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DTMF based Robotic Arm Design and Control for Robotic Coconut Tree Climber

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***Abstract*—This research work focuses on wireless controlled robotic arm using DTMF (Dual tone multi frequency) technique. The arm is designed to be a part of a coconut tree climbing robot. As the number of human coconut tree climbers is dwindling, there is a dire need for a robotic climber. The robotic arm is capable of a two axis rotational movement. The entire robotic arm can be controlled by using a remote device - mobile phone which hosts the DTMF Technology. The remote device can be used to control the movement of the arm. It can also be used to control the direction of rotation of the armatures. The use of DTMF technology for wireless transmission gives an edge over other wireless transmission techniques as the former incorporates a much better range for the transmitter and receiver.**

Keywords: Robotic Arm, DTMF, Coconut harvesting

I. Introduction

World production of coconuts is 64,897 million nuts and India leads in the production with 21,892 million nuts as of 2013. Though India has only two million hectares of coconut cultivation land compared to Philippines which has 3.8 million hectares of the land to produce coconuts, India leads in world coconut production. Coconut is cultivated all over India, particularly in 18 states and 3 union territories. Among these, southern India (Kerala, Tamil Nadu, Karnataka and Andhra Pradesh) alone contributes to 90% of the land and 91% of the coconut production. Farmers of very small and marginal income hold 98% of coconut harvesting in India. Coconut trees belong to a unique category where each and every part of the tree is used by people. From coconut is produced copra, oil, milk, chips, milk powder, toddy, refined sugar, jaggery/palm sugar, flower syrup, jam, vinegar, jelly, tender coconut water etc. Thousands of people get employment from coir industry which produces floor mats, geotextiles, coconut wood products, coconut based handicrafts etc. One of the main threats of this industry is the increasing cost of production and the decrease in the labour resource. Another constraint in this sector is the acute shortage of labour for harvesting coconuts.

Traditionally coconut harvesting is carried out by men who belong to the economically backward class of society. Due to increase in literacy rate and awareness about the high paid job opportunities, the number of men climbing coconut trees for harvesting coconuts has decreased a manifold. As these men do not have any insurance coverage, any accidents while climbing the trees would affect the entire family. In many such households, people suffer a lot because this would be the only source of income for their livelihood. In addition, the people who fall during climbing greater heights are bed-ridden for the rest of their life. In Kerala, there are families whose main source of income would be selling the coconut from a few coconut trees that belong to them. Even that is affected since there is an acute shortage of coconut tree climbers.

II. Problem Definition

Coconut production contributes to 10,000 crores of rupees to India's GDP. Recently there has been an acute shortage of coconut tree climbers in India. Also there is a high risk associated with coconut tree climbers because the accidents can lead to severe physical damage, some of which may even be fatal. On the other side there is a steep increase in price of coconut and coconut products. To tackle all these problems, the process of coconut harvesting can be machinated. It reduces the need of human labour and also reduces the risk factor involved in the process. Such machines if configured to be wireless, provides simpler implementation opportunities considering the difficulty in moving a bunch of wires up the tree. Wireless implementation also simplifies the external skeleton of the machinery. The robotic arm plays a crucial role in making the robotic coconut tree climber a successful machine. A robust and proper robotic arm would also help in balancing the body of such a robotic climber.

III. Related works

Robotic arms and control have been extensively studied and researched in the last two decades [1] - [6]. In the past decade the robotic arms were designed for wide range of applications. Authors in [7] and [8] discuss about the robotic arm developed for industrial applications. While [7] discusses about the gesture based control of the robotic arm using Kinect through Telemanipulation, [8] presents the accelerometer control of the industrial robotic arm. Robotic arm are inseparable part of humanoid robots. Control of an interactive robotic arm for humanoid applications is deliberated in the research work [9]. There are robotic arm developed for people with disabilities [10], stroke patients [11], educational purposes [12] etc. As robotic arms evolved to replicate a human arm, control methods too have evolved with the advent of technology. These control methods include man-machine control, neural networks, co-ordinate based control, EOG/EEG based control, voice-based, switch-based, sensor based, vision based etc. In addition there are many arm designs with various degrees of freedom ranging from 2DOF to 6 DOF and more. They use various algorithms and techniques including kinematics, reverse kinematics, neural networks, prediction algorithms, biologically inspired algorithms, fuzzy logic etc. In all these designs we see a stable support structure for balancing the arm while it is in action. Most of these arms are either fitted to the ground with a huge base in case of industrial applications or fitted to a stable structure like a table. But for a robotic arm to be fitted to the mobile structure which is climbing the tree against gravity is very challenging. In this research work, we are concentrating on exclusive design of a robotic arm to be fitted with the coconut tree climbing robot.

