Design and Develop a Robot Arm to Automatically Feed Workpieces for Laser Engraving Machines

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This study presents the design, development, and experimental evaluation of a 4-DOF SCARA robotic arm, integrated with a programmable logic controller (PLC) and stepper motors, for automating workpiece handling in laser engraving processes. The system enhances both safety and efficiency by autonomously managing the grasping, placement, and retrieval of workpieces, thereby reducing human exposure to laser hazards. The robotic arm, equipped with dual vacuum suction heads, enables precise "pick and place" operations by loading new workpieces and removing finished products simultaneously. This dual-action design minimizes cycle time by allowing continuous handling throughout the engraving process. Powered by stepper motors controlled via a PLC, the robotic arm achieves high precision in motion, allowing for accurate alignment of each workpiece. Experimental results demonstrate the system's capability to maintain consistent product quality and uniformity, even with the complex demands of grasping and aligning workpieces. This automated solution represents an efficient and reliable alternative to manual operations, addressing industry needs for precision, safety, and productivity in repetitive laser-based manufacturing environments.

Keywords: *SCARA robot, laser engraving machine, automatic feeding, Programing logic controller.*

1. INTRODUCTION

In modern industrial contexts, laser engraving has emerged as a leading method for precision marking and embellishment of product patterns, representing an effective and widely adopted technique [1-3]. The industry's substantial reliance on laser engraving is underscored by the expansive array of products necessitating intricate engraving processes, thereby engendering a high demand and subsequent operational intensification. This surge in operational throughput, characterized by a heightened density and repetition, contributes to an environment replete with potential risks that pose threats to operator safety. Notably, prolonged exposure to continuous and repetitive working conditions can reduce operator alertness, increasing the risk of accidents during laser engraving machine operations. Foremost among these hazards is the pronounced risk posed by laser rays, which can cause thermal burns upon human exposure [4]. Furthermore, protracted exposure to the luminosity emitted during the engraving process presents a notable risk to visual acuity over extended durations, contributing to the potential deterioration of the operator's ocular function [5,6]. This critical examination of the risks associated with laser engraving operations underscores the imperative for further research and the implementation of safety measures to mitigate potential hazards and ensure the well-being of operators in industrial settings. After the research process, to solve the safety issue for operators as well as improve production productivity, applying an automatic workpiece feeding system is necessary.

The automated workpiece feeding system plays a critical role in the autonomous storage, organization, and delivery of materials for subsequent production processes. This system eliminates the need for human intervention, thereby mitigating associated risks. Initially conceptualized as the utilization of a conveyor belt, as exemplified in [7], this system orchestrates the movement and delivery of bars to the production unit seamlessly. Additionally, innovative configurations, such as those detailed in [8], involve transporting materials from a silo to a conveyor belt coupled with a cylinder mechanism facilitating material positioning for a robot arm. Beyond conventional conveyor or cylinder-based systems, robotic arms have emerged as versatile contenders for automatic bar feeding. The evolution of robotic arm technology, from the 1960s to the present [9-11], has endowed them with attributes such as rapid working speeds, high precision, and adept Pick and Place capabilities, enabling efficient relocation of workpieces from material areas to later production units [12-14].

In [15], a 5-DOF robot arm was designed to automatically load and unload workpieces for the lathe machine. The robot consists of one translational motion in vertical and three rotational motions. A rotating gripper is designed to feed and eject workpieces into and out of the lathe machine. Similar ideas were developed in studies [16] and [17]. These papers designed, simulated,

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and manufactured 4-DOF robot arms to load and unload workpieces for machine tools. Exemplifying this trend, [18] engineered a workstation utilizing a 6-axis robot arm UR10 to automatically supply workpieces to MD laser engraving machines -X1000C, while [19] employed a 60 kg heated bar feeding robot arm to transport bars from a furnace to a press, covering a travel distance of 2.5 meters. A review of pertinent literature highlights the pivotal role of automated bar-feeding systems in industrial production, particularly the escalating integration of robotic arms, aligning with the prevailing trend of increased robotic applications in industrial production ecosystems.

While recent studies have made notable advancements in automating workpiece handling for industrial applications, several limitations remain. Many existing systems rely on pre-built robotic arms that, while effective, are often costly and may not provide the flexibility required for specific, repetitive tasks. These commercially available solutions are frequently constrained in design adaptability, making them challenging to customize for unique operational needs. Furthermore, conventional systems typically perform loading and unloading tasks sequentially, resulting in extended cycle times and limiting throughput.

In contrast, our study presents a custom-designed SCARA robotic arm that addresses these deficiencies by focusing on cost-effectiveness and efficiency. Using programmable logic controllers (PLCs) and stepper motors, our solution provides precise, synchronized motion control while remaining accessible for small to medium-sized enterprises. The dual vacuum suction heads allow for simultaneous "pick and place" operations, significantly reducing cycle time and aligning the workpiece handling speed with the laser engraving process. This approach demonstrates a novel way to achieve high-precision, flexible automation without the need for expensive commercial robotic systems, bridging the gap identified in previous studies.

The system designed in this study consists of a SCARA robot arm to grasp workpieces and place them on a laser graving machine. The laser machine conducts the process of graving on the workpiece. At the same time, the robot moves to the workpiece holder to take another workpiece. The end-effector of the robot arm consists of two grippers. The workpiece is attached to the first gripper. When the laser machine completes the graving process, the robot grasps the finished product by using the second gripper and de-attaches the workpiece at the first gripper to place it on the laser machine. Then, the robot moves the finished part to the finished product region and returns to the workpiece holder to take another workpiece. The process is repeated until all workpiece holders' workpieces have been machined.

The mechanical and electrical design of the SCARA robot arm is presented in detail in Section 2. The practical system and experimental results are pre–sented in Section 3. Finally, Section 4 is the conclusion and future works.

