Low Cost Robotic Arm Design for Pruning and Fruit Harvesting in Developing Nations

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Abstract- **It is often necessary to prune the trees which causes nuisance to public and transportation on the road sides or even within the house premises. Alternatively farmers struggle to reach to heights in order to harvest fruits in their orchards. Most of the robots used in pruning and harvesting fruits are very high cost and used in developed nations. They are also designed for fruits trees like apple, apricot etc. In this research paper, we introduce the design of a low cost robotic arm that can be used for pruning and harvesting fruits from trees in developing nations like India. The arm can be attached to the end of a pole and can be used for pruning and harvesting fruits. It is controlled in wireless fashion with bluetooth wireless interface from the ground. A smart phone based app is used to control the arm movement. The arm is attached with a powered cutter at the end, which can also be controlled in wireless manner. The design, implementation, testing, and results are presented in this paper.**

Key words: robotic arm, wireless, pruning, harvesting

I. Introduction

It is an interesting point in history as the world becomes urbanized and agriculture faces a critical loss of labor and investment in the farm. In a country like India, it is difficult to keep workers engaged on the farm when farmers routinely make only $1,000 per year. Case studies around the world support the absolute need for solutions to agricultural employment. The main area of application of robots in agriculture is at the harvesting stage and for pruning. Robots are very useful in places where manual laborers are hard to find. In case of flexible trunks, there is a chance of climber falling or trunks breaking. Hence in these cases pruning can only be done using the robots.

The design and development of such a pruning and harvesting robot is based on the farms in western countries where they are currently being used. For developing countries like India, the scenario is entirely different as the farms are tropical and the fruit trees grown vary a lot. In addition the cost of such a robot is also a factor when it comes to deployment of the robots after the design. For example the pruning robot being developed at Purdue University, USA, is expected to cost about $150,000. That is about one crore Indian rupees. As the labor cost is increasing severely there is a need for the development of such pruning and harvesting robots in India. Due to the rise in the literacy rate, people are no more interested in taking up the jobs of pruning and harvesting.

II. Motivation

In this modern world, humans are looking for alternatives by making use of technological advancement, to do their work. Researchers, scientists, and interested individuals etc. are striving to discover technologies which will reduce the human labour and carry out the task with ease. Humans do face a lot of limitations to carry out certain tasks which are out of their reach. This is the time when robots started to do activities which are physically impractical by humans. Robots can be moulded to different shapes and sizes thereby allowing them to reach any confined geographical area where humans can't reach. One such scenario we face is pruning and harvesting fruits from trees. It is a job which involves a certain amount of risk to get on the top of the tree and pluck all the fruits and cut all the unnecessary branches and leaves. This job can easily be done by a robotic arm with a rotating blade attached as it end-effector. This can be used to pluck coconuts, mangos, and other fruits which grow high up on the tree and can also be used for pruning which will ensure the proper growth of the tree. This can be extended to pruning trees on the roadside which is very necessary in cities which would avoid cutting down trees. This arm can either be attached to a robotic body which will climb on a long pole placed adjacent to the tree or it can be attached to a series of interlocking metallic rods which can be retracted back when not in use.

III. Related Works

Complex robotic arm structures with varying degrees of freedom have been in place for more than a decade. These robotic arms are widely used in industry for large scale processing in manufacturing field. There are robotic arms available for varied applications - for visually challenged, for stroke patients, cleaning cargo containers, surgery etc with various techniques and algorithms in place. A 6-DOF slave tele-operated anthropomorphic robotic arm is discussed in [1]. A man-machine interface is used to operate this robotic arm though it doesn't state clearly which algorithm is being used. Design of an intelligent robotic arm is presented in [2] for helping visually challenged people. This arm acts according to the voice command of such people. A robotic arm based on Surface Electromyography is proposed in [3] for stroke patients. This arm aids in extending and folding arms of stroke patients whose body and limbs are partly paralyzed.

Considering the health of the workers cleaning the cargo containers, the authors in [4] present a robotic arm design which can clean these containers without human intervention. Design and implementation of a minimally invasive robotic arm to be used in thorasic surgery is explained in [5]. There are also robotic arm with autonomous capability developed and tested by many researchers. Co-ordinate based robotic arm is discussed in [6] for pick and place applications. The robotic arm design and implementation that we propose in this paper is for an application which is not a common one - pruning and fruits harvesting.

