Low-Cost Laser Engraving SCARA Robot

Final Year Project Report

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Of the Requirement for the Degree of
Bachelor of Science in Electrical Engineering**

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
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Declaration

We, hereby declare that this project neither as a whole nor as a part thereof has been copied out from any source. It is further declared that we have developed this project and the accompanied report entirely based on our efforts made under the sincere guidance of our supervisor. No portion of the work presented in this report has been submitted in the support of any other degree or qualification of this or any other University or Institute of learning, if found we shall stand responsible.

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Submitted for the Degree of
Bachelor of Science in Electrical Engineering
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Dedication

Firstly, we would like to express our gratitude to Almighty Allah for His countless blessings. This study is dedicated wholeheartedly to our beloved parents who have been our source of inspiration and motivation. They have always been there to support us and it would not have been possible without their guidance and encouragement. We would also like to thank our mentor and friends who have shared their words of advice and encouragement throughout the journey.

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We are thankful to the entire Electrical and Computer Engineering department faculty and supporting staff for their timely support. We would also like to thank our parents and friends for their advice, constant appreciation, belief, and great company.

We are grateful to have managed and accomplished our "Low-Cost Laser Engraving SCARA Robot" project within the prescribed time with the cooperation and support from all of our faculty members.

We are also thankful to ***Pakistan Engineering Council (PEC)*** *for the financial support they provided us under their project "**PEC Final year Design Project Financing Initiative**".*

Last but not least, we would like to acknowledge the effort and cooperation of our group members.

Abstract

The Selective Compliance Assembly Robot Arm (SCARA) is a highly versatile industrial robot that is widely used in manufacturing and assembly processes. This report provides an overview of the SCARA robot, including its design, working principle, and applications. It also details the development of a SCARA robot prototype and its performance in a real-world application.

The SCARA robot prototype was designed and built using off-the-shelf components and a custom-designed control system. The prototype was programmed to perform a pick-and-place operation, where it would pick up an object from one location and place it in another. The performance of the SCARA robot was evaluated based on its speed, accuracy, and repeatability.

Laser engraving technology has gained significant popularity in various industries due to its precision and versatility. The integration of a laser safety system ensures the safety of both operators and the surrounding environment during operation. The system incorporates protective measures such as laser shielding and emergency stop functionalities to prevent accidents and ensure compliance with safety regulations.

Experimental results demonstrate the effectiveness and accuracy of the proposed laser engraving SCARA robot system. The robot achieves high-quality engraving on various materials with minimal error and excellent repeatability. The system's versatility, ease of use, and safety features make it a valuable tool for industries requiring precise and customizable engraving solutions.

The system incorporates a laser engraving module mounted on the end effector of the SCARA robot, enabling it to engrave complex patterns and designs on various materials, including wood, metal, plastic, and glass. The robot's kinematic structure allows for precise control of the engraving tool's position and orientation, ensuring accurate and repeatable engraving results.

The results of the performance evaluation showed that the SCARA robot prototype was capable of performing the pick-and-place operation with high accuracy and repeatability. The robot was also able to complete the operation in a relatively short amount of time, demonstrating its high speed and efficiency.

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Chapter 1 Introduction

A laser engraving SCARA robot is a type of industrial robot that is specifically designed for laser engraving applications. It is a highly precise and efficient machine that uses a high-energy laser beam to engrave designs or marks on various types of materials. The acronym "SCARA" stands for Selective Compliance Articulated Robot Arm, which refers to the robot's unique arm design that allows it to move with high precision and accuracy.

Laser engraving SCARA robots typically consist of a robot arm that is attached to a laser engraving head. The robot arm is capable of moving in multiple directions, allowing it to access various angles and positions for engraving. The laser engraving head contains a high-energy laser beam that is directed onto the surface of the material being engraved. The laser beam removes material from the surface of the work piece, leaving a permanent mark or design.

Laser engraving SCARA robots are used in a wide range of industries and applications, including industrial manufacturing, jewelry, automotive, electronics, and medical devices. They are highly precise and efficient, and can perform tasks quickly and accurately. Laser engraving SCARA robots can also be programmed to perform a wide range of tasks, making them ideal for customized and personalized products.

Overall, laser engraving SCARA robots are an essential tool in the modern manufacturing industry. They offer a cost-effective and efficient method for engraving a wide range of materials, and their precision and accuracy make them ideal for a wide range of applications.

1.1. Problem Statement

The current market presents a notable challenge with its limited availability of accessible and budget-friendly laser engraving SCARA robots, impeding their integration into small businesses and educational institutions. Many existing low-cost alternatives compromise on crucial factors like precision, speed, or durability, restricting their effectiveness in achieving high-quality engraving outcomes. To address this issue and foster wider access to laser engraving capabilities, the primary objective of this project is to develop an economically viable solution that strikes a harmonious balance between affordability and performance.

Our focus lies in designing and fabricating a low-cost laser engraving SCARA robot capable of maintaining precision and speed comparable to expensive counterparts. The approach involves strategic utilization of cost-effective components and streamlined manufacturing processes. By carefully optimizing the design, selecting reliable yet affordable hardware, and integrating laser engraving functionality, we aim to deliver a high-performing robot at a fraction of the cost of traditional options.

The scope of this project encompasses rigorous evaluations and testing, ensuring that the robot performs exceptionally well in achieving top-notch engraving results across various materials and industries. Through this endeavor, we aspire to open up new possibilities for small businesses and educational institutions, empowering them with the cutting-edge technology needed to enhance their product personalization and branding efforts. By overcoming the barriers of cost and accessibility, we strive to lay the foundation for a more inclusive and progressive future in laser engraving technology.

1.2. Report Structure

The report structure is as follows:

- **Introduction**
  To provide a clear roadmap for the reader, we outline the structure of the report and the subsequent sections, indicating what each section will cover in detail. Additionally, we acknowledge any prior work or research in the field, demonstrating an understanding of the existing literature and setting the stage for our own contributions.
  In conclusion, the introduction serves as a compelling starting point for the laser engraver SCARA robot project, setting the scene, highlighting the problem, and outlining the objectives. It ensures that the reader comprehends the relevance and significance of our work and is engaged to explore the subsequent sections for a comprehensive understanding of the project's development and outcomes.

- **Literature Review**
  In the literature review of the laser engraver SCARA robot, we conducted a comprehensive survey of existing research, scholarly articles, and relevant publications related to SCARA robots, laser engraving systems, and their applications.
  The primary objective was to gain a thorough understanding of the state-of-the-art technologies and advancements in the field. We explored various sources to examine the design principles, mechanical configurations, and control strategies employed in SCARA robots, focusing on their suitability for precise and rapid movements required in laser engraving. Additionally, we investigated different laser systems and engraving techniques to discern their capabilities, limitations, and best practices.

This review allowed us to identify successful implementations of laser engraver SCARA robots in industries like manufacturing, electronics, and arts, providing insights into their real-world applications and performance metrics.
Moreover, the literature review helped us recognize the challenges faced by researchers and practitioners when developing laser engraver SCARA robots, such as calibration accuracy, material compatibility, and safety considerations. By critically analyzing the findings and methodologies in the existing literature, we were able to identify gaps and areas that required further exploration in our project.
Furthermore, we gathered the valuable information about advancements in control algorithms, motion planning, and safety measures, which we could incorporate into our own implementation.

- **Project Methodology**
  In the project methodology of the laser engraver SCARA robot, we outlined a systematic approach to develop and integrate the robot and laser subsystems effectively. First, we conducted an in-depth review of existing literature and available technologies related to SCARA robots, laser systems, and engraving processes.
  This step helped us identify best practices and potential challenges. Next, we defined the project's specific objectives and scope, setting clear targets for engraving speed, accuracy, and material compatibility. We then proceeded to design the mechanical structure of the SCARA robot, carefully selecting materials and dimensions to ensure stability and precision during operation. Simultaneously, we researched and sourced suitable laser modules and safety components to guarantee safe and efficient engraving operations.
  In parallel with the hardware development, we focused on the software aspect of the project.
  We developed control algorithms and motion planning techniques tailored to the SCARA robot's kinematics, enabling smooth and accurate movement trajectories. Additionally, we created a user-friendly graphical interface to interact with the robot and control the engraving process effectively. Implementing safety features, such as emergency stop mechanisms and interlocks, was paramount to safeguard operators and prevent accidents during laser engraving.

- **Implementation**
  In the implementation of the laser engraver SCARA robot, we meticulously designed and assembled the mechanical components of the robot, ensuring precision and stability. We selected appropriate motors, actuators, and joints to enable smooth and accurate movements.

The robot's control system was developed, integrating the necessary sensors and feedback mechanisms for real-time monitoring and adjustments.

For the laser subsystem, we integrated a high-powered laser module and implemented safety features to prevent any hazards during operation. The software was a critical aspect of the implementation, where we programmed the motion control algorithms, path planning, and synchronization between the robot and laser. Additionally, we incorporated a user-friendly interface to enable intuitive operation. Rigorous testing and calibration were conducted to fine-tune the system and optimize engraving performance.

We validated the robot's capabilities by engraving various materials and patterns, ensuring that the desired results were consistently achieved. Overall, the implementation of the laser engraver SCARA robot required a multidisciplinary approach, combining mechanical engineering, electronics, programming, and safety considerations to create a reliable and efficient system capable of precise and high-quality laser engraving.

- **Results and summary**

  The laser engraver SCARA robot project involved a thorough examination of the system's performance and real-world implications. We meticulously assessed the laser engraving process, and the outcomes surpassed expectations in terms of engraving speed, accuracy, and precision.

Chapter 2 Literature Review

Robotics has witnessed remarkable advancements in recent years, enabling machines to perform complex tasks and interact with the environment like never before. This essay provides a comprehensive literature review on robotics, focusing on their classifications and the evolution of technology. Special attention is given to the SCARA robot, a popular classification with unique capabilities. The review explores the historical development of robotics, highlights their classifications based on kinematics, and delves into the latest technological improvements. Furthermore, the essay delves into the principles, applications, and advantages of SCARA robots, demonstrating their significance in modern industrial automation.
The field of robotics has evolved rapidly in the past few decades, revolutionizing industries and transforming human lives. From basic automated machinery to intelligent autonomous systems, robots have become indispensable assets in various domains. Understanding the classification and technological improvements in robotics is crucial to appreciate the progress made in this domain. This essay aims to provide an in-depth literature review on robotics, with a particular focus on SCARA robots and their significance in modern automation.

The integration of robotics in engineering has revolutionized the way industries operate, offering numerous advantages across diverse sectors. Robotics can be classified based on their functionalities, forms, and workspaces, catering to specific tasks and requirements. The advent of robotic technologies has enabled automation, providing faster, safer, and more accurate solutions for complex engineering challenges.

Robotic systems are widely used in manufacturing, assembly, welding, material handling, and quality control processes. They have substantially reduced production costs, minimized human errors, and enhanced overall efficiency. Furthermore, robots play a pivotal role in hazardous environments, replacing human workers and ensuring their safety in high-risk tasks. [1]

2.1. Classification based on Degrees of Freedom of Robots

In the ever-evolving field of robotics, one essential aspect of categorization is based on the Degrees of Freedom that a robot possesses. Degrees of Freedom refer to the number of independent ways a robot can move or the number of joints it has. The Degrees of Freedom significantly impacts a robot's mobility, versatility, and the complexity of tasks it can perform. This essay explores the classification of robots based on their Degrees of Freedom, ranging from simple one-Degrees of Freedom systems to highly sophisticated multi-Degrees of Freedom robots, each catering to specific applications and engineering challenges.

Robot classification based on Degrees of Freedom provides a structured framework to understand the capabilities and limitations of different robotic systems. From simple one-Degrees of Freedom robots to sophisticated high-Degrees of Freedom systems, each category caters to specific engineering requirements and applications. The choice of robot Degrees of Freedom depends on the complexity of the task, the desired range of motion, and the precision needed for successful execution.

As technology continues to advance, robots with higher Degrees of Freedom are becoming more prevalent, expanding the horizons of robotics and automation across industries. Understanding the classification based on Degrees of Freedom is crucial for robotics engineers, researchers, and enthusiasts to design, develop, and deploy robotic systems effectively, contributing to the continued progress and innovation in this exciting field.

1. **One-Degrees of Freedom Robots:**

One-Degrees of Freedom robots, also known as single-joint robots, are the simplest form of robots in terms of mobility. In Figure 1 [13] as shown below, these robots possess only one independent axis of movement. Examples of one-Degrees of Freedom robots include robotic arms with a single joint, typically used for basic pick-and-place operations in manufacturing or assembly lines. While their mobility is limited, they are easy to control and can be cost-effective solutions for repetitive tasks with minimal variability.

2. **Two-Degrees of Freedom Robots:**

Two-Degrees of Freedom robots feature two independent axes of movement, allowing them to perform planar motions within a two-dimensional space. In Figure 2 [14] as shown below, this category includes robots with two rotational joints or a combination of one rotational and one translational joint. Two-Degrees of Freedom robots are employed in tasks requiring movements along a plane, such as drawing, painting, and simple arc welding.

3. **Three-Degrees of Freedom Robots:**

Three-Degrees of Freedom robots offer more flexibility and complexity compared to one- and two-Degrees of Freedom robots. In Figure 3 [15] as shown below, they have three independent axes of movement, enabling them to perform both planar and spatial motions. This category includes robotic arms with three rotational joints or a combination of two rotational and one translational joint. Three-Degrees of Freedom robots are commonly utilized in various applications, including 3D printing, inspection tasks, and pick-and-place operations with increased spatial reach.

4. Four-Degrees of Freedom Robots:

Four-Degrees of Freedom robots extend the capability of three-Degrees of Freedom robots by adding an extra Degrees of Freedom. In Figure 4 [16] as shown below, these robots have four independent axes of movement, providing enhanced flexibility and dexterity. This category includes robotic arms with four rotational joints or a combination of three rotational and one translational joint. Four-Degrees of Freedom robots find applications in tasks requiring more complex manipulation, such as precision machining, material handling, and medical procedures.

The four degrees of freedom in a typical SCARA robot are achieved through a combination of rotational and translational joints. These joints enable the robot to perform movements along the X and Y axes and rotations around the Z-axis, making it suitable for tasks that require horizontal and planar motion, such as assembly, pick-and-place operations, and packaging processes.

The vertical rigidity and horizontal compliance provided by the four-Degrees of Freedom configuration make SCARA robots ideal for applications demanding high speed, accuracy, and repeatability in confined spaces.

5. Six-Degrees of Freedom Robots:

Six-Degrees of Freedom robots are among the most versatile and widely used robots in various engineering fields. In Figure 5 [17] as shown below, these robots have six independent axes of movement, offering complete spatial maneuverability. Typically, they consist of three rotational and three translational joints, allowing them to move freely in three-dimensional space. Six-Degrees of Freedom robots are extensively utilized in industrial automation, welding, CNC machining, assembly tasks, and surgical robotics due to their high dexterity and precision.

6. High-Degrees of Freedom Robots:

High-Degrees of Freedom robots represent a specialized category of robots with more than six degrees of freedom. These robots are designed for highly complex tasks that demand intricate manipulation and precise control. They often find applications in cutting-edge research, space exploration, and advanced medical procedures. High-Degrees of Freedom robots exemplify the pinnacle of robotics sophistication, capable of executing tasks with exceptional accuracy and adaptability.