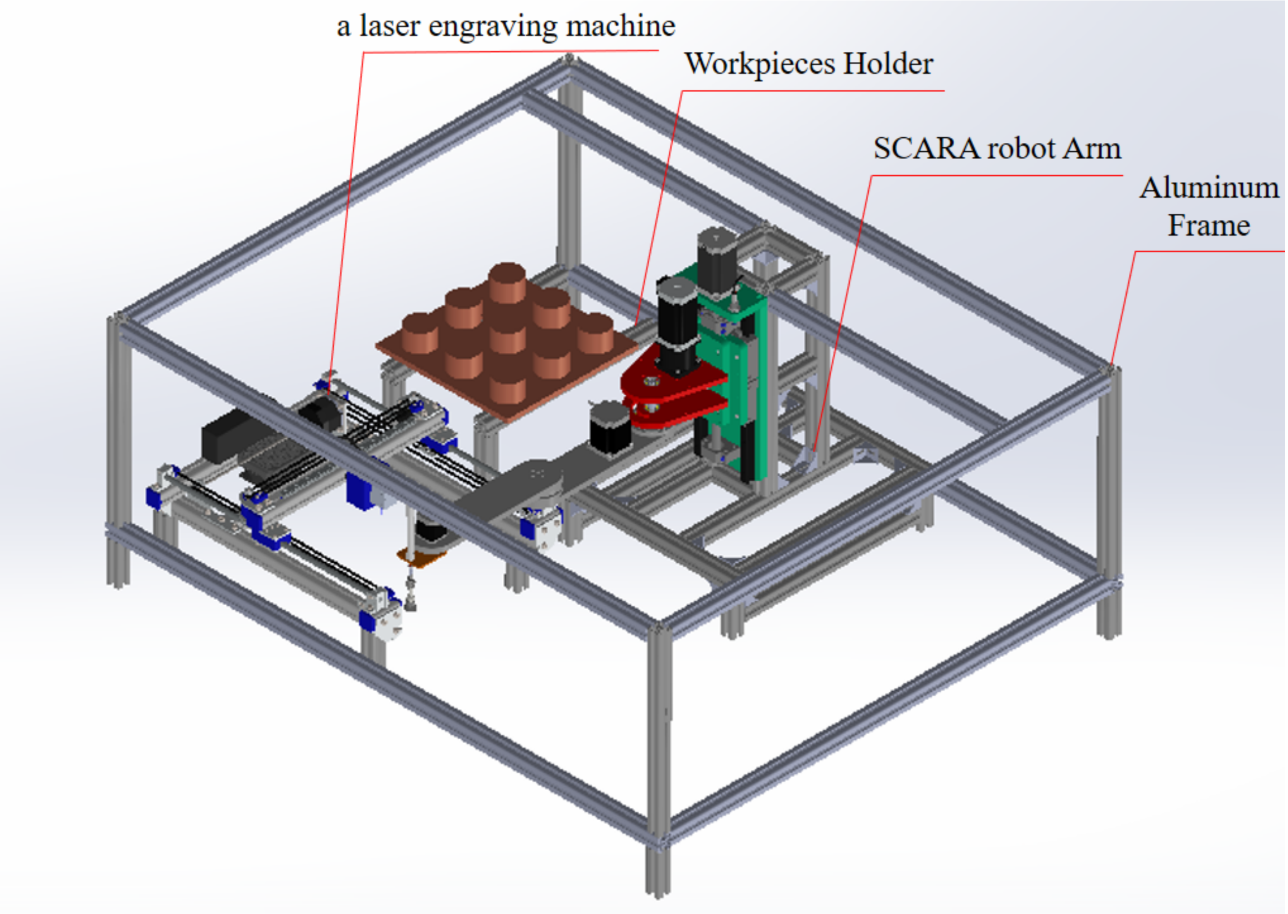

Figure 1. 3D model on Solidworks software.

2.

2. MATERIAL AND METHOD TO DESIGN THE SYSTEM

This article presents the development of a system using the SCARA robot arm to automatically feed workpieces to laser engraving machines. The system is designed using Solidworks software, as shown in Figure 1. The system includes an aluminum frame used to fix the robot arm, a workpiece holder where the workpiece needs to be laser engraved, a four-degree-of-freedom SCARA robot arm used to automatically feed workpieces to the laser engraving machine, and a laser engraving machine.

2.1 Mechanical design of SCARA robot arm

Figure 2 presents the design of the SCARA robot arm. The robot consists of three rotation joints to move the end-effector in the horizontal plane. Its maximum reach is 560mm. Stepper motors are selected to provide precise movement. The end-effector of the robot attaches two pneumatic cylinders along with vacuum suction cups for grasping objects.

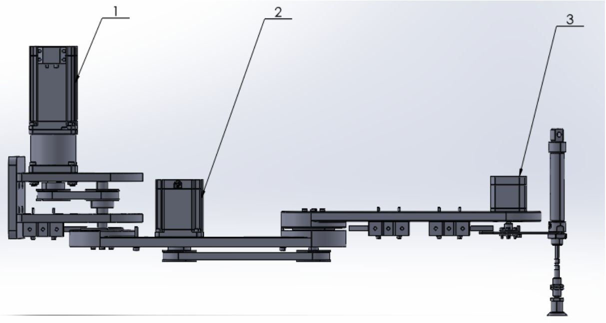

Figure 2. 3D Arm assembly.

