed DC motor is triggered to harvest the coconut. Human intelligence is used for coordination between camera and cutter for manual harvesting. An expert person can handle the harvesting operation from the ground.[20-26] Coordination between camera and cutter for semi-automated machines is achieved by observing the live stream on LCD and triggering the remote button by a human expert.[9,15,27,29] However, in an automated harvesting robot, coordination between the camera and the cutter is a challenge. A laser range method to track the robotic arm until it reaches the required location of the coconut bunch was reported.[13] But, these techniques are applicable only if, the laser red dot in the image is visible and distinguishable. The fixed camera on the frame can give a static location of the target point of cutting; therefore, fixing the position will be less complex. But it is complex to dynamically find the target location when both the camera and cutter are moving.

Table 11 — Different systems used for coordination between camera and cutter in coconut harvester robots

S. no.	Coordination between camera and cutter	Advantages	Disadvantage	References
1	Camera + PC or android phones + Zigbee module+ RF Remote. (The user has to manually command using an RF transmitter to cut the coconut bunch.)	Manually harvest the coconut.	Depends on human decisions.	9,15,27,29
2	Camera + Laser light. (The laser will act as a reference and using mathematical analysis, the arm with cutter can be guided.)	The cutter arm can be guided using a laser beam and a camera.	The position of the camera setup should be adjusted such that the laser pointer is pointed to the object to which the distance is to be calculated.	13

Controller Unit

Different controller boards were used in the earlier studies in which PIC 16F877A microcontroller/ PIC18 Microcontroller, Arduino Mega 2560 /Atmega 2560/ ATmega328, Arduino UNO and PDI 6255MG were used by different researchers.[9,14,15,17,20,24,27,29]. In order to develop autonomous robots, a controller board with Compute Unified Device Architecture (CUDA) can be useful as it can perform tasks with greater performance.

Remote Control

All manual and semi-automated robots use radio frequency (RF)-based wireless remote controlled to perform the operations of the robot remotely from the ground by human experts.[9,15,20-22,24-27,29] RF transmitter and receiver are used in RF-based wireless communication via a switch-based remote controller.

Most of the coconuts harvesting robots are manually controlled by means of remote control by seeing the output of the camera on screen. This process should be automated, so that manual intervention can be minimized.

Current status of automation in coconut harvesting machines and challenges

A number of studies have been conducted worldwide on the automation of coconut harvesting machines. None has reported 100% accuracy in performance. The limitations in previously developed models would help to identify the future work that helps to make a better harvesting robot with higher performance accuracy. The future scope for the development of autonomous coconut harvesting machines proposed by different researchers is discussed. In his design, hydraulic pistons were used instead of threaded rods in order to increase climbing speed. But at the same time, the system becomes more complex and expensive.[20] The increase in the climbing speed of the coconut harvesting machine was also suggested. The maximum reported speed of climbing on a coconut tree was 0.9 ms^{-1}.[17] There was a suggestion to place a camera at the tip of the movable arm so that the operator can easily find the target area of the sprayer. However, some researchers also used a camera to detect ripe coconuts and identify the branches to be cut.[21,23,29] One researcher suggested using a drone for the harvesting of coconut.[29] Increased movement of a robotic arm by increasing DOF and by using a telescopic rod was also suggested.[6,21,25,26,29] Development of a robot that can climb on irregularly shaped trees with branches, more intelligent with increased locomotory speed was suggested.[24] Further, the inclusion of pesticide sprayers, cleaning the treetops, etc. suggested for making it more versatile and profitable.[29]

Way Forward

The coconut harvesting machines developed so far are not fully autonomous. These machines require expert manpower and works on a single tree basis. Almost every developed machine is operated from the ground with the help of a remote. Whereas extensive research work is mandatory for the development of an autonomous robot that can perform coconut harvesting and other suitable jobs for coconut trees in the field without any continuous manual intervention. An autonomous robot should take initial instruction from the operator and then the rest of the work is performed automatically on their own using inbuilt intelligence.

The above component-wise review of already developed machines edifies to decide the best components for the development of a stable autonomous robot for these purposes. Using those components, a multipurpose robot that will be fully autonomous, comparatively light-weighted, modularly assembled, has durable battery life, is easy to operate, weather protected and robust may be developed. Also, additional sensors can be attached to the robot for better functionality. Broadly, this robot has three primary modules, an autonomous vehicle module for climbing up and down by adjusting the tree trunk diameter, a coconut harvesting module, and the inbuilt intelligence module which acts as the brain of the robot. The algorithms will be implemented on the intelligence module to achieve the autonomous feature of the robot and enhance the capability of the robot to achieve functionalities like moving across the ground, detecting trees, climbing the tree, harvesting coconut/applying insecticide, coming down from the tree, detect another tree automatically or semi-automatically using initial GPS guidance. A GPS-based localized map module can be developed to define the area of coconut fields or individual coconut trees. This acts as a path planner for the robot. Manual intervention only requires placing the robot in the coconut field, changing of battery, attaching/detaching the insecticide module or harvester module, etc. A master controller application can activate/ deactivate certain modules like deactivating insecticide modules while harvesting and so on.

Conclusion

In the past few years, much work has been done on developing an automated coconut harvesting machine but an autonomous coconut harvester is still a long way off. The above review on the coconut harvester robot shows a pathway for the development of an autonomous coconut harvesting machine. The review suggests that the most appropriate components to develop a stable multipurpose autonomous robot that will be low-cost, competitively light-weight, easy to operate, and robust. Additionally, a GPS-based module can also be equipped to the robot for creating a mission plan to achieve GPS-guided automated movement of an autonomous robot in the field. This mission plan helps to achieve the harvesting of coconuts from all the trees in a marked field area in a single instruction.

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