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## Autonomous control and implementation of coconut tree climbing and harvesting robot

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### Abstract

Last few decades have witnessed a rapid development in robotic technology. Different types of intelligent machines which facilitate various tasks in industry environment are becoming popular. This paper focuses on designing a low cost coconut tree climbing and harvesting robot. The kinematics and the motion of the robot are designed by referring to the motion of coconut harvester. The robot consists of two segments joined by a pair of threaded rods coupled to motors. The mechanical frame is designed in draft sight software and is implemented using aluminum segments and threaded rods. It has two arms driven by motors for holding. Locomotion of the robot is achieved using six motors out of which four motors are used in two hands and other two are used for upward and downward motion. The other part is a robotic arm for cutting down the coconuts. The robotic arm is attached on top of the climbing part. The operation of the cutting arm is done manually from the ground using a remote. The robot is automated using Arduino-Uno, motor H-bridge drivers, current and level sensors and other supporting circuits. The forward and the reverse motion of the motors are controlled by the Arduino through driver modules. Robot has automatic and manual functions fully controlled by the end-user. This paper has taken into account of the safety, reliability and the ease of use. A locomotion algorithm is developed to provide the robot with an autonomous capability for climbing. The prototype of the robot is implemented and tested successfully.

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**Keywords:** Tree climbing robot; Hexagonal structure; degree of freedom; DC high torque motors; bevel gears.

## 1. Introduction

Coconut and Coconut products have been in use for decades and have become an essential part of day to day life all around the globe. But the percentage of population taking up coconut plucking as their means of living is steadily decreasing. Moreover coconut tree climbing involves a lot of risk. Autonomous coconut tree climbing robot is a solution for this. The applications and capabilities of the climbing robots differ according to their mechanical structure and design. Climbing robots should be able to deal with trees having difference surfaces and cross sections. Robot is capable of climbing trees and by modifying the robot the applications can be extended to cutting down coconuts, cleaning the tree tops and spraying pesticides according to the end effector attached, which serves multi purposes. A locomotion algorithm was developed to provide the robot with an autonomous capability for climbing.

The aim of the project is to design a coconut tree climbing robot which can be replaced with the men climbing coconut trees. The robot should be able to control from the ground. The operation should be simple so that even an illiterate person can operate the robot with a little training. It should be safe to handle and at the same time, it should be eco-friendly and should not damage the tree it is climbing. And most importantly it should be simple and cost effective so that the normal people can afford it.

## 2. Mechanical Design and Implementation

The overall performance of the robot clearly depends on the mechanical design of the robot. The coconut tree climbing robot should be able to climb through the irregular surface of the coconut tree. After analyzing the various possibilities and interviewing various farmers, various methodologies were planned and analyzed and finally combined the advantages of all to build the final model. The front view and the top view of the final model are shown in fig. 1(a) and (b) respectively.

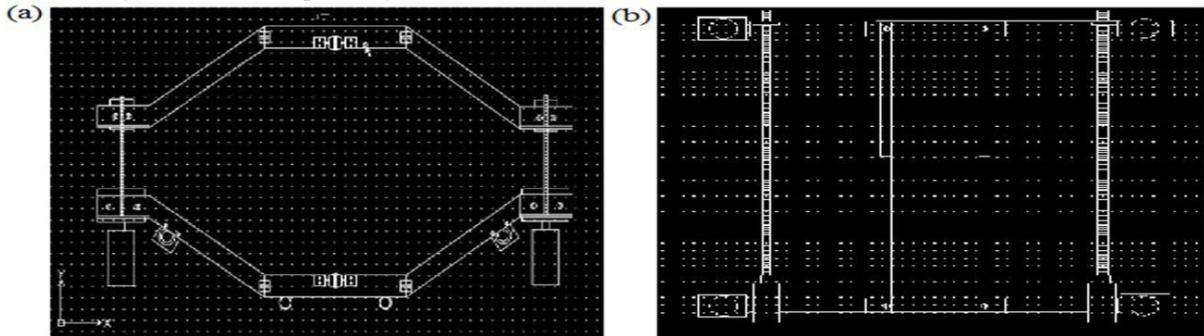


Fig. 1. (a) Top view; (b) Figure 2: Front view

Figure 1 shows the top view of the robot. The structure clearly shows the holding mechanism of the robot. A pair of such structures is provided at the top and the bottom of the robot. Figure 2 shows the front view of the robot. The two holding mechanisms in the top and the bottom are connected through a pair of pistons and threaded rod-nut arrangement. This mechanism provides the required linear motion for the robot to climb. The whole mechanical body of the robot is made of aluminum L sections to reduce the weight.