IV. RELATED WORKS

Figure 1 shows the system architecture block diagram. It consists of the Dual Tone Multi-Frequency (DTMF) generator, DTMF receiver, a DTMF decoder, Microcontroller Unit (MCU), Motor Driver module and the Robotic Arm.

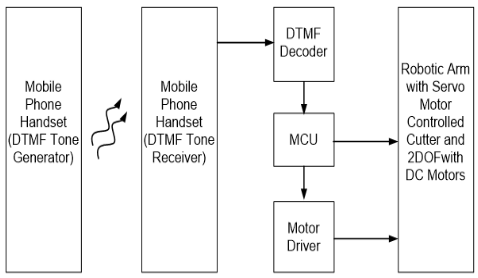

Fig. 1.System Architecture

When any key is pressed in the mobile phone handset at the transmitter side, the DTMF tone generator generates the corresponding tone frequency which is transmitted wirelessly to the receiver mobile phone. A mobile telephone receiver receives a call. Once the call is received, the DTMF control signals will be fed to the DTMF decoder unit. Since DTMF signals are simple tones having audible frequencies, we can take the receiver output from the headset jack (two lines). DTMF decoder decodes the tone and generates the corresponding binary output. This binary output of the DTMF decoder represents the key pressed for controlling the robotic arm. The DTMF decoder also generates an Interrupt.

The signals from the DTMF decoder is fed to the microcontroller unit (MCU). The MCU analyses the output of DTMF decoder and generates control signals for the motor driver. The motor speed is controlled via PWM signals generated from the MCU. There is also an option to run the motors at constant speed with the digital output (four bits) from the MCU. For our prototype model we use Arduino – ATMEGA328 based development board as the MCU.

Motor driver supply adequate current for driving the gear motors both clock wise and counter clockwisedirections.The motor driver used for this prototype work is L293D (H bridge) which is capable of driving two motors in both clockwise and anticlockwise direction. L293D can supply maximum of 1.2A peak current per channel. A servo motor can be directly driven from the Arduino. The gear motors used are 60 RPM each for both the base and the joint. Arduino IDE provides in-built library to attach and controls servo motors which makes interfacing servo motors with microcontrollers simpler.

The arm has two joints; one for the base and other for the elbow. There is also a cutter joint where a cutter can be attached via servo motor that can be directly controlled by the MCU. The base joint motor makes the arm to move 360° in the horizontal direction, both right and left. With the elbow joint motor, the upper arm can move 360° in vertical direction (perpendicular to that of base joint motion), both clockwise and anticlockwise. This robotic arm has 2 DOF so that it is simple to implement and control. The arm height can also be adjustable for it to reach the coconuts at greater heights. It is to be noted here that the arm is not cutting each coconut separately. It is intended to cut the coconut bunches instead of individual coconuts.

A. DTMF

For this Using DTMF to control electronic devices remotely is in use for more than a decade. We can find a research work published [13] by Ismail Coskunet all as early as 1998 using DTMF to control home and office appliances. The Holtek HT9170B DTMF receiver is used for our prototype which has both the decoder and filter. The question on how the motor interprets the signal from the mobile phones rests within the structure which is housed in an 18-pin DIP package. We are decoding the DTMF tone pairs which is specified for a key. The connection is made such that when a key is pressed, the corresponding DTMF pair is fed into the IC and the digital code assigned to that specific DTMF pair is obtained.