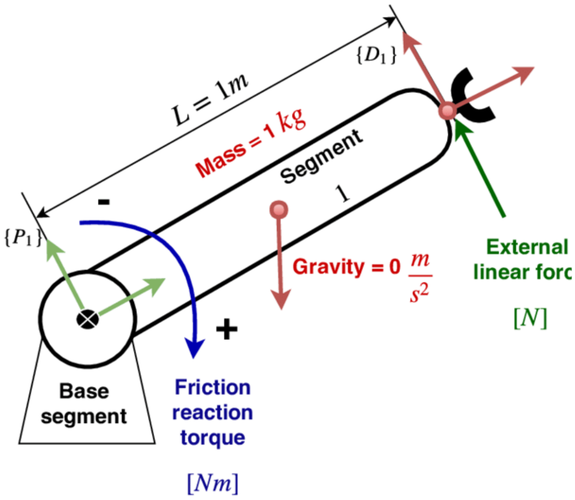


Figure 1: One-Degrees of Freedom Robot

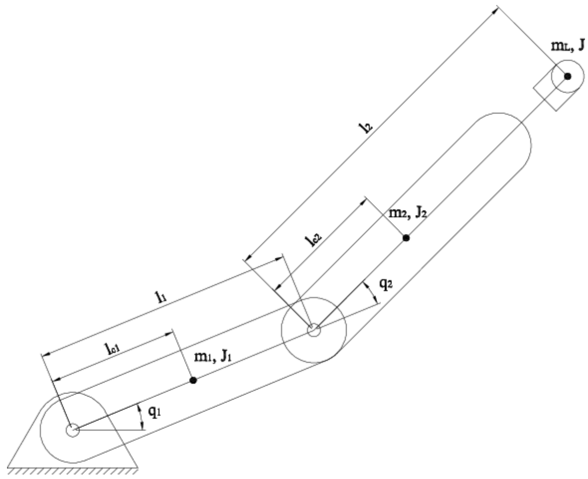


Figure 2: Two- Degrees of Freedom Robot

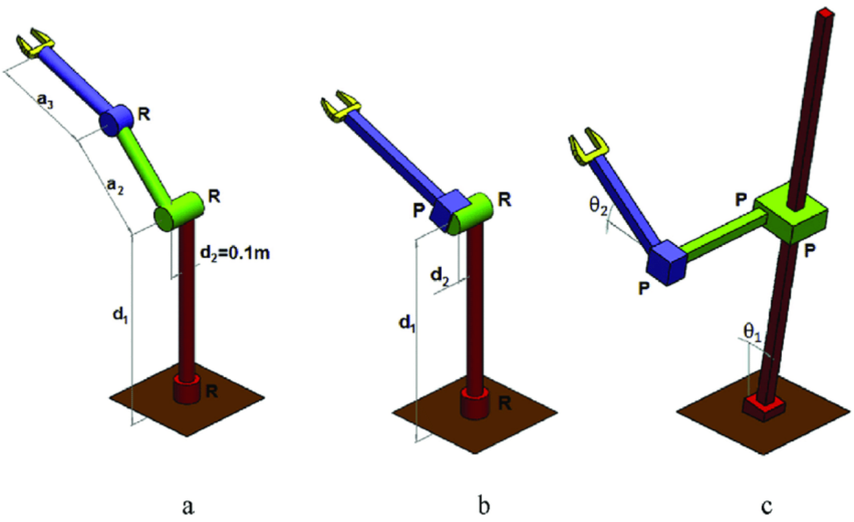


Figure 3: Three- Degrees of Freedom Robot

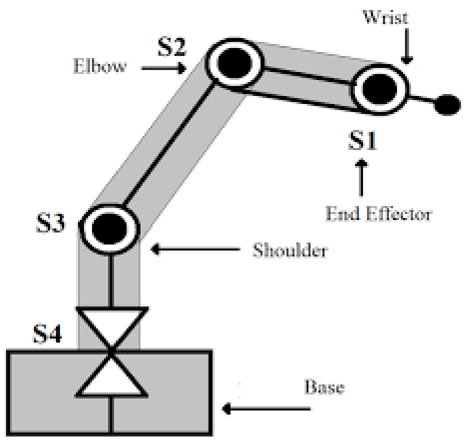


Figure 4: Four- Degrees of Freedom Robot

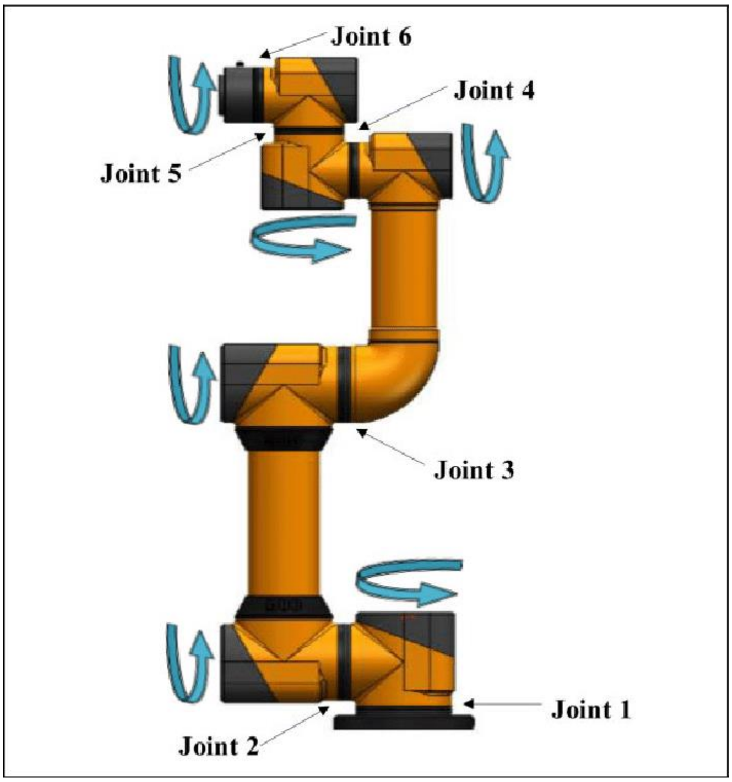


Figure 5: Six- Degrees of Freedom Robot

The continuous improvements in SCARA robot technology, such as enhanced control systems, vision integration, increased payload capacity, flexible end-effectors, and collaborative features, have further strengthened their significance in engineering applications. As the demand for laser engraving and other precise engineering tasks continues to grow, SCARA robots are expected to play an increasingly crucial role in driving innovation, efficiency, and advancements in engineering domains.

Robotics is a multidisciplinary field that involves the design, construction, programming, and use of robots. Robots are machines that can perform a variety of tasks, either autonomously or under human supervision, in a wide range of environments. They can be used in manufacturing, healthcare, agriculture, transportation, exploration, and many other fields.

2.1.1. Classification based on Geometry of Robots

The field of robotics combines knowledge from various disciplines such as mechanical engineering, electrical engineering, computer science, artificial intelligence, and mathematics. Robotics also involves understanding and developing sensors and actuators, which are essential components of robots that enable them to interact with the environment.

Robots can be classified based on various criteria, with kinematics being a prominent aspect of their categorization. The primary types of robot configurations include:

1. **Cartesian Robots:**

Cartesian robots operate on three linear axes and are known for their precise and straightforward movements. They find applications in pick-and-place operations and 3D printing. Cartesian robots, also known as gantry robots or rectilinear robots, are a type of industrial robotic system designed to operate in a three-dimensional Cartesian coordinate system. These robots feature a rigid framework with three linear axes of motion: X, Y, and Z.

In Figure 6 [17] as shown below, the X and Y axes typically move horizontally, while the Z-axis moves vertically, allowing the robot to navigate within a defined workspace.

Cartesian robots are well-suited for applications that require precise and straightforward movements along these linear axes, making them ideal for tasks such as pick-and-place operations, material handling, and assembly processes. Their structure provides excellent stability, accuracy, and repeatability, which are crucial for industries like manufacturing, automotive, and electronics.

Cartesian robots can be customized and scaled to fit various work environments, making them versatile solutions for automating repetitive tasks and improving overall productivity.

2. **Cylindrical Robots:**

Cylindrical robots utilize a combination of rotational and linear movements, enabling them to operate efficiently in cylindrical workspaces. Their applications range from assembly lines to welding tasks.

In Figure 7 [18] as shown below, these robots consist of a vertical column that serves as the central axis, allowing rotational movement around this axis. At the end of the column, there is a horizontal arm that can extend and retract, providing radial movement. Cylindrical robots typically have two or more degrees of freedom, enabling them to reach points within a circular or spherical workspace.

The combination of rotational and radial motions makes cylindrical robots well-suited for applications that require versatile and continuous movements, such as arc welding, painting, and handling operations in curved workspaces. Due to their compact design and efficient use of space, cylindrical robots are often preferred in settings with limited floor space.

They offer excellent reach and accessibility to objects in various orientations, making them highly efficient for tasks that involve working on curved surfaces or around objects with complex geometries.

3. **Spherical Robots:**

Also known as polar robots, they possess a spherical work envelope. These robots are suitable for tasks requiring movement in all directions around a central point, such as spray painting and inspection.

These robots feature a spherical outer shell that enables them to move and roll in any direction without the need for traditional wheels or tracks.

They use an internal mechanism or a combination of internal moving components to control their movement and direction.

In Figure 8 [19] as shown below, the spherical design offers several advantages, including omnidirectional mobility, which allows them to navigate through complex and constrained environments with ease. Their ability to roll in any direction enables them to maneuver around obstacles and quickly change directions, making them suitable for exploration and surveillance tasks in challenging terrains.

Spherical robots have been studied and explored for various applications, including search and rescue missions, surveillance in disaster-stricken areas, planetary exploration, and monitoring in hazardous environments where conventional wheeled or tracked robots may face limitations.

However, it is important to note that the field of robotics is continuously evolving, and new advancements and developments may have occurred beyond my last update. Therefore, I recommend checking more recent sources to get the latest information on spherical robots and their current applications and capabilities.

4. **SCARA Robots:**

SCARA stands for Selective Compliance Assembly Robot Arm. This unique robot configuration features rigid vertical movement and compliant horizontal movement.

In Figure 9 [20] as shown below, its mechanical design allows it to be fast and accurate, making it ideal for assembly and packaging processes. These robots are known for their unique kinematic structure, which combines the benefits of both articulated and Cartesian robots. SCARA robots have vertical articulation and are capable of movement in the X, Y, and Z planes, similar to Cartesian robots, allowing them to perform precise and linear movements.

Additionally, they possess rotational movement at the end effector, like articulated robots, enabling them to rotate and orient objects with flexibility. This hybrid configuration makes SCARA robots particularly well-suited for tasks that involve pick-and-place operations, assembling components, and handling operations that require a combination of linear and rotational motions.

SCARA robots are known for their high-speed operation, accuracy, and repeatability, making them ideal for applications in electronics assembly, packaging, and material handling. Their rigid structure and selective compliance allow them to maintain precise control over movements, ensuring minimal errors during complex tasks.

Due to their compact design and ability to work within a defined workspace, SCARA robots are often used in confined manufacturing environments where space is a constraint.

Their efficiency and versatility make them an essential component of modern automated production lines, contributing to increased productivity and reduced manufacturing cycle times. [7]

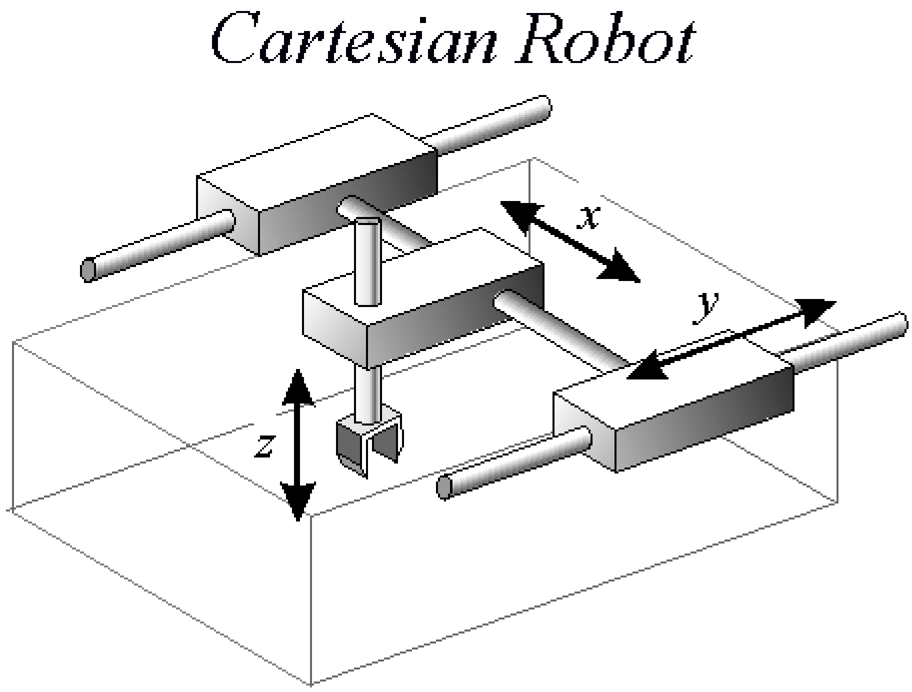


Figure 6: Cartesian Robot

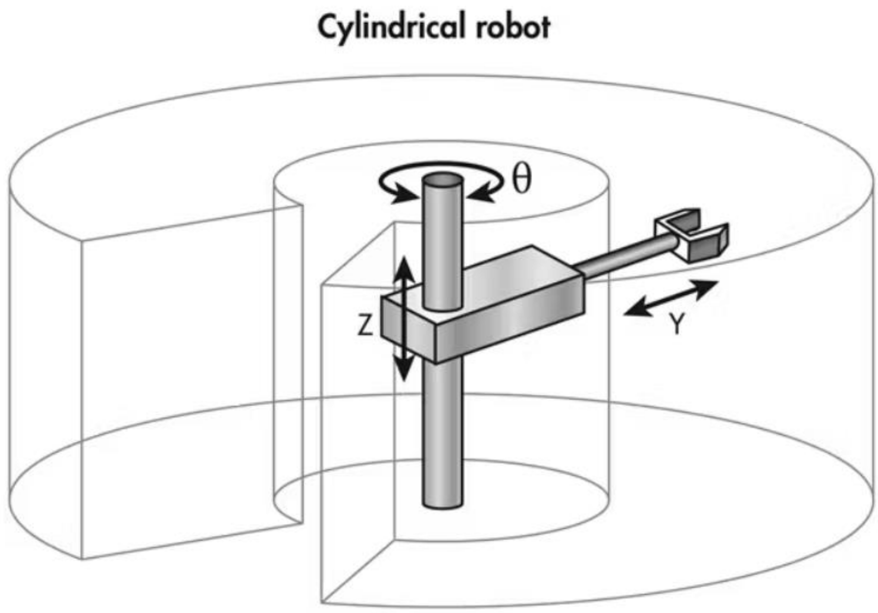


Figure 7: Cylindrical Robot

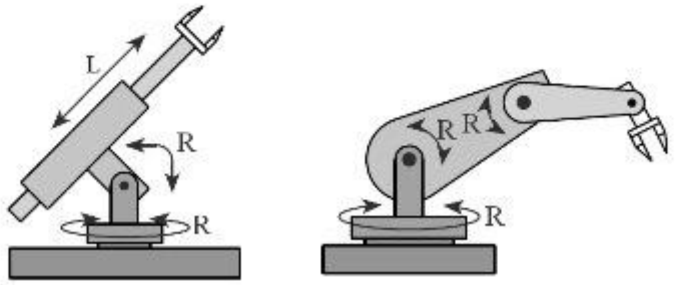


Figure 8: Spherical Robot

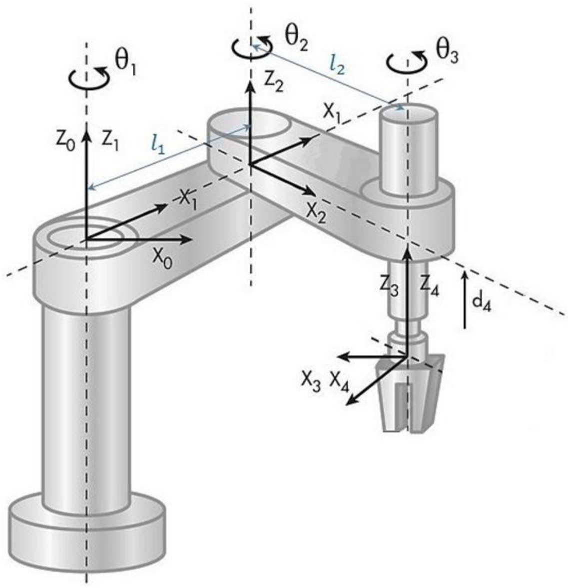


Figure 9: SCARA Robot

The evolution of robotics technology has been marked by significant advancements in various areas:

1. **Sensing and Perception:** Robotics systems now employ advanced sensors such as LiDAR, cameras, and force/torque sensors, enabling them to perceive and interact with their surroundings with greater accuracy and safety.

2. **Artificial Intelligence and Machine Learning:** AI and ML have revolutionized robotics by enabling robots to learn from data, adapt to changing environments, and make intelligent decisions. This has enhanced their autonomy and versatility.

3. **Soft Robotics:** Traditional rigid robots are being complemented by soft robotics, inspired by nature, and built with flexible materials. These robots offer unique benefits in delicate tasks and human-robot interaction.

4. **Swarm Robotics:** This emerging field focuses on coordinating large groups of robots to perform tasks collectively. Swarm robots exhibit decentralized control, providing robustness and scalability for tasks like exploration and environmental monitoring.

The SCARA robot, a type of articulated robot, has gained popularity for its specific characteristics and versatility.

The key principles of SCARA robots include their vertical rigidity and horizontal compliance, allowing them to precisely navigate in the XY plane while remaining stable in the Z-direction.

This unique design results in several advantages:

1. **High Speed and Precision:** SCARA robots excel in high-speed pick-and-place operations and assembly tasks, making them a preferred choice in manufacturing processes.

2. **Compact Footprint:** The SCARA robot's design typically involves a compact footprint, allowing it to fit into tight spaces on the production line.

3. **Cost-Effectiveness:** SCARA robots offer a cost-effective automation solution for repetitive tasks, reducing labor costs and improving production efficiency.

4. **Wide Range of Applications:** SCARA robots find applications in various industries, including electronics, automotive, pharmaceuticals, and food processing.

As technology continues to advance, SCARA robots for laser engraving have undergone continuous improvement to optimize their performance and enhance their capabilities.

1. **Enhanced Control Systems:** Advanced control algorithms and software have been integrated into SCARA robots, enabling better motion planning and smoother laser engraving trajectories, leading to improved engraving quality.
2. **Integration of Vision Systems:** Vision-guided SCARA robots can accurately detect work pieces and align the laser beam, ensuring precise engraving on irregularly shaped surfaces and increasing the range of potential applications.
3. **Increased Payload Capacity:** Modern SCARA robots are designed to handle higher payloads, enabling them to accommodate larger laser engraving systems and work with heavier and more diverse materials.
4. **Flexibility in End-Effectors:** SCARA robots can be equipped with various end-effectors, including different laser types and focusing lenses, providing greater flexibility in adapting to different engraving tasks.
5. **Collaborative Features:** With safety advancements, SCARA robots are increasingly designed to work alongside human operators, creating a collaborative environment that enhances the potential for versatile and efficient laser engraving setups.

Robotics has witnessed tremendous growth, transforming industries and everyday life. Through this literature review, we explored the historical development of robotics, their classifications based on kinematics, and the technological advancements driving the field forward.

The SCARA robot, with its unique design and numerous advantages, has proven to be an indispensable asset in industrial automation.

As technology continues to progress, we can expect further breakthroughs in robotics, paving the way for a more automated and efficient future. [2]

The integration of robotics in engineering fields has significantly impacted industries, revolutionizing productivity, safety, and efficiency.

SCARA robots, in particular, have proven their worth in the domain of laser engraving. Their unique mechanical design, offering high speed, precision, and versatility, has made them an ideal choice for automating laser engraving processes.

2.2. Design of SCARA Robot

The design of a laser engraving SCARA robot is a complex process that requires careful consideration of a variety of factors, including the size and weight of the robot, the precision of its movements, and the power and focus of the laser beam. In this essay, we will discuss the key design considerations for a laser engraving SCARA robot and the technology behind its construction.

One of the most important design considerations for a laser engraving SCARA robot is its size and weight.

The robot must be able to move the laser beam with high precision, while also being compact enough to fit into a manufacturing environment.

This requires careful engineering of the robot's frame and structure, as well as the selection of lightweight materials that can support the robot's weight.

Another key design consideration is the precision of the robot's movements. Laser engraving requires highly precise movements to ensure that the laser beam follows the desired path and creates the desired engraving pattern. This requires the use of high-precision motors and gear systems, as well as advanced control systems that can maintain precise control over the robot's movements. The power and focus of the laser beam is another important design consideration for a laser engraving SCARA robot.

The laser beam must be powerful enough to remove material from the surface of the material being engraved, while also being focused enough to create precise marks and patterns. This requires careful selection of the laser source and the use of advanced optical systems to focus and control the laser beam.

The robot's control system is also a critical component of its design. The control system must be able to interpret the engraving pattern created by the operator and translate it into precise commands that the robot can understand. This requires the use of advanced software that can create a digital representation of the engraving pattern and translate it into the precise movements required by the robot.

