Proceedings of the
International Conference on Mechanical Engineering and Renewable Energy 2017
(ICMERE2017) 18 – 20 December, 2017, Chittagong, Bangladesh

ICMERE2017-PI-125

AN AUTONOMOUS TREE CLIMBING ROBOT UTILIZING FOUR BAR LINKAGE SYSTEM

Asma Ul Hosna[1], Chandan Dev Sharma[2] and Dr. Md. Tazul Islam[3]

[1-3]Department of Mechanical Engineering, Chittagong University of Engineering and Technology, Chittagong-4349, Bangladesh
asmah2340@gmail.com*, chandandevsharma47@gmail.com, tazul2003@yahoo.com

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 project, focuses on designing Tree bot: a tree climbing robot. Our prime consideration in designing tree bot 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 result shows that the tree bot can successfully climb the trees with diameter in different ranges.*

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

1. 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.

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. 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. 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 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 Aluminum 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.

There are various models for tree climbing and plucking. I took into account the safety, reliability, the ease of use which is capable of climbing trees, cutting down coconuts, cleaning the tree tops and spraying pesticides. I designed a system that can be controlled by anyone. The designed prototype responds to human gestures with negligible gap in the response time and hence can be implemented in real time.

2. BACKGROUND RESEARCH AND REVIEW

There are three types of motion in climbing classified as; continuous, discrete and serpentine. 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 tree bot 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.

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 30 and 45 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. The climbing mechanism used in this paper is inspired from the technique used by inchworm. Inchworm design is one system of legs that all move relative to each other in a gait. The simplest form of this includes two gripping points at each end of the robot along the climbing axis with an actuated, bendable set of connections between the grip points that allow the grippers to move relative to each other. With this designs gait, one gripper releases to move to a new position and re-grip while the other gripper remains attached to the climbing surface to support the robot. The main advantage of the inchworm design is that it is a simpler mechanism than the system described in the literature. This greatly simplifies the mechanical dynamics and their design along with the corresponding overall cost, actuator programming, and weight.

Climbing robots constitute a challenging research topic that has gained much attention from researchers. Most of the climbing robots that are reported in the literature are designed to work on man-made structures, such as vertical walls and glass windows. Few climbing robots have been designed to work on natural structures, such as trees. WOODY is one of the climbing robots that are designed to replace human workers in the removal of branches from trees. The robot fastens onto a tree by encircling an entire tree trunk and climbs up by extending and contracting its body. Kawasaki developed a climbing robot for tree pruning. It uses a gripping mechanism that was inspired by lumberjacks and uses a wheel-based driving system for vertical climbing. Aracil proposed a climbing robot, i.e., climbing parallel robot (CPR), which uses a Stewart–Gough platform to maneuver. RisE V2 is a wall climbing robot that imitates the movement of an insect, using six legs to maneuver. The goal of this project was to build a tree climbing robot to satisfy the various requirements. The robot works on two sub-mechanisms: (a) Gripping (b) Climbing. The movement of the machine is like an ape climbing the tree. First, the upper pair of arms griped the tree then the body moves up then the lower pair of arms grip the tree then the upper pair leaves the contact and the body moves up.

We discuss the movements of tree bot influenced by locomotion. Tree bot 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. 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. MECHANICAL DESIGN AND IMPLEMENTATION

The most significant section of tree bot 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 Aluminum 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.

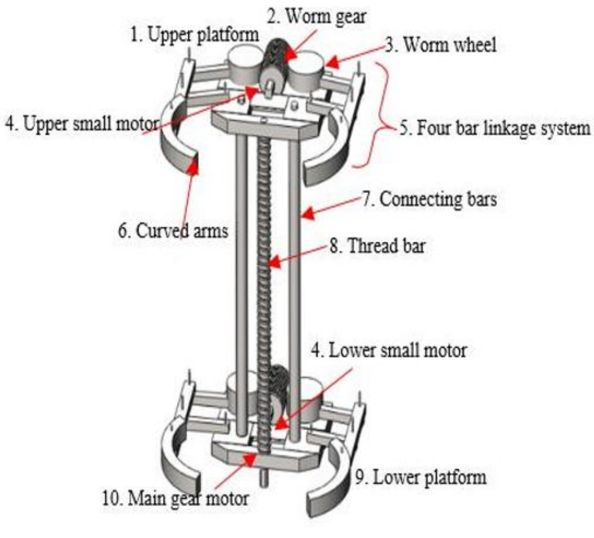

Fig.1: Mechanical Design and Implementation

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 Aluminum 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 2.

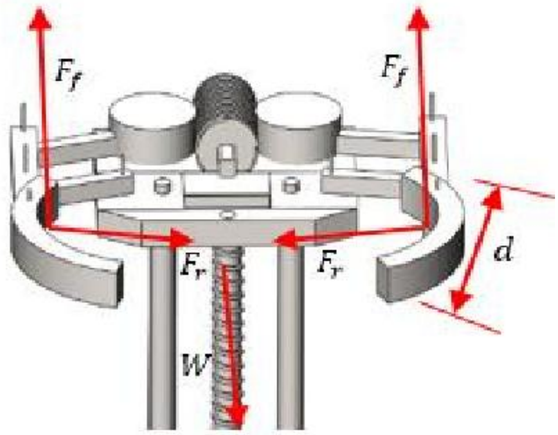

Fig.2: Force diagram of one platform

$$2F_{\mathrm{f}} = W \quad (1)$$

$$T_{\mathrm{s}} = F_{\mathrm{r}}d \quad (2)$$

$$F_{\mathrm{f}} = \mu F_{\mathrm{r}} \quad (3)$$

$$T_{\mathrm{s}} = Wd/2\mu \quad (4)$$

The minimum torque required to hold the body is calculated by the above equation. The net force in the vertical 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 coefficient 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 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.