The holding mechanism mainly consists of two structures connected through two threaded rods attached to the motors as shown in figure 1(a) [1]. The motors with the threaded rods are attached at one of the structures and the other structure consists of a nut which is properly aligned so that when the motor rotates, the threaded rod and the nut provide the to and fro motion. The structure to which motor is attached is fixed to the body and the other one is moving. As motor rotates, the moving part moves to and fro to hold and release. Due to the irregular surface of the coconut tree, small tires are provided for the smooth motion over the bark during climbing.

The vertical motion is also provided by the threaded rod and nut arrangement. [2]To provide the required

power, two motors are used for vertical motion. Two pistons are also used in the body as shown in figure 1(b). Such an arrangement will reduce the vibration, gives strong support, symmetrical structure maintains the center of gravity at the middle of the body and also reduces the possibilities of tilting sideways during climbing.



Fig. 2.(a) Top view; (b) Front view

The Fig.2. (a) and (b) shows the actual mechanical body made for the robot.

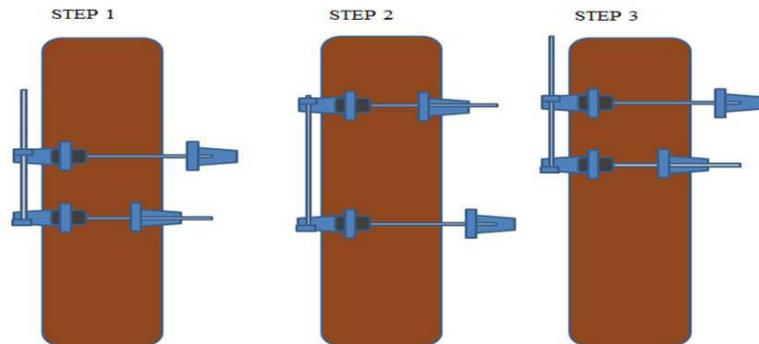


Fig.3. Process of tree climbing

Figure 3 shows the process of tree climbing. In the climbing process, first the robot will be attached to the tree. At the beginning both the upper part and the lower part will be closed. Then climbing process starts. Lower part will be released first. Metal geared motors rotate anticlockwise to provide the vertical motion. Lower part will be closed then. Now upper will be released. Metal geared motors rotate clockwise to provide the vertical motion again and the upper part will be closed. This completes one full step of climbing process.

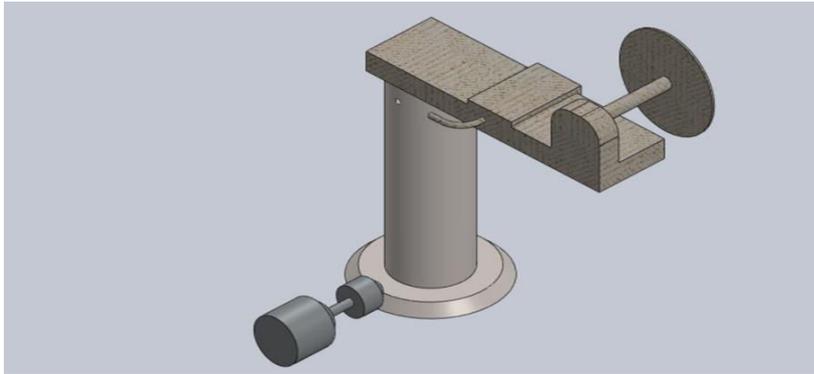


Fig.4. Design of end effector arm

The end effector of the robot shown in fig. 4 has a 3 degree of freedom. Here degree of freedom implies the number of free motions the joints of the robot are able to perform. As we have been told that the robot must be very light but hard enough to withstand any pressure, we have used a hollow, cylindrical steel pipe as the vertical arm of the robot. The arm used for cutting is mounted on top of the cylindrical part. The cutting arm has a manual length adjustment, used in case the branches are far away from each other. The length adjustment is made by using a knob, which when rotated increases or decreases the length of the arm. The vertical arm is rotated with the help of a high torque dc motor, coupled with a bevel gear system. The vertical arm is mounted atop the bevel gear so that the arm moves along with the gear. The motor for cutting has high speed of 1000rpm. The motors used have a rating of 12V DC.

