DESIGN AND DEVELOPMENT OF SCARA ROBOT FOR FRUIT HARVESTING

Shashikiran S.[1], Dr.Muralidhar[2]
[1]PG Student, [2]Professor
[1,2]Department of Mehanical Engineering, NMAMIT,Nitte,Karkala Taluk
Udupi District,Karnataka,India 574110
madhu.bengal@gmail.com[1], drmuralidhara@nitte.edu.in[2]

Abstract

The present work involves design and development of SCARA Robotic arm to be mounted on hydraulic ladder for fruit harvesting. This work involves CAD and mathematical modelling of the robotic configuration. The CAD modelling is carried out using Design software along with Kinematic simulation. The mathematical modelling involves Forward kinematics by D-H Parameter. The kinematic solution is verified using Kinematic simulation in design software, which are later used as input Algorithm for Robotic controller. The controller programme is compiled in Python language with necessary library packages. The prismatic joint parts are fabricated and assembled. The functional workspace of the robot is plotted using MATLAB and analysis of the robotic arm is performed in Ansys 18.1 Workbench. The deformation of the robotic arm under gravitational and cutting force is obtained using Ansys Workbench. The Robotic arm is fabricated by using aluminium for linkages and mild steel material for joints. The robotic arm was controlled by Python TKinter programme which displays graphical representation of the arm at each position. The experiment is carried out to find the joint displacement errors in robot by actuating prismatic joint and rotary joints separately and corresponding error plot is obtained based on sensor readings.

Keywords: Robot fruit harvester; ultasonic sensor; calibration; SCARA Robot; hydraulic ladder

I. INTRODUCTION

In horticultural industry, conventional harvesting is carried out by 'handpicking' methods to remove fruits. It is observed that the harvesting fruits by handpicking is inefficient and not economical in large scale harvesting. To overcome these limitations, mechanical harvesting systems have been proposed by many researchers. However, they frequently damage the fruits in the harvesting process. Hence it is essential to develop an economical method for fruit harvesting.

This work involves the Design and development of SCARA(Selective Compliance Articulated Robot Arm) Robot for fruit harvesting. General Steps involved in design are

- Design and development of SCARA (**Selective Compliance Articulated Robot Arm)** Robot for fruit harvesting.
- Kinematic analysis of Robotic arm.
- Determining the workspace of the SCARA Robot.
- Design and development of drive system.
- Simulation of robot system in Virtual Environment.
- Experimental evaluation Robot.

II. IMPORTANCE THE PROPOSED DESIGN

Traditional fruit harvesting methods are highly labour and time intensive. Hence it is not economical. Fruit harvesting systems by machines are a partial solution for this problem which will reduces the harvesting cost by 34 to 40%.

Mechanical harvesting systems are intended to achieve fruit harvesting in largescale during the harvesting season. This method has been practiced using shaker or air blast with chemicals as pre-harvesting agents to loosen the mature fruits. As discussed, the mechanical harvesting system damages fruits which will be unrecoverable loss to the farmers.

Hence it is needed to design an efficient and economical method for fruit harvesting which reduces harvesting cost and enhances the profitability.

III. METHODOLOGY

The Basic components of the system is shown in Fig.3.1 which involves Robotic arm, Hydraulic ladder and a controller.

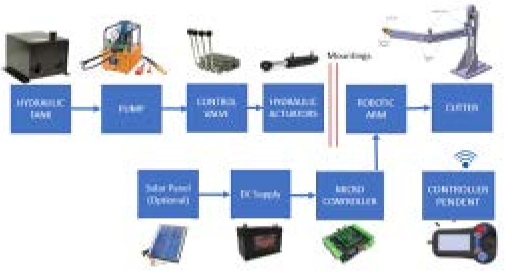

Fig.1: Block diagram of overall system

The components are explained in details as follows

A. Design of Hydraullic Ladder

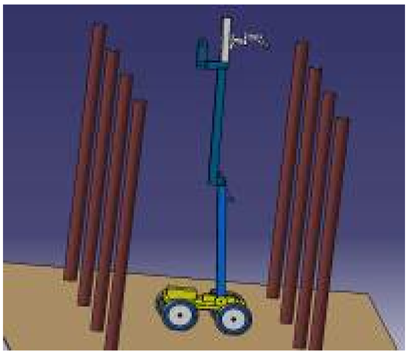

Fig. 2: CAD model of overall system

The Fig.2 shows the final system which contains a SCARA robot with rotory cutter as end effector which is mounted on the Hydraulic ladder.