IV. Design And Implementation

The robot arm and control diagram is given in Figure 1. A smart phone with bluetooth (BT) enabled interface is used to pair with the BT interface module attached to the arm. An open source app installed in the smart phone is used to control the motor drivers which in turn control the 2 DOF robotic arm. The Arduino based MCU processes the request from the smart phone and generates the necessary control signals to the motor drivers

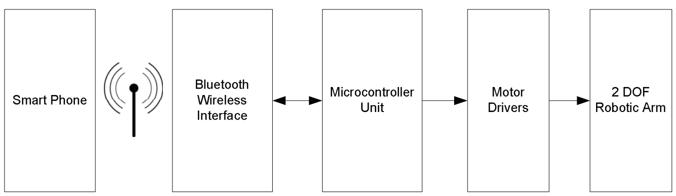

Figure 1. Architectural Diagram of the Propose System

The development of this robotic arm is done in three phases. In the first phase a 3 DOF miniature robotic arm is developed and controlled in a wired fashion by Arduino MCU. This 3 DOF miniature arm was designed to study the controlling of motors using arduino. This miniature model worked with the help of 3 Servo motors and the arm was made of hylum sheets. Though servo motors helped in accurate positioning, it required proper tuning and the cost of the motor was too high when compared with dc motors, so the idea of implementing the robotic arm using servo was avoided.

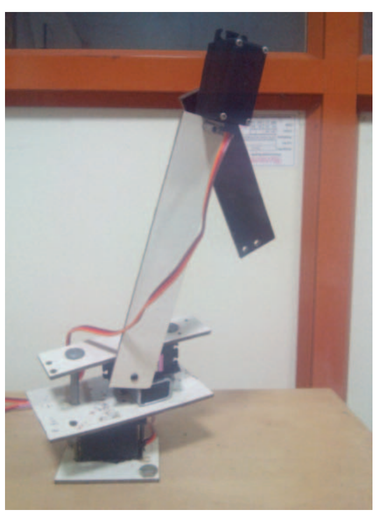

Figure 2. 3 DOF Miniature Arm

Figure 3 shows the diagram of the telescopic cylindrical pole with the platform at the top for holding the robotic arm. The robotic arm is shown with the cutter. The height of the telescopic pole can be raised or lowered. The user can control the increasing or decreasing height of the robotic arm. Disc type cutter is used which is attached to the robotic arm. The telescopic pole is expected to have a strong base for standing firmly on the ground.

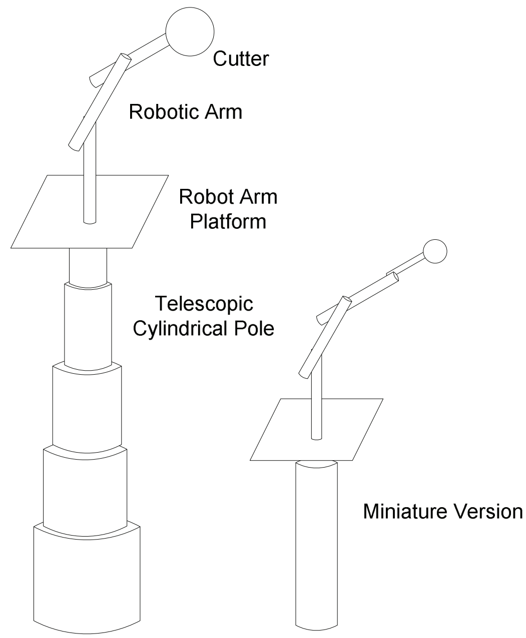

Figure 3. The diagram of robotic arm with cutter and the telescopic cylindrical pole

The next phase model was a simple robotic arm with 1 DOF using high torque 10 rpm 12 V DC gear motor which was controlled by Arduino on the basis of varying Pulse Width Modulation (PWM) as in Figure 4a. PWM was used to control the speed of the motor. The principle of PWM was implemented using a motor driver which was the common link between Arduino, Motor and Power supply. The arm is built with aluminium rods. Frequent load tests were done on the motor to find out the maximum weight it can hold and finally came to a conclusion that the motor can hold a maximum weight of 1 kg when the weight is applied 30 cm away from the shaft of the motor. The cutter motor (250 watts AC powered) was about 650 gm and it was tied at the end of the arm. The next step was upgrading the robotic arm to a wireless design with the addition of a BT module. With the help of BT module the arm can be controlled using a smart phone. The main disadvantage of this model was the motor not able to support the weight applied on the arm while in actions and this instability could lead to damage of the motor.

In the third phase, one more DOF was included in the arm and the base motor was changed to a 12V stepper motor with gear box as in Figure 4b. Cutter motor was changed to 350W, so that it could handle heavy items. The aluminium rods used for the arm is lighter than the base of the arm.