To identify the keys i.e. to identify the key pressed in a mobile phone, DTMF signaling is used. Earlier telephones used pulse dialing or loop disconnect signaling. In today's telephones and mobile phones, this type of signaling is replaced with the Dual Tone Multi Frequency dialing. The dialed numbers can be sent long distance in the voice frequency range. This is the major advantage of DTMF.

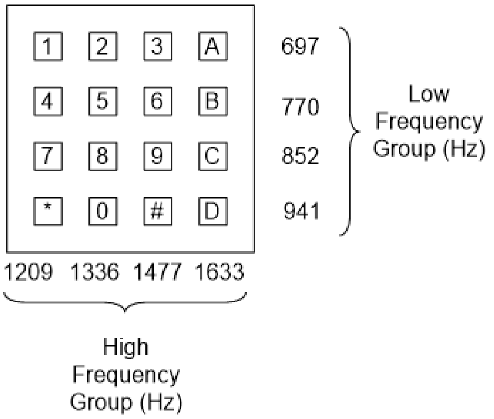

Fig. 2. Mobile Phone Keys and corresponding frequency values

Figure 2 shows the keypad and the corresponding signal frequencies generated. These signal frequencies are classified under two groups: a low frequency group and a high frequency group. When a key is pressed, the DTMF generator generates a mixture of these two frequency groups, which is a pure sinusoidal signal. For example if key 1 is pressed, a sinusoidal frequency of 1906 Hz is generated which is a mixture of the low frequency group signal 697 Hz and high frequency group signal 1209 Hz.

At the receiver side, HT9170B DTMF decoder consists of three band-pass filters and two digital decoder circuits. A highly accurate capacitor switching system is employed to split the DTMF pair. Using the filters, the input DTMF signal is split into high and low frequency signals. The digital decoder circuit converts the corresponding DTMF signal to a 4 digit binary signal. The 15th pin DV, goes high when a 'legal' frequency pair enters the IC. The BCD output is obtained through D0-D3. The basic structure of HT9170 gives output for 16 DTMF pairs, but we require only 4 pairs to control the two-dimensionally rotating structure. This IC works on 5V which can be obtained from the board itself and no external power source is required. The 4 BCD output is assigned/worth each value during its high state. During the high state of DV pin,D0 is worth 1, D1 is worth 2, D3 is worth 4 and D4 is worth 8. The MCU identifies the key pressed based on the D0 - D3 inputs and accordingly decides which motor to control: the base motor or the elbow motor.

V. IMPLEMENTATION

B. *Arm Model and Prototype*

The robotic arm model and the prototype that we have developed are shown in the Figures 3 (a) and (b). The 1 DOF and the 2 DOF Arm design used in Robotic coconut tree climber are shown in Figures 4(a) and (b). In Figure 3 (a) Axis 1 is where the base motor is fitted and Axis 2 is where the elbow motor is fixed. The lower arm is fixed to the base and can rotate in horizontal direction on either side up to 360^o. The upper arm is fixed to the Axis 2 and can be rotated in vertical direction perpendicular to the base, both in clockwise and anti-clockwise directions, up to 360^o. There is a provision for a cutter at the terminal of the upper arm. For our prototype model, we have not fixed the cutter.