### 2.1 DH Convention of the Arm

Every manipulator or robot has four main parameters which describes its kinematics. These parameters are given by the DH Convention or otherwise called as Denavit Hartenberg Convention [12], figure 5. The DH convention is used to find the coordinates of the final position of the robot with respect to the reference frame. The reference frames are attached to the links of the manipulator and using the procedure of DH Convention, we find out the transformation matrix. The transformation matrix is the matrix which forms after the reference matrix is transformed through the spatial kinematic chain. The four parameters are  $d$ ,  $\alpha$ ,  $\theta$ ,  $r$ . The DH convention and the transformation matrix of the 3DOF robot used is shown as:

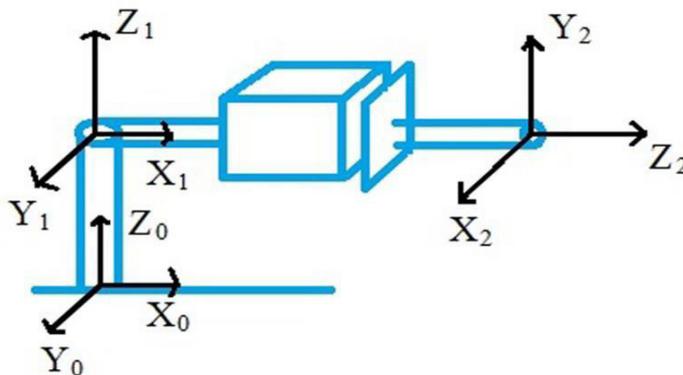


Fig.5. DH Convention

Table1. DH Convention of the arm

Link	Joint Angle ' $\theta_i$ '	Link Offset, ' $d_i$ '	Link Length, ' $a_i$ '	Link Twist, ' $\alpha_i$ '
1	0	$d_0$	0	$\theta_0$
2	0	$d_1$	$-90^\circ$	$-90^\circ$

$$A_0 = \begin{bmatrix} C_0 & -S_0 & 0 & 0 \\ S_0 & C_0 & 0 & 0 \\ 0 & 0 & 1 & d_0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_1 = \begin{bmatrix} 0 & 1 & 1 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & -1 & 0 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A = A_0 \cdot A_1 = \begin{bmatrix} S_0 & C_0 & C_0 & 0 \\ -C_0 & S_0 & S_0 & 0 \\ 0 & -1 & 0 & d_0 + d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

## 2.2 Bevel Gears

Bevel Gears are a type of gear system which has conical shaped gear system, figure 6. The teeth of the gear are on the surface of the conical shaped region. The gear system is mounted on the shafts which are perpendicularly coupled. There are different kinds of bevel gears. The types of bevel gears mostly depend on the type of teeth and shape of the gear. Here we use the kind of bevel gear as shown in the figure 6. The bevel gears once perfectly coupled along the perpendicular axis, it gives a steady and stable rotation. Hence bevel gears were preferred as the base rotating part of the robot.



Fig.6. Bevel Gear Assembly

## 3. Motor selection and design

The motors are usually selected based on the torque and rpm requirements. In the mechanical model of the robot, we are using a threaded rods and nuts attached to the motors to achieve the required motion. Hence while selecting the motors; we need to calculate the torque required by the motor to rotate the threaded rod in a nut. The power rating of the motor should be greater than the power required to rotate the threaded rod with load at required rpm. The motion between thread rod and the nut is like a body moving on an inclined plane.[5] Figure 7 (a) and (b) explains this motion.