(a) (b)

Figure 4 (a) 1 DOF and (b) 2 DOF real time arm

The movement of the arm is completely dependent on the input signal given via Bluetooth module, the Arduino code and the rotation of the motors. Once the circuit is set up and powered, the user can establish connection with the Bluetooth module, through an Arduino Bluetooth control mobile application. The program code is burned into the Arduino board prior to the pairing of the module with the mobile phone. It is desirable to include a user prompt in the Arduino code which displays a message on the mobile screen, once the pairing is complete. The prompt, say "hello from arm", flashes on the screen, provided there are no glitches in the program or the circuitry. The movement of the arm in any direction is triggered by the input from the user, which has to be in accordance with the Arduino code. Say, we have 1 and 2 keys for the forward and backward motions of the base shaft and keys 2 and 3 governing similar motions of the upper arm, and 0 to stop the motion altogether. The Bluetooth module relays the signal received to the microcontroller.

A motor driver have two output terminals, namely out A and out B, which are connected to the motor. When the input signal is set as, say 1, the program will be written in such a way so as to drive one of the output terminals as HIGH and the other as LOW. This acts as an impulse to move the base shaft in the forward direction. For the input 2, the values are reversed at the terminals, and so is the direction of the motors. When 0 is pressed, both the terminals are driven by LOW value, which halts the motor. Pruning is done by the cutter, which has to be positioned accordingly by the motion of the arm. Once the cutter is in place, the AC power supply is switched ON and the desired part is removed. If the cutter is not of required power rating, it may stop half way while cutting a branch. This leads to overheating of the motor and its wires.

Table 1 shows the materials used to build the robotic arm. Aluminium rods make up the three sections of the robotic arm - one meant to attach the arm to the host machine, while the other two provide for the dual degrees of freedom. Aluminium is lightweight, as compared to other metals, which is why it is chosen. The dimensions provided in Table 1 are the outcome of numerous load tests. Geared motor, owing to its wider base area, provide extra stability to the system as such. Also, it narrows the possibility of the motor being damaged while handling loads exceeding its normal operating range. While deciding on the power of the blender motor, it is important to keep the weight factor in mind. If the weight exceeds the maximum load that the motor can handle, the gear of the motor might get broken. The power of the motor is another matter of concern. Motors with lower power have been ineffective in pruning. The entire setup would cost less than \$100 which is about 4000 INR.

Motors with lower RPM and greater torque are more desirable as these features enhance the controllability of the system. Dual motor drivers enable the controlling of two motors with a single driver with two power outlets, thus reducing the circuit complexity. Bluetooth module, attached to the Arduino board, enables the wireless control of the system. It synchronizes the transmission and reception of control and feedback signals. While fixing the blade to the motor, it is important to tighten the blade in the direction of the rotation of the blade. Else, it comes off easily once the motor starts to rotate which is very dangerous leading to severe injuries.

Table 1. Materials used to build the Robotic Arm

Rectangular aluminium rods	1 × 70×6.5×4 (cm) 1 × 40×5×2.5(cm) 1 × 50× 5× 2.5(cm)
DC geared motor	12V-10rpm
Bluetooth module	1
DC motor	12V-10rpm
Blender motor	230V-350W
Cutter blade	5" diameter
Bolts	2 × 8×1.1(cm) 4 × 7×0.5(cm)
Screws - Flat headed -Socket head cap	4 × 2.5×0.25(cm) 1 × 3.5×0.5(cm)
Iron couplers	1 × 7cm diameter 1 × 5.5cm diameter
Dual DC motor driver	1 × 20A
11.1V Li-Po battery	1 × 4000mAh
U clamp with bolt	1
Nuts	As per the dimensions of the bolts
Arduino board	1 - Arduino Uno
Jumper wires	As per the requirement
AC power supply	For the cutter

V. Experiments and Results

Tests were conducted to find the load capacity of the motor. Since we were planning to use DC motors for the motion of the robotic arm, it was necessary to know how much weight the shaft of the motor could manage to rotate through

360 degrees angle keeping the weight vertically downwards. A high torque 12 VDC motor with maximum load current of 7.5 A was used for this purpose. At 10 RPM this motor can provide a torque of 120 KgCm as per the specification. But in reality we found that it is not matching with the load test we performed.