The Design of overall system for fruit harvesting is shown in Fig.2. The 270-degree rotating turntable with hydraulic motor forms the foundation of the fruit harvester assembly. The total vertical reach of this harvester is 25 feet. (upper arm of 10 feet. and lower arm of 10 feet length with robot stroke of 3 feet) when assembly is at 2feet height from ground level. The power to operate hydraulic pump is taken from auxiliary four stroke gasoline engine.

The hydraulic pump has two ports - inlet port connected to hydraulic tank and outlet port connected to the multi way hydraulic multi position direction control valves. The hydraulic direction control valve has 8 inlets and 8 outlets connected to the cylinder 1, cylinder 2, hydraulic motor, hydraulic valve and the hydraulic tank. operator can control the motion of the cylinders, harvesting bucket and hydraulic motor by operating directional control valves. In forward stroke, the oil circulates in insulated pipes from the pool to hydraulic pump and to cylinders. While in reverse stroke, the hydraulic oil returns to the pool and arms moves in reverse direction i.e. moves downward.

The Retracted position of the Hydraulic Ladder with locomotive is shown in Fig.3.

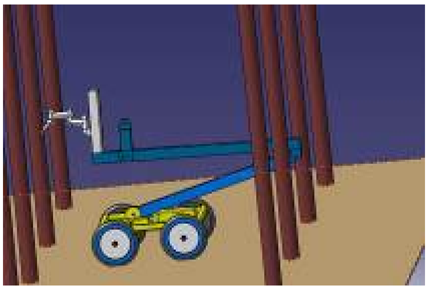

Fig. 3 CAD Model of system in retracted position

The Fig. 6.2 shows the final assembly of machine where SCARA robot is mounted on extendable hydraulic ladder in which has a mechanism to maintain horizontal position throughout the operation provided by linkage.

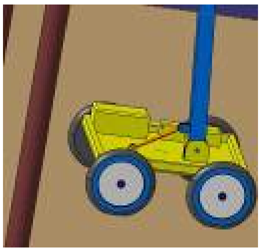

Fig.4. Locomotive system

The CAD model of the locomotive is as shown Fig.4 involves a 4 stoke engine which is auxullary connected to gear drive and also hydraulic pump.

IV. DESIGN AND FABRICATION

Based on the detailed review of the existing SCARA design SCARA Robotic arm with rotory cutter was designed using design software.

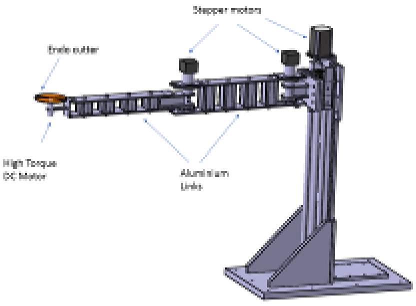

Fig. 5. CAD model of Designed SCARA Robot

The Fig. 5. shows the final CAD model of Designed SCARA Robot. The robotic system involves two Rotory joints and one prismatic joint at base. These joints are driven by planatary geared stepper motors.The end effector has a 4” saw cutting blade driven by high torque geared DC Motor.These motors are controlled by a Motor Drive unit which is inturn connected to Microcontroller.The height of the robotic arm is Approx. 0.85m and maximum reach of the arm is 0.8m.

The Robot assembly mainly consist of two parts.

1. BASE Prismatic system
2. Horizontal arm

A. Fabrication of Robotic arm

After selecting the parts and components required, the SCARA robot is fabricated.

Fig.6 shows the fabricated and assembled SCARA robot.

The Robotic arm length for fixed link length L_0=102 mm, Link1 is L_1= 350 mm and Link2 is L_2= 390 mm. The total weight of the SCARA robot is 9.85kg. Based on experiments, the motion range for Link1 is ±105° and Link2 are ±120°. As shown in Fig.4.19 two rotary sensors are coupled to the extended stepper shaft and placed at the bottom side of the rotary joints.