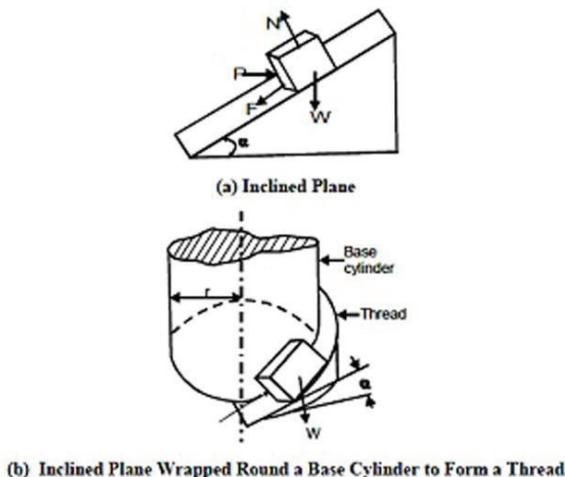


Fig.7.(a) and (b). Nut and screw motion

The body of weight  $W$  is pushed up the inclined plane by a force  $P$  which acts upon the body horizontally[5]. This inclined plane is bent round a cylinder in Figure 7(b) and same body is being pushed up the plane while force  $P$  remains horizontal but also tangential to circular path of the body. This illustrates how the motion of the nut on the thread is similar to motion of a body on an inclined plane. The weight of the body on the inclined plane is replaced by weight carried by the nut in axial direction. The force  $P$  is applied by the help of a wrench and  $W$  may be the reaction developed between surfaces of contact.

The force  $P$  has to overcome the friction as well as cause lifting of the body in vertical direction.[5] To find the relationship between the force  $P$ , called effort and weight of the body  $W$ , we have to consider the equilibrium of the body on inclined plane as shown in figure 8 (a) and (b). The sum of the forces perpendicular to the plane and sum of the forces along the plane should separately be zero to satisfy the condition of equilibrium.  $\mu$  is taken as coefficient of friction between body and the plane.  $\mu = \tan \phi$  where  $\phi$  is the angle of friction.

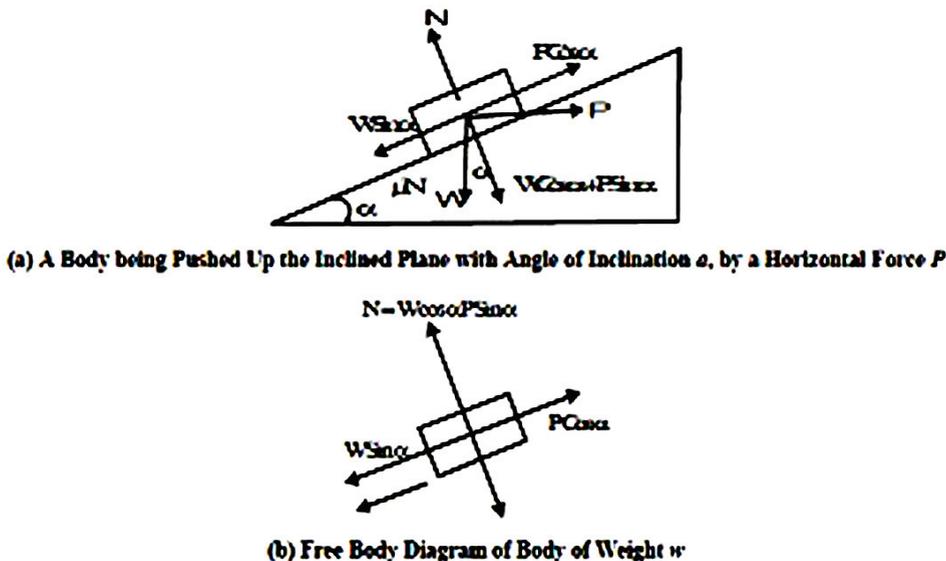


Fig.8 (a) and (b)

$$P = W \tan(\alpha + \phi)$$

Hence the torque required to move the screw against the (1)

$$M_t = W \tan(\alpha + \phi) \frac{d_m}{2} \quad (2)$$

Coefficient of friction between nut and screw  $\mu = 0.16$

The major diameter is  $d = 10\text{mm}$

Pitch = 2mm

We know the relation between  $p$ ,  $d$  and  $d_1$  as

$$P = d - d_1 \quad (3)$$

$$d_m = \frac{d_1 + d}{2} \quad (4)$$

$$d_1 = 2d_m - d$$

$$p = 2(d - d_m) \quad (5)$$

$$d_m = d - \frac{p}{2} \quad (1)$$

$$\text{Hence } d_m = 10 - \frac{2}{2} = 9$$

$$\tan \alpha = \frac{p}{\pi d_m} \quad (6)$$

$$= \frac{2}{\pi \cdot 9} = 0.0707355$$

$$\therefore \alpha = 4.06106$$

Now, coefficient of friction between nut and screw

$$\mu = 0.16 = \tan \phi$$

$$\text{Hence } \phi = 9.0927$$

Now we need to find out the weight acting on the screw. Consider the free body diagram shown in figure 9. The total weight of the robot is 3kg and let the weight of the hand be 2kg which makes total weight as 5kg.

