International Journal of Current Engineering and Technology
ISSN 2277 - 4106

Available at http://inpressco.com/category/ijcet

Research Article

Design of Climbing Mechanism for a Tree Climbing Robot

Hariskrishna TV[Á*], PDPR Harshavardhan[Á] and Vineet Pandey[Á]

[Á]Department of Mechanical Engineering , Amrita school of engineering, Amrita Vishwavidyapeetham , Amrita Nagar, Coimbatore, INDIA, 641112

Accepted 18 March 2014, Available online 01 April 2014, **Special Issue-3, (April 2014)**

Abstract

Evolution in nature has given organisms a highly efficient body. These organisms if imitated can be very useful in design of efficient tools, structures or machines. We have devised a mechanism inspired by shrimp known as Stomatapod-whose entire body acts like a distributed foot facilitating it move in the most rugged terrains with agility. Hence this locomotive mechanism has been imitated to make an efficient climber. The grippers are designed in such a way that they hold the trunk of the tree-within a defined range, using the concept of passive compliance. This mechanism can be used to climb poles or straight trees. This mechanism is different from the existing ones.

Keywords: *Bio-inspired, Stomatapod, gripper, tree climbing robot.*

1. Introduction

Researchers all around the world work on climbing robots, most of these climbing robots are capable of climbing regular structures like poles, walls, domes etc. But a very few are capable of climbing trees, main reason being irregular surface and variation of diameter with length .It also requires greater agility and high manoeuvrability to be used as a product. Also the bark of some trees may not be strong enough to bear the weight of the climbing device, hence conventional climbing robots cannot be used for tree climbing applications. Many trees like Coconut tree, Arecanut tree, and palm trees are so tall that climbing them becomes risky. Hence harvesting fruits and nuts and maintaining them becomes difficult. So development of a unique tree climbing mechanism is necessary which may be used for maintaining and harvesting applications.

Most commonly used design for tree climbing is inch worm design. These models are very slow. The main body of this type of robot is divided into two parts and each part has a gripper. These models using inch worm mechanism are continuous in their motion and can manoeuvre in complex tree environments involving multiple branches. Next common type of design is wheeled robot wherein instead of grippers wheels are used for climbing up. The robot engulfs the tree and locks against it and as the motor rotates, it moves up. The sizes of these robots are comparable to the diameter of tree. These models are suitable for trees with straight and plain trunks .The main drawback is it being slow and there is a possibility of them damaging the tree trunk. Hence most of the models are slow, less agile, have less load carrying capacity. As a result we propose a tree climbing mechanism that can be used to climb trees that are almost straight, like coconut trees and poles with greater agility. The main locomotion of the robot is caused due to the two motors which facilitates simultaneous motion of two consecutive links (figure3). This robot grasps the tree with the help of grippers which is acted by a spring. When the motor is ON it unclamps and clamps while the motor is OFF by spring action while harnessing the spring energy for gripping. When one gripper grasps the tree, the whole body makes a revolution such that the next gripper comes up and grips while the other ungrasps and the whole process continues. Attachments like pesticide sprayer, weed remover or some harvesting mechanism can be mounted on the robot. With these attachments this robot can act as harvesting or maintenance equipment by the farmers.

2. Mechanical Design

Design of our robot is aimed at increasing the maneuverability and at the same time account for continuously varying center of gravity of the body due to its Stomatapod –like movement. Also reduction in weight of the bot is a critical parameter and is achieved by reducing the number of actuators and adopting a light weight and rigid materials. Our bot has the entire body divided into two parts:
(i) Gripping part
(ii) Main body

2.1 Gripping Part

The proposed gripper is much diversified and can be used on a wide variety of trees which are almost straight. The gripper is designed in such a way that the gripping force is

*Corresponding author: Hariskrishna TV

maximized. Each gripper is actuated by a single linear motor; there are four grippers. When the motor is in retracted position the gripper's grips due to spring force and get clamped to the tree and unclamps when motor is actuated, by this principle of harnessing spring energy, power consumption will be reduced and control becomes easy. This mechanism can be achieved by using a push plate in the gripper which will be connected to the shaft of linear motor, when the linear motor actuates the push plate pushes the claws and unclamps from the tree (Figure 2). This gripper is attached to a casing (Figure 3) .This casing uses the theory of passive compliance to engulf the tree trunk. Torsional springs will be attached which will enable to expand and contract.