The first joint and base configuration of the robot is shown in Figure 3. Three 10mm-thick aluminum plates are used to assemble other components such as motors, bearings, shafts, etc. The steel shaft, with a diameter of 8mm and a length of 100mm, establishes the connection between the first joint and the first link through a flange joint. The extremities of this steel shaft are affixed with two ball bearings strategically positioned to stabilize the shaft while facilitating its movement when actuated. Along with circular ball bearings, cylindrical ball bearings are also installed with the shaft and are located in the joint between the two links. A NEMA 23 motor provides the motive torque for the first joint. A Planetary Gearbox is integrated with the motor to mitigate the impact of torque on the motor's shaft, especially considering that the first joint bears the load of the subsequent joints. This gearbox serves to limit the torque affecting the motor's shaft, which can be considerable given the load-bearing nature of the first joint. A timing belt transmission is incorporated into the system to transmit motion from the motor's shaft to the steel shaft. This arrangement is pivotal in maintaining the safety of the motor, particularly when subjected to potential overloading conditions. By effectively distributing the load and managing torque, the belt transmission acts as a protective mechanism to ensure the stable and secure operation of the NEMA 23 motor within the context of the first joint of the robotic arm.

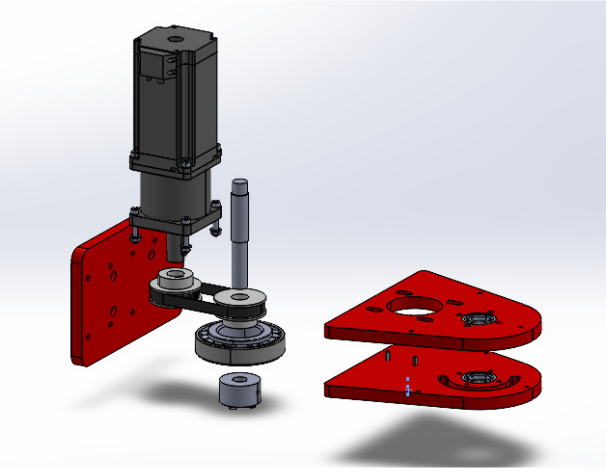

Figure 3. The First Joint Configuration.

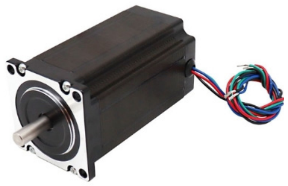

Figure 4. Stepper motor NEMA 23.

The NEMA 23 motor employed in the first joint is the Leads stepper motor model HS57-54-1M (Figure 4). Noteworthy specifications of this motor include an 8 mm shaft diameter, a torque capacity of up to 2.2 Nm, and a maximum rotation speed reaching 2000 RPM. These characteristics highlight the motor's suitability for precision operations, rendering it well-suited for applications in robot arm systems. The toothed belt transmission serves as a mechanism for transmitting motion between two parallel shafts, ensuring motion in the same direction. This system incorporates two pulleys installed on the drive shaft and a toothed belt. When the tension belt is engaged, the teeth on the belt mesh with the grooves on the pulley, resulting in the movement of one shaft driving the other. Specifically, in the toothed belt transmission utilized for the first joint, two Timing Pulleys HTD 5M with 40 teethes, featuring an outer diameter of 42mm and an inner diameter of 8mm, are securely fixed on the shaft using M3 bolts. The transmission system is complemented by an M5 belt with a length of 110mm, contributing to the effective transfer of motion within the joint.

a. Ball bearing **b. cylindrical bearing**

Figure 5. Ball bearing SKF 6001 and cylindrical bearing.

The integral round ball bearings utilized in the system are identified as the 6001 round ball bearings. These bearings play a critical role in converting sliding friction into rolling friction, thereby mitigating friction between moving parts that support the rotating shaft. The SKF 6001 rolling bearing (Figure 5. a), selected for this purpose, is specified with technical parameters detailed in Table 1. The adoption of these ball bearings contributes to the efficiency of the system by facilitating smoother movements and reducing frictional resistance along the rotating shaft, ultimately enhancing the overall performance and longevity of the mechanical components within the system. In the context of a long, straight robot arm, the axial force tends to amplify towards the arm's end, potentially impacting operational efficiency. To address this concern, cylindrical ball bearings (Figure 5. b) are employed at the second joint to support the steel shaft. Distinguished from conventional round ball bearings, cylindrical ball bearings exhibit enhanced capabilities to withstand high-speed operation and substantial axial forces. The specific cylindrical roller bearing integrated into the model is the SKF 30207 cylindrical roller bearing; its parameters are detailed in Table 2.

Table 1. Dimension of the SKF 6001 rolling bearing

Dimensions	**Value**
Bore diameter	12mm
Outside diameter	28mm
Width	8mm

Table 2. Dimension of the SKF 30207 cylindrical roller bearing

Dimensions	Value
Bore diameter	35mm
Outside diameter	72mm
Width, total	18,25mm
Width, inner ring	17mm
Width, outer ring	15mm

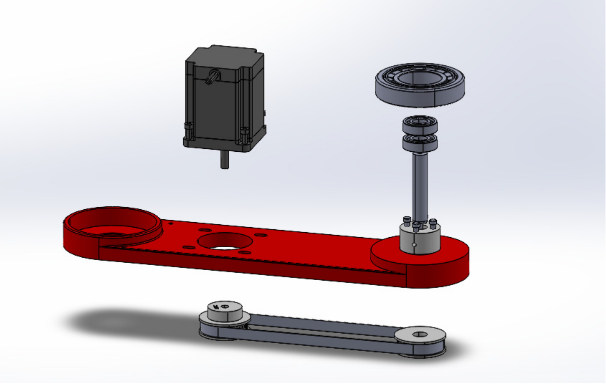

Figure 6. The Second joint design.

The first link is designed in the form of an aluminum plate 260mm long and 10mm thick. This link is used to fix the motor and transmission drive for the second joint. Unlike the first joint, the second joint is propelled by a NEMA 23 motor without the intermediary of a gearbox, positioned close to the first joint to minimize the bending moment and inertial torque on the arm and uphold stability during operation. The motor imparts motion to the steel shaft through a toothed belt transmission, adhering to the same specifications as the motor and maintaining uniformity with the first joint's transmission system, differing only in the length of the M5 belt, which is 400mm for the second joint. A limit switch, integrated into the lower surface of the aluminum plate, ensures precise control over the joint's travel, contributing to the comprehensive and efficient operation of the second joint within the robotic arm system. The components that make up the second joint are similar to the first joint, the only difference being the mounting position on the steel shaft. Figure 6 details the design of the first and the second joint.

