TREEBOT: AN AUTONOMOUS TREE CLIMBING ROBOT UTILIZING FOUR BAR LINKAGE SYSTEM

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ABSTRACT

Last few decades has witnessed a rapid development in robotic technology. Different types of intelligent machines which facilitate various tasks in industry environment are becoming popular. The work presented in this paper, focuses on designing Treebot: a tree climbing robot. Our prime consideration in designing treebot is of the mechanical structure and method of gripping. With arms involving a four bar linkage system and screw mechanism. The mechanical structure is designed to move the structure upwards against the gravitational forces in successive upper body and lower body movements similar to a tree climber. The gripping is designed in a way to hold the upper or lower part of the structure to the tree facilitating the upward movement. The results shows that the treebot can successfully climb the trees with diameter in the range 15 cm to 25 cm.

Keywords: Tree climbing, Gripping, Robotic arm, Four-bar linked arms, Bio-inspired design

1.0 INTRODUCTION

Climbing robots have many applications and their capabilities of the robot differ according to the mechanical design. Climbing robots should be capable of dealing with different surfaces and adapt with a variety of cross-sections. The most critical challenge here is to move one part of the structure with respect to the other part against gravitational force.

The scope of this project is limited to climb coconut trees having diameters between 15 and 25 cm. Therefore, maintaining sufficient friction force capable of handling the self-weight, maintaining the stability of the structure while in motion, reducing the total weight, and achieving the precise gripping are the important parameters that have to be considered.

We identified several features such as: *Weight*; It effects the gripping system of robot and power consumption. *Variation of cross-section;* the robot should be capable of adjusting to the varying cross-section of the tree during upward and downward movements. *Gripping system;* the robot should grab the tree firmly to maintain its positions during the operation.

There are several techniques discussed in research for gripper design in vertical climbing robots. Vacuum suction method was one technique which we were trying to implement. Although, this method perfectly suits a wall climbing robot it was rejected as we would not achieve precise gripping due to irregularities on the surface [1]. Further, although it is advisable to use pneumatic system in order to expect better performance out of suction method, the cost is high. Tire based climbing system can climb the tree fast but the problem is that they require a strong braking system which can control the fast linear motion during the downward journey [1]. Further, if our robot only had one platform that wrapped around the whole tree and had its own wheels to drag itself up, could climb the tree without much problem, but during the decent it would face a

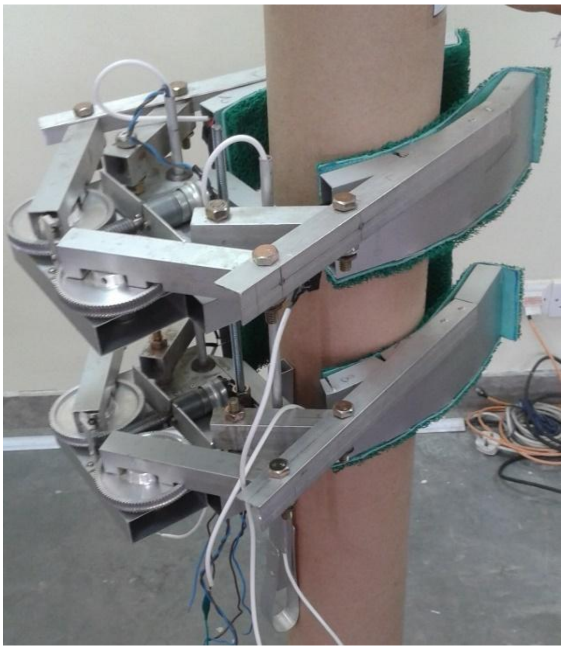


Figure 1: Treebot

huge problem while trying to adjust to the changing cross-section while not losing the contact with tree. In this case, if it expands the arms too much robot will drop. We used Aluminium to reduce the weight, as it was estimated that the maximum weight should not exceed 5 kg as per the mechanical calculations carried out. The major factor that caused the imbalance of the robot is the irregularities of the tree trunk surface. We therefore use rubber material for the inner contact section of the arm to grab the tree regardless of the irregularities.