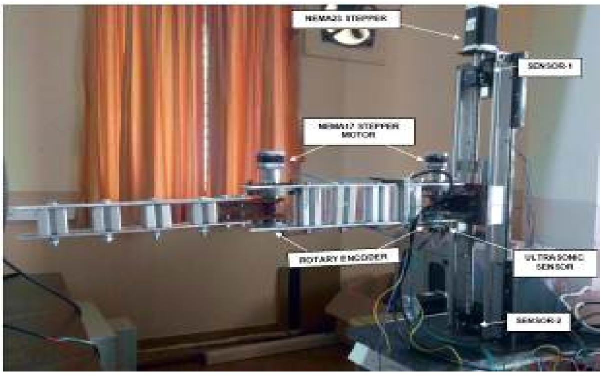

Fig.6. Overview of the SCARA Robot

Ultrasonic sensor is fixed to the base coupling plate by means of L shaped plate to measure vertical displacements.

V. ELECTRICAL COMPONENTS OF SYSTEM

A. Electrical Components

The electrical components of the system are shown in Fig.7.

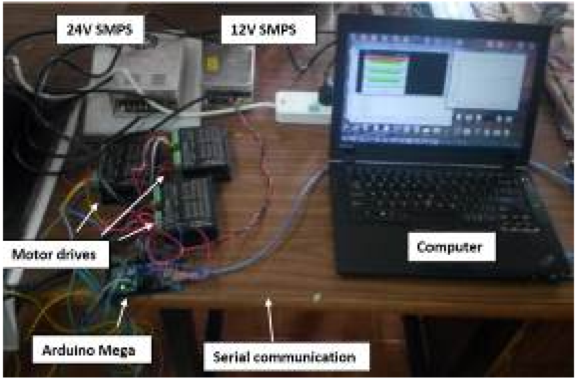

Fig.7. Electrical component of the system

The electrical components of the system which comprises of following devices

1) Computer: The software designed for the robot controller is executed in the computer to perform a movement of the robot to the required position. The minimum requirement of the software is computer running windows OS with preinstalled python packages. The minimum hardware requirement is 1GB RAM and 1GHZ processor.

2) Stepper motor controller: This involves an Arduino Mega which acquires required signals from computer through serial communication port i.e. by USB. Each stepper motor drives are connected to Arduino by digital pins. The Arduino generates required pulses based on the kinematic solutions obtained from raspberry pi /computer.

The Kinematics algorithm is not compiled and uploaded in Arduino because based on test, Arduino takes approx. 4 sec to calculate kinematic solution. When the same algorithm is compiled in python language which gives considerable speed on comparing with Arduino.

3) Motor Drive: In this project three ST-4045 A1 CNC stepper motor drives are used. The stepper motor rotates at 1.8deg/step which means the minimum resolution of stepper motor is 1.8 deg. Since smaller the step higher will be the accuracy. So, it is required to micro step the rotation. Which is accomplished by motor drives.

4) Switched mode power supply (SMPS): The SMPS transfers AC to DC Supply commonly

used in Desktop Computers. In this project two SMPSs are used one for supplying a 24V power to NEMA23 motor and another 12v SMPS for two NEMA17 motors.

5) Stepper Motor: Three stepper motors are used in this project. Single JK57HS112-3004-03 stepper motor with 2.8Nm Torque is used to drive prismatic joint by directly coupling it into ball screw placed at the top of the prismatic part by motor bracket and two 17HS3410-AG26.8 planatary geared stepper motor with 4.8 Nm torque and 1:26.8 gear ratio is used to drive two rotary joints of the robotic arm.

6) Limit switches/Sensors: Limit switches is a switch operated by the motion of the machine part or presence of object. Here two Inductive pickup sensors are used for prismatic joint and two angle measuring potentiometer for measuring stepper motor angles. The ultrasonic sensor is used to measure the position of the robotic arm in the vertical position.

