Autonomous Tree Climbing Robot (TREEBOT)

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Abstract — **This project paper is proposed on an autonomous tree climbing robot, making the robot realize the environment and climb on a tree autonomously. Inspired by inchworms, the algorithm reconstructs the shape of a tree simply by the use of limit switches. It reveals how the realization of an environment can be achieved with limited information. It is a challenging task as the shape of tree is complex and irregular. The robot with its well balanced mechanical design is so equipped that it can climb tree surfaces with minimal sensing resources(limit switches).We have limited out project for the robot to climb only regular and irregular shaped trees but not trees with branches. The robot also equips with a pair of Omni-directional tree grippers that enable the robot to adhere on a wide variety of trees with a wide range of gripping curvature.**

Keywords – **Treebot, continuum, gripping mechanism**

I. INTRODUCTION

Climbing robot is a challenging research topic that has obtained much researchers attention in the recent decade [1], [2], [3], [4], [5], [6]. In the literature, most of the climbing robots are working on climbing urban settings but seldom of robots are designed for climbing natural environment such as trees. The nature of trees and manmade structures is very different. For example, trees have an irregular shape and their surface is not smooth. Some types of trees have soft bark that peels off easily. Hence, most of the methods applied in the development of wall climbing robots are not applicable for tree climbing robots.

Since climbing up trees to perform forestry works is dangerous for human being, a robot with tree climbing ability should be developed to assist or replace human's works.

Preventing trees from failing is important to protect human life and property in urban areas. Most trees in urban areas require regular maintenance. To reach the upper parts of a tree to perform such maintenance, workers need to climb the tree. However, tree climbing is dangerous, and thus the development of a tree-climbing robot could assist or replace manual work.

This paper proposes a novel tree climbing robot named (as shown in Fig. 1) that has high maneuverability on tree. This robot equips with a pair of omni-directional tree grippers that are able to grip on tree surfaces in a wide range of gripping curvature. It enables the robot to grip tightly on large tree trunks and small branches. The applied continuum maneuver mechanism has large workspace and high degrees of freedom (DOF).

This robot works on a gripping mechanism wherein there is alternative claw motion along with a linear motion achieved by the dc motor making the robot possible to move upward or downwards. The robot is but using 4 servo motors and a single dc motor and the mechanical design was built using solid works.

The special gripping mechanism allows zero energy consumption in static gripping. With the appropriate equipment, Treebot could assist workers to perform arboricultural tasks such as inspection and maintenance. It could also be used as a mobile surveillance system to observe the living behavior of tree living animals.

The paper is organized as follow. Section II describes the mechanical design and mechanism of the robot. In Section III, the motion of the robot is described. The working of the robot and the algorithm of its operation is introduced in Section IV while applications of the robot in Section V. Finally, conclusion is given in Section VI.

II. MECHANICAL DESIGN OF TREEBOT

The overall test design of the robot is as shown in Fig. 1. The robot structure mainly is composed of three parts. 1) Front Gripper, 2) Continuum body, 3) Rear Gripper.

Two grippers are connected to the ends of the continuum body respectively. The gripper is designed for fastening on a tree surface. The locomotion of Treebot is similar to an inchworm robot except the moving forward motion is achieved by body extension and contraction rather than body bending.

Figure 1-Test Structure T

A. Front Gripper & Rear Gripper

There are many innovative approaches to provide adhesive force such as vacuum suction magnetic attraction, elastomeric adhesive etc. These methods work well on urban settings such as vertical walls and glass windows that are smooth and flat. However, they are not applicable on tree surface, as the nature of trees is totally different from urban settings. Claw climbing method is widely used in tree living animals such as squirrels and birds. Through the observation of the tree living animals, the claw gripping is reliable on a tree surface. As a result, the claw gripping method is adopted to provide adhesive force.

The proposed design of front & rear grippers consists of four claws and 2 servo motors on each section. These servo motor movements are responsible for the claw section gripping the tree surface. The claws are designed using aluminum fiber because of its light weight strong structure. The proposed CAD design for front gripper claw & rear gripper claw is as shown in Fig. 2 and Fig. 3.

In addition, since the moving mechanism of each claw is independent, it allows the claws to travel in different angle. This ensures that all of the claws penetrate into the gripping substrate, even if the tree has an irregular shape, to generate the maximum force. The edges of the claw structure are placed with thick piercing material to ensure perfect gripping on tree surfaces with barks.