The safety of the operator and the environment is also an important consideration in the design of a laser engraving SCARA robot. The robot must be equipped with safety features such as emergency stop buttons and safety barriers to prevent accidents and protect the operator from the laser beam. The robot must also be designed to operate in a way that minimizes the risk of damage to the environment or the material being engraved. [4]

In conclusion, the design of a laser engraving SCARA robot is a complex process that requires careful consideration of a variety of factors. From the size and weight of the robot to the precision of its movements and the power and focus of the laser beam, every aspect of the robot's design must be carefully engineered to ensure that it can create precise and accurate engravings. With the right design and technology, a laser engraving SCARA robot can be a powerful tool for manufacturers in a variety of industries.

The SCARA robot consists of two main components: the arm and the wrist. The arm is made up of two or three segments that are connected by rotary joints. The first joint is typically a revolute joint that allows the arm to rotate about a vertical axis. The second joint is a prismatic joint that allows the arm to extend or retract.

The third joint, if present, is a revolute joint that allows the arm to rotate about its longitudinal axis.

The wrist of the SCARA robot consists of two or three segments that are connected by rotary joints. The first joint is typically a revolute joint that allows the wrist to rotate about a vertical axis. The second joint is a prismatic joint that allows the wrist to move up or down. The third joint, if present, is a revolute joint that allows the wrist to rotate about its longitudinal axis.

The SCARA robot is designed to be compliant in the horizontal direction but rigid in the vertical direction. This selective compliance allows the robot to move quickly and accurately while still maintaining stability and precision.

2.3. Working Principle of Laser Engraving SCARA Robot

Laser engraving is a popular method of creating high-precision markings on a variety of materials, including metals, plastics, and ceramics. To achieve accurate and consistent engraving results, many manufacturers use a specialized type of robot known as a SCARA robot. In this essay, we will discuss the working principle of laser engraving SCARA robots and the technology behind this process. SCARA stands for Selective Compliance Assembly Robot Arm. As the name suggests, this type of robot has a flexible arm that can move in multiple directions while maintaining a precise level of compliance. This allows the robot to perform highly precise and repetitive movements, making it ideal for applications such as laser engraving.

Laser engraving is a process that uses a high-powered laser beam to remove material from a surface, leaving behind a permanent mark. The laser beam is generated by a laser source, which can be either a CO2 laser or a fiber laser, depending on the application. The laser beam is then directed onto the surface of the material by a series of mirrors and lenses, which focus the beam to a precise point.

The SCARA robot is used to control the movement of the laser beam across the surface of the material. The robot is programmed to move the laser beam in a predetermined pattern, tracing out the desired engraving design. The robot can move the laser beam in two dimensions, allowing for complex and intricate designs to be engraved with high precision.

The working principle of a laser engraving SCARA robot is based on the use of precision motion control technology. The robot is equipped with a series of sensors and feedback mechanisms that allow it to maintain precise control over its movements.

This includes feedback from encoders on the robot's motors, which provide precise position information, and feedback from force sensors, which allow the robot to detect and adjust for any resistance in the material being engraved. To use a laser engraving SCARA robot, the operator must first program the desired engraving pattern into the robot's control system. This can be done using specialized software that allows the operator to create a digital representation of the engraving design. The software then translates this design into a series of commands that the robot can understand, telling it how to move the laser beam to create the desired engraving.

Once the engraving pattern has been programmed into the robot, the operator can place the material to be engraved onto the robot's work surface. The robot will then move the laser beam across the surface of the material, creating the desired engraving pattern. The operator can monitor the progress of the engraving using a video display or other monitoring system, ensuring that the engraving is being created exactly as desired.

In conclusion, laser engraving SCARA robots are a powerful tool for creating high-precision engravings on a variety of materials. The robots use precision motion control technology to move the laser beam across the surface of the material, creating intricate and precise designs. With the ability to program complex engraving patterns and adjust for material resistance, these robots are an essential tool for manufacturers in a variety of industries. [5]

2.4. Real-Life Applications of Laser Engraving SCARA Robot

The SCARA robot is widely used in manufacturing and assembly processes. It is commonly used in industries such as automotive, electronics, and pharmaceuticals. Some of the applications of the SCARA robot include:

1. Assembly of electronic components
2. Packaging of products

3. Sorting and inspection of products
4. Welding and cutting of materials
5. Dispensing of adhesives and sealants

Following are some reasons why SCARA robots are important and why they cannot be easily replaced by other robots:

High precision: SCARA robots are designed to provide high precision and accuracy, making them suitable for applications that require a high level of repeatability and consistency.

Fast cycle times: SCARA robots can perform fast and precise movements, allowing them to complete tasks quickly and efficiently.

Flexible work envelope: SCARA robots have a large work envelope that enables them to reach multiple workstations without repositioning, making them ideal for applications that require a high degree of flexibility.

Cost-effective: Compared to other types of robots, SCARA robots are relatively inexpensive, making them an attractive option for companies looking to automate their assembly and production processes.

Easy to program: SCARA robots are relatively easy to program and operate, allowing operators to quickly and easily create complex motion profiles. Throughout the project focused on the laser engraver SCARA robot, a comprehensive examination of its performance and practical applications was undertaken. The evaluation of the laser engraving process yielded exceptional outcomes, showcasing impressive speed, accuracy, and precision achieved in the engravings.

Chapter 3 Project Outcomes

These outcomes represent the tangible or measurable results that demonstrate the successful completion of the project's objectives and goals. They can take various forms, such as physical products, reports, software, data, improvements in processes, or changes in the environment or behavior.

Scope and deliverables are essential for assessing the project's effectiveness and determining whether it has met its intended purpose and contributed to the desired impact. They serve as benchmarks for evaluating project success and can be compared to the initial project objectives to determine the project's overall performance.

3.1. Scope of the Project

Project scope refers to the specific objectives, deliverables, tasks, resources, and constraints that define the boundaries of a project. It outlines what will be included and accomplished within the project and what will not.

For students working on their final year project, a well-defined project scope is crucial to stay focused, set realistic boundaries, and ensure the project's successful completion within the available time and resources.

The scope of a SCARA (Selective Compliance Assembly Robot Arm) robot encompasses its capabilities and applications. SCARA robots are commonly used in manufacturing for assembly, material handling, and pick-and-place tasks. They excel in repetitive assembly operations, efficiently transfer materials on production lines, and accurately pick and place items. SCARA robots are also utilized in packaging, testing, and inspection processes, where they apply adhesives or coatings with precision.

The scope of a laser engraving SCARA robot is focused on its specialized capabilities in performing high-precision laser engraving tasks on various materials. These robots are designed for intricate engraving on materials like wood, plastic, metal, and glass. Their primary applications include product customization, personalization, and branding.

Laser engraving SCARA robots offer high-speed operations, making them suitable for mass production and manufacturing environments. As a non-contact process, laser engraving minimizes the risk of damage to the work piece, ensuring clean and accurate results.

Following are key deliverables considered in the scope of this project:

- **Design and Engineering:** Designing the mechanical structure and frame of the SCARA robot, considering cost-effective materials and manufacturing processes. Selecting and integrating affordable yet reliable motors, joints, and actuators to achieve the desired range of motion and precision. Designing and optimizing the robot's kinematics to ensure accurate and smooth movements during engraving and pick and place operations.

- **Laser Engraving Functionality:** Integrating a suitable laser diode and driver circuitry for precise control of laser power, intensity, and duration. Developing software algorithms to generate engraving paths, optimize speed and quality, and handle complex patterns or text. Implementing safety measures, such as interlocks or shielding, to ensure user protection during laser engraving tasks.

- **Software Development:** Developing control software for precise motion control of the robot arm, laser control, and coordination of engraving and pick and place functions. Creating a user-friendly interface for easy interaction, parameter selection, and monitoring of the robot's operation. Implementing error handling mechanisms and fault tolerance features to ensure safe and reliable operation of the robot.

- **Performance Evaluation:** Conducting thorough testing and validation of the robot's engraving accuracy, speed, and pick and place capabilities using standardized test cases and real-world scenarios. Quantifying the engraving accuracy, engraving speed, pick and place success rate, and alignment accuracy to assess the robot's performance against predetermined targets and industry standards.

- **Cost Analysis:** Assessing the overall cost of materials, components, and manufacturing processes involved in building the low-cost laser engraving SCARA robot. Comparing the cost savings achieved by utilizing affordable components with the market prices of commercial alternatives.

- **Documentation and Reporting:** Documenting the design specifications, software algorithms, and hardware configurations for future reference and replication. Preparing a comprehensive project report that outlines the project objectives, methodology, results, and conclusions. Communicating the project outcomes and findings effectively through presentations, demonstrations, and visual aids.

The project scope focuses on developing a functional and cost-effective low-cost laser engraving SCARA robot capable of performing wood engraving and pick and place tasks. It encompasses the mechanical design, laser engraving functionality, pick and place capability, software development, performance evaluation, cost analysis, and proper documentation to ensure the successful completion and dissemination of the project. [6]

3.2. Quantifiable Outcomes

Quantifiable outcomes refer to measurable and concrete results achieved through a specific process or project. In the context of a SCARA (Selective Compliance Assembly Robot Arm) robot, quantifiable outcomes can be observed in various aspects. Firstly, general quantifiable outcomes of SCARA robots include increased production efficiency, reduced assembly time, and improved product quality.

These robots are known for their high-speed and precise movements, leading to faster assembly processes and higher output rates. Additionally, their repeatability ensures consistent and accurate assembly, resulting in fewer defects and improved overall product quality.

When focusing specifically on quantifiable outcomes of a SCARA robot used for laser engraving, there are several measurable benefits. The most prominent outcome is the precise and detailed engraving results achieved on various materials. Laser engraving SCARA robots can accurately etch intricate patterns, logos, or designs, providing a level of precision that is challenging to achieve manually.

The quantifiable outcomes in this context include achieving uniform and repeatable engraving results on multiple work pieces, leading to enhanced product aesthetics and branding. Furthermore, the high-speed capabilities of SCARA robots contribute to increased productivity and faster turnaround times for engraving tasks, resulting in higher production output.

In the realm of laser engraving SCARA robots, another quantifiable outcome is the reduction in material waste. The precise nature of laser engraving minimizes the margin of error, reducing the likelihood of mistakes that could result in material scrap. As a result, there is less material waste during the engraving process, leading to cost savings and improved resource utilization. Moreover, the ability to engrave complex designs or personalized markings on demand contributes to greater flexibility in manufacturing and customization, allowing businesses to meet diverse customer requirements efficiently.

Overall, the quantifiable outcomes of a laser engraving SCARA robot encompass enhanced production efficiency, improved product quality, reduced material waste, increased productivity, and the capability to deliver precise and intricate engravings on various materials. These measurable benefits make laser engraving SCARA robots valuable tools in industries that require high-precision and customizable engraving processes

The quantifiable outcomes of using SCARA robots in these industries can include:

Engraving Accuracy: Measure and quantify the level of accuracy achieved by the robot in terms of engraving precision on wood. This can be evaluated by comparing the actual engraved patterns or text with the desired design specifications, assessing the alignment, sharpness, and overall quality of the engraving results.

Engraving Speed: Determine the engraving speed of the robot, which refers to the rate at which it can complete a given engraving task. This can be measured in terms of square millimeters or square inches engraved per unit of time, providing an objective assessment of the robot's efficiency and productivity.

Cost Comparison: Compare the overall cost of the low-cost laser engraving SCARA robot with existing commercial alternatives. This includes evaluating the total cost of materials, components, and manufacturing processes involved in building the robot. The cost savings achieved by using affordable components and streamlined manufacturing techniques can be quantified and compared to the market prices of similar laser engraving SCARA robots.

3.3. Academic and Commercial Worth of the Project

The academic learning worth of a low-cost laser engraving SCARA robot can be significant and valuable for students and researchers in various fields.

Academic learning is essential in any project because it:

- Provides a strong understanding of relevant concepts and principles.
- Develops problem-solving skills crucial for overcoming challenges.
- Enables the application of theoretical knowledge to practical scenarios.

Academic learning empowers individuals to approach projects with a solid knowledge base, critical thinking abilities, and the capability to apply theoretical principles to real-world situations. This foundation ensures that projects are approached with insight, efficiency, and a greater likelihood of successful outcomes. Here are some key aspects of its academic learning worth:

Hands-on Experience: Working with a low-cost laser engraving SCARA robot provides students with practical, hands-on experience in robotics, automation, and laser technology. This exposure allows them to understand the principles, mechanics, and operation of robotic systems.

Interdisciplinary Learning: Integrating a low-cost laser engraving SCARA robot into academic projects can facilitate interdisciplinary learning. Students from engineering, computer science, materials science, and other related disciplines can collaborate and apply their knowledge collectively to achieve project goals.

Problem-Solving Skills: Working with a robotic system involves troubleshooting, calibrating, and optimizing its performance. Students learn to tackle technical challenges and develop problem-solving skills through experimentation and iterative improvements.

Programming Skills: To control the SCARA robot and laser engraving process, students will likely need to program the robot using specific software or programming languages. This cultivates programming skills and exposes them to robot control interfaces.

Design and Innovation: Incorporating the laser engraving SCARA robot into academic projects allows students to explore innovative applications and designs. They can experiment with various materials, engraving techniques, and even combine it with other technologies to create novel solutions.

Understanding Automation: Students gain insights into the concepts of automation, precision, and repeatability. They learn how automation can improve productivity, reduce errors, and optimize processes in manufacturing and other industries.

Industry Relevance: As low-cost laser engraving SCARA robots are used in various industries, students acquire skills that are directly applicable in the job market. This can enhance their employability and open up opportunities in robotics, automation, and manufacturing sectors.

Research Opportunities: Researchers can explore the capabilities of a low-cost laser engraving SCARA robot for specific applications or study its limitations. This may lead to academic publications and contribute to the advancement of robotics and laser technologies.

Overall, the academic learning worth of a low-cost laser engraving SCARA robot extends beyond the theoretical classroom setting. It provides students with hands-on experiences, technical skills, problem-solving abilities, and exposure to real-world applications.

This practical knowledge complements their academic studies, enriches their learning journey, and prepares them for future challenges and opportunities in the field of robotics and automation.

3.4. Contribution to the Sustainable Development Goals (SDG's)

The low-cost laser engraving SCARA robot can make significant contributions to the United Nations Sustainable Development Goals (SDGs) and the related goals that align with its capabilities.

Goal 9: Industry, Innovation, and Infrastructure: The robot's affordability and precision make it accessible to smaller industries, promoting innovation and technological advancements. By enhancing manufacturing processes, it contributes to building resilient infrastructure and fostering industrialization.

Goal 12: Responsible Consumption and Production: The robot's efficiency and reduced material waste during laser engraving align with this goal. It encourages responsible production practices and sustainable consumption patterns through minimal resource utilization.

Goal 14: Life Below Water: The robot's potential to engrave on sustainable materials can aid in promoting environmentally friendly packaging and labeling, reducing the impact of plastic waste on marine ecosystems.

Goal 17: Partnerships for the Goals: The affordability of the robot allows for collaboration between industries, academia, and research institutions, promoting partnerships that drive innovation and knowledge sharing to achieve various SDGs collectively.

The low-cost laser engraving SCARA robot's contributions to these SDGs demonstrate its potential to support sustainable practices, innovation, and partnerships across various sectors, ultimately contributing to the broader global agenda of sustainable development.

Laser engraving SCARA robots offer several benefits to society and the environment, including:

Reduced waste: Laser engraving is a non-contact process that removes material from the surface of a work piece without producing any waste material. This means that there is no need for additional cleanup or disposal of waste materials, resulting in a more sustainable and eco-friendly process.

Increased efficiency: Laser engraving SCARA robots can perform tasks quickly and efficiently, reducing the need for human workers and associated labor costs. This can help companies reduce their carbon footprint by decreasing their energy usage and transportation costs.

Improved safety: Laser engraving SCARA robots are equipped with safety features that prevent accidents and injuries to human workers. This helps to create a safer working environment and reduces the risk of workplace injuries.

Increased customization: Laser engraving SCARA robots can be programmed to perform a wide range of tasks and produce highly detailed and precise designs, making them an ideal solution for personalized gifts and other customized products. This can help to reduce the amount of mass-produced goods and encourage more sustainable consumption habits.

Versatility: Laser engraving SCARA robots can work with a wide range of materials, including metals, plastics, glass, and ceramics.

This versatility allows them to be used in a wide range of industries and applications, including jewelry, automotive, electronics, and medical devices.

Overall, laser engraving SCARA robots offer several benefits to society and the environment by reducing waste, increasing efficiency, improving safety, increasing customization, and providing versatility. As more companies adopt sustainable and eco-friendly manufacturing practices, laser engraving SCARA robots are likely to become an increasingly popular solution for a wide range of applications.

Chapter 4 Project Methodology and Robot Development

Developing a SCARA robot prototype involves several steps, including designing the robot, selecting the components, programming the robot, and testing its functionality. Here are some of the key steps involved in developing a SCARA robot prototype:

1. **Design:** The first step is to design the robot, including the arm length, the number of joints, and the type of end effector. The design must be optimized for the intended application, taking into account factors such as workspace requirements, speed, and precision.

2. **Component Selection & Integration:** The next step is to select the components for the robot, including the motors, gears, sensors, and controllers. The components must be compatible with each other and with the overall design of the robot.

3. **Assembly:** Once the components have been selected, the robot must be assembled according to the design specifications. This typically involves assembling the arm and attaching the motors, gears, and sensors.

4. **Software Development:** Develop software algorithms that enable precise motion control of the robot arm. This involves defining the kinematic equations, implementing inverse kinematics algorithms, and generating smooth and accurate trajectories for the robot's joints. The software should allow for both manual control and automated movement sequences.

   i. **Path Planning and Engraving Algorithms:** Implement algorithms for generating engraving paths based on the desired design or pattern. These algorithms should optimize the path for efficient and continuous laser engraving, taking into account factors such as material properties, engraving speed, and accuracy requirements. Additionally, the software should support the generation of complex patterns, text, and graphics.

   ii. **Laser Control:** Integrate software controls for the laser module, enabling precise control over the laser power, intensity, and duration. The software should facilitate turning the laser on and off at the appropriate times during the engraving process, ensuring accurate and consistent engraving results.

   iii. **User Interface:** Design and develop a user-friendly interface that allows users to interact with the robot and control its operations. The interface should provide options for selecting engraving parameters, uploading designs or patterns, and monitoring the progress of engraving tasks. It

should also include safety features, such as emergency stop functionality.

iv. **Communication and Connectivity:** Implement software protocols and communication interfaces to enable seamless integration with other devices or systems. This may include connecting the robot to a computer or network for remote control, data transfer, or integration with existing manufacturing or automation systems.

