Palm Tree Climbing Robot

Khaled R. Asfar
Department of Mechanical Engineering, Jordan University of Science and Technology, Irbid, Jordan
Email: kasfar@just.edu.jo

***Abstract*—Palm trees have a significant economical value as source of income for the countries that have them. It is dangerous to climb those high trees to perform some operations, therefore, a robot has been designed to climb the tree and carry out some tasks such as spraying insecticides or picking dates. The mechanism adopted for this climbing robot consists of three pneumatic actuators; one main actuator and two auxiliary ones, two encircling arms, springs and pneumatic valves. The arms embrace the trunk of the tree and both springs and the two auxiliary actuators will keep the arms in suitable positions either to allow the arm to move up or to carry the weight of the robot. The motion that comes from the main actuator is applied to the upper arm and the lower one to raise the robot up the tree trunk and is controlled by the valves. Air pressure used does not exceed 6 bars. The movement of the robot to climb up and down is controlled by an Arduino controller. The pneumatic circuit uses three solenoid actuated 4-2 way pneumatic valves with spring return. These valves are powered with a 12Volt DC signal coming from a double H-bridge. The microcontroller and the solenoids share the same power source, a 12V rechargeable battery, with a 9V voltage regulator on the microcontroller side.**

***Index Terms*—climbing robots, palm trees, pneumatic actuators, autonomous systems**

I. Introduction

Climbing robots exist in various forms and for various applications [1]-[11]. Here we focus on climbing palm trees by robots. There are several types of palm trees in the world such as coconut palm trees, Washington palm trees, dates palm trees, …etc. Productive palm trees carry fruit near the high top of the tree. Most of these trees are normally pruned to produce a slender nearly smooth trunk. However, the dates palm tree is typically pruned such that short 'steps' are left in each leaf around the trunk. One reason of such pruning is to enable human climbers to go up the tree for further pruning, pollination and harvesting dates. It is a dangerous task to climb those trees due to their height, therefore, a robot has been designed and built to climb the tree and carry out some of these tasks instead of human climbers.

The basic design of this climbing robot is outlined in Ref. [12]. It uses a pneumatic actuator for the climbing process with one upper hand and one lower leg. The limbs for this robot are made from cladded aluminum tubing that is wrapped around the tree trunk as shown below. The gripping force of this robot can sustain considerable loads especially with the rough outer surface of the palm tree. The power source for the mechanism is obtained from a compressed air pressure vessel on the ground. Small Pneumatic tubes carry high pressure air to the actuators through a solenoid valve. The climbing motion can be controlled either manually or by a programmable microcontroller as desired. The robot motion can be controlled manually using push button valves if desired. However, the robot motion was automated and a control circuit was designed, built, and tested successfully.

II. Mechanism Design

The robot consists of three pneumatic actuators. The main actuator has a 30cm effective stroke and can deliver 500 Newton force at 5 bar (it could carry a 50kg payload). The two other actuators are smaller with a stroke of 8cm and their task is to open and close the upper arm and lower leg. Special aluminum seats were designed to hold the small actuators in a horizontal position on the arm and leg. Each small actuator is attached with two seats one for the base and another for the shaft. Two bases of Teflon blocks have been manufactured to connect the main actuator with the arms. The upper base is cubic with one hole on the datum to join with the main actuator and another on the side connecting with the arm. The lower end of the main actuator is attached directly to the base of the actuator with four screws. It has a part to connect the lower arm to it. The arms were manufactured from aluminum to keep minimum weight. Each Arm consists of a fork shaped bar and circular tube separated from each other by an aluminum block.

It connects together to embrace the trunk. Another two aluminum blocks were manufactured to connect the aluminum pipe with the fork arm. The need of these blocks comes from the inability to make holes within the pipe because it will be a weak point which will cause the pipe to fail. Also aluminum rods were fitted into the pipe to give it strength to hold the load that comes from the weight of the robot and the force that comes from the actuators. To control the system manually at first, two 3/2 way push button control valves were used. One is responsible for raising the upper arm and opening it while keeping the grip of the lower arm to the trunk of the tree. Providing compressed air to the other small actuator does the opposite; opening the lower arm while closing the upper arm to grip the trunk.

Manuscript received March 1, 2015; revised June 12, 2015.

doi: 10.18178/joace.4.3.220-224

The air that operates the system comes from a 7 bar compressor. The assembly drawing of the robot mechanism and an exploded view of this robot are shown below Fig. 1.

