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SCARA Robot with Laser Engraver

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Abstract- The aim of this paper is to describe the method and the components used to build a simple and low-cost SCARA robot with Laser Engraver. SCARA stands for Selective Compliance Assembly Robot Arm, which is a kind of industrial Robot that is often used for pick-and-place tasks. The Laser Engraving process is a complex work that needs high accuracy and precision in engraving intricate designs or lettering on various materials. This paper focuses on engraving on the wood surface, which needs flexibility and versatility that will help in making different designs. For this purpose, the SCARA robot is combined with the Laser Engraver. It will help make accurate and highly precise design paths that the laser will trace and engrave on the wood surface, by using the G-code and M-code instructions for the path of engraving. The paper also examines the technical analysis of the assembly process of the SCARA robot and the Laser Engraver, as well as future work to enhance the performance and functionality of the robot.

I. Introduction

Laser engraving is a process that uses a laser beam to create visible marks on various materials by removing microscopic layers of material from the surface. The laser-material interactions depend on the type of materials and the laser parameters. Laser engraving is a complex and sophisticated work that requires high accuracy and precision in creating intricate designs or lettering. However, most of the existing laser engravers are fixed and rigid, which limits their flexibility and adaptability in engraving different designs on different materials. Therefore, there is a need for a more versatile and dynamic laser engraver that can engrave various designs on various materials with ease and efficiency.

In this paper, we propose a novel solution that integrates a laser engraver with a SCARA robot. SCARA stands for Selective Compliance Assembly Robot Arm, which is a type of industrial robot that has four degrees of freedom and is commonly used for pick-and-place applications. SCARA robots are known for their high speed, accuracy and repeatability. By combining a SCARA robot with a laser engraver, we can create a flexible and adaptable laser engraving system that can engrave 3D designs on various materials, especially wood surfaces. We use an Arduino MEGA board in combination with a RAMPs board to control the SCARA robot and the laser engraver using the Marlin 3D Printer firmware. We also use software like Marlin Open and Inkscape Laser Tools to upload the 3D designs and generate the G-code and M-code commands for the path of engraving. [1]

The main contributions of this paper are as follows:

- We design and build a simple and low-cost 4 Degrees of Freedom SCARA robot with Laser Engraver using readily available components.
- We demonstrate the functionality and performance of our system by engraving various 3D designs on wood surfaces.
- We analyze the technical aspects of our system such as the assembly process, the calibration process, the accuracy and precision of the engraving, and the safety measures.
- We discuss the future work to improve our system such as adding more features, enhancing the quality of the engraving, and expanding the applications.

The rest of this paper is organized as follows: Section 2 reviews the related literature and research papers on laser engraving and SCARA robots. Section 3 describes the problem statement, objectives and scope of the project. Section 4 describes the methodology and the components used to build our system. Section 5 presents the results and analysis of our system. Section 6 concludes the paper and suggests future work

Fig 1.1 SCARA Robot for Industrial use[8]

II. Literature Review

1. Pattern Carving Intelligent Control Integrated Device by *Yan Li*

The intelligent carving device consists of three parts: engraving machining module based on X-NET bus multi-axis servo linkage, machine vision recognition module based on Canny algorithm and Hough transform, and engraving product sorting module based on SCARA robot.

The engraving process is mainly driven by a four-joint manipulator. Among them, the three joints constitute a three-dimensional module, which is driven by three servo motors to control the displacement of the tool in the X, Y, and Z axes during the machining process; the fourth joint is mainly used to control the tool's displacement.

This research paper adopts multi-axis servo linkage control method based on X-NET bus to drive. In the engraving machining module's hardware configuration, the hardware circuit connection design extends a network communication module XDNE- BD on the PLC controller and connects a communication board to the three-axis motion servo driver of the robot. In addition, it uses R485 communication standard for channel connection and realizes data exchange through X-NET protocol.

2. Design, Manufacturing, and analysis of Robotic Arm with SCARA Configuration by *Kaushik Phasale*, *Praveen Kumar*, *Akshay Raut* and *Ravi Singh*

The paper discusses the design of a 4-Axis SCARA Robot with Creo software for designing the robotic arm. The animation was done with various constraints in the software. This research study also includes the manufacturing and assembly processes of the robot.

The experimental model was used to analyze the location of motors, length of links and its movements. The designing of the robotic arm was done in Creo software which is a 3D CAD software that enables users to design products with ease and precision. Ansys is a finite element analysis software that enables users to simulate and analyze the behavior of structures. The animation was done with various constraints in the software which means that the movement of the robotic arm was limited by certain conditions.