It was decided to use DC motors for the automated tree climbing robot equipped with worm gear systems which rotates the gripping arms. First, treebot is attached to the trunk with the aid of grippers which held onto the trunk and provide adequate friction such that it does not slip. The driver motors used for climbing overcome the gravitational force due to its weight. The number of arms implies a greater degree of freedom for movement, with motors and sensors for each, results increasing the complexity of control, the weight of machine and cost. There are tree climbing robots which operates either by means of mechanical or pneumatic controlling. We have chosen mechanical controlling system as it is easier to operate, control with great accuracy, and cost effective.

We did many research on different designs and gripping methods: Robots like Dante II [2] navigated using tether assisted climbing and rappelling. Lemur [3] robot, which climb near vertical surfaces in a static fashion with prior knowledge of adequate holds focusing on space exploration. Mini-Whegs [4] has impressive horizontal mobility and capable of climbing smooth vertical glass surfaces.

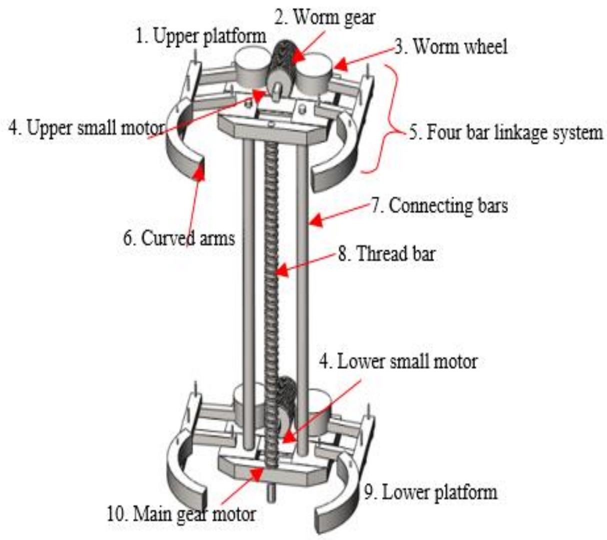
2.0 BACKGROUND RESEARCH AND REVIEW

There are three types of motion in climbing classified as; continuous, discrete and serpentine [4]. In the continuous type, energy consumption is reduced and speed is increased. But it is difficult to implement continuous motion, thus discrete motion is adopted in this project. First treebot is attached to the trunk with the aid of grippers and provides adequate friction such that it does not slip. The motors used for climbing overcome the moments caused by weight.

We discuss the movements of treebot influenced by locomotion [4]. Treebot comprises of two main frames, one being the upper platform and the other being the lower platform. The two frames (platforms) are connected to each other by a thread bar and two supporting bars. Frames moves up one at a time with aid of connecting bars. The entire body is supported by only one frame for a moment and it changes periodically. To identify the exact moment when arms get the sufficient force by motors, suitable sensor feedback has to be accompanied.

The sensors are selected based on their ability to maintain the required vertical motion. As the jaw closes, the position with optimal gripping is identified with sensor feedback. We use load sensors to identify the exact pressure at the gripping surface of the arm when grabbing the tree. Load sensors output signals when a force is applied to it due to deformation of the strain gauge. A load sensor has four terminals, two terminals are responsible for the excitation supply voltages whereas other two are to get the output signal and keep one as reference. An instrumentation amplifier is involved here to amplify the output signal of load cell. It is a closed-loop gain block that has a differential input and an output that is single-ended with respect to a reference terminal. Instrumentation amplifiers are a kind of differential amplifier with additional input buffer stages. The addition of input buffer stages makes it easy to match (impedance matching) the amplifier with the preceding stage [8]. These are commonly used in industrial test and measurement application. It also has useful features such as low offset voltage, high CMRR (Common mode rejection ratio), high input resistance, high gain etc. The purpose of using a differential circuit is to amplify the voltage value of one signal with respect to the other signal (amplifying a voltage difference).

3.0 MECHANICAL DESIGN AND IMPLEMENTATION



The most significant section of treebot is its mechanical structure. Because the overall performance depends on how it is mechanically assembled: especially center of gravity defines stability, tendency to rotate, total weight, torque needed to handle the gripping and hence total power consumption relies. Using Aluminium makes the structure lighter and strong, in addition hollow bars causes to reduce the weight. Placing the connecting bars closer to arms brings the center of gravity forward thus it helps not to drop down losing contact with tree.

The design contains two mechanical arm systems which can move relative to each other. We use screw mechanism, shown in figure1 displaying the structure of the robot. Each platform (1 and 9) is driven by its own gear and worm wheel systems (5).