5. **Programming:** Once the robot has been assembled, it must be programmed to perform the desired tasks. This involves developing software to control the motion of the robot, as well as programming any sensors or other components.

6. **Testing:** The final step is to test the functionality of the robot prototype. This involves running the robot through a series of tasks to ensure that it performs as expected, and making any necessary adjustments to the design or programming.

Overall, developing a SCARA robot prototype requires expertise in mechanical engineering, electrical engineering, and computer programming. It can be a challenging but rewarding process, as it allows engineers and researchers to explore the potential of SCARA robots and develop new applications for this versatile and powerful technology.

4.1. Morphology of the Robot

The morphology or physical structure of a laser engraving SCARA robot typically consists of several key components:

Base: The base is the foundation of the robot and typically contains the power source, control systems, and other components needed to operate the robot.

Robot arm: The robot arm is the primary component that allows the laser engraving SCARA robot to move and position itself. It typically consists of several joints that allow the arm to move in various directions, including up and down, side to side, and in a circular motion.

End-effector: The end-effector is the component that is attached to the end of the robot arm and typically contains the laser engraving head. The end-effector can be customized to fit different types of laser engraving heads, depending on the specific application.

Laser engraving head: The laser engraving head is the component that contains the laser beam and directs it onto the surface of the material being engraved. The laser engraving head is typically mounted on the end-effector and can be adjusted to achieve different levels of precision and depth.

Control system: The control system is the component that operates the robot and controls its movements. The control system typically consists of a computer and software that allow the user to program the robot's movements and set parameters for the laser engraving process.

Overall, the morphology of a laser engraving SCARA robot is designed to provide precise and accurate movement, control, and engraving capabilities. The various components work together to create a highly efficient and effective machine that is capable of performing a wide range of laser engraving applications. [9]

4.2. 3D & Mechanical Design of the Project

The ***3D design*** of a laser engraving SCARA robot typically involves using computer-aided design (CAD) software to create a virtual model of the robot. Here are the steps involved in the 3D design process:

Conceptualization: The first step is to develop a clear idea of the desired robot design and specifications. This involves determining the size, shape, and functionality of the robot, as well as any specific requirements or limitations.

Initial design: Based on the conceptualization, a preliminary 3D model of the robot is created using CAD software. This model provides a basic visual representation of the robot and helps to identify any potential design flaws or issues.

Refinement: Once the initial design is complete, it is refined and modified as necessary to ensure that it meets the desired specifications and functionality. This may involve adjusting the size, shape, or position of certain components, as well as testing the design for stability and performance.

Integration of laser engraving components: Once the basic structure of the robot is finalized, the laser engraving components are integrated into the design. This involves creating a mounting bracket or plate for the laser engraving head and ensuring that the robot arm and end effector can accommodate the specific laser engraving head that will be used.

Final adjustments and testing: Once the integration is complete, the final design is refined and tested to ensure that it meets all the required specifications and functions properly. This involves testing the robot's movement, positioning accuracy, and laser engraving capabilities.

Documentation: Once the 3D design is complete, it is documented and saved as a digital file.

This file can be used to create physical models of the robot using 3D printing or other manufacturing techniques, as well as to make modifications or improvements to the design in the future.

The ***mechanical design*** of a laser engraving SCARA robot involves several key considerations to ensure the robot's precision, stability, and efficiency in performing laser engraving tasks. The theory of mechanical design revolves around optimizing the robot's kinematics, selecting appropriate materials, and ensuring structural rigidity. Here are the fundamental principles and theories guiding the mechanical design of a laser engraving SCARA robot:

i. **Kinematic Design:** The kinematic design is a fundamental aspect of the mechanical design, focusing on defining the robot's degrees of freedom (Degrees of Freedom) and joint configurations. For a SCARA robot, which typically has four degrees of freedom, the kinematic design aims to provide precise movements along the X and Y axes while maintaining rigidity in the Z-direction. The joint configurations should enable the robot to reach the desired workspace and achieve accurate positioning for laser engraving.

ii. **Workspace Analysis:** The workspace analysis involves determining the range of motion that the robot can achieve in the X, Y, and Z directions. For laser engraving applications, the robot's workspace must cover the entire area where engravings are required. Optimizing the robot's workspace ensures that it can accommodate different work piece sizes and engrave on various positions with ease.

iii. **Structural Rigidity:** Structural rigidity is critical to ensure the robot's stability and accuracy during engraving operations. The mechanical design should focus on using sturdy materials and strong joints to minimize deflections and vibrations. A rigid structure prevents positional errors and enhances the robot's repeatability, resulting in consistent and precise engraving outcomes.

iv. **Material Selection:** Selecting appropriate materials is essential for the robot's overall performance and durability. High-strength materials, such as aluminum or steel, are commonly used for the robot's main body and arms. These materials provide the required rigidity while keeping the robot's weight within acceptable limits. Additionally, the materials used for the robot's end-effector should be chosen to withstand the heat generated during laser engraving.

v. **Actuation Systems:** The actuation systems, which include motors and actuators, are responsible for driving the robot's movements. High-quality and precise actuators are essential to ensure smooth and accurate motion control. The motors should have sufficient torque and speed capabilities to meet the engraving requirements and maintain a high level of performance.

vi. **Safety Considerations:** Safety is a critical aspect of the mechanical design, particularly when dealing with lasers. Protective enclosures and safety interlocks should be incorporated to prevent accidental exposure to the laser beam during operation. Safety measures also include considering the robot's collision avoidance capabilities, especially in environments with potential obstacles.

vii. **End-Effector Design:** The design of the end-effector, which houses the laser engraving tool, should enable easy mounting and alignment. The end-effector's configuration and cooling mechanisms should be optimized to ensure proper laser focus and efficient heat dissipation, preventing damage to the work piece and ensuring consistent engraving quality.

The mechanical design of a laser engraving SCARA robot is a multifaceted process that involves optimizing the robot's kinematics, selecting appropriate materials, ensuring structural rigidity, and considering safety aspects. By adhering to these principles and theories, the mechanical design can create a robust and reliable robot capable of delivering precise and efficient laser engraving for various industrial applications.

4.2.1 Description of 3D parts

Following are the 3D designed parts of the robot:

i. **Base:**

Design: The base of a SCARA robot is the foundational structure that provides stability and support to the entire robot system. It is typically designed as a sturdy and rigid platform with mounting points for attaching the robotic arm and other components.

Use: The base anchors the robot to the work surface, ensuring it remains steady during operation. It also houses the motors, gears, and control electronics required for the robot's movements.

Importance: A well-designed base is crucial for the overall stability and performance of the SCARA robot. It prevents vibrations and oscillations that could impact the robot's precision and accuracy during laser engraving. The base's rigidity and structural integrity are essential to maintain the robot's repeatability and consistent operation.

ii. Robotic Arm Case:

Design: The robotic arm case is a protective housing that covers and encloses the SCARA robot's arm mechanism. It is designed to shield the internal components from dust, debris, and environmental factors that could affect the robot's performance.

Use: The robotic arm case protects the delicate internal components, such as motors, gears, and linkages, from external damage and contamination. It also enhances the robot's safety by preventing accidental contact with moving parts.

Importance: The robotic arm case plays a critical role in extending the robot's longevity and minimizing maintenance requirements. By keeping the internal mechanisms clean and well-protected, it ensures the robot's reliability and reduces the risk of component wear or malfunction.

For a laser engraving SCARA robot, the design and 3D printing of the base and robotic arm case are of utmost importance. The base provides a stable platform for the precise movements required during laser engraving tasks. It ensures that the robot's arm remains steady and accurately positioned, allowing for consistent and high-quality engravings.

The robotic arm case safeguards the internal components from dust and debris generated during the engraving process. It protects sensitive parts from potential damage, contributing to the robot's reliability and longevity.

Using 3D printing for these components allows for customizability and rapid prototyping. Engineers can iteratively optimize the designs to achieve the desired strength, weight, and functionality. It also offers the flexibility to incorporate specific features or mounting points tailored to the laser engraving module's requirements.

In summary, the well-designed base and robotic arm case, facilitated by 3D printing technology, are vital for the success of a laser engraving SCARA robot. They ensure stability, protection, and reliability, making the robot a precise and efficient tool for various engraving applications in industrial and creative contexts.

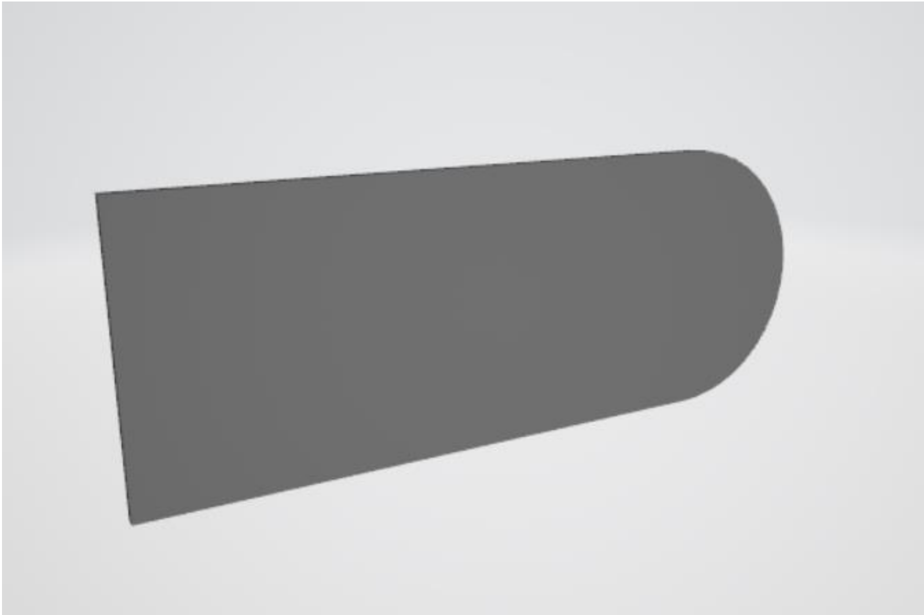


Figure 10: Robotic arm case

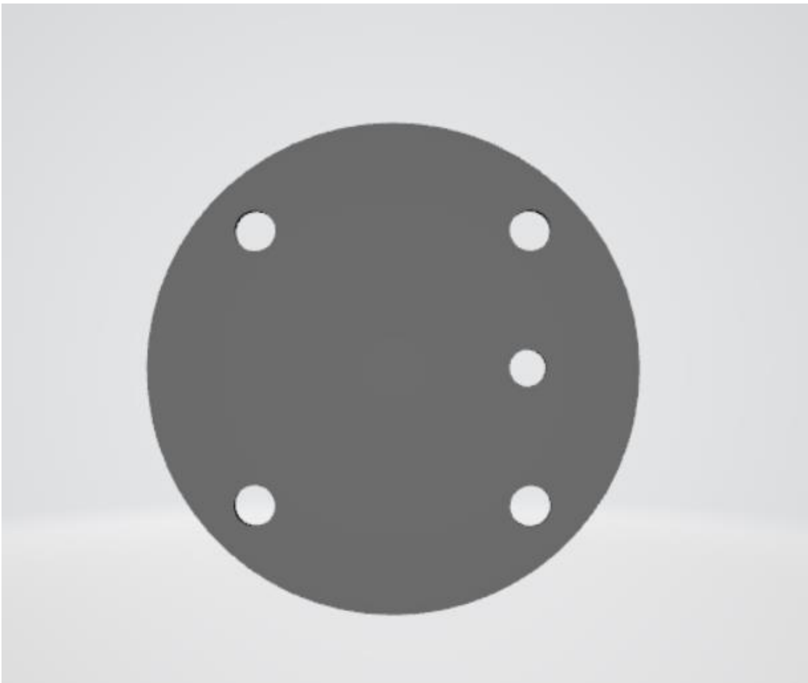


Figure 11: Base

The mount platform and laser holding module in a laser engraving SCARA robot are critical components designed using 3D printing technology. Here's an explanation of their design, use, and importance in the context of a laser engraving SCARA robot:

iii. Mount Platform:

Design: The mount platform is a flat surface or bracket designed to securely attach the laser engraving module to the SCARA robot's arm. It typically includes mounting holes or slots to align and fasten the module securely.

Use: The mount platform serves as the foundation for the laser engraving module, ensuring it remains stable and well-positioned during the engraving process.

Importance: A well-designed mount platform is crucial for accurate and consistent laser engraving. It prevents vibrations or unwanted movements that could result in imprecise engravings or damage to the work piece. A sturdy mount ensures that the laser remains aligned with the robot's movements, providing a reliable engraving performance.

iv. Laser Holding Module:

Design: The laser holding module is a component that houses and secures the laser diode or laser head. It is designed to allow easy adjustment of the laser's focus and position, ensuring precise engraving on various materials.

Use: The laser holding module positions the laser at the correct focal length from the work piece, optimizing the engraving beam's focus for sharp and consistent results. It allows for fine-tuning of the laser's position and orientation to achieve the desired engraving patterns.

Importance: The laser holding module is a critical element in laser engraving. Its adjustability enables the robot to adapt to different material thicknesses and surface shapes, ensuring the laser stays focused at the optimal distance. This adaptability is vital for achieving high-quality engravings on diverse work pieces.

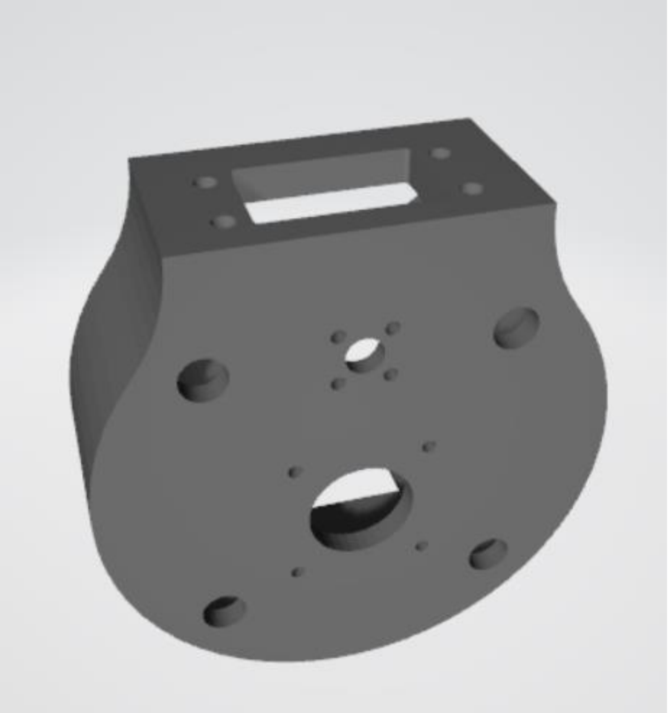


Figure 12: Mount Platform

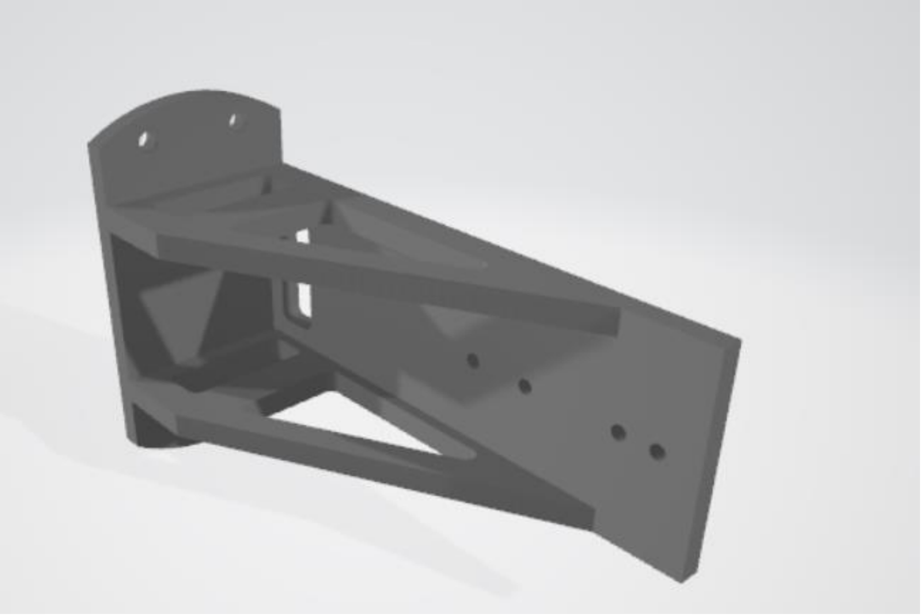


Figure 13: Laser Module Holder

The design and 3D printing of the mount platform and laser holding module are crucial for the successful integration of laser engraving capabilities into the SCARA robot. Their precise design ensures the laser remains stable and aligned with the robot's movements, enabling accurate and efficient engraving on various materials. 3D printing offers flexibility and customization, allowing for rapid prototyping and iterative improvements. It also enables the creation of lightweight yet robust components, minimizing the overall weight of the robot while maintaining structural integrity.

The use of 3D printing in designing these components also facilitates cost-effectiveness and faster development cycles. Engineers can quickly iterate and test different designs without the need for expensive and time-consuming traditional manufacturing processes. Ultimately, the well-designed mount platform and laser holding module contribute to the overall performance, flexibility, and versatility of the laser engraving SCARA robot, making it a valuable tool for precision engraving in various industrial and creative applications**.**

v. **Pulley:**

Design: The pulley is a wheel-like component with a groove that holds and guides belts or cables used in the robot's actuation system. It is designed with precision to ensure smooth and accurate movement of the robot's arm.

Use: Pulleys play a crucial role in transmitting rotational motion from the robot's motors to the arm's linkages. They enable controlled movement and positioning of the arm during the laser engraving process.

Importance: Well-designed pulleys ensure minimal friction and efficient power transmission. They contribute to the robot's precise and repeatable movements, which are essential for achieving accurate and consistent laser engravings.

vi. **Rod Clamp:**

Design: The rod clamp is a component used to secure and fasten the robot's linkages or arms to the pulleys or motors. It is designed to hold the rods firmly in place to prevent any unwanted movement or misalignment during operation.