III. Problem Statement, Objectives & Scope

Engraving various items for customization, personal marking, and gifts have been very common since the Middle Ages. For years, the art of engraving was done manually by artisans. Not only was it a lengthy and tedious task but also the flexibility of designs was bare minimum. With the advent of technology, lasers have been commonplace for engraving complex designs with high accuracy, precision and in less time.

The objective of this project is to engineer a simple laser engraving SCARA robot and provide the methodology to move the robotic arm in 4 degrees of freedom with a 360° rotational movement about the Z–axis so that the complex designs can be made easy along with maximized time efficiency [2]. The Inverse kinematics and data interpolation allow the robot to move dynamically, quickly, and intelligently.

The scope of the project includes creating a well-defined project plan (over 2 semesters), procuring of economical components and assembly using assistance from guide. The Robot (finished product) may be used to carve designs on wood for personal or commercial purposes. Further work may be done in improving the robot by the addition of a Z Axis Focus Master Kit, Belt Tensioner Set and Retainer feet.

IV. Material and Methodology

The methodology adopted for the project setup is as follows. Rough designing and modelling was done on paper followed by rough 3D designs on SOLIDWORKS. Next we calculated the link lengths, joint angles and expected forces followed my modifying the design as needed. Next, we designed each mechanical component followed by the assembly of the components on SOLIDWORKS. Based on results, we modified the project as required and maintained design efficient improvements. Project guide was also consulted for improvements in feasibility and accuracy.

A. Components

The robot basically requires 4 NEMA 17 stepper motors [3] for movement on x, y, z axes, an Arduino MEGA board to control and handle the motors and sensors, an A4988 stepper driver for the stepper motors, a RAMPS 1.6 board which is an Arduino shield that is capable of controlling stepper motor drivers, taking temperature readings, powering heating elements, and other tasks necessary for 3D printing and lastly the laser module used for engraving. Miscellaneous components include limit switches, DC power supply and MG996R Servo Motor for gripper.

B. Modelling

The robot was designed in such a way that most of its parts can be made through carpentry work (wood) or 3D printing. The GT2 pulleys are also 3D printable. The robot was modelled using Parametric design to allow size variability. The first joint has a 20:1 reduction ratio achieved in two stages with custom designed pulleys. The two GT2 belts are closed loop with lengths of 200mm and 300mm respectively. The robot joints are composed of two thrust bearings and one radial bearing. For the second joint, a 16:1 reduction ratio is achieved as mentioned, and the third joint has a 4:1 reduction ratio with just a single stage reduction. The joints are hollow for easier pull ability through the wires from the motors and micro switches. For each of the belts, there are slots to attach idler pulleys for tensioning them. The Z axis of the robot is driven by an 8mm lead screw while the whole arm assembly slides on four 10mm smooth rods and linear ball bearings. The height of the robot simply depends on the length of the smooth rods which in this case are 40cm. The lead screw needs to be 2cm shorter in order to fit in this configuration, or if not, the Z motor can be raised by 2 cm using spacer nuts [5].

C. Mechanical Assembly

The assembly process begins with the base by inserting a

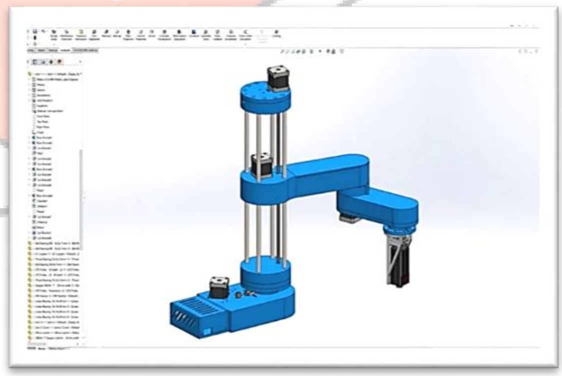

Fig 4.2 SCARA Robot Model design on SOLIDWORKS

radial ball bearing with a 35mm inner and 47mm outer diameter. It then goes through the first thrust bearing which has 40mm inner and 60mm outer diameter. This bearing will sit between the pulley and the base. Next, the middle pulley is installed. This pulley is paired with the joint pulley with a 300mm GT2 belt. For pulley installation, two 608 ball bearings, one on the top and the other at bottom side of the base. A 45mm M8 bolt, a washer and a self-locking nut secures the pulley in place. The stepper motor is then installed followed by a micro switch leading to the assembly of the first joint. For assembling the Z-axis, the Z-axis bottom plate part is secured. The four clamps for the smooth rods are secured on top [4].

Next, to assemble the first arm of the robot, the arm will be made out of two parts bolted together. The first part includes installation of the linear bearings which will slide through the smooth rods. The second part is done using 25 mm M5 bolts.