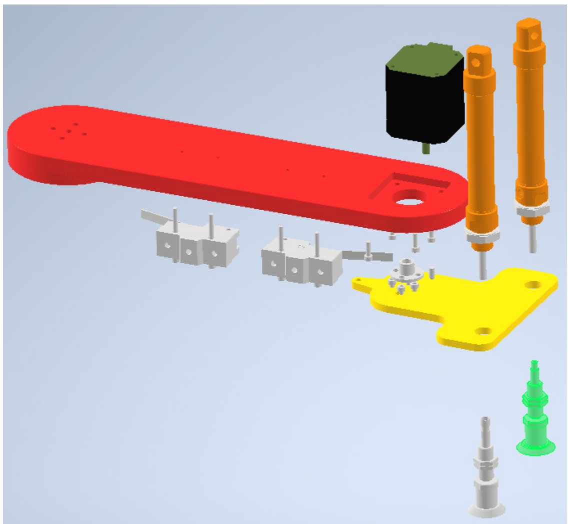

Figure 7. The Third Joint Design.

Figure 7 is the design of the second and third links. The second link is constructed from the same aluminum sheet as the first link and spans a length of 240mm. The first end of the second link is assembled with the shaft of the second joint. The remainder is mounted with a stepper motor to rotate the third joint. The stepper motor shaft is directly mounted with a 60mm long swing arm (the third link). This arm houses the cylinder and vacuum at the end to grasp objects. In this configuration, an NEMA 17 motor is employed to drive the swing arm directly and is positioned at the aluminum plate's end. Similar to the first joint, two limit switches are situated at the bottom of the aluminum plate, serving the crucial role of controlling the travel of the joints.

Figure 8. Stepper motor NEMA 17.

Table 3

Specifications	**Value**
Current	2A
Step Angle	1.8 degree
Holding Torque	59Ncm
Phase	2

The decision to transition to a NEMA 17 motor, model 17HS8401 (Figure 8), with technical specifications shown in Table 3, is prompted by the lightweight nature of the swing arm structure, comprised of cylinders and vacuums. This motor substitution aims to optimize costs and alleviate the load borne by the preceding joints. The robot's end-effector assembles two pneumatic cylinders and vacuum suction cups to grasp workpieces. Using two suction heads helps take finished products from the laser engraving machine and insert workpieces at the same time, optimizing workpiece feeding time.

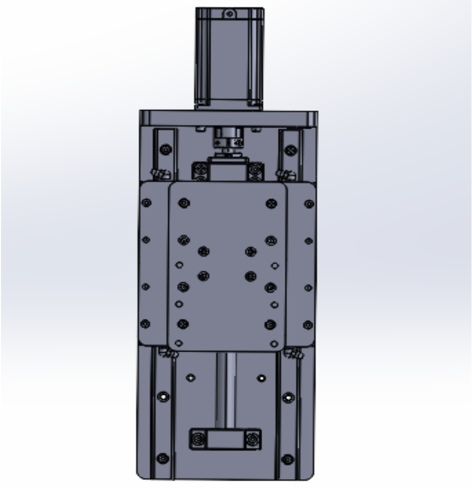

Figure 9. 3D Screw assembly.

To extend the Z-axis travel distance of the end-effector, the robot arm is equipped with a screw transmission, as shown in Figure 9. This assembly comprises a screw shaft to transform rotational motion to translational motion and two linear guide sliders for guidance. The rotational motion is derived from a NEMA 23 motor, which has the same configuration as the motor employed in the first joint. To effectively transmit motion from the motor shaft to the screw, a shaft coupling is employed to establish a secure connection between the two shafts.

2.2 Electronic system design

The operational effectiveness of a robotic arm is contingent upon the integration of an essential electrical system. The electrical system's role is to create electrical signals to control the motor to move accurately based on signals from sensors and requests received from other control devices through communication standards. A schematic overview of the electrical system is presented in Figure 10. In this project, the electrical system is designed to control the motion of four stepper motors, control four pneumatic valves, and read signals from the limit switches.

A programmable logic controller (PLC) functions as a device enabling the programming of logic control algorithms. It receives external information through inputs and regulates devices via outputs. Utilizing ladder language, users can easily program the PLC. The flexibility of PLC programs allows adaptation to business requirements and promotes reusability. During operation, a PLC facilitates system control without the need for replacement. In addition to programming and control signal provision, PLC integrates timers and counters for comprehensive control functionality. The widespread applicability of PLC in industrial settings helps reduce costs and possesses a broad impact on system operations.

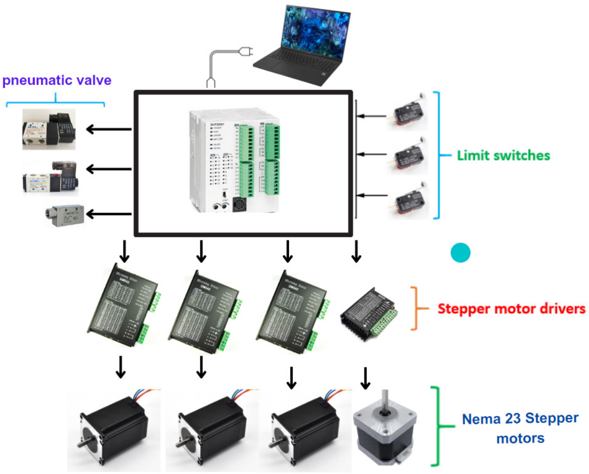

Figure 10. Components in the electrical system.