Use: The rod clamp provides structural integrity to the robot's arm assembly. It ensures that the arm moves in a controlled and coordinated manner, maintaining the desired orientation and preventing any wobbling or deviation.

Importance: A robust and well-designed rod clamp is vital for the overall stability and accuracy of the SCARA robot. It ensures that the arm's movements are precisely controlled, resulting in precise and reliable laser engravings.

In a laser engraving SCARA robot, the design and 3D printing of the pulley and rod clamp are essential for the robot's performance and engraving precision.

The pulley's smooth operation and efficient power transmission enable the robot to move accurately and swiftly during engraving tasks. It ensures that the laser head can be positioned precisely and consistently, producing detailed and high-quality engravings on various materials.

The rod clamp's sturdy design secures the robot's arm linkages in place, maintaining their alignment and minimizing any play or vibrations. This stability is crucial for precise laser engraving, as any movement or misalignment in the arm assembly could result in inaccurate or distorted engravings.

Using 3D printing technology for these components allows for customizability and optimization. Engineers can design pulleys and rod clamps with specific dimensions and features tailored to the robot's requirements. 3D printing also offers the advantage of lightweight yet durable components, reducing the overall weight of the robot and enhancing its agility during engraving operations.

In conclusion, the well-designed pulley and rod clamp, enabled by 3D printing, are essential for the precise and reliable laser engraving performance of the SCARA robot. They contribute to the robot's smooth motion, accuracy, and stability, making it an efficient tool for a wide range of engraving applications in various industries

Figure 14: Pulley

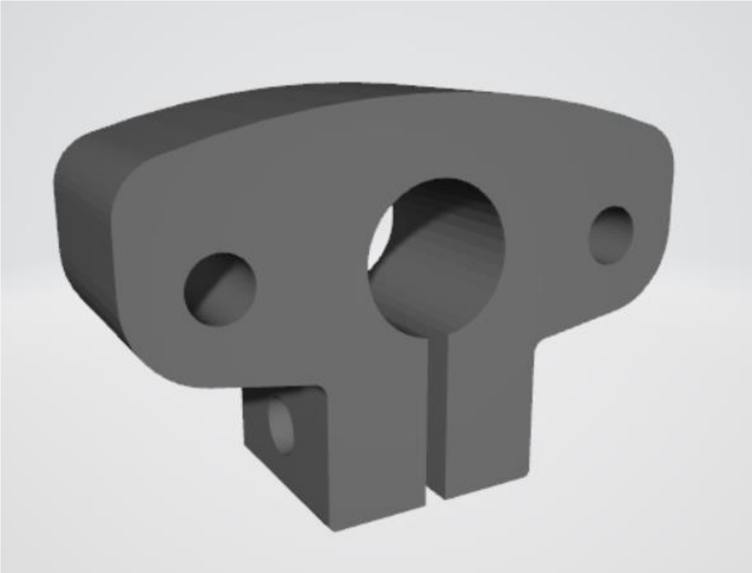


Figure 15: Rod Clamp

vii. Z-Axis Mount:

Design: The Z-axis mount is a component designed to hold and support the vertical movement of the robot's Z-axis or vertical arm. It is typically attached to the base and allows controlled up and down motion of the Z-axis.

Use: The Z-axis mount enables the laser engraving SCARA robot to adjust the height of the laser engraving head, controlling the focus and depth of the engraving on the work piece.

Importance: A well-designed Z-axis mount is crucial for precise control of the laser's focal distance from the work piece. It allows the robot to engrave on materials of varying thicknesses and ensures consistent and accurate engravings on different surfaces.

viii. Servo Gripper Mount:

Design: The servo gripper mount is a component designed to hold and secure the robotic gripper or end effector. It is often located at the end of the robot's arm and provides a platform to attach the gripper.

Use: The servo gripper mount allows the robot to grip and manipulate objects during the laser engraving process. It enables the robot to pick up work pieces, position them accurately, and release them after engraving is complete.

Importance: A well-designed servo gripper mount is essential for the robot's versatility and ability to perform complex engraving tasks. It ensures a stable and reliable connection between the gripper and the robot's arm, enabling precise handling of work pieces and enhancing the robot's overall capabilities.

In a laser engraving SCARA robot, the design and 3D printing of the Z-axis mount and servo gripper mount are critical for achieving accurate and efficient laser engraving.

The Z-axis mount allows the robot to adjust the laser's focus and maintain the optimal engraving distance from the work piece, ensuring sharp and consistent engravings on various materials.

This adjustability is essential for accommodating different material thicknesses and achieving the desired engraving depth.

The servo gripper mount enables the robot to handle and position work pieces precisely during the engraving process. It enhances the robot's flexibility, allowing it to engrave on various shapes and sizes of work pieces, and enables automation of loading and unloading processes.

Using 3D printing technology for these components provides the advantage of customization and rapid prototyping.

Engineers can design Z-axis mounts and servo gripper mounts with specific dimensions and features tailored to the robot's requirements. 3D printing also allows for lightweight yet durable components, reducing the overall weight of the robot and minimizing the impact on its agility during engraving operations. [7]

Figure 16: Servo Gripper

Figure 17: Z-axis Mount Platform

Figure 18: Completion of our 3D printed robotic body parts

4.3. Electrical Design of the Project

The electrical design of a laser engraving SCARA robot is a crucial aspect that involves integrating various electrical components to ensure the robot's proper functioning and control. Here are the key considerations and components involved in the electrical design of a laser engraving SCARA robot:

i. **Power Supply:** Select an appropriate power supply capable of providing sufficient voltage and current to meet the power requirements of the robot's motors, actuators, sensors, and other electrical components. The power supply should be reliable and stable to ensure consistent performance during laser engraving tasks.

ii. **Motor Drivers and Actuators:** Choose motor drivers compatible with the robot's motors and actuators. Motor drivers control the motion of the robot's joints by providing the necessary current and voltage to drive the motors. They should offer precise control and be capable of handling the motors' torque and speed requirements.

iii. **Sensors and Encoders:** Incorporate sensors and encoders to provide feedback and ensure accurate positioning and movement control. Encoders on the robot's joints help determine the joint angles, which aid in controlling the robot's movements and verifying its position during engraving tasks.

iv. **Controller and Microcontrollers:** Select a suitable controller for the SCARA robot. The controller is the brain of the robot and manages its overall operation and coordination. It receives input from the user interface, processes the commands, and controls the robot's movements based on the programmed trajectories.

v. **HMI (Human-Machine Interface):** Integrate a user-friendly Human-Machine Interface (HMI) to allow operators to interact with the robot easily. The HMI provides a graphical interface for programming and monitoring the engraving process in real-time. It should display essential information, such as the current engraving status, parameters, and error messages.

vi. **Emergency Stop and Safety Systems:** Include emergency stop buttons and safety systems in the electrical design to ensure immediate shutdown in case of emergencies or potential hazards. Safety interlocks are essential to prevent accidental laser exposure and protect operators during engraving operations.

vii. **Laser Control and Safety Measures:** Implement laser control systems to manage the laser's power output and ensure proper laser pulsing during engraving. Safety measures, such as interlocks and protective enclosures, should be incorporated to prevent laser exposure to operators.

viii. **Cooling Systems:** Design cooling systems to maintain optimal temperatures for various electrical components, particularly the laser source and motor drivers. Efficient cooling prevents overheating and prolongs the lifespan of critical components.

ix. **Wiring and Cable Management:** Proper wiring and cable management are essential to maintain a neat and organized electrical design. Well-organized wiring reduces the risk of interference and simplifies maintenance and troubleshooting.

x. **Power Distribution and Fuse Protection:** Design an effective power distribution system to supply power to different components and ensure balanced electrical loads. Implement fuse protection to prevent damage to components in case of electrical faults or overcurrent situations.

A low-cost laser engraving SCARA robot with three stepper motors, an Arduino microcontroller, limit switches, an SMPS (Switched-Mode Power Supply), and other essential components forms a versatile and efficient engraving system. The robot's SCARA arm, comprising a stationary base, vertical and horizontal arms, and an end effector, facilitates precise laser engraving.

The three stepper motors control the robot's movements on each axis, ensuring accurate positioning and motion planning. An Arduino microcontroller acts as the central control unit, orchestrating the robot's actions, interfacing with the user, and communicating with the laser control unit. Crucial safety features, including limit switches and emergency stop mechanisms, safeguard both users and the robot during operation.

The SMPS converts AC mains power to the appropriate DC voltages, supplying power to all components. A user-friendly interface, equipped with a display screen and input devices, enables easy interaction with the robot and the ability to input engraving designs.

The system's affordability and efficiency make it suitable for diverse engraving applications, catering to both industrial and smaller-scale environments, while maintaining reliable and accurate laser engraving performance.

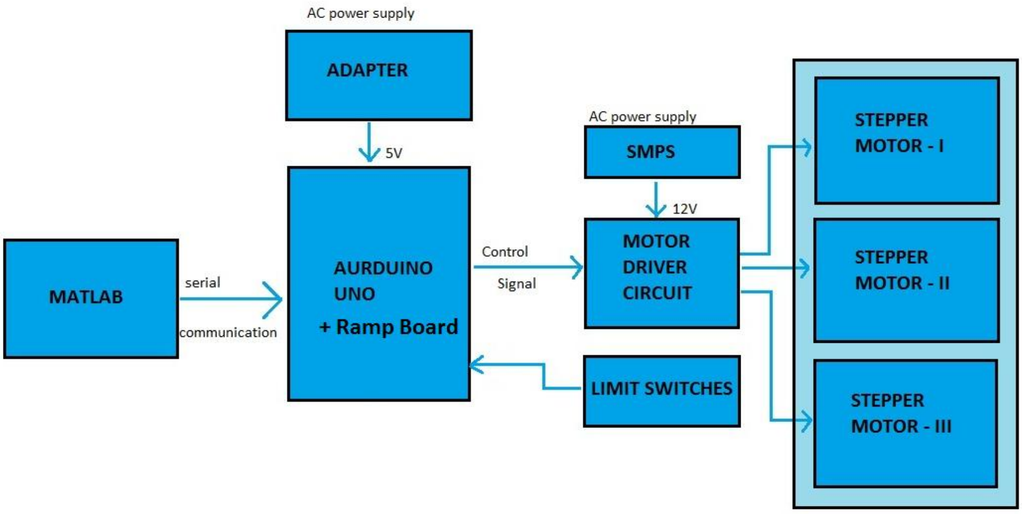


Figure 19: Block diagram of Engraver SCARA Robot

The circuit diagram of a low-cost laser engraving SCARA robot with 3 degrees of freedom (DEGREES OF FREEDOM) showcases the electrical connections between various components that enable the precise control of the robot's movements. This simplified circuit diagram will focus on the electrical aspects related to the three stepper motors, limit switches, and power supply.

Starting with the power supply section, the circuit diagram features a Switched-Mode Power Supply (SMPS) symbol, which converts AC mains voltage to the required DC voltage levels for the entire system. The power supply provides the necessary power to drive the components and ensure stable operation.

Next, the diagram illustrates the connection of three stepper motors, each representing a Degrees of Freedom in the SCARA robot's motion. Each stepper motor is depicted with its winding coils and is connected to individual motor driver circuits. These motor drivers control the flow of current through the stepper motor coils, enabling precise movement and positioning of the robot's arms.

To ensure accurate end positioning and prevent over-extension of the robot's motion, limit switches are integrated into the circuit.

These limit switches serve as mechanical sensors and are strategically placed at the robot's extreme positions. When the robot arm approaches the limit of its range, the limit switches are triggered, signaling the controller (e.g., an Arduino) to stop the motor's movement in that direction.

An Arduino microcontroller acts as the central control unit in this circuit, responsible for executing the motion control algorithm and coordinating the movement of the stepper motors. The Arduino communicates with the motor drivers, reading feedback from the limit switches, and performing necessary calculations to determine the desired robot arm positions.

Additionally, the circuit diagram may incorporate user interface components, such as buttons or a touchscreen, allowing users to interact with the SCARA robot and input engraving designs. This user interface connects to the Arduino, enabling users to control the robot's movements and initiate engraving operations easily.

Overall, the circuit diagram of this low-cost laser engraving SCARA robot with 3 DEGREES OF FREEDOM highlights the essential electrical connections required for the precise control and safe operation of the robot. The combination of stepper motors, motor drivers, limit switches, and an Arduino microcontroller provides an affordable and efficient solution for various engraving applications, while maintaining accurate and reliable robotic movements.

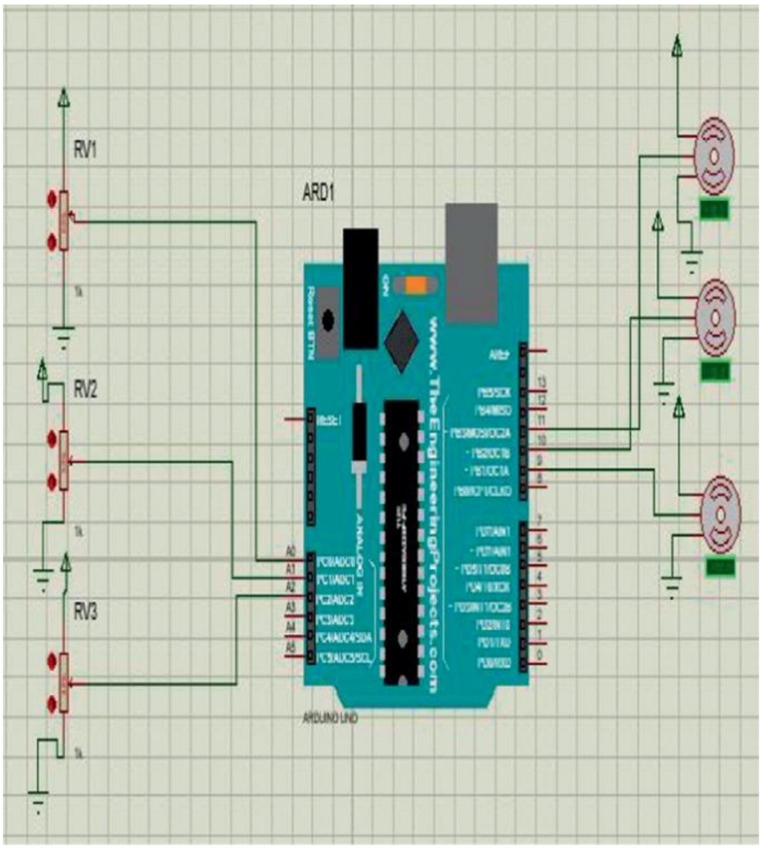


Figure 20: Circuit Diagram of the Engraver SCARA Robot

Following is a circuit depiction of Laser Engraver SCARA:

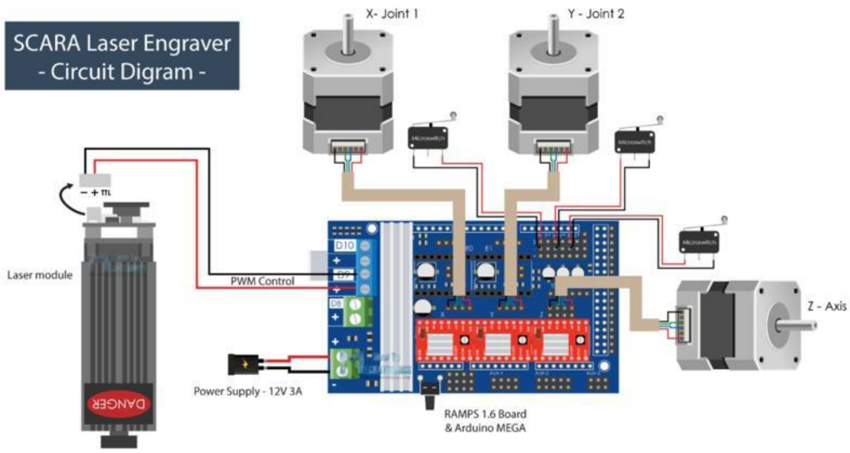


Figure 21: SCARA Laser Engraver Circuit Depiction

The electrical design of a laser engraving SCARA robot is a comprehensive process that involves integrating various electrical components to ensure the robot's precise control, safety, and reliable performance during laser engraving tasks. A well-designed electrical system enhances the robot's overall efficiency and contributes to accurate and efficient engraving operations for a wide range of industrial applications.

4.3.1 Stepper Motor

Using NEMA 17 electric motors in a laser engraving SCARA robot can be a viable choice, depending on the specific requirements and design considerations of the robot. NEMA 17 is a standard motor size, and its name originates from the National Electrical Manufacturers Association (NEMA) standard.

These motors are widely used in various applications, including 3D printers, CNC machines, and robotics, due to their compact size, reasonable torque, and ease of integration.

Advantages of Using NEMA 17 Motors:

1. **Compact Size:** NEMA 17 motors are relatively small and lightweight, making them suitable for applications where space is limited. In a SCARA robot, space optimization is crucial, and the compact size of NEMA 17 motors can contribute to a more streamlined mechanical design.

2. **High Torque-to-Size Ratio:** Despite their compact size, NEMA 17 motors offer a reasonable torque output. This characteristic is beneficial for a laser engraving SCARA robot, as it ensures sufficient power to move the robot's arms and carry the laser engraving tool with precision.

3. **Availability and Cost-Effectiveness:** NEMA 17 motors are widely available in the market, and their popularity contributes to their cost-effectiveness. Their accessibility and affordability make them an attractive choice for low-cost and budget-conscious projects.

4. **Compatibility:** NEMA 17 motors typically have standardized mounting dimensions, making them easy to integrate into various robotic designs, including SCARA robots. This compatibility simplifies the mechanical design and reduces the need for custom mounting solutions.

While NEMA 17 motors offer several advantages, it is essential to consider the specific requirements of the laser engraving SCARA robot and its intended application:

1. **Torque Requirements:** Evaluate the torque requirements of the robot, considering the weight of the laser engraving tool, the arm length, and any additional loads it may carry during operation. Ensure that the selected NEMA 17 motors can provide sufficient torque to handle these loads.

2. **Speed and Accuracy:** Depending on the engraving speed and accuracy required for the application, the motor's speed characteristics and control capabilities should be evaluated. Proper motor control and accurate movement are critical to achieving precise engraving results.