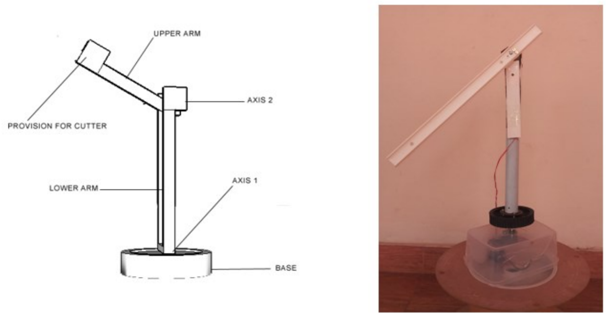

Fig. 3 (a) The Arm Model; (b) the 2 DOF Arm Prototype

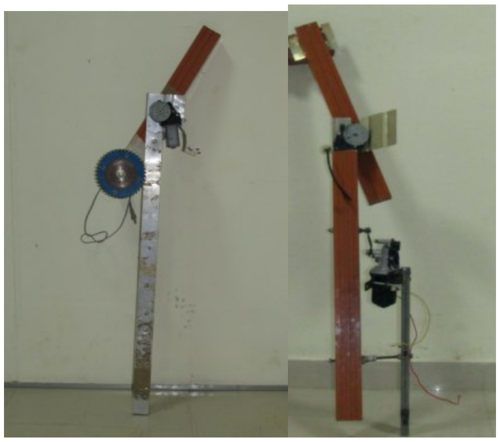

Fig. 4 (a) The 1 DOF Arm Model; (b) the 2 DOF Arm Model

C. *Arm Control*

The detailed implementation diagram which includes the DTMF Decoder [14], the MCU - ArduinoInduino board, the motor driver module and the robotic arm is shown in Figure 4. The DTMF Decoder receives the multi-tone frequency signals received by the mobile phone at the receiver end which is sent from a remote mobile phone. The mobile at the receiver end provides the MF signals via an audio jack which is connected to the decoder via a two line wiring. One of these lines carries the sinusoidal signal of the tone frequency and the other line is a signal ground. For our prototype implementation, we do not generate the PWM signal for the speed control of the motors of the arm. Instead the motors are run at constant speed. This requires only digital signals to be generated to the motor controller module. Based on the decoded signals from the DTMF decoder, the MCU generated binary pattern to run either the base motor or the elbow motor.

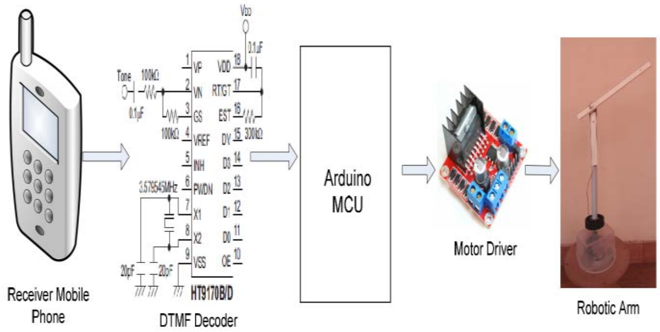

Fig 5. Control Diagram with receiver mobile phone

VI. Experiment and Evaluation

The test setup consisted of a DTMF generator mobile phone, a DTMF Receiver mobile phone and the entire circuitry as shown in Figure 5. First the user dials the number of the DTMF receiver mobile phone from the remote mobile phone. The receiver mobile phone is always in the hands-free mode which accepts any call from the remote mobile phone. After this setup is completed, when the user wants to control the robotic arm, the corresponding key in the remote mobile phone is pressed. The key values and their corresponding control information are provided in Table 1.

TABLE I. KEY PRESSED AND CONTROL INFORMATION

S.No	Key Pressed	Control Information
1	4	Base Motor Clockwise Rotation
2	5	Base Motor Anti-Clockwise Rotation
3	7	Elbow Motor Clockwise Rotation
4	8	Elbow Motor Anti-Clockwise Rotation
5	0	Stop any motor
6	All others	No action

The flow chart for the key identification and control algorithm we implemented in MCU is given in Figure 6. The MCU waits for the DV signal from the DTMF decoder to start the process. Once DV is asserted high, the corresponding decimal value of the key pressed is calculated by the MCU with the help of D0 - D3 signals of the decoder. The MCU then checks for a valid key press which can be 4/5/7/8/0 to identify the control information and generates the in1, in2, in3 and in4 signals to the motor control module as shown in the flowchart. If there is no valid key press, then there is no change in the state of the MCU or the motor control module.

The evaluation of the arm prototype is based on the response time, i.e. the time take by the base motor or the elbow motor to start rotating from the moment a key is pressed from the remote mobile phone. For evaluation purpose, the remote mobile phone key press was also done in the same area of the arm testing. This key press and the corresponding motor rotation, either base motor or elbow motor is captured in a video.