The next movement is moving up the lower platform losing its contact with trunk along the thread bar and supporting bars. 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.

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

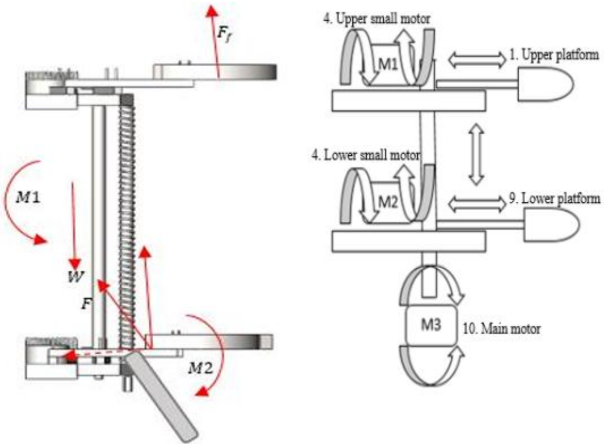

Fig.3: Moment diagram of one platform

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
Body frame	3500 g
Circuits, Sensors & Wiring	150 g
Power Suppliers	200 g
Total	4168 g

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

The 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

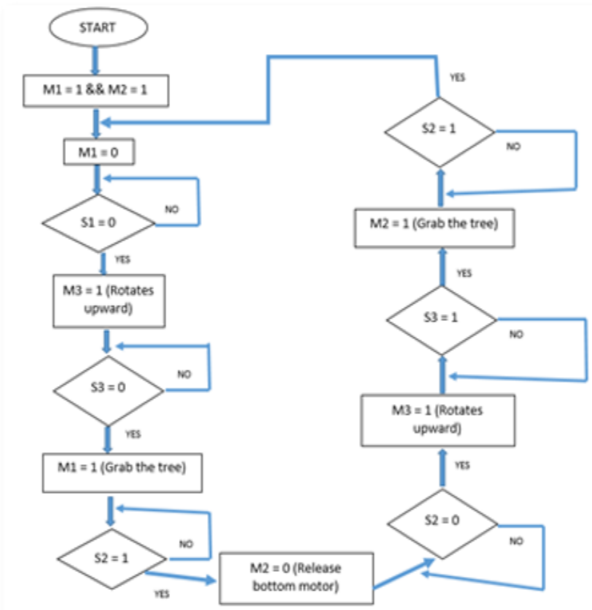

Fig.4: Control algorithm of operation

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. 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 link to two bars each. The robot adjusted 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 tree climbing robot 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.

5. ACKOWLEDGEMENT

I would like to express the special and heartfelt sense of gratitude to honorable supervisor Dr. Md. Tazul Islam, professor of department of Mechanical Engineering, Chittagong University of Engineering and Technology, Chittagong, who has encouraged me in selecting this important and interesting topic and for his valuable suggestions, instructions, encouragement, guidance, co-operation and other necessary help to initiate the project successfully. Without his guidance, it would not be possible for me to carry out this kind of project.
My heartfelt gratitude is extended to all of the teachers of the department of mechanical engineering, Chittagong University of Engineering and Technology who gave light on various academic aspects.
Nevertheless, my great appreciation dedicated to my friends and those who involve directly or indirectly with this project.

6. REFERENCES

[1] Yeorem Yoon, Daniela Rus “Shady 3D: A Robot that climbs 3D Trusses”, *IEEE International Conference on Robotics and Automation*, Italy, April 2007
[2] Hamed Shokripour, Wan Ishak Wan Ismail and Zahra Moez Karimi “Development of an automatic self-balancing control system for a tree climbing robot”, *African Journal of Agricultural Research*, Vol.5(21), pp.2961-2971, November 2010 .
[3] John E.Bares, David S. Wettergreen “Dante II: Technical Description, Results, and Lessons Learned”, *The International Journal of robotics research*, Vol.18, No.7, July 1999.
[4] Brett Kennedy, Avi Oken, Hrand Aghazarian, Mircea Badescu, Xiaoqi Bao, Yoseph Bar Cohen, Zensheu Chang, Borna E.Dabiri, Mike Garrett, Lee Magnone, Stewart Sherrit “Lemur IIb: a robotic System for Steep Terrain Access” – California.
[5] Bram G.A. Lambrecht “A small, Insect-inspired Robot that runs and jumps”, Department of Mechanical and Aerospace Engineering, Case Western Reverse University, Jan 2005.
[6] Reinaldo de Bernardi, Jose Jaime da Cruz “A tree climbing robot platform: Mechnical Concept, Control software and Electronic Architectures” – ISBN 789537619169, October 2008.
[7] Fengyu Xu, Xingsong Wang, Guoping Jiang “Design

and Analysis of a Wall climbing robot based on a mechanism Utilizing Hook-Like Claws" , *International Journal of Advanced Robotic Systems*, Sep 2012.
[8] Charles Kitchin, Lew Counts "A designer's guide to Instrumentation amplifiers", 3rd edition

7. NOMENCLATURE

Symbol	Meaning	Unit
F_f	Friction force	(N)
F_r	Normal force	(N)
W	Total weight	(N)
μ	Coefficient of friction	Dimentio-nless
T_s	Minimum torque	(N-m)
d	Arm length	(m)
V	Voltage	(V)
I	Current Flow	(A)
R	Resistance	(Ω)
ω	Rotational speed	(rad/sec)
τ_m	torque	(N-m)