The system employs a Delta PLC DVP 28SV11T2 (Figure 11). PLC Delta is preferred due to its cost-effectiveness, making it suitable for model applications. The DVP28SV11T2 model features up to 16 inputs and 11 outputs, along with four high-speed pulse output pins ideal for controlling four stepper motors of the robot arm. In the system, the PLC functions as the control center, outputs signal to command both motor drives and pneumatic valves and reads signals from the limit switch.

Figure 11. PLC Delta DVP28SV11T2

a. DM542 drive **b. TB6600 drive**

Figure 12. Stepper motor drives

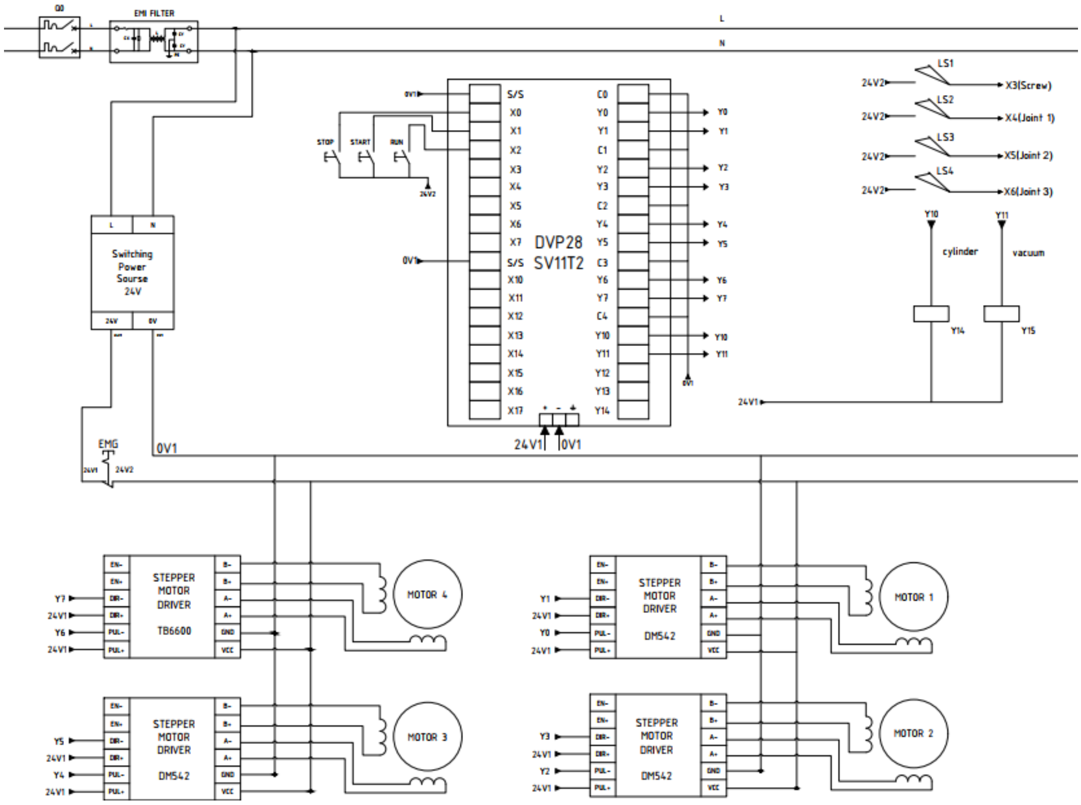

Figure 13. Electrical wiring diagram.

The pulse signal from the PLC is sent to motor drives to control stepper motors. The system employs three DM542 motor drives for the NEMA 23 motors, along with one TB6600 motor drive for the NEMA 17 motor. The primary function of these motor drives is to convert the received pulses from the PLC into the requisite voltage for motor control. Additionally, they offer the capability to adjust the motor's rotation mode and current intensity. As shown in Figure 12. a, the DM542 can adjust 15 different micro-step modes with a maximum micro-step of 25600 pulse/revolution. The current provided for the motor can adjust from 1.0 A to 4.2A. Meanwhile, the TB6600 drive can only adjust 8 different micro-step modes with a maximum micro-step of 6400 pulse/revolution (Figure 12. b). The maximum current for the motors is 3.5A. The power supply is from 9-42VDC.

Simultaneously, the PLC governs the pneumatic valve operation by providing a digital signal to the solenoid coil, effecting a change in the valve's state. The pneumatic valve configuration in the model includes a 3/2 pneumatic valve and a mono-stable 5/2 pneumatic valve, contributing to the versatility and control of the pneumatic system within the overall setup.

The wiring diagram and electrical components are utilized in Figure 13. Beyond the Programmable Logic Controller (PLC) and motor drives, the system incorporates additional devices, including a Circuit Breaker (CB), power noise filter, power supply, start/stop buttons, and emergency stop button. The CB functions as a protective device for the system's operation and is serially connected to the power noise filter. The power noise filter, in turn, reduces current noise and enhances power supply stability. The power supply transforms 220V AC into a 24V DC. These electrical components are interconnected to form a comprehensive and integrated system. Further insights into the wiring of these electrical devices are detailed in the subsequent paragraphs.

For PLC, the 24V pin from the power supply will be connected to the + pin of the PLC, the 0V pin from the power filter will be connected to the S/S pins, four common pins (C1, C2, C3, C4) on the PLC. Inputs X0, X1, and X2 of the PLC are connected to the push buttons, and inputs X4, X5, X6, and X7 are connected to the signal input of the limit switch. The four high-speed pulse outputs Y0, Y2, Y4, and Y6, are connected to the pulse pin on the motor drive, and Y1, Y3, Y5, and Y7 are connected to the direction (DIR) pin of the drive motor, Y10 and Y11 pins of the PLC is connected with solenoids of pneumatic valves. For Motor drives, pins (A^+, A^-, B^+, B^-) are connected to the pole pairs of the motor. The GND pin of the motor drive is connected to the 0V pin, and the VCC pin is connected to the system's 24 V pin.