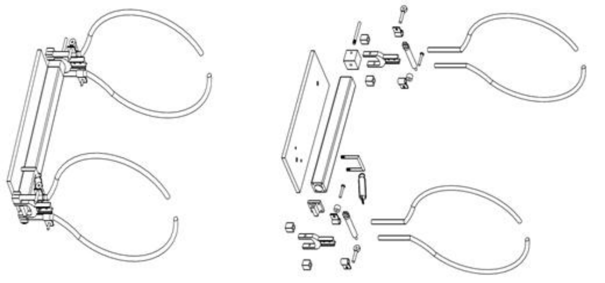


Figure 1. Exploded view of the palm tree climbing robot.

Below is a list of components used in the climbing robot:

(1): The Main Actuator:
(2): The auxiliary actuator (x2)
(3): Fork arm.
(4): Circular tube.
(5): Upper base.
(6): Lower base.
(7): The platform.
(8): Holding box (x4)
(9): Auxiliary Actuator seat (x4)
(10): Rotate key (x2)
(11): Cylindrical box (x2)
(12): U-shaped Bar.
(13): Extension Springs.
(14): Rods

Final Design:

From the primary design to the "final" design there were many experiments and iterations that led to several modifications to the robot design and consequently arrived at the "final" design shown in Fig. 2.

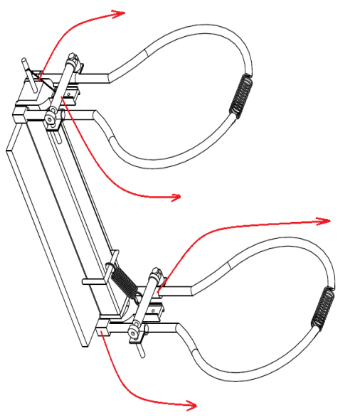


Figure 2. Final design assembly of the palm tree climbing ROBOT.

III. Operation

The motion starts from the main actuator. The shaft of the actuator will push the upper arm from its position up with 30cm-stroke while one of the auxiliary actuators opens the upper arm and the other lower one ensures the closing of the lower arm. At the end of its stroke the upper arm will grip the trunk due to the angle that the circular tube makes with the trunk and the steps on the trunk. The lower arm and the body of the actuator will follow the upper arm when the air pressure is switched to supply the other port of the actuator. The springs are necessary to make a variable diameter arm also to close the arm in the period of switching the motion between upper and lower arms. During the stroke of the lower arm the upper arm will carry the whole assembly weight and prevent it from falling. The sequence of strokes for the climbing process is detailed below Fig. 3.

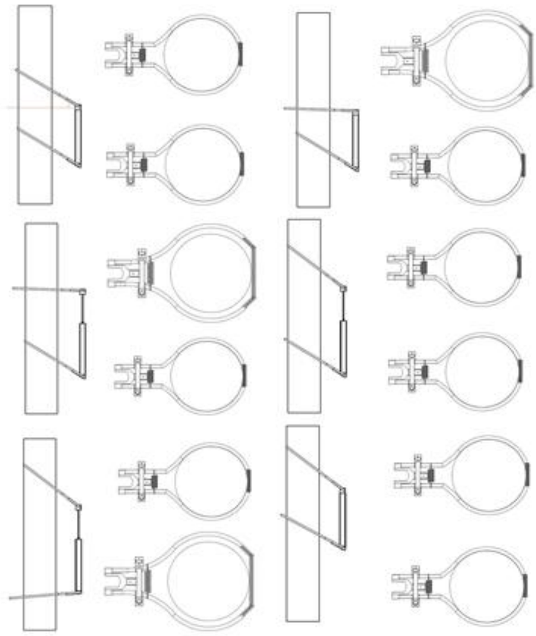


Figure 3. The sequence of strokes for the climbing operation.

The Electro-Pneumatic Circuit:

The pneumatic Circuit used to drive the robot manually has been replaced with an electro-pneumatic one for the sake of automation. This enabled us to automate the movement of the robot and change the sequence it uses to climb up and down easily by loading it into a microcontroller. The circuit uses three solenoid actuated 4-2 way pneumatic valves with spring return. These valves are controlled with a 12Volt DC signal coming from a double H-bridge which is controlled by a microcontroller. The microcontroller and the solenoids share the same power source, a 12V rechargeable battery, with a 9V voltage regulator on the microcontroller side. The electrical circuit is shown below Fig. 4.