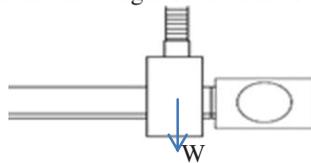


Fig.9. Force acting on the axis of the threaded rod

Let  $W$  be the force in Newton acting on the axis of the threaded rod. Then the total force can be calculated using the free body diagram of the system. The total force acting at that point will be the sum of weights of the structure, frictional force on either sides of the robot. When the robot moves upward, the frictional force will be acting against the motion, which will be proportional to the weight of the structure which is in contact with the surface. But since robot is placed with wheels which aid the smooth motion over the coconut tree, let us neglect the frictional force. We have two motors. Hence let us assume that we are equally distributing the work with two motors.

Hence  $W$  for each motor be  $W = 2.5\text{ N}$

The torque required to move the screw against the load

$$M_t = W \tan(\alpha + \phi) \frac{d_m}{2} \quad (7)$$

$$= 2.5 \times \tan(4.06106 + 9.0927) \times \frac{9}{2} = 2.62\text{ Nm} \quad (1)$$

In order to select the motor, we need to consider the power. Suppose we need to rotate the motor at 100rpm and the at a torque of 2.62 Nm, the power required is

$$\text{Power} = \frac{2\pi N_{\text{requ}} T_{\text{requ}}}{60} \quad (8)$$

$$\text{The actual power that a motor can deliver} = \frac{2\pi N_{\text{rated}} T_{\text{rated}}}{60} \times \text{efficiency of the motor} \quad (9)$$

(1)

The power which can be delivered should be greater than the power required. The power required = 27.436 watts. We are using 12V DC metal geared motor which has an rpm of 200 at a rated torque of 1.8Nm and an efficiency of 0.95. The power that can be delivered by this motor = 35.8141watts. This motor is the only motor which can deliver this power. The design is restricted to availability of the motor. Hence this motor can be used.

For our end effector we have used two DC motors. One motor has low rpm, high torque, which is coupled to the bevel gear system, figure 10. We have chosen the high torque motor to rotate the gear system as it forms the base of the robot and the robot needs to withstand a lot of force while in operation. We have used a Johnson 12V dc, 10 RPM, 38kg-cm motor for the gear system.

For the cutting operation we have used a high speed motor, figure 10. This high speed motor is attached with a chiselled teeth circular blade, capable of cutting the strong coconut branches. The blade is made up of steel, like the ones used for cutting wood. We have used a Johnson 12V dc, 1000 RPM motor for the cutting part.



Fig.10.The arm with bevel gear arrangement and circular saw teeth blade for cutting

#### 4. Automation

The tree climbing robot is automated using Arduino Uno. Figure 11 (a) shows Arduino Uno [7]. Arduino Uno is having a 16MHz Atmega328 processor with 32KB flash memory and 2kb RAM. It has 6 analog input ports and 14 digital I/O ports out of which 6 of them are PWM. The controller is coded to control the drivers in the sequence required for climbing.