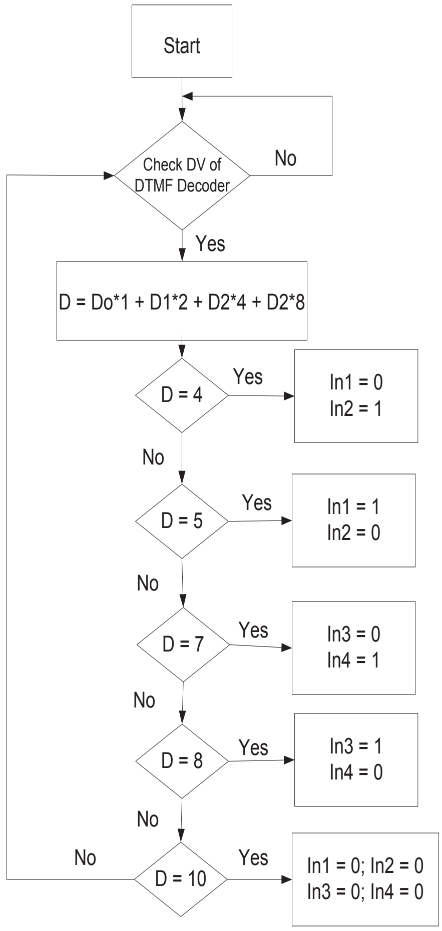

Fig. 6. The MCU Programming Flow Control

TABLE II. KEY PRESSED AND CONTROL INFORMATION

S.No	K1 (Sec)	K2 (Sec)	K3 (Sec)	K4 (Sec)
1	1.084	1.124	0.883	0.918
2	1.043	1.088	0.923	0.954
3	1.065	1.092	0.842	0.898
4	1.102	1.182	0.864	0.924
5	1.063	1.103	0.816	0.904
6	1.108	1.186	0.912	0.889
7	1.089	1.191	0.893	0.878
8	1.058	1.148	0.868	0.922

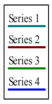

Fig 7. No of test versus response timing plot

The response time calculation is based on the video analysis, frame by frame. The response time is calculated for the following cases: key press for base motor clockwise rotation K1, key press for base motor anti-clockwise rotation K2, key press for elbow motor clockwise rotation K3 and key press for elbow motor anti-clockwise rotation K4. The response timings for each of the cases K1 to K4 is repeated 8 times and are listed as shown in the Table 2.

The response timings for the case in which the base motor rotates in horizontal clockwise direction (Table 2) show that there is a delay of about one second which cannot be ignored. This is a justifiable delay as the remote phone signals to reach the phone at the receiver end is going to take some delay. In addition there is delay associated with decoding at DTMF decoder and processing at the MCU. The motor controller delay too cannot be ignored. Similar is the case with K2, K3 and K4. The response timings graph is plotted and shown in Figure 7. The timings do not deviate much from the mean value validating the working of the arm prototype model.

The implementations of the robotic arm takes into account its efficiency and cost. For the arm to be efficient, an important factor is the material used for constructing its body. The build should be sturdy and the arm should be able to withstand mediocre impacts with ease. But since the arm has to be taken to the top of the coconut tree, the build material should also be light-weight. The material should also meet with the economic constraints. Taking all the above factors into consideration, plastic/PVC has been chosen for construction. Being cost-effective, reasonably strong and also light-weight, this choice fulfils the above requirements.The base axis of the arm consists of a high-torque DC motor. The other axis is equipped with a servomotor, which would require enough torque to lift an electrically powered cutter attached to the upper arm.

VII. Future Work

There is lot of scope to develop this prototype arm to be used with the robotic coconut tree climber. The cutter part is to be fixed to the arm and tested. Field testing can be carried out and the design can be evaluated based on the success of the test where the arm is attached to the climber and tested live. Other than DTMF based control of the arm, various wireless technologies can be explored and analyzed for the best response timings.

VIII. Conclusion

A robotic arm with 2DOF is designed and implemented which is to be used in a tree climbing robot, specifically for coconut tree climbing. The design was tested with remote mobile phone, receiver mobile phone, DTMF decoder, MCU, Motor Driver and the robotic arm, in the lab. The response timings were measured and plotted and they show a sizeable delay which cannot be ignored.

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