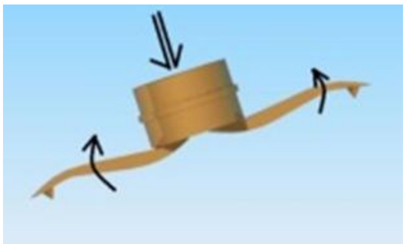

Fig 1. Actuation of the claws by pressure plate when linear motor expands

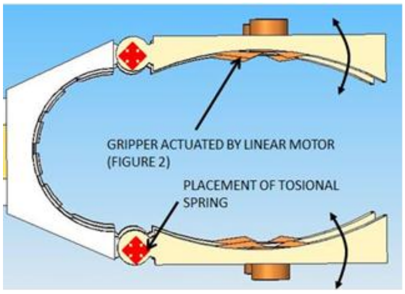

Fig 2. Casing in which gripper is placed in presence of torsional spring enables to engulf the tree

The gripper used in the prototype is different from the one proposed. In the prototype extendable slinky- type- pipes with micro-cellulose layer attached at each surface is used. It reduces the weight of the actuators to a very considerable amount but cannot be used for high load carrying tasks for which the gripper explained earlier is more efficient.

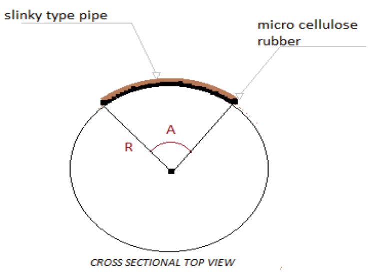

Fig 3. Schematic of the gripper used in prototype

The figure 3 shows the schematics of the gripper used in prototype. The circle represents a tree. The brown arc is the slinky type pipe which is supporting the micro cellulose rubber below (in black). The force acted upon the gripper by the pipe is normal to the surface at each point. The gripping force is calculated as :

$$f=q*N \tag{1}$$

Where, q is coefficient of friction and N is the force generated by the slinky material on MCR material. It can be observed from the equation no that gripping force can be increased by (i) increasing the coefficient of friction or (ii) by increasing the force on the MCR. Coefficient of friction can be altered by changing the gripping material. Force on the gripping material (in this case MCR) can be increased by introduction of a smart material. This can increase the load carrying capacity and at the same time decrease the load due to actuators hence by making the gripper even more efficient. Use of Electro active polymers which respond to change in electric field by changing their shape are a good option for this purpose.

3. Motion of robot

3.1. Locomotion of robot

There three types of motion, classified as continuous, discrete and serpentine. As we get closer to continuum type, energy consumption is reduced and speed is increased. But it is difficult to achieve continuous motion so discrete form is followed in the construction. First, the bot is attached to the tree trunk with the help of grippers which grips on to the tree trunk and provides adequate friction such that it does not slip. The motors used for climbing overcome the moments caused by its weight.
The movement takes place as follows:

1. First the arm with first motor will hold the tree.
2. Then the link with second motor will release the grip and the whole setup will rotate about motor one as shown in figure.
3. After half a rotation, the arm with second motor will grip the tree and the process continues.

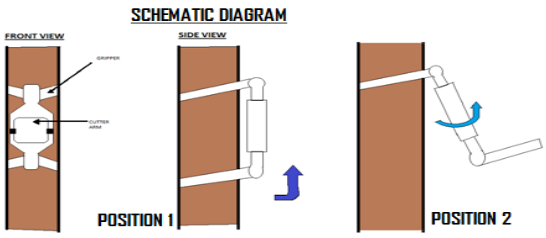

Fig 4. Schematics of climbing mechanism

Once the Robot reaches the topmost point of the tree trunk, the whole body is gripped on to the trunk without any further movement, i.e., the body is grounded, thereafter miscellaneous action like harvesting or maintenance work can be performed.

3.2. Kinematics of robot

The free body diagrams of the robot at various stances are as follows

Stage 1:

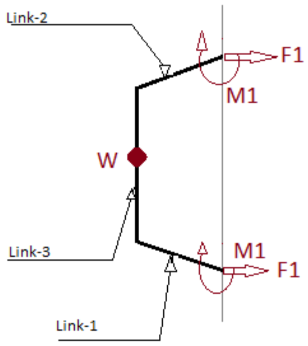

Fig 5. Free body diagram initially

f_1 *is* the force given by the gripper to hold the body intact on the tree. m_1 is the moment generated by the gripper motor to balance the centre of gravity w, which is at a distance of l from the surface of the tree. Hence,

$$2 * m_1 = w * l \tag{2}$$

Stage 2:

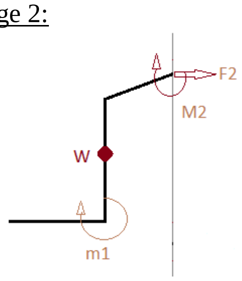

Fig 6. Free body diagram at start

In the second stage link-1 rotates (Figure 6) until it becomes perpendicular to the *link-3*. m_1 is the moment generated by the motor -1 to lift and hold the link-1 and 3. In this stage,

$f_1 = f_2$

$$m_2 = w * l \tag{3}$$

Stage 3:

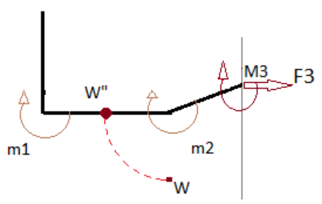

Fig 7.FBD at mid phase

In this stage the COG W travels along **W-W,** hence the moment created by the COG varies along the curve as

$$m_3 = (w * l) + w * r * sin(a) \tag{4}$$

M_2 is the moment created by the 2nd motor to lift the link-3 along with link-1.