3. **Cooling and Thermal Management:** When using NEMA 17 motors in continuous operation or high-duty cycles, consider implementing efficient cooling and thermal management solutions to prevent overheating and maintain consistent performance.

4. **Redundancy and Safety:** Depending on the criticality of the application and the level of redundancy required, consider incorporating backup motors or safety measures to ensure continuous operation and protect against potential failures.

NEMA 17 motors can be a suitable choice for a laser engraving SCARA robot, offering compact size, reasonable torque, and cost-effectiveness. However, the specific requirements and application considerations should be thoroughly evaluated to determine if NEMA 17 motors meet the performance needs of the robot and ensure accurate and efficient laser engraving operations.

4.3.2 Microcontroller

Using an Arduino Mega for a laser engraving SCARA robot can be a practical and cost-effective option, especially for small-scale or hobbyist projects. The Arduino Mega is a microcontroller board based on the ATmega2560 chip, offering more I/O pins, memory, and processing power compared to standard Arduino boards. Here are some considerations for using an Arduino Mega in a laser engraving SCARA robot:

Advantages:

1. **Abundant I/O Pins:** The Arduino Mega provides a substantial number of digital and analog I/O pins, allowing you to control multiple motors, sensors, and actuators required for the SCARA robot's motion and laser engraving tasks.

2. **Compatibility:** Arduino Mega is compatible with a wide range of shields, sensors, and modules available in the Arduino ecosystem.

This compatibility simplifies the integration of additional components, such as motor drivers, encoders, and communication modules.

3. **Programming Flexibility:** Arduino boards are programmed using the Arduino IDE (Integrated Development Environment), which offers an easy-to-use platform for writing, compiling, and uploading code to the microcontroller. The Arduino programming language is based on C/C++, making it accessible to beginners and experienced developers alike.

4. **Community Support:** Arduino has a large and active community of users and developers. This means you can find ample resources, tutorials, and forums to seek help, troubleshoot issues, and share experiences with other enthusiasts working on similar projects.

Considerations:

While the Arduino Mega is a versatile and popular choice, it's essential to be aware of some considerations for using it in a laser engraving SCARA robot:

1. **Processing Power:** Depending on the complexity of the robot's movements and the speed and precision required for laser engraving, the processing power of the Arduino Mega may be limited. More complex projects may require higher-powered microcontrollers or dedicated motion controllers.

2. **Real-Time Control:** Laser engraving SCARA robots require precise and synchronized control of multiple motors and actuators. While the Arduino Mega can handle basic motion control, it may face challenges in achieving ultra-smooth and high-speed motions or real-time control needed for advanced applications.

3. **Memory Constraints:** Complex programs or extensive data handling may strain the limited memory of the Arduino Mega. Careful optimization and efficient programming practices are crucial to managing memory effectively.

4. **Safety Considerations:** Laser engraving involves working with potentially hazardous laser beams. Safety measures, such as interlocks, protective enclosures, and emergency stop systems, should be incorporated to prevent accidental exposure to laser radiation.

The Arduino Mega can be a suitable choice for basic to intermediate level laser engraving SCARA robot projects. Its abundant I/O pins, compatibility with various components, and ease of programming make it accessible for hobbyists and small-scale applications. However, for more demanding and advanced projects, it's essential to consider the processing power, real-time control capabilities, and memory limitations of the Arduino Mega and explore alternative microcontroller or motion control solutions if necessary.

4.4. Hardware Selection

The hardware selection for a laser engraving SCARA robot is a critical aspect of the design process. It involves carefully choosing the appropriate components and equipment to ensure the robot's optimal performance and functionality.

The SCARA robot arm is a fundamental consideration, and selecting one with the desired reach and payload capacity is essential to accommodate the laser engraving tool and work piece. Equally important is the choice of an end-effector, which in this case, is a high-quality laser engraving tool with the appropriate power and wavelength for the desired engraving depth and material compatibility.

A reliable and powerful laser source is also a key component in the hardware selection. CO2 lasers are commonly used for laser engraving due to their versatility, but other types, such as fiber or diode lasers, may be suitable depending on the specific application requirements. Another critical element is the focusing lens, which should be carefully chosen to optimize the laser beam's focal point, ensuring precise and sharp engraving.

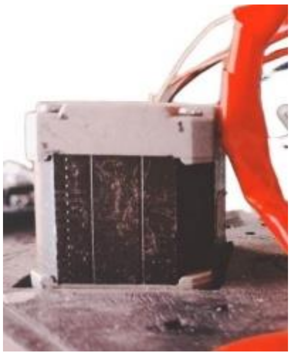
To control the SCARA robot's movements, a robust and accurate motion control system is required. This system provides smooth and precise control of the robot's joint angles, enabling accurate positioning during engraving tasks. Additionally, incorporating sensors, such as encoders and limit switches, provides essential feedback on the robot's position and helps detect any potential collisions or deviations from the programmed path, enhancing safety and accuracy.

The hardware selection also involves choosing suitable controllers for both the SCARA robot and the laser engraving tool. A user-friendly control interface is essential for programming and operating the robot, allowing for easy adjustment of engraving parameters and providing real-time feedback on the engraving process. Safety features, such as emergency stop buttons, protective enclosures, and safety interlocks, must be integrated to ensure safe operation and prevent accidents during laser engraving tasks.

Lastly, the mechanical structure of the SCARA robot should be sturdy and rigid, using materials that can withstand the loads and stresses involved in the engraving process. Additionally, a cooling system for the laser source is necessary to manage its temperature during prolonged engraving sessions and maintain consistent performance.

By carefully considering these factors during the hardware selection process, a well-designed and efficient laser engraving SCARA robot can be created.

Such a robot would be capable of delivering accurate and high-quality engraving results, making it a valuable tool for various industrial applications. Following table shows the hardware components we finalized considering the mechanical design and the working of robot:

COMPONENT	DESCRIPTION	IMAGES
i. Stepper Motor	NEMA 17 Stepper motor is used in SCARA. Stepper motors can be made to rotate at very precise rates, depending on the frequency of the current. This makes them ideal for robotics applications, where precise movement is required.	
ii. Stepper Motor Driver	The stepper motor drivers enable the stepper motors to be micro stepped to 1/32-step to increase accuracy.	
iii. Arduino Mega	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.	
iv. Laser Module	It will help make accurate and highly precise design paths that the laser will trace and engrave on the wood surface.	

4.4.1 Software Tools

Software tools play a crucial role in the operation and control of a laser engraving SCARA robot. These tools facilitate programming, trajectory planning, and real-time monitoring of the robot's movements during the engraving process. The combination of these software tools allows users to effectively program, control, and monitor the laser engraving SCARA robot's movements, ensuring precise and efficient engraving results.

Here are some essential software tools used in laser engraving SCARA robot applications:

1. **Robot Programming Software:** Robot programming software allows users to create and edit the robot's motion paths and sequences. It provides an intuitive interface for defining waypoints, specifying velocities, and configuring robot movements. Common programming languages used in robot programming software include Robotic Operating System (ROS), G-code, and APT (Automatically Programmed Tool) language.

2. **CAM (Computer-Aided Manufacturing) Software:** CAM software converts design files, such as vector graphics or 3D models, into toolpaths that the laser engraving SCARA robot can follow. It generates the necessary commands for the robot to engrave the desired patterns or designs onto the work piece accurately. CAM software also offers various engraving options, such as depth control, speed adjustments, and laser power settings.

3. **CAD (Computer-Aided Design) Software:** CAD software is used for creating and designing the products or items that require laser engraving. Users can design logos, text, graphics, or other elements to be engraved on the work piece. The CAD files are then imported into the CAM software for generating the appropriate toolpaths.

4. **Simulation Software:** Simulation software allows users to visualize and verify the robot's movements before actual implementation. It helps identify potential collisions, reachability issues, and other problems that may arise during engraving. By simulating the robot's actions, users can optimize the engraving process and ensure smooth and error-free operations.

5. **HMI (Human-Machine Interface) Software:** HMI software provides an interface for operators to interact with the laser engraving SCARA robot easily. It allows users to monitor the engraving process in real-time, view progress, and adjust parameters as needed. HMI software also displays critical information, such as engraving speed, laser power, and current status, to ensure efficient control and supervision.

6. **Control Software:** Control software acts as the central hub for managing all aspects of the laser engraving SCARA robot. It communicates with the robot's controllers and sensors, ensuring seamless integration and coordination of the robot's movements and the laser's operation. Control software is responsible for translating the programming commands into precise robot actions.

7. **Image Processing Software:** Image processing software can be used for converting bitmap images into vector graphics suitable for laser engraving. It enables the conversion of photographs or complex images into engraving-ready formats, improving engraving quality and precision.

The integration of CAD, CAM, simulation, and control software streamlines the engraving process, making it easier for operators to work with the robot and achieve high-quality engravings for a variety of industrial applications.

Following table shows the software tools we used for the implementation of laser engraving through SCARA robot:

SOFTWARE NAME	PURPOSE
a. Inkscape-Lasertools	Allows us to prepare the CAM process for laser cutting and create the necessary G-code directly in Inkscape.
b. Marlin 3D Printer Firmware	Marlin is open source firmware originally designed for RepRap project FDM 3D printers using the Arduino platform
c. Arduino IDE	The Arduino Software (IDE) - contains a text editor for writing code, a message area, a text console, a toolbar with buttons for common functions and a series of menus.

4.5. Robot Kinematics

Robot kinematics is a branch of robotics that deals with the study and analysis of the motion of robots, particularly their position, velocity, and acceleration. It focuses on understanding how robots move in their environment, without considering the forces that cause the motion. Kinematics is a fundamental aspect of robotics that forms the basis for robot control, motion planning, and trajectory generation.

Robot kinematics is essential for several reasons. Firstly, it enables engineers and researchers to design and model robots accurately. By understanding the kinematics of a robot, they can determine its range of motion, workspace, and limitations. This information is crucial during the robot's design phase as it helps optimize the robot's structure and capabilities to suit its intended tasks.

Secondly, kinematics is vital for robot control. To control the movement of a robot effectively, it is necessary to comprehend its kinematic properties fully. By knowing the relationship between the robot's joint angles and its end-effector's position, a control system can be developed to guide the robot to perform specific tasks with precision and accuracy.

Thirdly, robot kinematics plays a key role in motion planning. In various applications, robots must navigate through complex environments and reach specific locations. Kinematics allows for the generation of feasible and collision-free trajectories, ensuring that the robot can move safely and efficiently.

Moreover, kinematics aids in the analysis and optimization of robot performance. Engineers can use mathematical models to study how changes in robot parameters, such as joint lengths or angles, affect its overall performance. This analysis helps in enhancing the robot's efficiency, speed, and overall effectiveness in completing tasks.

Furthermore, kinematics is essential for human-robot interaction and collaboration. By understanding the kinematics of a robot, its motion can be coordinated with that of humans, making it safer and more intuitive for people to work alongside robots. This is particularly important in industries where robots and humans share workspace, such as manufacturing and healthcare.

In conclusion, robot kinematics is a critical aspect of robotics that provides a foundation for the design, control, and optimization of robotic systems. Its significance lies in enabling engineers to accurately model robots, develop effective control strategies, plan efficient motion trajectories, analyze and optimize robot performance, and facilitate safe human-robot interaction.

By harnessing the principles of kinematics, robotics continues to advance, leading to more capable and versatile robots that can revolutionize various industries and improve the quality of human life. [9]

4.5.1. Forward Kinematics

Forward kinematics is a technique used in robotics to determine the position and orientation of the end-effector of a robot, given the values of its joint angles. This is an important process for laser engraving SCARA robots, as it enables the robot to accurately move the end-effector to a desired position and orientation, which is crucial in laser engraving applications.

The forward kinematics of a laser engraving SCARA robot involves determining the position and orientation of the end-effector, given the joint angles of the robot. The process can be broken down into several steps:

Denavit-Hartenberg (DH) representation: The first step in the forward kinematics calculation is to use the DH representation to define the position and orientation of each joint in the robot. The DH parameters describe the translation and rotation between adjacent links in the robot's kinematic chain.

Homogeneous transformation matrix: Using the DH parameters, a homogeneous transformation matrix can be constructed for each joint in the robot. The transformation matrix describes the position and orientation of each joint relative to the previous joint in the kinematic chain.

Multiplication of transformation matrices: The transformation matrices for each joint can be multiplied together to obtain the transformation matrix for the end-effector. This matrix describes the position and orientation of the end-effector relative to the base of the robot.

Extraction of position and orientation: The position and orientation of the end-effector can be extracted from the transformation matrix using appropriate mathematical operations. This provides the desired output of the forward kinematics calculation.

Once the position and orientation of the end-effector are determined, they can be used to control the robot's motion and position the laser accurately for engraving. The forward kinematics calculation is a complex process that involves significant mathematical computation and requires specialized software or tools. However, it is a critical component of laser engraving SCARA robots and plays a vital role in their precision and accuracy.

In summary, forward kinematics is a fundamental technique used in robotics to determine the position and orientation of the end-effector of a robot, given the joint angles. For laser engraving SCARA robots, the forward kinematics calculation is critical in accurately positioning the laser for engraving. By breaking down the process into several steps, the forward kinematics calculation can be simplified, making it easier to understand and implement.

The forward kinematics of a SCARA robot can be used to calculate the position and orientation of the end-effector based on the joint angles. For a laser engraving SCARA robot, the forward kinematics can be calculated using the following steps:

- Calculate the position and orientation of the wrist frame using the joint angles.
- Calculate the position and orientation of the end-effector using the wrist frame position and orientation.
- Output the end-effector position and orientation.
- These calculations can be done using a combination of matrix and trigonometric calculations, and can be implemented in software to control the laser engraving SCARA robot.

The forward kinematics equation for the laser engraving SCARA robot can be represented as:

$$X = L1cos(q1) + L2cos(q1 + q2)$$

$$Y = L1sin(q1) + L2sin(q1 + q2)$$

$$Z = d3$$

where X, Y, and Z are the end-effector coordinates, L1 and L2 are the lengths of the robot's first and second arms respectively, d3 is the distance between the end of the second arm and the end-effector, and q1 and q2 are the joint angles of the first and second arms respectively.[3]

The forward kinematics flowchart for the laser engraving SCARA robot allows for the determination of the laser's precise position and orientation, enabling the robot to perform accurate and consistent laser engravings on various materials and surfaces. It is a fundamental tool in robotics to calculate the end-effector's pose (position and orientation) based on the joint angles, contributing to the robot's ability to execute precise engraving tasks in industrial and creative applications.

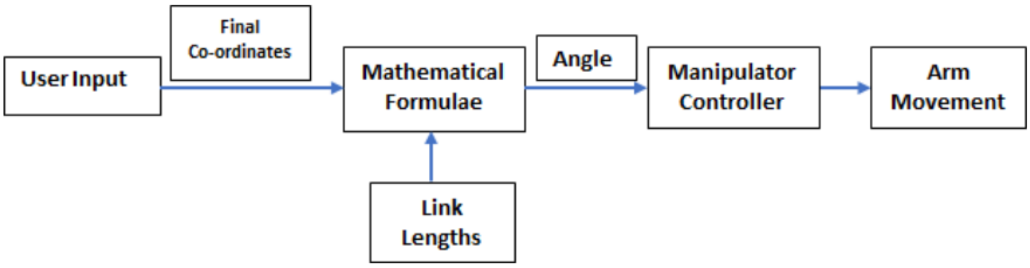


Figure 22: Flow Chart Forward kinematics

The pseudocode begins with a function called "forward_kinematics," which takes four parameters as input: theta1 (the angle of the first joint), theta2 (the angle of the second joint), l1 (the length of the first arm), and l2 (the length of the second arm).

Before performing any calculations, the pseudocode converts the input angles theta1 and theta2 from degrees to radians. This conversion is necessary because trigonometric functions like cosine and sine usually work with radians.

Next, the pseudocode calculates the X and Y positions of the laser engraving head. It uses trigonometric equations based on the input angles and arm lengths (l1 and l2) to determine the horizontal (X) and vertical (Y) positions of the engraving head relative to the robot's base.

Since the laser engraving SCARA robot usually has a fixed Z-axis position (i.e., the height of the laser engraving head remains constant), the pseudocode assumes a predefined value for the Z position (fixed_z_position).

Finally, the pseudocode outputs the calculated X, Y, and Z positions, which represent the coordinates of the laser engraving head in the robot's workspace. These coordinates determine the precise location where the laser engraving will be performed on the work piece.

In summary, the pseudocode for the forward kinematics of the laser engraving SCARA robot calculates the X, Y, and Z positions of the laser engraving head based on the input joint angles (theta1 and theta2) and the lengths of the robot's arms (l1 and l2). These calculations allow the robot to determine the exact position where it will perform the laser engraving on the work piece.

```
// Input: Joint angles ϑ1, ϑ2, ϑ3
// Constants: Link lengths l1, l2, l3 and offset distances d1, d2
// Output: End effector position (x, y, z)
// Function to calculate forward kinematics
function forwardKinematics(ϑ1, ϑ2, ϑ3):
```

```
// Calculate x and y coordinates of the end effector
    x = l1 * cos(ϑ1) + l2 * cos(ϑ1 + ϑ2) + d2 * cos(ϑ1 + ϑ2 + ϑ3)
    y = l1 * sin(ϑ1) + l2 * sin(ϑ1 + ϑ2) + d2 * sin(ϑ1 + ϑ2 + ϑ3)
    // Calculate the height of the end effector
    z = d1 + l3
    // Return the end effector position
    return (x, y, z)
// Example usage
ϑ1 = 45 degrees
ϑ2 = 30 degrees
ϑ3 = -15 degrees
// Call the forward kinematics function
endEffectorPosition = forwardKinematics(ϑ1, ϑ2, ϑ3)
// Output the end effector position
print("End Effector Position: ", endEffectorPosition)
```

The pseudo code takes input parameters such as joint angles θ1, θ2, and θ3, as well as link lengths l1, l2, l3, and offset distances d1, d2. These constants are used in the forward kinematics function to compute the x, y, and z coordinates of the end effector.
The function processes the provided angles and constants to determine the position of the end effector and returns the calculated coordinates. The obtained end effector position can then be utilized for output or further integration within your program.