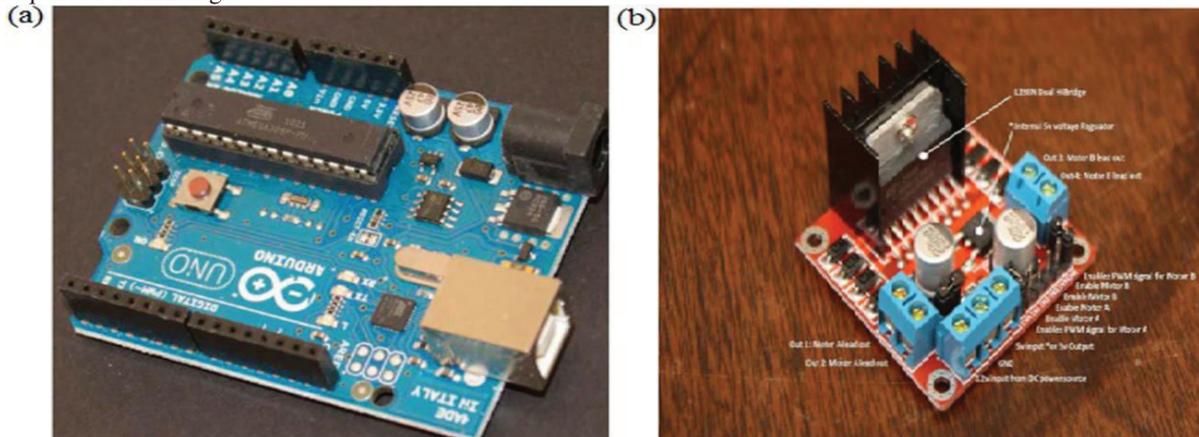


Fig. 11(a) Arduino Uno Board; (b) L298N H bridge driver

The robot has six motors which are controlled by three L298N H bridge motor controllers[8]. Figure 11 (b) shows L298N H bridge motor controllers. This driver contains a dual H bridge L298 IC with freewheeling diodes and internal regulators. The 12V supply given to the input of the driver will be switched to each channel according to program. The maximum current carrying capacity of each channel is 2Amps. The driver has six control pins[8]. Two pins are used to enable or disable the channels and the rest of the pins are used for the polarity control of the channels hence the direction of rotation of the motor.

During the climbing process, we need to detect the point of tightening and stop the motors. We also need to detect the upper and lower extremes of level for vertical motion. When the load on the motors increases, motor draws more current. By detecting the increase in current, the motor tightening can be detected. Current sensors can be used for this purpose. Properly calibrated timers can also do the job which saves the cost of current sensors. Another method is the use of very low value resistance in series with the terminal of the motors and calibrating the voltage drop which is proportional to the current drawn by the motor. To detect the upper and lower extremes of vertical motion, either IR sensors or push button – disk arrangement can be used. To keep the cost to the minimum, the prototype uses push button-disk arrangement. Two disks are mounted on the upper and lower extremes of the threaded rod. Push buttons are placed on the stationary part of holding part and are aligned with the disks so that during vertical motion, when the robot reaches upper and lower extremes, the disks press the push button and send signals to the controller. The system requires regulated 5V power supply for difference ICs and 12V power supply for motors. This can be provided using batteries or by rectifying and filtering the single phase power supply. The power supply should be capable of providing a maximum current of 2 amps. The whole circuitry is made into a board shown in figure 12 (a).