There was an old pneumatic circuit implemented earlier that used to supply the air pressure to the three pistons simultaneously, and thus significantly reducing the force the pistons exert and increasing the time they take to reach their full stroke. This meant that the robot was unable to maintain its grip while climbing the tree. The sequence also had a part where both the upper and the lower pistons were open for a short time, allowing the robot to slip down.

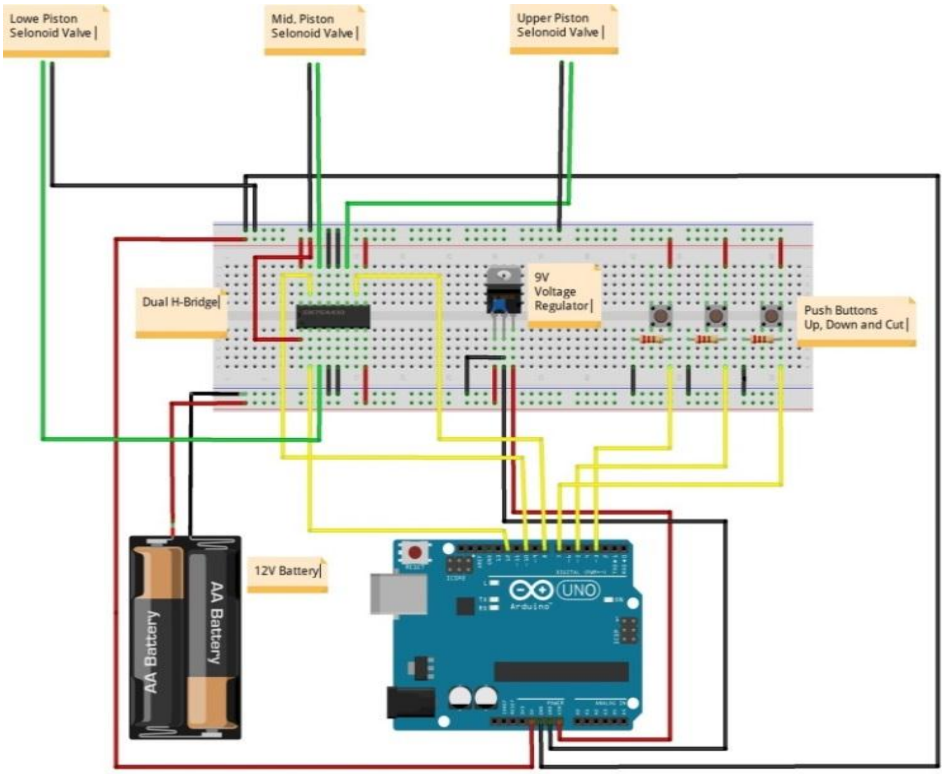


Figure 4. The electrical circuit of the climbing robot.

The new electro-pneumatic circuit solves these problems by moving one piston at a time. At no point in the sequence are two pistons splitting the pressure between each other, and the sequence has no part in it where both the upper and the lower pistons are open. The same circuit can be used to control another climbing robot of the Washingtonia palm trees with some modifications (currently under development). Below is a schematic of the electro-pneumatic circuit Fig. 5.

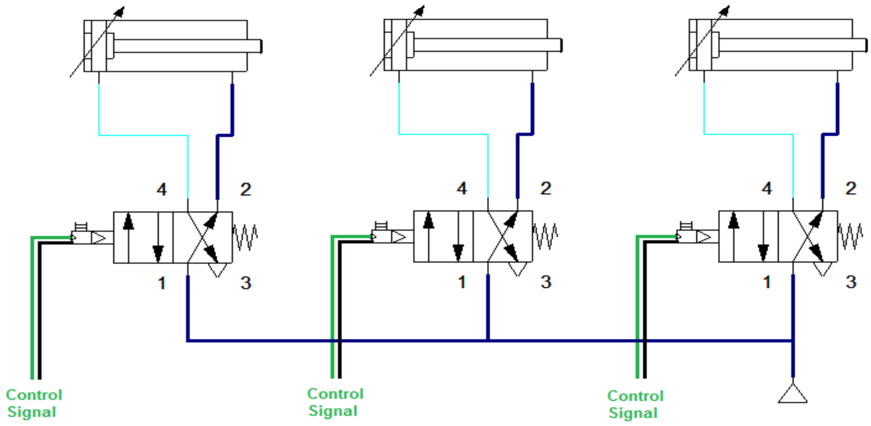


Figure 5. The electro-pneumatic circuit of the climbing robot

The microcontroller used in this circuit is the Arduino Uno. When we reach a final design the Atmel chip could be removed from the Uno and used in a custom printed PCB board to function just as it did inside the development board.