VI. MATHEMATICAL MODEL

The mathematical modelling of the robot is carried out in order to relate joint displacements into end effector positions

Fig.8 Block diagrams of mathematical model

Mathematical modelling of the robot involves forward kinematics. In forward kinematics the end effector position is unknown which can be found by using given joint displacements and inverse kinematics is converse of forward kinematics. The block diagram of mathematical modelling is shown in Fig.8. In his project forward kinematics is obtained by D-H Method.

A. *Forward kinematics by D-H method*

The Fig.9 shows the coordinate system of Designed robot which has 2 rotary and a prismatic joint as shown.

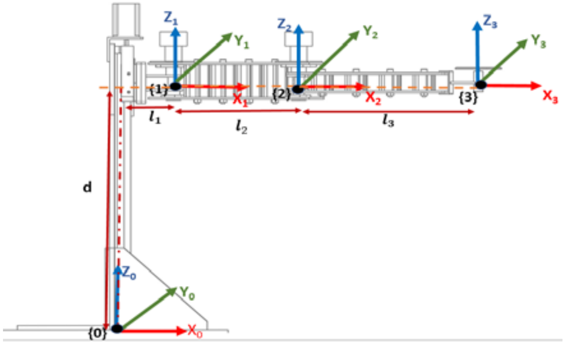

Fig.9 Coordinate system of Designed robot

Table 1 D-H Parameter Table

Links	Joint angle(θ_i)	Joint distance(d_i)	Link length (a_i)	Angle of twist
1	**0**	**d**	l_1	**0**
2	Θ_1	**0**	l_2	**0**
3	Θ_2	**0**	l_3	**0**

The table 1 shows the D-H parameter of the SCARA Robot designed.

The standard formula Transformation matrix is given by

$$^{n-1}T_n = \begin{bmatrix} \mathrm{Cos}\,\theta_n & -S\,\mathrm{in}\,\theta_n\,\mathrm{Cos}\,\alpha n & Sin\theta_n Cos\alpha_n & a_n Cos\theta_n \\ Sin\theta_n & Cos\theta_n Cos\alpha_n & -Cos\theta_n Sin\alpha_n & a_n Sin\theta_n \\ 0 & Sin\alpha_n & Cos\alpha_n & d_n \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

Following are the Transformation matrix

$$^{0}T_1 = \begin{pmatrix} 1 & 0 & 0 & l_1 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_1 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

$$^{1}T_2 = \begin{pmatrix} C_1 & -S_1 & 0 & l_2{*}C_1 \\ S_1 & C_1 & 0 & l_2{*}S_1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

$$^{2}T_3 = \begin{pmatrix} C_2 & -S_2 & 0 & l_3{*}C_2 \\ S_2 & C_2 & 0 & l_3{*}S_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Total transformation of end effector with base is found by

$$\mathbf{^{0}T_3 = {}^{0}T_1\,{}^{1}T_2\,{}^{2}T_3}$$

$$^{0}T_3 = \begin{pmatrix} C_{12} & S_{12} & 0 & l_1 + (l_3{*}C_{12}) + (l_2{*}C_1) \\ S_{123} & C_{12} & 0 & (l_3{*}S_{12}) + (l_2{*}S_1) \\ 0 & 0 & 1 & d \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Here $S_{12} = \sin(\theta_1 + \theta_2)$
$C_{12} = \cos(\theta_1 + \theta_2)$
$S_1 = \sin\theta_1$
$C_1 = \cos\theta_1$

IV. EXPERIMENTAL SETUP

The experimental setup shown in Fig.10 consist of SCARA robot interfaced with Computer running python script and arduino c++ codes.

Fig.10 Experimental setup of SCARA Robot.

Experiment is commenced by executing a python script on the computer. When the cordinate value is entered manually in GUI of programme, based on the kinematics algorithm, it calculates the joint displacements required to reach endeffector into commanded position. These displacement values are then converted into steps in arduino mega which is used as controller for stepper motor. The steps calculated is then sent to motor drives as pulses with direction which drives the stepper motor to achieve required joint displacement to reach the endeffector to the desired positions. Motor drives are powered by SMPS. 12v SMPS for NEMA17 Planatary geared stepper motors and 24V for NEMA23 Stepper motor are used.The steps required for one rotation is set to 800 and 200 for NEMA23 and NEMA17 drive respectively.