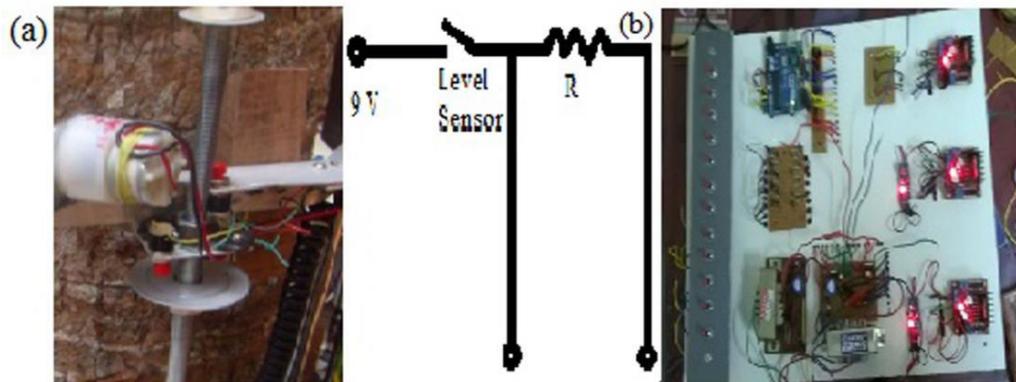
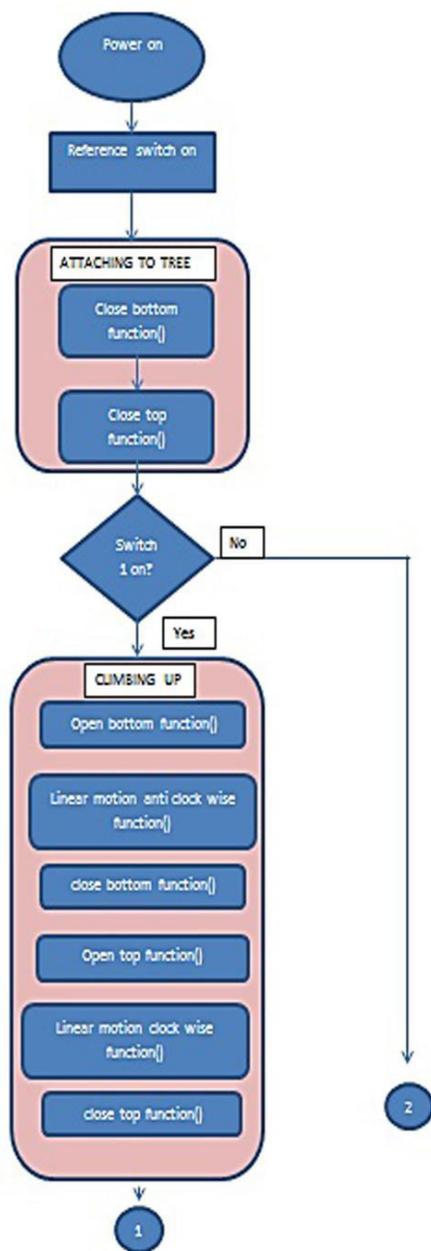
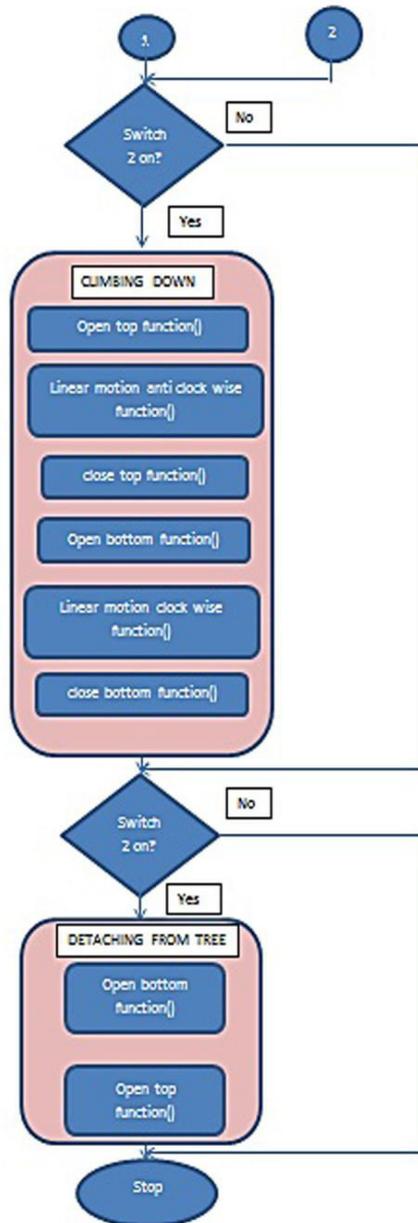


Fig.12. (a) Level sensing; (b) Final Control Board

Due to the irregular surface of the coconut tree, there are chances for the failure in proper holding while climbing. The failure may be detected only when the other arm is released. To prevent the robot from falling, the controller is programmed such a way that, a set of pulses of holding signal is given to one arm when the other arm is releasing. This will make sure that the holding is perfect. Apart from automatic climbing up and down, the controller is also programmed with manual override in which the person controlling the robot can control each and every part of the robot manually using couple of switches. Finally the end effector can be controlled manually using switches to control the rotation of the arm and the chiseled.

## 5. Control algorithm flow chart





## 6. Future work

The disadvantage of the prototype is that the climbing process is slow. Also the climbing process fails if there is misalignment in threaded rod and nut. We can overcome these disadvantages by using hydraulic pistons instead of threaded rod but the cost and weight of the product will increase drastically. Depending on the end effector attached to the robotic arm, the applications can be extended to cutting down branches, spraying pesticides etc. By using hydraulic pistons instead of threaded rods, the speed of climbing can be increased. But the system becomes more complex and expensive.

## 7. Conclusion

The paper presents the design and implementation of a low cost autonomous coconut tree climbing and harvesting robot. By considering the advantages of different models of mechanical frames, a final model is selected

and implemented. The selected model is automated using Arduino Uno, drivers, sensors and other supporting circuits. The prototype of coconut tree climbing robot is made and tested successfully. The overall cost of the product is less than 4000. So people can afford the robot at this price. Depending on the end effector attached to the robotic arm, the applications can be extended. By using hydraulic or pneumatic pistons instead of the threaded rods, the process of climbing can be made faster.

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