The second stepper motor is installed using a 3D printed GT2 pulley with 20 teeth. For the second joint and third one, smaller bearings are utilized compared to the first one. The radial ball bearing has 30mm inner and 42mm outer diameter, and the thrust bearing has 35mm inner and 52mm outer diameter.

For the third joint, a smaller NEMA 17 motor is utilized. The same procedure for installing belts and pulleys for third joint except that just a single stage reduction with a 400mm belt. Finally, four wires cable are inserted from a stepper motor which are used for driving the servo motor for gripper which is secured by M4 nuts.

D. Electronic Configuration

The circuit design includes an Arduino MEGA and RAMPS 1.6 board in combination with four A4988 stepper drives. The Arduino MEGA is attached to the base of the robot and a case was made for it. Quarter step resolution is utilized for driving the steppers, so jumpers are placed in the appropriate pins. The stepper motors and micro switches are connected to the CNC shield. A 12V power supply capable of providing a minimum of 4A is used to power the robot depending on how the stepper motor current limitation is set which is the lowest for the robot. The wires are put in the case making sure the heat sinks are free.

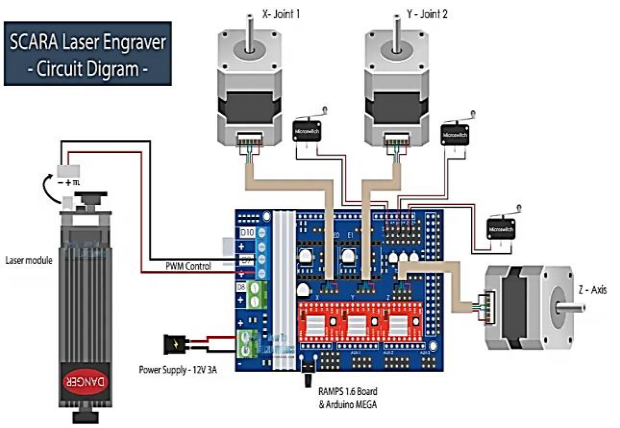

Fig 4.4 SCARA Robot Circuit Diagram [6]

E. Programming

Programming the robot was the final phase of the project before the testing could be comprehensively done.

For forward kinematics the X and Y value of the end-effector is calculated, according to the set joint angles of the robots two arms, theta1 and theta2, as well as their lengths L1 and L2.

```
// FORWARD KINEMATICS
void forwardKinematics() {
  float theta1F = theta1 * PI / 180;   // degrees to radians
  float theta2F = theta2 * PI / 180;
  xP = round(L1 * cos(theta1F) + L2 * cos(theta1F + theta2F));
  yP = round(L1 * sin(theta1F) + L2 * sin(theta1F + theta2F));
}
```

With inverse kinematics we calculate the joint angles, theta2 and theta1, according the given position or the X and Y coordinates. Depending in which quadrant the position is set to, adjustments are made to the joint angles with these "if" statements.

```
/ INVERSE KINEMATICS
void inverseKinematics(float x, float y) {
  theta2 = acos((sq(x) + sq(y) - sq(L1) - sq(L2)) / (2 * L1 * L2));
  if (x < 0 & y < 0) {
    theta2 = (-1) * theta2;
  }

  theta1 = atan(x / y) - atan((L2 * sin(theta2)) / (L1 + L2 * cos(theta2)));

  theta2 = (-1) * theta2 * 180 / PI;
  theta1 = theta1 * 180 / PI;
```

The Graphic User Interface is made using the controlP5 library for the Processing IDE. With this library, buttons, sliders, text fields etc. can be created with ease.

For example, the sliders on the left side are used to control the joint angles, and the text fields are used to enter the position of where we want our robot to position. With each action relating to the program, data is sent to the Arduino board through the serial port. This data includes the joint angles, the gripper value, speed and acceleration values, and indicators for knowing whether we have clicked the save or the run buttons.

For controlling the stepper motors, the AccelStepper library is used. Although this is a great library for controlling multiple steppers at the same time, it has some limitations when it comes to controlling a robot like this. When controlling multiple steppers, the library cannot implement acceleration and deceleration, which are important for smoother operation of the robot.

V. Result & Analysis

A. Equations

This SCARA robot has four NEMA 17 stepper motors that control its four degrees of freedom. It also has a small servo motor that operates the end effector, which in this case is a robot gripper. The Arduino MEGA acts as the brain of this SCARA robot, and it works together with a RAMPS shield and four A4988 stepper drivers to control the motors. There are two methods for controlling robots in terms of positioning and orientation: forward and inverse kinematics. Forward kinematics is used to find the position and orientation of the end-effector when the joint angles are given. Inverse kinematics is used to find the joint angles when the position and orientation of the end-effector are given. The equations we obtained for forward and inverse kinematics are shown in Fig 5.1. We can calculate the position and orientation of the end effector by using joint angles 1 and 2 mm, and we can calculate the joint angles by using x and y for a given position of the end-effector.