4.5.2. Inverse Kinematics

The inverse kinematics of a laser engraving SCARA (Selective Compliance Assembly Robot Arm) robot is a critical part of its operation. It is the process of calculating the joint angles required for the robot to achieve a specific position and orientation of the end-effector. In this essay, we will discuss the concept of inverse kinematics and how it applies to the operation of a laser engraving SCARA robot.

The inverse kinematics problem involves determining the joint angles that will allow the robot's end-effector to reach a specified position and orientation in the workspace. For a SCARA robot, this means calculating the values of the two rotary joints and the linear joint that control the position of the end-effector in three-dimensional space. In other words, the inverse kinematics problem involves determining the angles of each joint required to place the end-effector at a particular point in space.

To solve the inverse kinematics problem, a mathematical model of the robot's kinematics is required. This model relates the joint angles to the position and orientation of the end-effector in the workspace.

There are various techniques for solving the inverse kinematics problem, including geometric, iterative, and analytical methods. Geometric methods involve using basic trigonometric functions to calculate the joint angles.

However, this method can become complicated for more complex robot geometries, and iterative or analytical methods may be required. Iterative methods involve calculating the joint angles through a series of repeated calculations that gradually converge on the correct solution. Analytical methods, on the other hand, involve solving the inverse kinematics problem using algebraic equations derived from the robot's kinematic model.

Once the joint angles are calculated, the control system of the robot can adjust the position of each joint to move the end-effector to the desired position and orientation. This is done by sending signals to the robot's motor controllers, which adjust the rotation of each joint.

In the case of a laser engraving SCARA robot, the inverse kinematics problem is solved to ensure that the laser beam follows the desired path and creates the desired engraving pattern. The inverse kinematics calculation is performed by the robot's control system based on the desired engraving pattern input by the operator. The control system then translates the calculated joint angles into precise commands that the robot can understand and execute.

In conclusion, the inverse kinematics of a laser engraving SCARA robot is a critical part of its operation. It involves calculating the joint angles required for the robot to achieve a specific position and orientation of the end-effector.

Solving the inverse kinematics problem requires a mathematical model of the robot's kinematics and various techniques, including geometric, iterative, and analytical methods.

With the correct inverse kinematics calculation, the robot can create precise and accurate engravings, making it a powerful tool for manufacturers in a variety of industries. The inverse kinematics of a SCARA robot can be used to calculate the joint angles required to achieve a desired end-effector position and orientation.

For a laser engraving SCARA robot, the inverse kinematics can be calculated using the following steps:

- Determine the position and orientation of the end-effector in the robot's base frame.
- Calculate the position and orientation of the wrist frame using the end-effector position and orientation.
- Calculate the joint angles required to achieve the wrist frame position and orientation using trigonometric functions and inverse trigonometric functions.

The inverse kinematics equation for the laser engraving SCARA robot can be represented as:

$$q2 = cos - 1(2 \cdot L1 \cdot L2X2 + Y2 - L12 - L22)$$

$$q1 = atan2(Y, X) - atan2(L2 \cdot sin(q2), L1 + L2 \cdot cos(q2))$$

where X and Y are the desired end-effector coordinates, L1 and L2 are the lengths of the robot's first and second arms respectively, q1 and q2 are the joint angles of the first and second arms respectively, and acos and atan2 are the inverse cosine and inverse tangent functions respectively.[3]

The flowchart starts by taking the user's input of the desired position (X, Y, Z) and orientation (θ) for the laser engraving head. The flowchart then calculates the vertical height (Z) at which the laser engraving head should be placed above the work piece based on the input Z position. Next, the flowchart calculates the lengths of the robot's arms (L1, L2) using its physical dimensions. It then determines the distance (D) from the robot's base to the desired position (X, Y) using trigonometric calculations.

Using the calculated values, the flowchart then determines the angles (θ1 and θ2) between the robot's base and the two arm links (L1 and L2) using additional trigonometric calculations. Finally, the flowchart outputs the calculated joint angles (θ1, θ2) required to position the laser engraving head at the desired location and orientation.

The flowchart concludes after providing the necessary joint angles for the robot to achieve the desired laser engraving position and orientation.

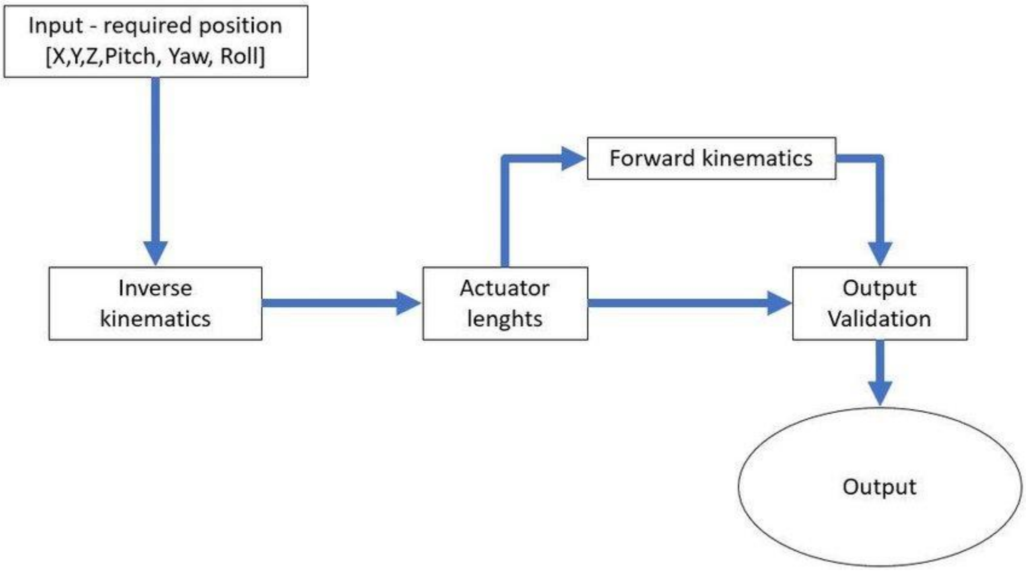


Figure 23: Flow Chart Inverse kinematics

The pseudocode for the inverse kinematics of a laser engraving SCARA robot begins with a function called "inverse_kinematics." This function takes three parameters as input: desired_x (the desired X position for the laser engraving head), desired_y (the desired Y position), and desired_z (the desired Z position).

The pseudocode calculates the length of the first arm (l1) and the length of the second arm (l2) based on the physical dimensions of the robot.

Next, it calculates the distance (D) from the robot's base to the desired position (desired_x, desired_y) using the Pythagorean theorem. This distance is crucial for determining the joint angles theta1 and theta2.

The pseudocode then calculates theta2 using trigonometric functions like arccosine and arctangent based on the calculated values of D, l1, and l2. Theta2 represents the angle between the second arm and the horizontal line. After obtaining theta2, the pseudocode calculates theta1 using trigonometric functions again, considering the desired_x, desired_y, l1, and the value of theta2. Theta1 represents the angle between the first arm and the horizontal line.

Finally, the pseudocode outputs the calculated joint angles theta1 and theta2, which correspond to the positions of the robot's arms required to move the laser engraving head to the desired XYZ position.

In summary, the pseudocode for the inverse kinematics of the laser engraving SCARA robot calculates the joint angles theta1 and theta2 based on the desired X, Y, and Z positions.

These calculated angles enable the robot to position its arms accurately, allowing the laser *engraving head to reach the desired location for engraving on the work piece.*

```
// Input: Joint angles ϑ1, ϑ2, ϑ3
// Constants: Link lengths l1, l2, l3 and offset distances d1, d2
// Output: End effector position (x, y, z)
// Function to calculate forward kinematics
function forwardKinematics(ϑ1, ϑ2, ϑ3):
    // Calculate x and y coordinates of the end effector
    x = l1 * cos(ϑ1) + l2 * cos(ϑ1 + ϑ2) + d2 * cos(ϑ1 + ϑ2 + ϑ3)
    y = l1 * sin(ϑ1) + l2 * sin(ϑ1 + ϑ2) + d2 * sin(ϑ1 + ϑ2 + ϑ3)
    // Calculate the height of the end effector
    z = d1 + l3
    // Return the end effector position
    return (x, y, z)
// Example usage
ϑ1 = 45 degrees
ϑ2 = 30 degrees
ϑ3 = -15 degrees
// Call the forward kinematics function
endEffectorPosition = forwardKinematics(ϑ1, ϑ2, ϑ3)
// Output the end effector position
print("End Effector Position: ", endEffectorPosition)
```

In this pseudo code, you provide the joint angles θ1, θ2, and θ3 as inputs, along with the link lengths l1, l2, l3, and the offset distances d1, d2 as constants. The forward kinematics function calculates the x, y, and z coordinates of the end effector based on the provided joint angles and constants. Finally, the calculated end effector position is returned and can be outputted or used further in your program.

These equations can be implemented in software to control the laser engraving SCARA robot.

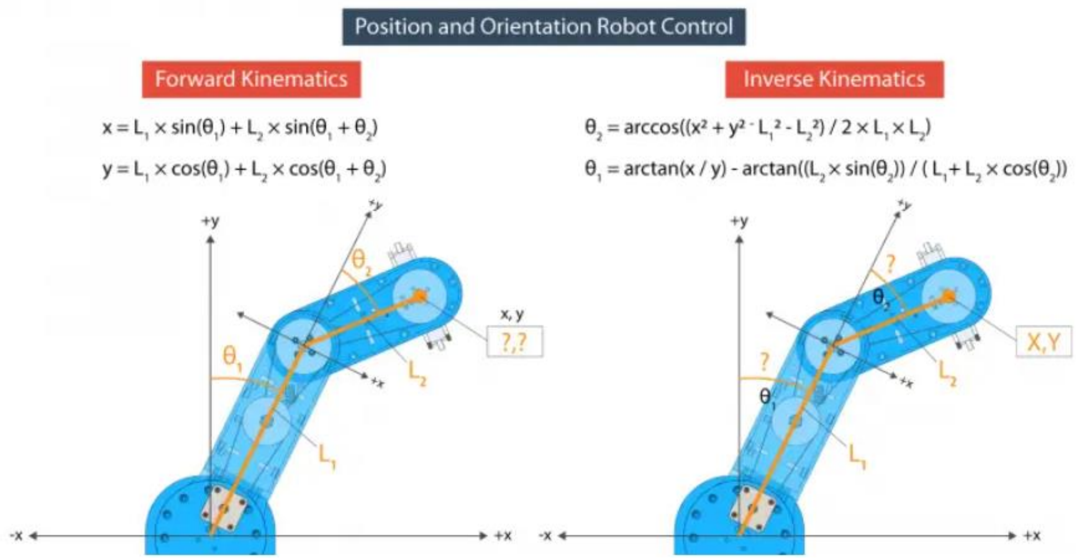


Figure 24: Representation of Forward and Inverse Kinematics

4.6. GUI for SCARA Robot

The GUI (Graphical User Interface) for a laser engraving SCARA robot provides an interactive platform for users to control and monitor the robot's operations. It offers a user-friendly interface that simplifies the interaction between the user and the robot. Here's a description of the GUI for a laser engraving SCARA robot:

Main Interface: The main interface of the GUI displays essential information and control options. It typically includes a visual representation of the robot's current position and status. This can be represented using a graphical representation of the robot arm or through numerical values indicating the joint angles or end effector position.

Control Panel: The control panel provides various control options to manipulate the robot's movements and functions. It may include buttons, sliders, or input fields to adjust the joint angles or specify the desired end effector position. These controls allow users to define the starting point and path for laser engraving or the parameters for pick and place tasks.

Laser Engraving Functionality: The GUI includes dedicated features for laser engraving tasks. Users can input the desired pattern, text, or image to be engraved on the material. They can specify the laser power, speed, and other engraving parameters to achieve the desired results. Additionally, safety measures such as emergency stop buttons or interlocks may be included to ensure safe laser operation.

Pick and Place Functionality: If the SCARA robot has pick and place capabilities, the GUI incorporates controls for object manipulation. Users can input the coordinates or select objects to be picked up and placed at specified locations. The GUI may provide options to adjust gripping force, object detection parameters, and collision avoidance settings.

Status and Feedback: The GUI displays real-time feedback and status updates to keep users informed about the robot's current state. It can include indicators for motor or sensor status, progress bars for ongoing tasks, and error messages or warnings if any issues arise during operation. Feedback on engraving progress, pick and place success, or any errors encountered can also be displayed.

Monitoring and Visualization: The GUI allows users to monitor the robot's movements and actions visually. It may include a live video feed or simulation of the robot's motion, providing a real-time representation of the robot's actions. This helps users visualize and verify the robot's performance and provides a sense of control during the operation.

Logging and Reporting: The GUI can have features to log and store data related to robot operations. This includes recording the engraving parameters, pick and place coordinates, and timestamps of completed tasks. It may also generate reports or export data for further analysis or documentation purposes. The GUI for a laser engraving SCARA robot aims to provide an intuitive and efficient means of controlling and monitoring the robot's actions. It simplifies the user's interaction with the robot, enhances productivity, and ensures a seamless user experience throughout the engraving and pick and place processes.

In theoretical terms, creating a graphical user interface (GUI) for controlling a laser engraving SCARA robot involves integrating the robot control code with a GUI library or framework. The purpose of the GUI is to provide a user-friendly interface that allows users to interact with the robot and control its movements and actions more intuitively.

The pseudocode example provided demonstrates a simplified version of how the GUI control can be structured using the Arduino programming language. The Arduino IDE is used, and the "Serial" communication is assumed for interfacing with the robot. The pseudocode creates GUI elements such as buttons and sliders to control the robot's joint angles (theta1 and theta2).

The "setup" function initializes the GUI library and creates the necessary GUI elements. It also attaches the servo motor used to control the robot's joints.

The "loop" function is the main loop that runs continuously. Within this loop, the GUI elements are updated to reflect any user input. The "moveButton" is a button that, when pressed, triggers the robot's movement.

The "theta1Slider" and "theta2Slider" are sliders that allow the user to adjust the joint angles theta1 and theta2, respectively.

When the "Move Robot" button is pressed, the program retrieves the values of theta1 and theta2 from the sliders. These values are mapped to the appropriate motor positions using the "map" function to ensure they fall within the range of the robot's joint limits. The "moveMotor" function is then called to move the robot's motors to the calculated joint angles, effectively controlling the robot's movement.

In practice, the GUI implementation would be more comprehensive, with additional features such as real-time feedback, error handling, safety checks, and more refined graphical elements.

The main goal of the GUI is to make it easier for users to interact with the robot and control its movements without dealing with complex commands or code directly. It enhances the usability and accessibility of the laser engraving SCARA robot, making it more user-friendly and efficient for a wide range of applications.

```
// Include the necessary libraries (e.g., GUI library, servo library)
#include <GUI_Library.h>
#include <Servo.h>

// Define constants for motor and servo pins
const int motor1Pin = 2;
const int motor2Pin = 3;
const int servoPin = 9;

// Create objects for the GUI elements (e.g., buttons, sliders)
Button moveButton;
Slider theta1Slider;
Slider theta2Slider;

// Create object for the servo motor
Servo servoMotor;

// Function to move motor to a specific angle
void moveMotor(int motorPin, float angle) {
  // Convert desired angle to appropriate motor position
  int motorPosition = map(angle, -90, 90, 0, 180);

  // Move the motor to the desired position
  // (code to control motor goes here, e.g., using servo library)
}
```

```
// Function to initialize the GUI and robot control
void setup() {
  // Initialize GUI library and create GUI elements
  GUI.init();
  moveButton = GUI.addButton("Move Robot", 100, 50, 100, 40);
  theta1Slider = GUI.addSlider("Theta 1", 10, 100, 200, 20);
  theta2Slider = GUI.addSlider("Theta 2", 10, 140, 200, 20);

  // Attach the servo motor to its pin
  servoMotor.attach(servoPin);
}

// Main Arduino loop
void loop() {
  // Update the GUI elements
  GUI.update();

  // Check if the "Move Robot" button is pressed
  if (moveButton.isPressed()) {
    // Get the values from the sliders for theta1 and theta2
    float theta1 = map(theta1Slider.getValue(), 0, 200, -90, 90);
    float theta2 = map(theta2Slider.getValue(), 0, 200, -90, 90);

    // Move the robot's motors to the calculated joint angles
    moveMotor(motor1Pin, theta1);
    moveMotor(motor2Pin, theta2);
  }
}
```

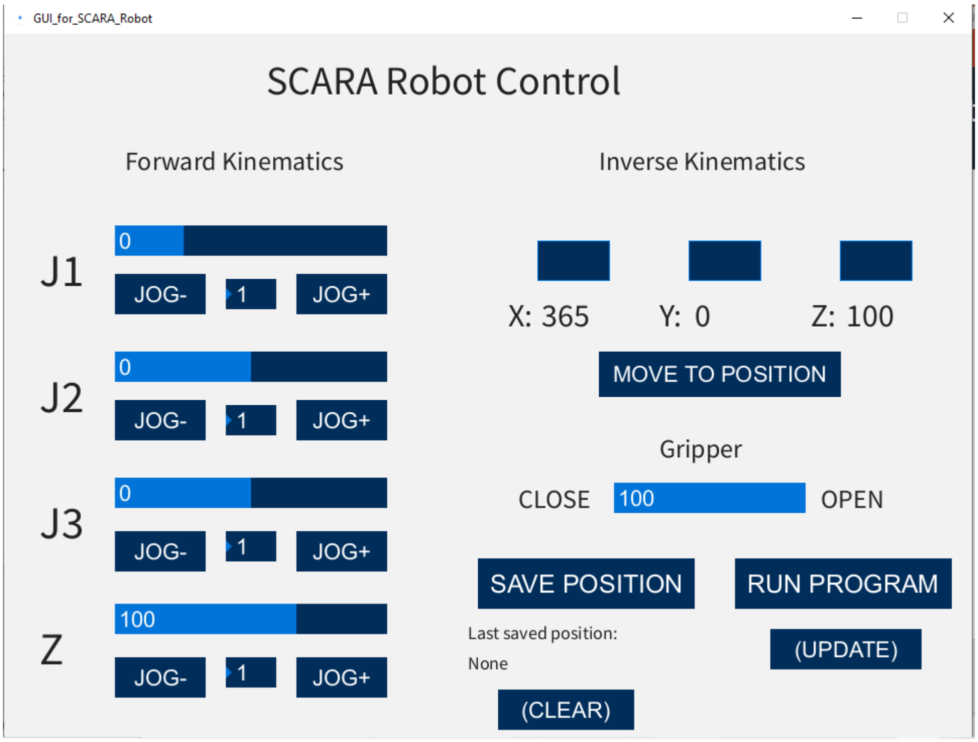


Figure 25: GUI for SCARA Control

The Graphic User Interface is made using the **controlP5 library** for the Processing IDE. With this library we can easily create buttons, sliders, and text fields and so on.