For NEMA23 stepper motor the speed and acceleration set to be 400 steps/sec and 400 steps/sec^2 respectively in the arduino programme, 50 steps/sec and 50 steps/sec^2 for NEMA17 motor.

A. *Circuite Layout*

The Fig.11 shows the block diagram of the circuite layout

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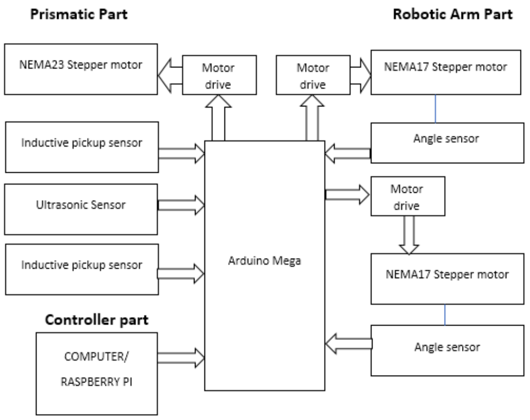

Fig.11 Circuite layout of designed SCARA robot

The micro controller used for the project is Arduino Mega which has more pins than UNO version.

The layout has three parts i.e Prismatic part,Robotic arm part and Controler part.

1) Prismatic part: This part drives base prismatic joint of the robotic arm,which involves NEMA23 stepper motor with 2.8N-m torque which is driven by stepper motor driver connected to 24v powersupply and signal to arduino mega.In feedback system it involves two Inductive pickup sensor/Limit switch which is fixed at top and bottom of the prismatic joint respectively connected to 24v powersupply and signal to arduino Mega.

2) Horizontal arm part: This part drives arm of the robot, which includes two NEMA17 stepper motor with 4.8N-m torque in each joints. In the feedback system it involves two potentiometer seperatly connected to shaft axis.The motor is powered by 24v DC supply which connected to motor drive and potentiometer is directly connected to arduino mega with 5v DC.

3) Controller part: This part involves Raspberry pi /Computer where arduino mega is connected by USB cable.

The motor is controlled by python programme graphical interface tkinter module shown in Fig.12.

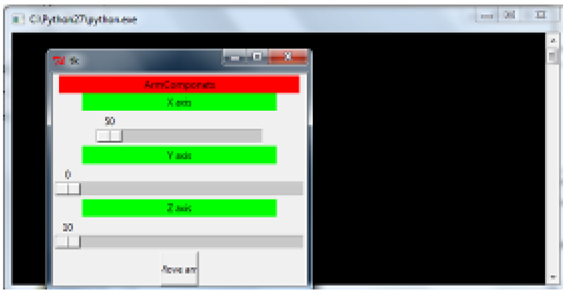

Fig.12. Tkinter User Interface

On executing python script it creates userinterface with three slider bar, top one is for controlling arm in X,middle one is for y and Bottom is for Z-directions.

The algorithm for the programme is a solution from Kinematics.

A. Calibration of Sensors

Before proceeding experiment, it is necessary to calibrate the sensors used in the designed SCARA.

Calibration of ultrasonic sensor is performed by using graph sheet with proper dimensions noted on sheet and by use of fiber glass plate as shown in Fig.13.

The calibration is performed on two ultrasonic sensors. The calibration procedure involves a fiber glass plate which is mounted vertically on work bench over the graph sheet. The glass plate is displaced for each 5mm increment and corresponding sensor reading is recorded, this task is performed from 50 mm to 400mm i.e. actual measuring range required from ultrasonic sensor and corresponding sensor values are recorded using PLX DAQ software.

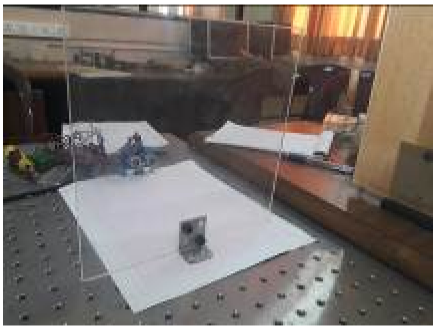

Fig.13 Calibration of ultrasonic sensor.