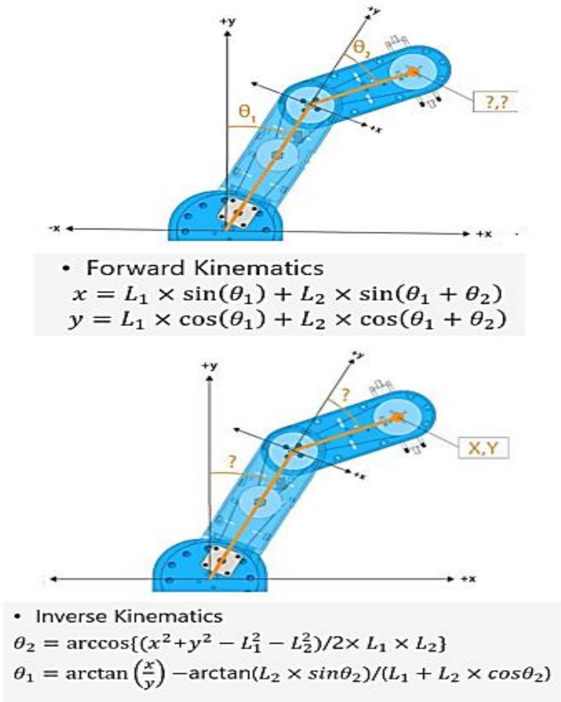

Fig 5.1 Forward and inverse kinematic equations [7]

B. Working

After uploading the code to the Arduino, we can run the processing program. The power is connected and the SCARA robot will move to its home position. Then, we can use the robot to move around manually or work automatically. In the slicing software, we applied Horizontal expansion of 0.1mm for all the parts. This helps the parts to have more accurate dimensions and fit better with other mechanical components such as bearings, rods, and bolts. The laser module and all the joints performed as expected and designs were accurately cut on wooden material but we also observed some drawbacks on the rigidity and design. The robot was not as sturdy as expected due to lower quality parts used for economic feasibility. Upgrading to higher quality parts may be considered in the future scope of the project. The issue is that almost the entire SCARA robot, the Z-axis and the arms are supported mainly by the first joint. The whole weight and the inertial forces generated when moving, can cause quite a stress to base where the first joint is located, and as it's just a plastic it tends to bend a little bit. Also, these belts are not backlash free so we reduce the robot sturdiness with that too. One more point to be noted is that acceleration and deceleration using the AccelStepper library was not as smooth as expected but did the work as required. To improve the performance of the robot, we could use metal parts instead of plastic, use backlash-free belts or gears, and use a different library for smoother motion control. We could also add more sensors and feedback mechanisms to increase the accuracy and reliability of the robot.

VI. Conclusion

We created a SCARA Robot with four degrees of freedom, and it became a platform for testing and studying various control approaches. We shared the parts designed with the online audience and applied SCARA in actual form for further testing of strength, efficiency, economic viability, and use in many industrial domains. The morphology we chose for the robot's design and execution enabled it to perform a variety of demonstrations and activities, which were easily and quickly programmed using an intuitive graphic interface we built specifically for that purpose. The robotic arm we built can be used in various ways, and any type of end-effector can be attached to the robot for different purposes. For example, we can attach a 3D printer hot end to the robot to make it a 3D printer or attach a laser head to make it a laser cutter. The overall project was a great success in learning the basics of SCARA robots, their functioning and experience in building one. We also gained valuable insights into the challenges and opportunities of using SCARA robots for different applications. We hope that our project will inspire others to explore the potential of SCARA robots and contribute to their development and innovation.

A. Future Work

The robot can be improved in many ways to make it more precise and accurate. One way is to update the AccelStepper library to enhance movement, acceleration and deceleration. Another way is to attach any kind of end-effector and create unique designs with it. For example, we can attach a 3D printer hot end to the robot and turn it into a 3D printer, or attach a laser head and turn it into a laser cutter. A third way is to upgrade to higher quality parts to increase the rigidity of the robot and reduce problems in balance and structure. These improvements can make the robot more versatile, reliable and efficient for various purposes.

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[6] Image courtesy, Dejan Nedelkovski, site link - https://howtomechatronics.com/projects/scara-robot-how-to-build-your-own-arduino-based-robot/

[7] Image courtesy, Dejan Nedelkovski, site link - https://howtomechatronics.com/projects/scara-robot-how-to-build-your-own-arduino-based-robot/

[8] Image source - Robot SCARA - G6-651S - EPSON Robotic Solutions - 4 ejes / para ensamblaje / pick and place (directindustry.es)