Stage-4

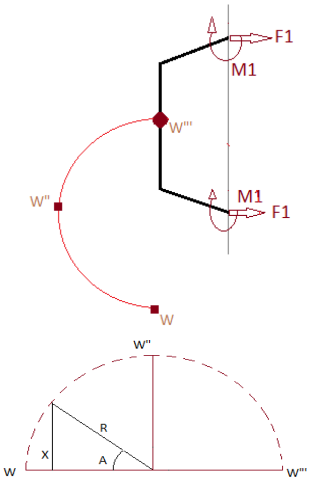

Fig 8. shows the path of shift of mass center

The robot returns to the original state while the COG has travelled along W-W-W'. The transformation matrix of the kinematic model is given by $T = T_1^0 T_2^1$, where T_n^{n-1} is the DH notation for the links.

$$T_n^{n-1} = \begin{pmatrix} 1 & 0 & 0 & x \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 0 & 1 & 0 & x \\ -1 & 0 & 0 & y \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} -1 & 0 & 0 & 0 \\ 0 & -1 & 0 & y \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \tag{5}$$

Where, y is the larger link (main body) and x is the other two equal links (gripper)

This mechanism was simulated in multi body dynamics software (ADAMS). It was found that it takes 6 second to complete one cycle of revolution (Figure 9) at an input speed of 30reveloutions per minute and a plot between power, torque and time was obtained which is shown in Figure 10.

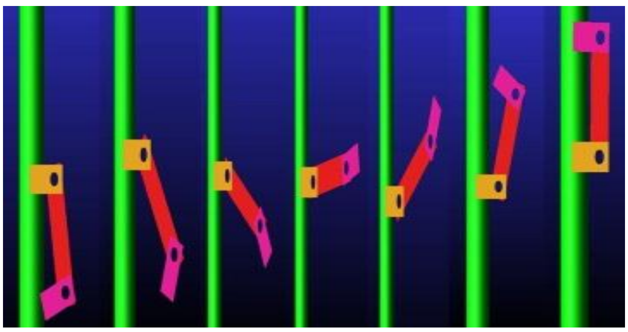

Fig 9. The snapshot of movement of geometric model of robot(using Adams software)

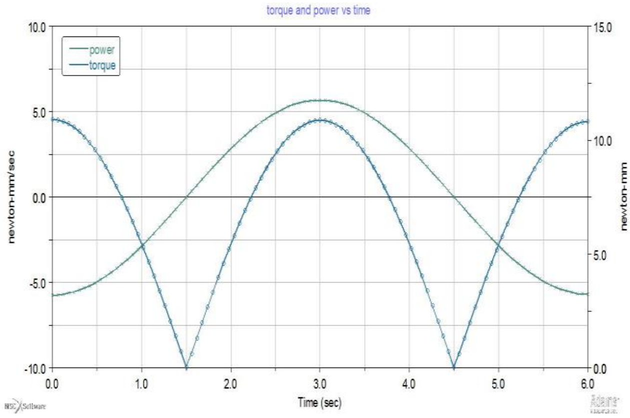

Fig 10. Plot between torque power and time (generated by Adams)

It can be observed from the graph that when the bot is stationary and fixed to the tree, the motors needs to have some torque to hold it in its place and as time progresses the torque decreases an then increased at the middle or half time this is because the mass centre will be at the farthest point from the centre of rotation. The power consumption increases till the first half as the work has to done against the gravity and in second half it gradually decreases.

3.3. Problems Faced

- First of all it is important to find important physical and mechanical properties of coconut tree to do the necessary calculations.0 The tree trunks average strengths results showed that the longitudinal tensile strength and longitudinal compressive strength are 60 and 5.34 MPa respectively.
- The challenge of climbing: A proper design for the climbing mechanism was required. We had to take into account the speed, stability and cost for constructing it.
- Gripper design: A proper design for maximum gripping during upward and downward motion was necessary to prevent the robot from falling.
- Stability while climbing: Gripper design is closely related to the stability of the robot. It should climb without any swaying and perfect gripping must be there between the gripper and the surface of the coconut tree trunk.

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Conclusion

In this work a tree climbing mechanism for coconut trees has been proposed this mechanism can also be used to climb structures and other trees which are almost straight like palm trees, poles etc. the mechanism used in this robot is a bio inspired mechanism which is derived from an organism called Stomatapod. This mechanism appears to be more agile compared to other available mechanisms but the main limitation being used for a small class of trees. A prototype of robot was made and the efficiency of the slinky type gripper was tested on few trees. Also software simulation was done for this mechanism. Our future works includes the addition of agricultural equipment's like harvester sprayer etc. also to develop upon the gripping materials as discussed.

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