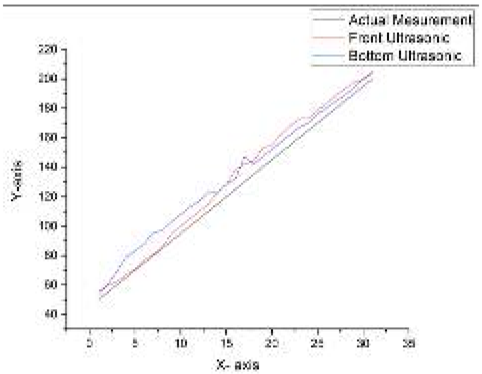

Fig.14 Calibration result of ultrasonic sensor

A graph is plotted with actual measurement vs sensor readings for individual sensor as shown in Fig.14. Based on the plot the ultrasonic sensor with minimum error is selected for prismatic joint. Later the analysis of recorded data is performed to trigger the average error of ultrasonic sensor which later is used as correction factor in the compiled controller programme.

V. RESULT AND DISCUSSION

A. Analysis of Robotic arm

The Fig.15 shows the Total Deformation of the robotic arm Design-I

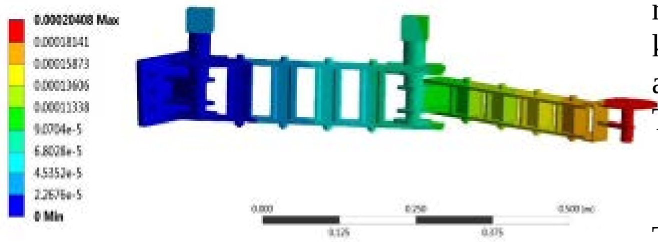

Fig.15 Total Deformation of the robotic arm Design-I.

The analysis of Robotic arm assembly was performed in order to know the displacement characteristics. The two type of design was evaluated, in design-I, second and first links are connected with an offset in order to enable the end effector to reach minimum possible positions in X-direction. whereas in Design-II, the links are connected in series to form pure SCARA configuration. The analysis was performed under static analysis using ANSYS 19.1 WORKBENCH. The material selected during the analysis is Structural steel for arm joints and Aluminium for two links. The corresponding results data is interpreted.

The static analysis was performed by fixing the base coupling plate ,then applying inertial force along Z- direction, normal force of 2.5N at the cutting blades and corresponding deflection is measured.The Fig.15 shows total deformation of the robotic arm design-I and Fig.16 shows total deflection of the robotic arm design-II.

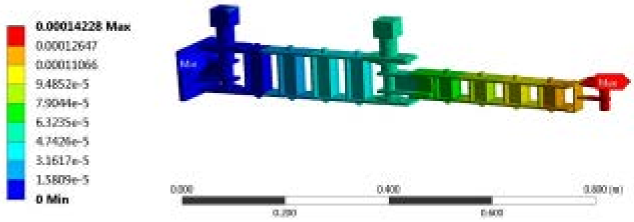

Fig.16 Total deflection of the robotic arm design-II.

From the analysis of the robotic arm the maximum deflection due to mass and applied force is found to be 0.2mm and 0.15 for Design-I and Design-II respectively. The maximum deflection occures at the blade end which is indicated by red colour in the Fig.15 and 16. Thus in our application these values of deformations are acceptable. Hence deformation due to loads are not taken into consideration during kinematic modeling of the robot.

B. Functional workspace of the Robotic arm

To find the functional workspace of the robot,following steps is to be followed Forward kinematics by DH Method to relate the joint angles and end effector position of the robot.

The joint limits for Design-I robotic arm

$$-90 \le \theta_1 \le +90$$

$$-10 \le \theta_2 \le +170$$

The joint limits for Design-II robotic arm

$$-105 \le \theta_1 \le +105$$

$$-120 \le \theta_2 \le +120$$

By using the cordinate transformation matrix from DH method and coding in MATLAB,the workspace of the robot is plotted as shown in Fig. 17 and Fig.18.