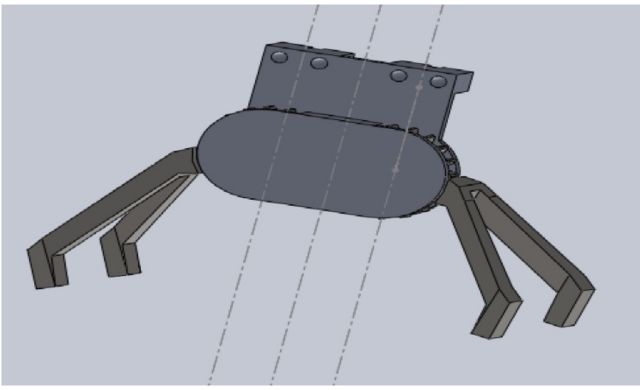

Figure 2-Front Gripper Claw Cad

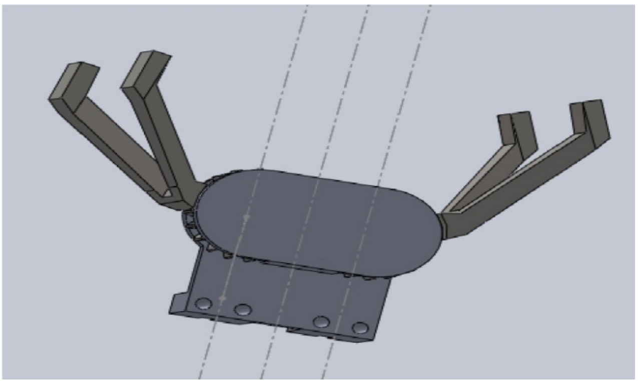

Figure 3-Rear Gripper Claw CAD Design

The different features of the gripper section are the following:

1) Compact and light weight

2) Adaptive to irregular shape-This feature is achieved as each claw section is mechanically decoupled.

3) Zero energy in static gripping-The gripping force is provided by the preloaded mechanical spring

B. Continuum Manipulator

This section is the most important section of the proposed design. The functioning of this section determines position of the previously discussed front and rear grippers. The continuum body is extendable and bendable and is made up of 3 bendable tendons (springs).A rack and pinion mechanism is applied move the structure. The dc motor which is connected to the gears is moved along the spring which makes the grippers to either move upwards or downwards. The Fig. 4 describes the structure of the continuum body.

There are many types of continuum manipulators, such as wire-driven and pneumatic-driven. Most of them are able to bend in any direction and some are even able to extend to a certain extent. Most current research uses the continuum structure in robot arms, but few researchers have realized that it can also be applied to maneuvering. The continuum mechanism is a compliant structure, as it does not contain fixed joints. Its inherent passive compliance is particular benefit for maneuvering in an arboreal environment, as it can often eliminates the need for complex force sensing and feedback control.

For climbing purposes, the manipulator must be compact and lightweight. There are many types of continuum manipulator, but none of them fulfills all of these requirements. Existing continuum manipulators need to connect to large external boxes that contain wire, drivers, motors, or air pumps. Although some pure wire-driven continuum manipulators have the potential to be more compact and lightweight, the manipulators are not extendable. Extendibility is important, the inclusion of extension ability for continuum manipulators extends the workspace considerably.

Figure 4-Continuum body with actuator.

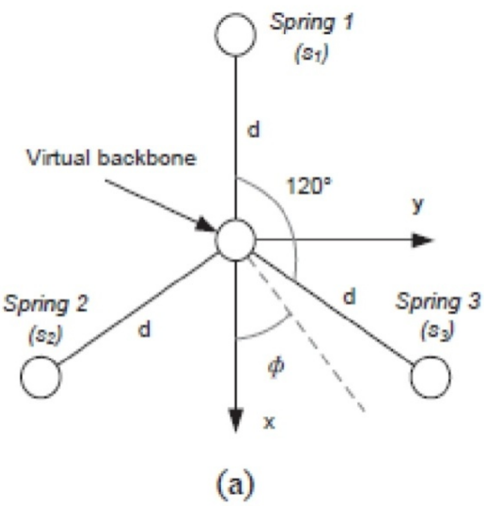

Fig.5 Spacing between the springs in the continuum body.

Due to these limitations, a novel design of continuum manipulator to maneuver with both bendable and extendable functionalities is proposed as shown in Fig. 5. The proposed continuum manipulator is a self-contained module that actuators are integrated and hence no external control box is required. It makes the proposed continuum manipulator compact and lightweight. In addition, the special driving mechanism allows superior extension ability that the existing designs cannot achieve.