2.3 Laser engraving machine

Figure 14 illustrates the design of the CNC laser engraving machine. The machine uses a 500mW near-infrared Laser Diode Module Focusing Head. The laser head is driven in X and Y directions by stepper motors and GT2 timing belt drives. The robust frame of the laser engraving machine is crafted from extruded aluminum profile, featuring 20mm square edges, ensuring structural stability.

The electronic diagram for the laser machine, shown in Figure 15, uses the CNC Shield V4 board to connect devices. The Arduino Nano is the central control unit of the system. It assumes the pivotal role of generating control signals for the connected devices within the circuit. In the system model, three NEMA 17 motors are employed to drive the laser engraving machine header in both the X and Y directions. Specifically, a motor provides motion in the X direction, while the two others provide motion in the Y direction. The motion stepper motor is controlled by two A4998 motor drivers.

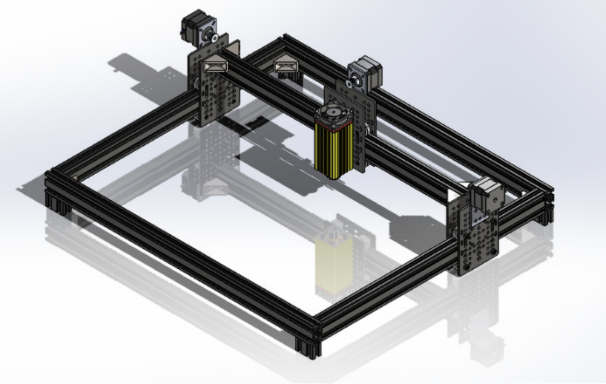

Figure 14. Laser engraving machine design.

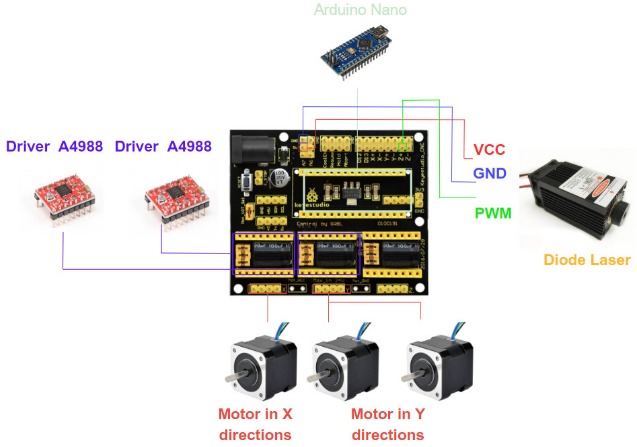

Figure 15. Laser engraving electronic system.

After completing the Arduino programming, the laser engraving machine can be operated through specialized software. There are several options available, such as Benbox, LightBurn, and GRBL Controller, but LaserGRBL software is used in this model. The software provides a user-friendly interface with functions including motor control in the X and Y directions and the ability to set an origin point for the engraver. To start engraving, users simply upload the desired pattern and press start, and the machine will perform the engraving according to the specified pattern. Laser GRBL's intuitive design streamlines the engraving process, making it accessible and efficient.

3. EXPERIMENTAL RESULTS

Figure 17 depicts the operating sequence of the robot arm. When powered on, the robot moves to the home position by rotating all joints to reach the limit switches. Then, the robot moves to the workpiece holder to pick a workpiece and bring it to a waiting position near the laser engraving machine. The robot will wait until the engraving process finishes. The laser machine sends a signal to the robot controller to announce that the workpiece has been completely engraved. Then, the robot moves to the laser machine to take out the finished product and take in the new workpiece. Finally, the robot brings the finished product out of the machine to the finished product zone. To continuously process, the robot returns to the workpiece holder to pick up another workpiece. The process will be repeated until all workpieces have been engraved and the robot returns to its home position.

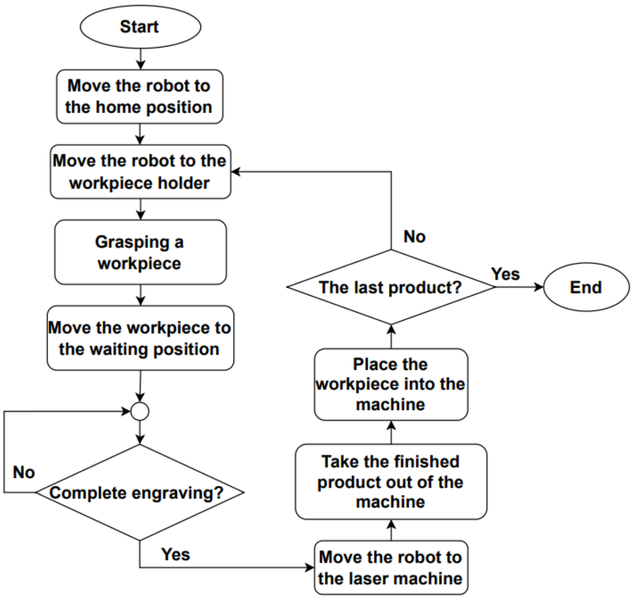

Figure 17. The operation sequence of the robot arm

An experimental model has been built to perform the automatic workpiece feeding process for the engraving machine, as shown in Figure 18. The setup consisted of a workpiece holder where stacks of circular workpieces, each with a radius of 20 mm, were arranged in a 3x3 grid. A total of 90 workpieces were divided into stacks of 10 in each position, allowing the robot to operate continuously for extended periods without manual reloading. The SCARA robot was programmed to follow a specific operation sequence, starting from a home position to precisely locate and grasp workpieces in the holder. The dual vacuum suction heads played a crucial role in optimizing the process by allowing the robot to pick a new workpiece and place it on the laser engraving machine while simultaneously removing the finished product. This dual-action capability minimizes the idle time between engraving cycles, enabling continuous operation.