Special features of the mechanical design are:

- Light weight – Achieved by using Aluminium material and L shaped bars instead of solid bars
- Improved gripping ability - By introducing rubber material contacts with the tree surface
- Four bar linkage system (5) - Easily transform the rotational motion into linear motion
- Worm gear & wheel system (2 & 3) – Worm gear attached to the motor leads to rotational motion of worm wheel and ultimately to the motion of arms
- Screw mechanism (8) – Enable the vertical movement by rotating the attached motor to thread bar
- Supporting bars connecting two platforms (7) – Thread bar does not provide sufficient stability on its own and so we have added supporting bars

At the beginning power is supplied for both platform motors (4), two platforms held contact with each other while both arms grab the trunk. Next, upper arm release its contact and moves up by the rotation of main motor (10). The upper and lower platforms get intact and stretched then upper arms grab the tree. Until it is done lower arms hold the entire body. The force diagram corresponding to the above scenario is presented in figure 3.

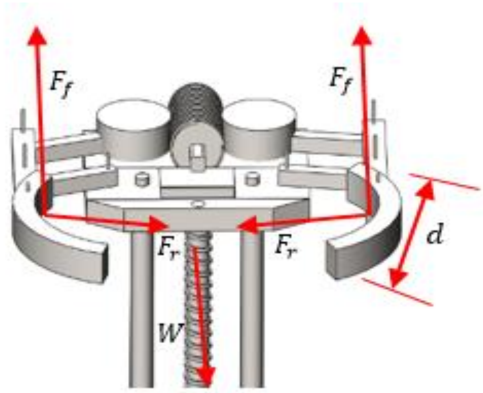


Figure 3: Force diagram of one platform

$$2F_f = W \quad (1)$$

$$\tau_s = F_r d \quad (2)$$

$$F_f = \mu F_r \quad (3)$$

$$\tau_s = \frac{Wd}{2\mu} \quad (4)$$

The minimum torque required to hold the body is calculated by equation 1. F_f = Friction force, F_r = Normal force, W = Total weight, μ = coefficient of friction, τ_s = Minimum torque. The net force in the verical direction has to be equal zero. Torque supplied by motor is converted into force as normal force. According to the Newton's law, friction force is equal to normal force times coeffcient of friction between wood and metal. Combining the above three equations, equation 4 can be derived.The main function of the above motor is to hold the total weight until both arms grab the tree. While one arm holds the tree, the other has freed its grip and is moving freely. The one arm should be capable of holding without slipping due the rubber added to the gripping surface in addition to the torque supplied by motors.

In this project, we use load cell to get feedback on gripping inside the arms and limit switches to control

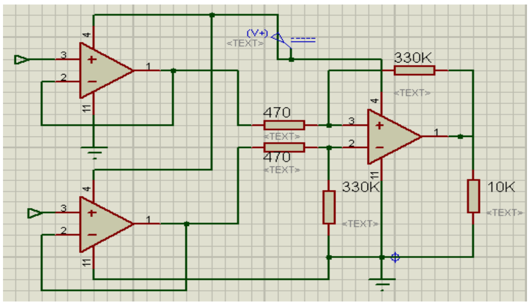


Figure 4: Load sensor and instrumentation amplifier diagram

the arm's movements. Since the output voltage of sensor is not sufficient enough to feed into the micro-controller, it is necessary to use an instrumentation amplifier as shown in figure 4.

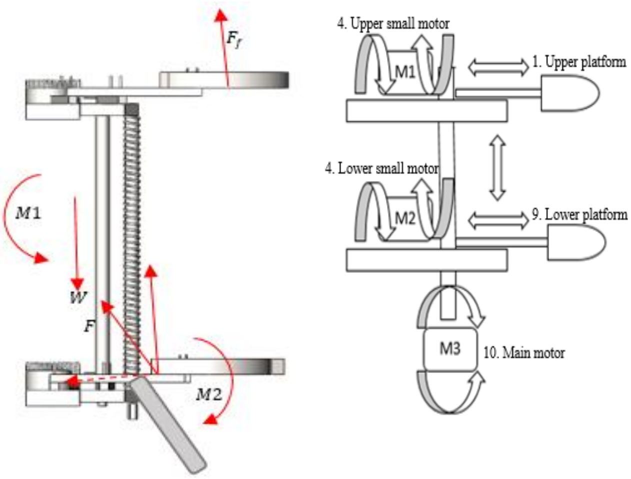
The next movement is moving up the lower platform losing its contact with trunk along the thread bar (8) and supporting bars (7). After that, lower platform grab the tree resulting the same initial position; two platforms in contact with each other. The mathematical approach to the above discussed scenario is as follows:

M1 = Moment generated from weight

M2 = Moment from tail part

When the upper arms holds the entire body, the body tends to rotate around lower touching point. To avoid the rotation generated by moment of weight (M1), we use a tail part attached to the lower platform. The above moment is cancelled by the M2 moment. Thus stability is achieved.

$$VI - I^2R = \tau_m\omega \quad (5)$$



The minimum required torque of main motor is calculated by equation 5. In this case, power is used to rotate motors. The total consumed power ($\tau_m \omega$) is equal to total input power (VI) minus power losses due to coil resistance (I^2R).
When treebot becomes lighter, easier to move up the body, consumes less power. Hence our main concern is on reducing the weight as it directly affects ultimate performance of product. We could limit the total weight to less than 5 kg which is the upper limit of weight as analyzed (Table 1).

Table 1: Weight description

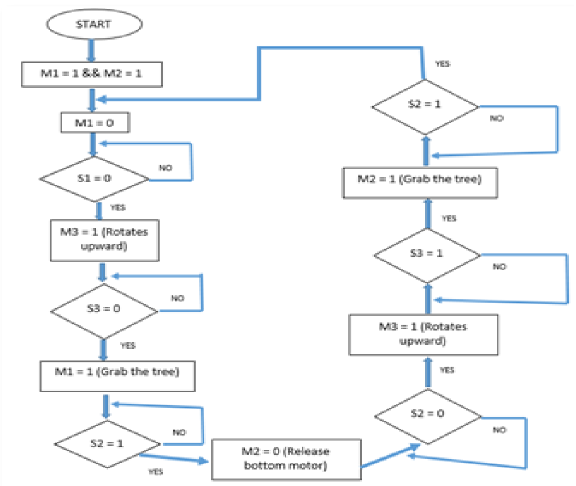
Part	Weight (approximately)
Main DC gear motor	318 g
Small Dc gear motors	99.5 g * 2 = 199g
Body frame	3500 g
Circuits, Sensors and wiring	150 g
Batteries	200 g
Total	4367 g

The M1 and M2 represents the small motors which rotates in the directions as shown in figure 5(b). These motors are rotated in one direction when arms move forward and rotated in the opposite direction when arms move backward. Apart from that, another motor (M3) is used to move the two platforms vertically. The linear arrows accompanied with the motors describes the direction of movement. There exists a three degree of freedom motion.

All three motors are controlled by H-bridge circuit, which is implemented using L298 IC because it saves troubles with offset voltages. We control two motors and have two enable lines, which can be controlled by a PWM line for each motor. This chip can handle 2A maximum continuous current on each channel. We provide protection diodes to protect the circuit from negative voltages; those diodes are wired backward across the motor supply.

3.1 Control Algorithm

The process can be described in terms of a logical manner as figure 6 shows.



S1: Upper arm sensor (If sensor touches the surface; S1=1)
S2: Lower arm sensor (If sensor touches the surface; S2=1)
S3: Threaded bar switch (If switch presses; S3=1)
M1: Upper motor (If motor on; M1=1)
M2: Middle motor (If motor on; M2=1)
M3: Lower motor (If motor on; M3=1)
Summarizing: The entire system is made up of four sections:

Power unit: 12V battery used as the main power supply to the circuits and motors. Input: Supplied By load sensor and limit switches placed in the arm. Output: Output motors are driven by motors driver circuit according the input. Control unit: Main parts are the micro-controller and PWM modules.

4.0 CONCLUSION AND FURTHER WORK

This paper present about an autonomous tree climbing robot which moves along coconut tree by its arms using worm gear and wheel system and moves vertically in a constant specified velocity using screw mechanism while maintaining the sufficient gripping and stability. Precise gripping is achieved by curved arms that links to two bars each. The robot adjust its arms according to the varying cross-sections. Bending of the robot is prevented by attaching a tail part of lower platform.

Design of a treebot which capable of not only climbing but also as advanced speed detecting systems with recording feature is possible. We suggest in doing such a development as a further extension of this project. Also this project can be extended to replace humans from plucking coconuts as it reduces the possibilities of accidents.

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Figure 6: Control algorithm of operation

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