The PWM supported by the Arduino MCU can be used for changing the RPM of the motor. But it was essential to know how much weight the motor supported as such or without any change in the rpm. The first procedure was to test how much weight the shaft could carry vertically upwards, and this test was conducted by keeping the motor on a table such that the shaft of the motor was tied to the load whose weight can be adjusted. This load was placed at ground level and the motor was placed on the table in such a way that the shaft could lift the load from the ground level. It is to be noted that the height of the table from the ground level is 82 cm. After each stage the weight of the load was increased by by 100 gm with the initial weight of 600 gm. Tables 2, 3 and 4 shows the results of load tests carried with our arm design.

Table 2. Load test for a 10 RPM DC motor (without PWM).

Weight	Pass/Fail
1 kg	Pass
1.25 kg	Pass
1.5 kg	Pass
1.75 kg	Pass
2 kg	Pass
2.1 kg	Pass
2.2 kg	Pass
2.3 kg	Fail

Table 2 lists the load test results carried with 10 RPM DC motor without PWM. It was found that the 12 VDC, 10 RPM motor could support a weight of about 2.2 kg. If the weight was restricted to 2 kg the motion of the arm using this motor will be smooth.

Table 3. Load test for a 12 VDC, 60 RPM DC motor (without PWM)

Weight	Pass/Fail
400 gm	Pass
500 gm	Pass
700 gm	Pass
1 kg	Pass
1.4 kg	Pass
1.7 kg	Pass
2.1 kg	Pass
2.2 kg	Pass
3 kg	Pass
3.1 kg	Fail

The result of the load tests in Table 3, indicates that the 12VDC 60 RPM motor could support a maximum weight of about 3 Kg, but for smooth functioning of the arm, the load should be restricted to 2.5 Kg.

Table 4. Load test for a 10 rpm motor (with PWM)

Weight	Pass/Fail
200 gm	Pass
400 gm	Pass
600 gm	Pass
800 gm	Pass
1000 gm	Pass
1200 gm	Fail

From the load tests conducted as shown in Table 4, we can infer that a motor with 10 rpm (12 V, 6A ,120 kg cm torque) could support a weight of about 2.2 Kg without any alterations in the motor, and with change in the PWM using Arduino program as a result of which the RPM of the motor will be changed. It is possible to support the smooth motion of an arm that weighed about a 1Kg, keeping in mind the weight of the cutter of 0.65 Kg has to be fixed at top end of the arm.

After we decided the motors for the first and the second arm (since we are providing two degrees of freedom), it was necessary to know the length of the arm it could support. We did calculate the length of the arm using the torque-force and force -length calculations. Since the design of the robotic arm is for pruning purpose, it is necessary to fix a cutter and test the same. The cutter could cut the branches as in coconut tree that were attached to a firm platform as show in Figure 5.

Figure 5. The robotic arm in action

The first and foremost design was a miniature model of robotic arm with 3 DOF. Servo motors were used to control each arm which produced impulsive movements and the tuning of each arm was a difficult task. In the second phase, a one degree of freedom robotic arm was designed using high torque dc motor. Load tests were conducted on different weights. The motor was not able to hold weights above 1 Kg when the weight was placed 30cm away from the motor. This was because of the low holding torque capacity of the dc motor. And as a result, the gear of the dc motor was damaged due to the excessive weight. Another problem that arose with this model was the limitation of 1 DOF. Since the arm was restricted to one degree of motion, it was not able to cover a large workspace. Due to this, the end effector was not able to reach the required point to carry out its task. The 2 DOF model succeeded in covering more workspace and the end effector was able to reach its desired point without any difficulty.

VI. Conclusion

In most of the rural places, especially in India, coconut harvesting is considered to be a big deal. Coconut trees are seen everywhere but to pluck them from the tree is a big challenge. Only trained people who are rarely available can climb on the tree and pluck them. This results in the rotting of the fruit if they are not plucked in time. Similar problems account for the pruning of trees. Due to lack of availability of trained people to cut the unwanted branches and leaves of a tree, the growth of the tree is affected and they are left with numerous diseases and infestations. In addition the trees on the streets of highly developed cities needs constant pruning as some branches might disrupt the regular traffic. Through this work, we are beginning to find solution to such issues. As a result, a robotic arm with 2 DOF was developed with a cutter at a very low cost of only 4000 INR. This could be easily attached to a pole that can be raised mechanically or to the body of robots like pole climbing robots. The work presented in this research paper is an ongoing work with the robotic arm design and cutter in action being successfully tested. The tests were performed inside the lab with a tree setup as shown in the figure 5. The results were extremely promising and we hope that with proper field test conducted and evaluated, the proposed arm and the cutter along with the telescopic pole would be of great help to the farmer community in the developing nations.

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