The PLC controls the motion of the stepper motors, which provide precise rotational and linear movements. This setup allows the robotic arm to position each workpiece accurately. The stepper motors were configured to move the robot arm with high repeatability, ensuring that each grasp and placement action was within tight tolerances to maintain alignment with the laser engraving machine.

Figure 19 shows some the finish products conducted by the system. It can be seen that the product has high uniformity. The image is properly aligned with the circle's centroid. With the design of using 2 different vacuum heads for loading and unloading the workpiece at the same time, the workpiece feeding process is shortened. While the machine is performing laser engraving, the robot is also performing the workpiece picking. Therefore, the time to complete a process is equal to the laser engraving time.

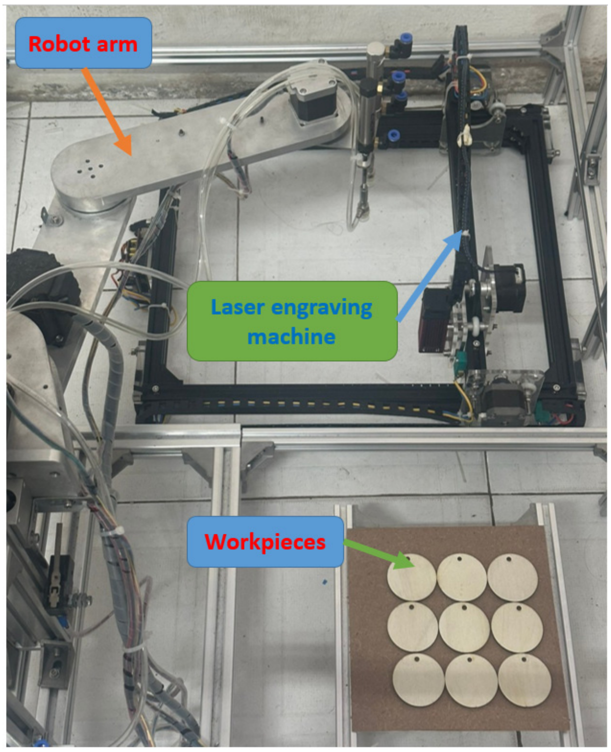

Figure 18. The experimental model to perform the automatic workpiece feeding process for the engraving machine.

The experimental results underscore the robotic arm's effectiveness in managing complex, repetitive tasks required in the automatic feeding process. Throughout the experiment, the robotic arm successfully handled 90 workpieces, demonstrating high precision in both loading and unloading operations. The robot was capable of consistently aligning each workpiece on the laser machine, maintaining uniformity in the finished products. Observations confirmed that each engraved workpiece was centered accurately, with minimal deviation from the ideal position.

The use of dual vacuum suction heads not only shortened the cycle time but also enhanced productivity by allowing simultaneous operations. While the laser machine was engaged in engraving, the robotic arm was able to retrieve the next workpiece from the holder, ensuring seamless transitions between cycles. This design allowed the processing time to be dictated primarily by the engraving speed of the laser machine, as the robotic arm's handling speed exceeded that requirement, thereby removing bottlenecks in the workflow.

Moreover, this automated system significantly improved safety by reducing human exposure to laser hazards and the physical strain associated with manual handling. The SCARA robotic arm operated without error or need for human intervention during the entire test cycle, highlighting its reliability and robustness in industrial settings.

The experimental results suggest that the system is well-suited for applications that require high-precision, repetitive handling tasks, particularly in environments where safety and productivity are critical. The successful implementation of the automatic workpiece feeding process demonstrates the potential of this robotic arm to streamline laser engraving workflows, with promising implications for broader use in automated manufacturing environments.

Figure 19. The finished productions.

4. CONCLUSIONS

This study successfully developed a 4-DOF SCARA robotic arm, integrated with a programmable logic controller (PLC) and stepper motors, to automate the workpiece feeding process for a laser engraving machine. The experimental model was designed specifically to address the complexities of automatic workpiece feeding, focusing on precise and efficient grasping, positioning, and retrieval of finished products. The dual vacuum suction heads on the robotic arm allowed for simultaneous loading of new workpieces and unloading of finished products, minimizing cycle time and maximizing efficiency. Through the integration of programmable logic controllers (PLCs) and stepper motors, the system achieves precise, synchronized motion control, proving to be a viable solution for small to medium-sized enterprises seeking automation without the high costs associated with commercial robotic arms.

The experimental results demonstrated the system's ability to handle 90 workpieces with high precision and consistency, accurately aligning each workpiece during the engraving process. The dual-action design enabled seamless "pick and place" operations, ensuring a continuous workflow by preparing the next workpiece while the laser machine was engaged. This approach optimized the process time to match the laser engraving speed, eliminating bottlenecks and enhancing productivity.

In practical terms, this automated workpiece feeding system enhances productivity by seamlessly synchronizing with the engraving process, reducing manual labor requirements, and promoting a safer work environment by eliminating the need for operator involvement in hazardous laser areas. These results highlight the potential of this system to improve efficiency and safety in precision-driven manufacturing settings, with broader applications across various industrial domains where repetitive handling tasks are essential.

For future work, this study aims to integrate computer vision technology to automate the detection and localization of workpieces, reducing the need for initial manual setup. By using deep learning models for object recognition and positioning, the system could automatically adjust its grasping and alignment processes, further enhancing productivity and operational flexibility. Additionally, the system could more readily adapt to workpieces of various sizes and shapes, expanding its potential applications across different automated manufacturing environments.

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REFERENCES

[1] P. Jamaleswara Kumar, A. Siva Sai Tarun, M. Gowtham, P. Thamma Rao, G. Yashwanth: Design and fabrication of portable laser cutting and engraving machine, International Journal of Engineering & Technology, Vol. 7, No. 11, 2018.

[2] Mohammad, N.K., Ambuj, M., Ambuj M., Himanshu, V.: Study and Design of Arduino Based CNC Laser Cutting Machine, IOP Conference Series: Materials Science and Engineering, 2022.