A program was written and loaded to the microcontroller to do the described functions. This program that was used to control the robot solenoid valves is shown below Fig. 6.

IV. Spraying Pesticides

The main body of the dates palm trees climbing robot ready to carry some accessories on board. The robot is capable of carrying 50 kg load including its own weight. For the spraying pesticides task, a compact small unit (made by Black and Decker) is acquired which can be attached to the robot frame. The unit has a small tank which can carry up to 5 liters of liquids. It has an electric small pump which takes its power from a rechargeable battery. The unit has a switch for the pump which can be switched on from the ground.

```
#define up  3                   //Pin 3 is to be connected to the Up Button
#define down  5                 //Pin 5 is to be connected to the Down Button
#define cut  7                  //Pin 7 is to be connected to the Cut Button
#define upperPiston  12         //Pin 12 is to be connected to the H-Bridge pin that drives the upper piston
#define lowerPiston  10         //Pin 10 is to be connected to the H-Bridge pin that drives the Lower piston
#define midPiston  8            //Pin 8 is to be connected to the H-Bridge pin that drives the Middle piston
#define blade  13               //Pin 8 is to be connected to the H-Bridge pin that drives the Cutting Blade which is yet to be implemented
void setup(){                    //This function runs only one time at the beginning of the program
  pinMode (up, INPUT);           //This defines pin 3 as an input pin
  pinMode (down,INPUT);          //This defines pin 5 as an input pin
  pinMode (cut,INPUT);           //This defines pin 7 as an input pin
  pinMode (upperPiston,OUTPUT);  //This defines pin 4 as an output pin
  pinMode (lowerPiston,OUTPUT);  //This defines pin 6 as an output pin
  pinMode (midPiston,OUTPUT);    //This defines pin 8 as an output pin
  pinMode (blade,OUTPUT);        //This defines pin 10 as an output pin
}
void loop(){                                 //This function repeats as long as the arduino is on
  if (digitalRead(up)<1){                    //checks if the up switch is pressed
    MoveUp();                                //if it was the MoveUp function is performed
    Serial.println(digitalRead(up));
  }
  else if (digitalRead(down)<1){             //if it wasn't pressed the program checks if the down switch is pressed
    MoveDown();                              //if it was the MoveDown function is performed
  }
  if (digitalRead(cut)<1){                   //if the cut button is pressed
    digitalWrite(blade,HIGH);                //if it was start the cutting process by setting the blade pin to high
  }
  else {
    digitalWrite(blade, LOW);                //if it wasn't set it to low
}
}
void MoveUp(){                               //This function starts a sequence to move the robot up
  digitalWrite(lowerPiston, LOW);            //Closes the lower piston
  digitalWrite(upperPiston, HIGH);           //opens the upper piston
  delay (1000);                              //waits for 1 seconds for the piston to complete its action
  digitalWrite(midPiston, HIGH);             //Opens the middle piston
  delay (2000);                              //waits for 2 seconds for the piston to complete its action
  digitalWrite(upperPiston, LOW);            //and so on...
  delay (1000);
  digitalWrite(lowerPiston, HIGH);
  delay (1000);
  digitalWrite(midPiston, LOW);
  delay (2000);
  digitalWrite(lowerPiston, LOW);
  delay(1000);
}
void MoveDown(){                            //This function starts a sequence to move the robot down
  digitalWrite(upperPiston, LOW);           //Interpret as before
  digitalWrite(lowerPiston, HIGH);
  delay (1000);
  digitalWrite(midPiston, HIGH);
  delay (2000);
  digitalWrite(lowerPiston, LOW);
  delay (1000);
  digitalWrite(upperPiston, HIGH);
  delay (1000);
  digitalWrite(midPiston, LOW);
  delay (2000);
  digitalWrite(upperPiston, LOW);
  delay (1000);
}
```

Figure 6. The microcontroller program to control the solenoid valves.

V. Pollination

It is proposed to perform pollination by spraying the pollen collected from the male palm tree onto female palm trees in a similar process to spraying pesticides. For this purpose, a small portable air blower has been acquired with a cloth bag that is used for the storage of pollen. Alternatively, the same spraying unit may be used but some modification is necessary. The pollen may be collected in the tank and air pressure is introduced in the tank. The pollen may be pushed out of the tank through a tube which has a suitable opening. Also, the process can be achieved by using a paint spraying can where pollen can be sucked into the tube by the air stream.