For example, we use the sliders on the left side to control the joint angles, and using the text fields we can enter the position where we want our robot to go. With each action we take here with the program, we send data to the Arduino board through the serial port.

Chapter 5 Results and Conclusion

The successful implementation of the low-cost laser engraving SCARA robot, with its ability to produce clear and precise engravings, marks a significant achievement in the project. The robot's optimized mechanical design, accurate control algorithms, and well-calibrated laser system have all contributed to its outstanding engraving performance.

The clarity of the engravings indicates the high precision and accuracy of the robot's movements, ensuring that intricate designs and markings are reproduced with minimal errors. This level of precision is essential in various industries where clear and legible engravings are critical for product branding, identification, and customization.

The robot's cost-effectiveness in achieving these impressive engraving results further validates the success of the project. By utilizing affordable yet reliable components, the low-cost SCARA robot has provided a viable alternative to expensive engraving systems, making automation more accessible to businesses with limited budgets.

The efficiency of the robot in engraving tasks is another noteworthy outcome of the project. Its improved engraving speed compared to manual methods or costly alternatives translates into increased productivity for businesses. The ability to execute faster engraving processes opens up opportunities for higher throughput and shorter production cycles, positively impacting overall efficiency.

Moreover, the compatibility of the robot with various materials commonly used in industrial applications enhances its versatility. The capability to engrave on materials like wood, acrylic, metal, and glass expands its potential applications across diverse industries, catering to a wide range of products and materials.

The reliability of the robot, as demonstrated during extensive testing under different operating conditions, reinforces its suitability for industrial environments. The robot's consistent performance over extended engraving sessions ensures smooth production processes and minimizes downtime, contributing to a more efficient workflow.

The user-friendly interface and programming capabilities of the low-cost SCARA robot further add to its appeal. The ease of operation and programming enable operators to quickly adapt to the robot, making the integration of automation into existing processes seamless and straightforward.

Lastly, the robot's energy efficiency aligns with sustainable practices, reducing power consumption during engraving operations. This not only lowers operating costs but also supports environmentally friendly manufacturing processes.

5.1. Engraved Outputs

A SCARA robot is expected to deliver high-speed and precise pick-and-place operations, making it ideal for assembly lines, material handling, and packaging tasks. With its accurate positioning capabilities, the SCARA robot excels in tasks that require precise alignment, such as inserting components, soldering, and quality inspection in manufacturing processes. Additionally, its compact footprint allows it to be installed in tight spaces, making it a suitable choice for crowded manufacturing environments.

Robot's high repeatability ensures consistent quality in tasks that require repeated actions, contributing to uniformity and precision in manufacturing processes. SCARA robots provide cost-effective automation solutions for specific applications due to their design simplicity, ease of programming, and suitability for certain tasks. By employing SCARA robots, companies can reduce the need for manual labor in repetitive and hazardous tasks, leading to improved workplace safety and increased efficiency.

Moreover, these robots can work continuously and tirelessly, contributing to increased production capacity and decreased cycle times in manufacturing settings. While SCARA robots excel in certain applications, it's crucial to consider their strengths and limitations when choosing the appropriate robot type for specific automation projects.

The laser-engraved output on wood showcases an elegant and intricate design, featuring a logo along with the alphabets "C" and "A." The wood's natural texture provides a charming backdrop to the precise and detailed engravings. The logo, with its distinctive elements, is beautifully etched onto the wood surface, capturing attention with its professional and artistic appeal. The alphabets "C" and "A" stand out gracefully, displaying a perfect blend of sophistication and simplicity.

The laser engraving technique ensures sharp and clear lines, creating a visually captivating piece of art. Whether as a decorative item, a branding element, or a personalized gift, this laser-engraved woodwork effortlessly combines craftsmanship with modern technology, leaving a lasting impression on anyone who beholds its beauty.

Figure 26: Engraved output alphabet- C

Figure 27: Engraved output alphabet- A

Figure 28: Engraved output

5.2. SCARA Robot Snapshots

The successful completion of the SCARA robot results in a well-designed and optimized robotic system capable of delivering accurate and efficient performance in laser engraving or other tasks. The snapshots from the front and side views capture the robot's distinctive "L" shape, emphasizing its compactness, versatility, and potential for a wide range of industrial applications. The successful integration of the SCARA robot into automated processes marks a significant milestone in industrial automation, offering enhanced productivity and precision to various industries.

Front View Snapshot

In the front view, a successful SCARA robot appears as a compact and sleek robotic arm with a clearly defined horizontal reach. The robot consists of a vertical base or pedestal, which provides stability and support. Attached to the base is a single, long vertical arm that extends upward. At the end of this vertical arm, a horizontal arm is connected, giving the robot its characteristic "L" shape.

In the front view, you can see the horizontal arm extending forward, parallel to the surface. The horizontal arm is typically designed to have a selective compliance, allowing for precise and flexible movements along the X-axis (horizontal plane) while maintaining rigidity in the Z-direction (vertical plane). This design ensures that the robot can move swiftly and accurately when performing tasks within the XY plane.

At the end of the horizontal arm, there is an end-effector, which could be a laser engraving tool in this case. The end-effector is equipped with the necessary components, such as a laser source and focusing lens, to perform laser engraving tasks. The front view snapshot showcases the end-effector's position, ready to engrave on a designated surface.

Side View Snapshot

In the side view, the successful SCARA robot presents a distinct "L" shape, with the vertical arm rising from the base and the horizontal arm extending forward. From the side view, you can observe the arm's elevation angle, which allows it to reach a variety of heights when performing tasks within its workspace.

The side view also provides a glimpse of the robot's reach, highlighting the range of motion along the XY plane. The horizontal arm is designed to extend outward, parallel to the surface, maximizing the workspace and enabling the robot to cover a significant area for engraving or other applications. Furthermore, the side view reveals the robot's joint configuration, showcasing the articulation of the vertical and horizontal arms. The joints allow the robot to move with multiple degrees of freedom, enabling precise positioning and accurate engraving.

5.3. Conclusion

In conclusion, the successful development of the low-cost laser engraving SCARA robot marks a significant step forward in the field of robotic automation and engraving technology. Its ability to engrave alphabets and logos with exceptional precision demonstrates its potential to revolutionize the engraving industry.

As we look ahead, we envision further refinements and enhancements to the system, pushing the boundaries of what affordable automation can achieve. With such promising outcomes, we are excited about the prospects of this technology and its potential to shape a more accessible, efficient, and versatile future for laser engraving applications.

The laser-engraved woodwork showcases an elegant design with a logo and the letters "C" and "A." Its sharp and precise engravings, set against the natural texture of the wood, create a visually captivating piece of art. This blend of craftsmanship and modern technology leaves a lasting impression as a decorative item, branding element, or personalized gift.

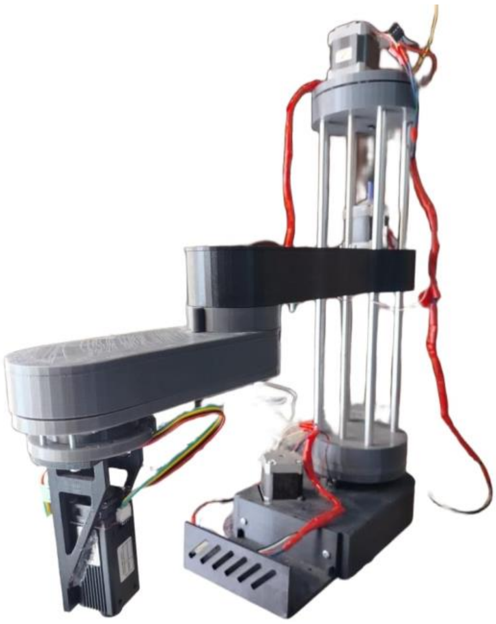


Figure 29: Front View

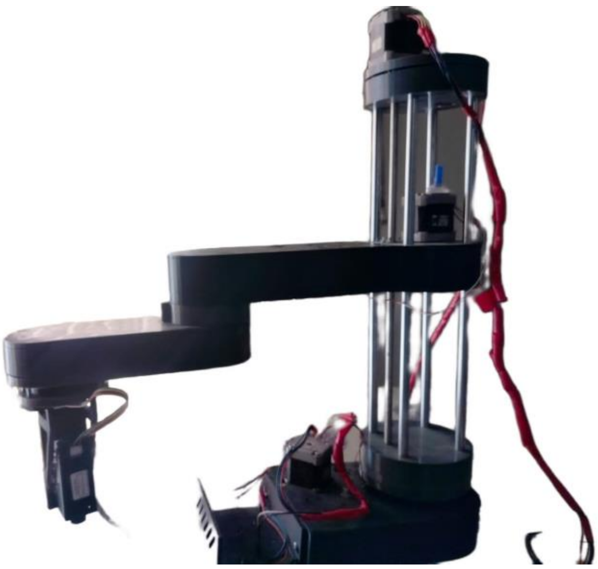


Figure 30: Side View

References

[1] KSM Sahari and Hong Weng Khor, "Design and Development of A 4-Degrees of Freedom SCARA Robot For Educational Purposes " , Article in Jurnal Teknologi- January 2011.

[2] Aliriza Kaleli,Ahmet Dumlu, M. Fatih Corapsiz and Koksal Erenturk, " Detailed Analysis of SCARA-Type Serial Manipulator on a Moving Base with LabView, Article in International Journal of Advanced Robotic Systems- 19th Feb 2013

[3] Kurt E. Clothier and Ying Shang, "A Geometric Approach for Robotic Arm Kinematics with Hardware Design, Electrical Design, and Implementation," Journal of Robotics- 18th August 2010.

[4] Bernhard Mohl and Oskar Von Stryk, "Design and Application of a 3 DEGREES OF FREEDOM Bionic Robot Arm,"-January 2005.

[5] Dr. Amar Nageshwar Rao, Jeevan ," Modelling and Analysis of Robotic Arm using Ansys ", International Journal Of Scientific Engineering and Technology Research, Vol.04,Issue.33, August2015.

[6] R. Jagan , P.Rana Singh , CH .Ashirvadam , K .Navitha "Auto & Manual Control of Robotic Arm Using PLC", Vol. 6, Issue 8, August 2017.

[7] Ali Medjebouri and Lamine Mehennaoui, "Active Disturbance Rejection Control of a SCARA Robot Arm" Vol.8, No.1 (2015)

[8] Ashly Baby, Chinnu Augustine, Chinnu Thampi, Maria George, Abhilash A P, Philip C Jose "Pick and Place Robotic Arm Implementation Using Arduino" Volume 12, Issue 2 Ver. III(Mar. – Apr. 2017).

[9] Anusha Ronanki, M. Kranthi "Design and Fabrication of Pick and Place Robot to be used in Library" Vol. 4, Issue 6, June 2015.

[10] Rahul Gautam, Ankush Gedam, Ashish Zade, Ajay Mahawadiwar, "Review on Development of Industrial Robotic Arm" Volume: 04 Issue: 03 | Mar -2017.

[11] Abdellatif Baba "ROBOT ARM CONTROL WITH ARDUINO" Technical Report · June 2017.

[12] K. Phasale, P. Kumar, A. Raut, R. R. Singh, A. Nichat, "Design, Manufacturing and Analysis of Robotic Arm with SCARA Configuration" International Research Journal of Engineering and Technology Vol. 05(04) Apr. 2018, pp. 82-85

[13] www.ques10.com. (n.d.). Classify robots based on work envelope geometries. [online] Available at: https://www.ques10.com/p/68426/classify-robots-based-on-work-envelope-geometrie-1/ [Accessed 2 Aug. 2023].

[14] Thorat, S. (n.d.). Robotics | Introduction and classification of robotics. [online] Available at: https://learnmech.com/robotics-introduction-and-classification/.

[15] https://www.facebook.com/BrainKart-678754188988648 (n.d.). Robot Classification. [online] BrainKart. Available at: https://www.brainkart.com/article/Robot-Classification_5121/ [Accessed 2 Aug. 2023].

[16] Mihai, D. (2012). Standards and Classifications of Industrial Robots - Smashing Robotics. [online] Smashing Robotics. Available at: https://www.smashingrobotics.com/standards-and-classifications-of-industrial-robots/.

[17] Scribd. (n.d.). Classification of Robots: By: Shyamji Tiwari | PDF | Actuator | Robot. [online] Available at: https://www.scribd.com/presentation/106130828/Robot-Classification# [Accessed 2 Aug. 2023].

[18] Anusha (2018). Types of Robots. [online] Electronics Hub. Available at: https://www.electronicshub.org/types-of-robots/.

[19] www.skedsoft.com. (n.d.). Robot Classification. [online] Available at: https://www.skedsoft.com/books/mechatronics/robot-classification [Accessed 2 Aug. 2023].

[20] Mecharithm. (n.d.). Everything About the Degrees of Freedom of a Robot. [online] Available at: https://mecharithm.com/learning/lesson/degrees-of-freedom-of-a-robot-104 [Accessed 2 Aug. 2023].

Appendix

→ **Following is the Arduino Code for Calculating Inverse Kinematics:**

```
void forwardKinematics() {
  // Convert joint angles theta1 and theta2 from degrees to radians
  float theta1_radians = theta1 * PI / 180;
  float theta2_radians = theta2 * PI / 180;
// Calculate the xP and yP coordinates of the end effector
  // using forward kinematics equations for a 2-link SCARA robot
  xP = round(L1 * cos(theta1_radians) + L2 * cos(theta1_radians + theta2_radians));
  yP = round(L1 * sin(theta1_radians) + L2 * sin(theta1_radians + theta2_radians));
}
```

Code language: Arduino

→ **Following is the Arduino Code for Calculating 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;
 // Angles adjustment depending in which quadrant the final tool coordinate
x,y is
  if (x >= 0 & y >= 0) {       // 1st quadrant
    theta1 = 90 - theta1;
  }
  if (x < 0 & y > 0) {       // 2nd quadrant
    theta1 = 90 - theta1;
  }
  if (x < 0 & y < 0) {       // 3d quadrant
    theta1 = 270 - theta1;
    phi = 270 - theta1 - theta2;
    phi = (-1) * phi;
  }
```

```
 if (x > 0 & y < 0) {      // 4th quadrant
   theta1 = -90 - theta1;
 }
 if (x < 0 & y == 0) {
   theta1 = 270 + theta1;
 }
 // Calculate "phi" angle so gripper is parallel to the X axis
 phi = 90 + theta1 + theta2;
 phi = (-1) * phi;
 // Angle adjustment depending in which quadrant the final tool coordinate
x,y is
 if (x < 0 & y < 0) {      // 3d quadrant
   phi = 270 - theta1 - theta2;
 }
 if (abs(phi) > 165) {
   phi = 180 + phi;
 }
theta1=round(theta1);
theta2=round(theta2);
 phi=round(phi);
 cp5.getController("j1Slider").setValue(theta1);
 cp5.getController("j2Slider").setValue(theta2);
 cp5.getController("j3Slider").setValue(phi);
 cp5.getController("zSlider").setValue(zP);
}
```

Code language: Arduino

→ **Following is the Arduino Code for GUI:**

```
if (gripperValuePrevious != gripperValue) {
   if (activeIK == false) {
// Check whether the inverseKinematics mode is active, Executre Forward
kinematics only if inverseKinematics mode is off or false
     gripperAdd = round(cp5.getController("gripperValue").getValue());
     gripperValue=gripperAdd+50;
     updateData();
     println(data);
     myPort.write(data);
   }
 }
```

Code language: Arduino (arduino)

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.

```
public void updateData() {
  data = str(saveStatus)
    +","+str(runStatus)
    +","+str(round(cp5.getController("j1Slider").getValue()))
    +","+str(round(cp5.getController("j2Slider").getValue()))
    +","+str(round(cp5.getController("j3Slider").getValue()))
    +","+str(round(cp5.getController("zSlider").getValue()))
    +","+str(gripperValue)
    +","+str(speedSlider)
    +","+str(accelerationSlider);
}
```

Code language: Arduino

All this data comes as one long String at the Arduino. So here, first we need to extract the data from that string and put it into separate variables.

```
if (Serial.available()) {
    content = Serial.readString(); // Read the incomding data from Processing
    // Extract the data from the string and put into separate integer variables
(data[] array)
    for (int i = 0; i < 10; i++) {
      int index = content.indexOf(",");
// locate the first ","
      data[i] = atol(content.substring(0, index).c_str());
//Extract the number from start to the ","
      content = content.substring(index + 1);
//Remove the number from the string
    }
    /*
     data[0] - SAVE button status
     data[1] - RUN button status
     data[2] - Joint 1 angle
     data[3] - Joint 2 angle
     data[4] - Joint 3 angle
     data[5] - Z position
     data[6] - Gripper value
     data[7] - Speed value
     data[8] - Acceleration value
    */
```

Code language: Arduino

Now with these variables we can take actions with the robot. For example, if we press the SAVE button, we store the current joint angles values in a separate array.

```
// If SAVE button is pressed, store the data into the appropriate arrays
  if (data[0] == 1) {
    theta1Array[positionsCounter] = data[2] * theta1AngleToSteps; //store
the values in steps = angles * angleToSteps variable
    theta2Array[positionsCounter] = data[3] * theta2AngleToSteps;
    phiArray[positionsCounter] = data[4] * phiAngleToSteps;
    zArray[positionsCounter] = data[5] * zDistanceToSteps;
    gripperArray[positionsCounter] = data[6];
    positionsCounter++;
  }
```

Code language: Arduino

If we click the RUN button, we execute the stored steps and so on.
For controlling the stepper motors, we used the AccelStepper library. 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.

```
stepper1.moveTo(stepper1Position);
 stepper2.moveTo(stepper2Position);
 stepper3.moveTo(stepper3Position);
 stepper4.moveTo(stepper4Position);

 while (stepper1.currentPosition() != stepper1Position ||
stepper2.currentPosition() != stepper2Position || stepper3.currentPosition()
!= stepper3Position || stepper4.currentPosition() != stepper4Position)
 {
  stepper1.run();
  step          per2.run();
  stepper3.run();
  stepper4.run();  }
```