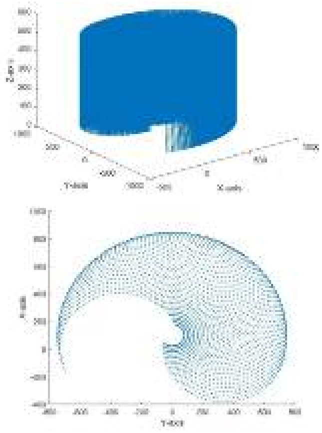

Fig.17 Workspace of the robotic arm Design-I

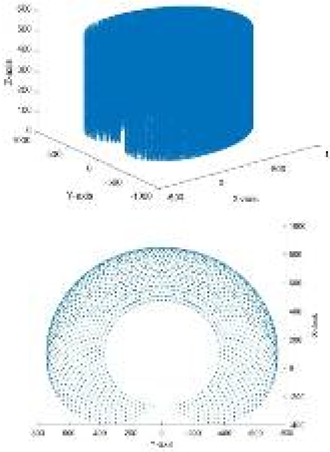

Fig.18 Workspace of the robotic arm Design-II

The Fig.17 and 18 shows the Functional workspace of the Design-I and Design-II robotic arm respectively. From the Fig.ures, it is observed that the Design-I robotic end effector can reach minimum possible position compared with Design-II offset robot conFig.uration.

From workspace of the robot it is clear that Design -II follows pure SCARA workspace which is more suitable in our application.

C. Experimental Evaluation of Prismatic Joint

The evaluation of the prismatic joint is carried out by giving predefined value of Z (Vertical position of the horizontal arm) in GUI slider and corresponding Z value is measured using ultrasonic sensor fixed at the base coupling plate. For each increment in the Z values, the corresponding sensor readings are displayed in the serial window are noted down and a plot of commanded vs sensor values is obtained.

The below Fig. 19 shows the plot of commanded Z value vs sensor reading of the prismatic joint.

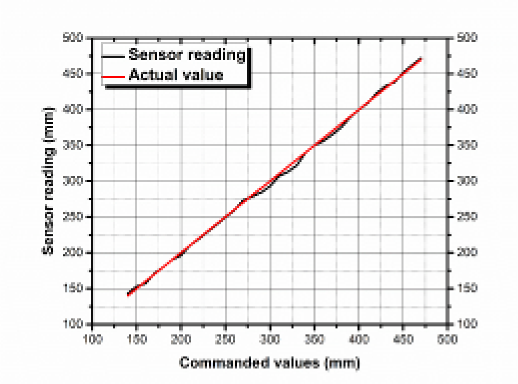

Fig.19 Graph of commanded values vs sensor readings of prismatic joint.

D. Experimental Evaluation of Rotary Joint

The Experimental evaluation of the rotary joint is carried out by giving predefined values of angles in serial monitor window. After initial home position setup of the robot, the angles are measured using potentiometer rotary encoders.

The experiment is initiated by entering angles to be tested manually in the Arduino serial monitor window and corresponding sensor readings are displayed in the serial window are noted down. The plot of commanded vs sensor values is obtained.

The below graph 20 shows the plot of commanded angle values vs sensor reading of the rotary joint.

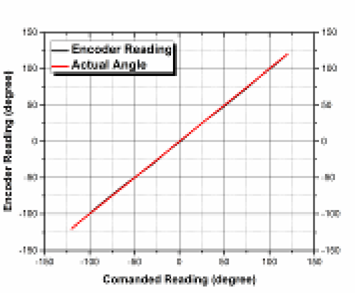

Fig.20 Graph of commanded values vs sensor readings of rotary joint.

VI. CONCLUSION

In this project, a SCARA Robotic arm for fruit harvesting was designed and fabricated. Mathematical modelling of the robot is carried out using D-H method. Forward kinematic modelling was performed using D-H Method. The kinematic solution was verified using kinematic simulation in design software and it was found to be satisfactory. By using the cordinate transformation matrix from DH method, the functional workspace of the robot is plotted using MATLAB software. The solutions obtained from kinematic model is used for the development of the robot controller. The controller was successfully designed using TKinter module in python language. The controller developed is tested on robotic arm and found to be capable of generating the joint displacements required to reach the desired positions at the end effector. The experiment is carried out to find the robotic joint errors by measuring prismatic joint and rotary joint displacements separately and plot of corresponding errors are obtained based on the sensor readings.

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