It is formed by three mechanical springs that are connected in parallel. The distance between the center of the continuum manipulator and springs are equal and the springs are equally separated by 120 degrees as shown in Fig. 5. One end of spring is fixed on a plate, while the other end does not have any fixed connection. The springs pass through a plate which contains a single DC motors along with a simple gear mechanism to control the length of springs between two plates independently as shown in Fig.4. Through the control of the length of each spring, the continuum manipulator can perform bending and extension motions.

In practice, it is limited by the length of the springs only. The spring can be treated as a bendable rack. The spring should only be allowed to bend in any direction but not able to compress or extend so as to keep a constant gap distance for pinion to drive. On top of that, keeping the springs in constant distance through the entire manipulator is important to keep a uniform shape.

The CAD design for the open assembly of the continuum body where the spring assembly with proper spacing as described earlier is to be placed is shown in Fig. 6.1 and Fig. 6.2. From the figure it is to be noted that spring assembly of the continuum body are placed in appropriate slots. The linear motion of the continuum body is obtained by the gear mechanism which is moved along the spring by the actuator and thus both front and rear claw are moved.

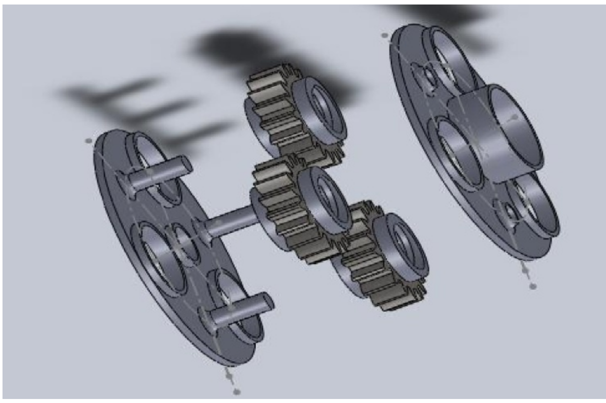

Figure 6.1-Spring Gear Assembly CAD Design

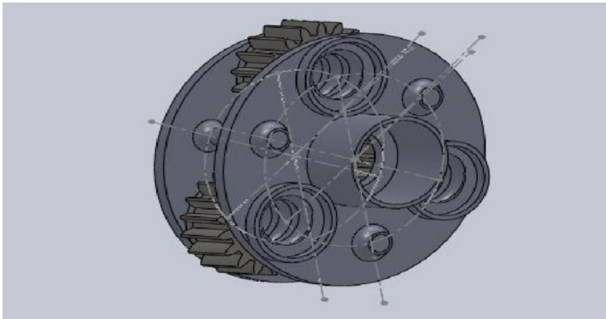

Figure 6.2-Cross-sectional view of Spring Gear Assembly

III. MOTION OF ROBOT

A. *Locomotion of robot*

The locomotion of Treebot is similar to inchworms which is a kind of biped locomotion. Fig.7 shows a complete climbing gait of the locomotion. It is composed of six climbing steps. The square colored in grey represents the closed gripper that attached on the substrate while the square colored in white represents the opened gripper that detached on the substrate. The order of motion in the Fig. 7 represents the locomotion of moving forward. The locomotion of moving backward is just in reverse order.

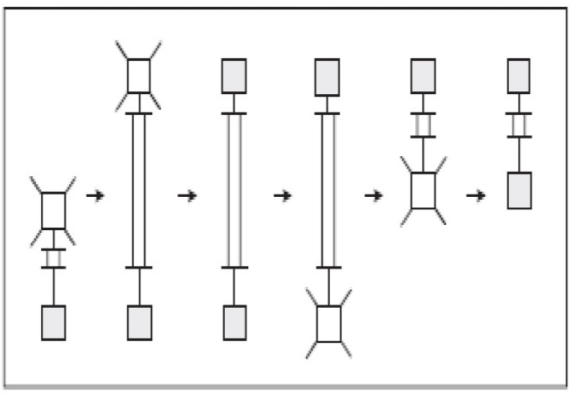

Fig. 7. A complete climbing gait of Treebot (moving forward).

IV. WORKING OF ROBOT

The proposed design of the robot and is being controlled using a PIC (18f2431) microcontroller and the software used is Mplab. The robot designed is made to follow the following algorithm to move it in an efficient manner.

Limit switches are used to detect if the claws of the gripper have gripped on to the tree or have released the tree. The explanation of the working robot along with the limit switch action is as shown in the flowchart in Fig.8.The master control to the robot i.e. giving higher level commands like instructing when to stop the robot motion and when to reverse motion of the robot is achieved by Zigbee protocols.

The following algorithm describes the basic upward (forward) motion of the robot.