VI. Conclusions

A palm tree climbing robot has been designed, built and tested Fig. 7. This robot has one upper hand and one lower leg. The hand and leg are made from cladded aluminum tubing which encircles the trunk of the tree with provision for varying diameters. The driving power source for this climbing robot is pneumatic power. The source of pressurized air to operate this robot is a portable air compressor with a pressure vessel for storage (~10 Liters) on the ground. The compressor unit is powered from a portable power generation unit. An Electro pneumatic control circuit was designed, built, and tested on the climbing robot successfully. This circuit controlled all valves leading pressurized air into the desired pneumatic actuator at the specified time with appropriate delay time between strokes. The program was written for the Arduino microcontroller with all necessary steps. This robot and circuit can also be used with slight modification to climb the Washingtonia palm tree.

Figure 7. The palm tree climbing robot prototype

ACKNOWLEDGMENT

This research work has been supported by a grant from the Scientific Research Fund of Jordan under Grant Number (EIT/2/06/2011).

REFERENCES

[1] Balaguer, A. Gimenez, and A. Jardon, "Climbing robots mobility for inspection and maintenance of 3D complex environment," *Autono. Robots*, vol. 18, no. 3, pp. 157-169, 2005.

[2] A. Nishi, "Development of wall-climbing robots," *Computers and Electrical Engineering*, vol. 22, no. 2, pp. 123-149, 1996.

[3] M. Almonacid, R. Saltaren, R. Aracil, and O. Reinoso, "Motion planning of a climbing parallel robot," *IEEE Trans. Robot. Automat.*, vol. 19, no. 3, pp. 485-489, 2003.

[4] P. Kroczynski, "Robot with climbing feet," US Patent No. 4, 674, 949, (1987).

[5] H. Iida and R. Nakayama, "Apparatus for moving carriages along ladders," US Patent No. 4,637,494, (1987).

[6] L. Paris, "Climbing robot, movable along a trestle structure, particularly of a pole for high-voltage overhead electric lines," US Patent No. 5,213,172, 1993.

[7] I. Macconochie, M. Mikulas, J. Pennington, R. Kinkead, and C. Bryan, "Space spider crane," US Patent No. 4,738, 583, 1988.

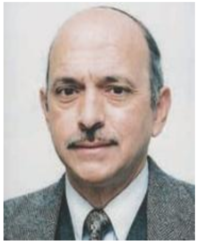
[8] G. Vastianos. Sloth: Rope climbing robot. [Online]. Available: www.vastianov.com

[9] B. Yazdani, M. Ahmadabadi, A. Harati, H. Moaveni, and N. Soltani, "Design and development of a pole climbing robot mechanism," in *Proc. Mechatronics & Robotics*, Germany, Sept. 2004.

[10] R. Aracil, R. Saltaren, and O. Reinoso, "A climbing parallel robot," *IEEE Robotics and Automation Magazine*, March 2006.

[11] X. Wang and F. Xu, "Conceptual design and initial experiments on cable inspection robotic system," in *Proc. the 2007 IEEE*, 2007.

[12] K. R. Asfar, "Pole climbing robot," *Patent Application*, 2013.



Khaled Asfar is a professor in the Mechanical Engineering Department at Jordan University of Science and Technology (JUST). He is the Director of the Center of Excellence for Innovative Projects at JUST University and Manager of the Technological Incubator at the Center. He was a visiting research scholar at the Aerospace Engineering Department at Texas A & M University, 2007/2008 and a visiting professor at the School of Mechanical Engineering/Purdue University from 2008 to 2010. He received his Ph.D. degree from Virginia Tech in 1980, his M.S. from Virginia Tech in 1978, and his B.S. from Riyadh University in 1975. He received many scientific honors and awards such as the Hisham Hijjawi Award (1995 and 2001), JUST University Award for Scientific Distinction (1997 and 2006), and the Alexander von Humboldt Research Fellowship (1991-1992). He published numerous articles in several fields and holds three US Patents, five patent pending applications, and several medals for his inventions from international exhibitions. He is Associate Editor of Journal of Vibration and Control, and Applied Water Science Journal. His current research interests are in Robotic System Design (Unmanned Submarines, Spherical Robots, Climbing Robots, Helicopters,…), Vibrations, and Renewable Energy Systems (Wind and Solar).