The proposed design of the robot uses 4 limit switches on each of front and rear claw and 2 switches for the dc motor action. A total of 8 limit switches on both the claws and so designed that the effect of only 4 limits switches are felt.

This decreases the programming complexity and in turn the sensitive action of the robot increases. Fig. 9 describes the exact arrangement of the limit switches on the claws.

Once the limit switches in one the grippers produces a logic high (ON) it remains in that particular state (gripped state) thus activating the dc motor and other gripper. This process continues and the entire locomotion is achieved by this repeated action of the switches which is placed in both rear and front claw structure.

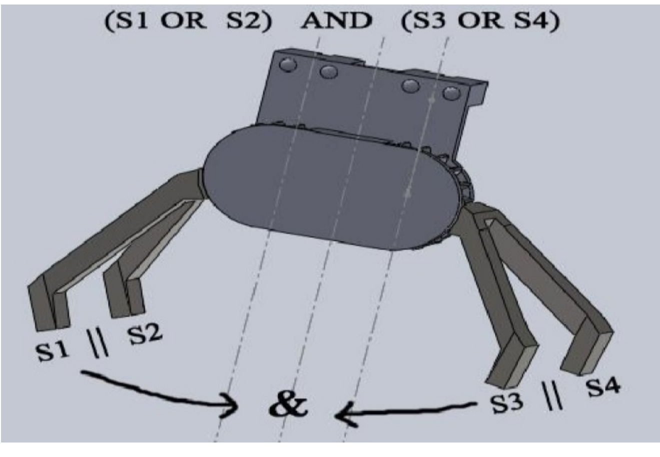

Figure 9-Limit switch action on Claw design

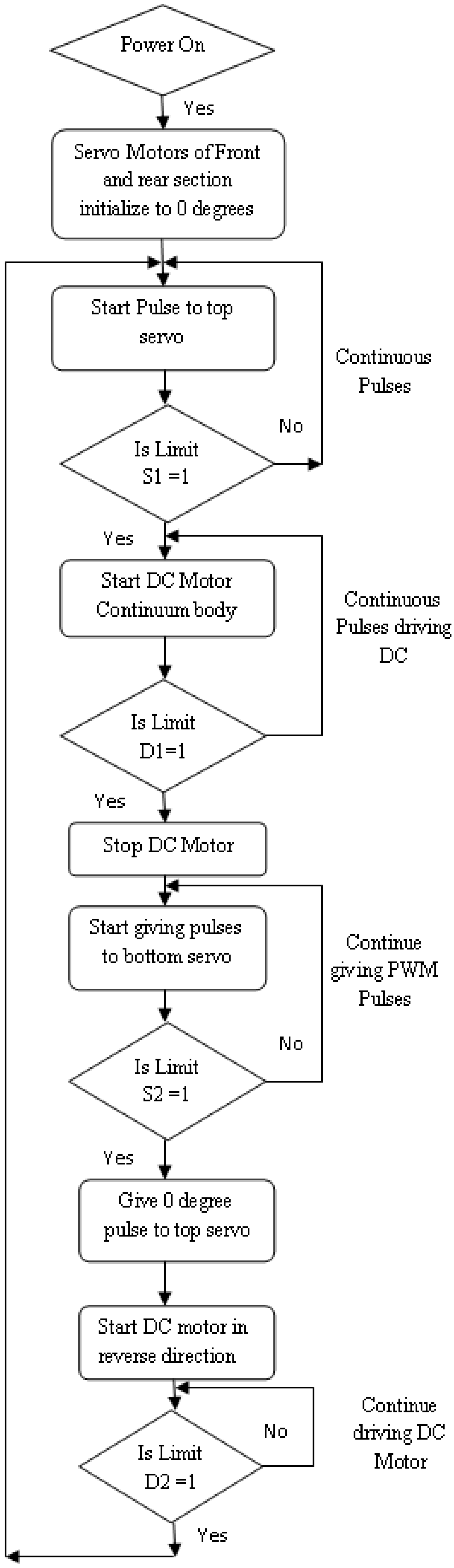

Fig.8- Flowchart explaining the working of the robot

V. APPLICATIONS

- Assist or replace human forestry works
- Military applications
- Security assistance

VI. CONCLUSION

In this paper, a novel tree climbing robot is presented that the maneuverability surpasses the state of the art tree climbing robots. It is composed of a pair of omni-directional tree grippers for holding the robot on a tree surface and a novel 3 DOF continuum manipulator for maneuvering. The locomotion and workspace of the robot are also discussed.

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