[3] Kumar, S.G. et al.: CNC Machine Based Laser Engraver with Arduino UNO, International Journal of Scientific Research and Engineering Development, Vol. 4, No. 2, 2021.

[4] Smalley, P.J.: Laser safety: Risks, hazards, and control measures, Laser Ther., Vol. 20, No. 2, pp. 95-106, 2011.

[5] Glover C, Richer V.: Preventing Eye Injuries From Light and Laser-Based Dermatologic Procedures: A Practical Review, J Cutan Med Surg, Vol. 27, No. 5, pp. 509-515, 2023.

[6] Khalifian S., Vazirnia A., Mohan GC., Thompson KV., Jalian HR., Avram MM.: Causes of injury and litigation in cutaneous laser surgery: an update from 2012 to 2020, Dermatol Surg., Vol. 48, No. 3, pp. 315-319, 2022.

[7] Liang, H., Kaige, Y., Junjing W.: Conceptual Design and Research on Automatic Feeding Device Based on Linear Servo Motor, Proceedings of the 2015 International Conference on Intelligent Systems Research and Mechatronics Engineering, 2015.

[8] Rajasekar, D., Sengupta, G.: Hybrid material feeding system for a large sized high variety with low volume parts assembly a case study, International Journal of Engineering & Scientific Research, Vol. 9, No. 3, 2021.

[9] Abdelaal, M.: A Study of Robot Control Programing for an Industrial Robotic Arm," 2019 6th International Conference on Advanced Control Circuits and Systems (ACCS) & 2019 5th International Conference on New Paradigms in Electronics & Information Technology (PEIT), Hurgada, Egypt, pp. 23-28, 2019.

[10] Bogue, R.: The first half century of industrial robot: 50 years of robotic developments, Industrial Robot, Vol. 50, No. 1, pp. 1-10, 2023. https://doi.org/10.1108/IR-10-2022-0251

[11] Dzedzickis, A., Subačiūtė-Žemaitienė, J., Šutinys, E., Samukaitė-Bubnienė, U., Bučinskas, V.: Advanced Applications of Industrial Robotics: New Trends and Possibilities, Applied Sciences, Vol. 12, No. 1, 2022. https://doi.org/10.3390/app12010135

[12] Ponikelský, J., Černohlávek, V., Štěrba, J., Houška, P.: Research of Robots in Cooperative Mode in Human Body Part Detection. Manufacturing Technology., Vol. 23, No. 1, pp. 99-109, 2023.

[13] Nguyen, H.V., Cong, V.D., Trung, P.X.: Development of a SCARA Robot Arm for Palletizing Applications Based on Computer Vision, FME Transactions, Vol. 51, pp.541-549, 2023.

[14] Phuong, L.H., Cong, V.D., Hiep, T.T: Design a Low-cost Delta Robot Arm for Pick and Place Applications Based on Computer Vision, FME Transactions, Vol. 51, pp. 99-108, 2023.

[15] Kim, HS., Kim, GS.: 5-Axis Robot Design for Loading and Unloading Workpieces. Int. J. Precis. Eng. Manuf., Vol. 24, pp. 2279–2289, 2023. https://doi.org/10.1007/s12541-023-00874-9

[16] Kim, H. S., and Kim, G. S.: Modeling and simulation of 4-axis dedicated robot for CNC lathe. Journal of the Korean Society of Manufacturing Process Engineers, Vol. 20, No. 4, pp. 49–56, 2021.

[17] Yang, S. G., and Kim, G. S.: Design of 4-axis Scara-type robot for attaching and detaching workpieces of machine tools. Journal of Korean Society for Precision Engineering, Vol. 38, No. 5, pp. 351–358, 2021.

[18] Klimenda, F., Sterba, J., Cernohlavek, V., Ponikelsky, J., Maran, P.: Draft of robotic workstation for laser engraving. Manufacturing Technology. Vol. 21, No. 3, pp. 357-363, 2021. doi: 10.21062/mft.2021.049.

[19] Chu A. My, Chi Hieu Le, Michael Packianather & Erik L.J. Bohez.: Novel robot arm design and implementation for hot forging press automation, International Journal of Production Research, Vol. 57, pp. 4579-4593, 2019.

[20] Rishabh Jain, Mohd. Nayab Zafar, Jagadish Chandra Mohanta.: Modeling and Analysis of Articulated Robotic Arm for Material Handling Applications, IOP Conference Series: Materials Science and Engineering, 2019.

ДИЗАЈНИРАЈТЕ И РАЗВИЈТЕ РОБОТСКУ РУКУ ЗА АУТОМАТСКО ДОВОЂЕЊЕ РАДНИХ КОМАДА ЗА МАШИНЕ ЗА ЛАСЕРСКО ГРАВИРАЊЕ

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Ова студија представља дизајн, развој и експери–менталну процену 4-DOF SCARA роботске руке, интегрисане са програмабилним логичким контролером (ПЛЦ) и корачним моторима, за аутоматизацију руковања радним комадом у процесима ласерског гравирања. Систем побољшава безбедност и ефикасност аутономним управљањем хватањем, постављањем и извлачењем радних комада, чиме се смањује изложеност људи опасностима од ласера. Роботска рука, опремљена са двоструким вакуумским усисним главама, омогућава прецизне операције "pick and place" утоваром нових радних комада и уклањањем готових производа истовремено. Овај дизајн двоструке акције минимизира време циклуса омогућавајући континуирано руковање током процеса гравирања. Покренута корачним моторима контролисаним преко ПЛЦ-а, роботска рука постиже високу прецизност у кретању, омогућавајући прецизно поравнање сваког радног комада. Експериментални резултати показују способност система да одржи доследан квалитет и униформност производа, чак и са сложеним захтевима хватања и поравнања радних комада. Ово аутоматизовано решење представља ефикасну и поуздану алтернативу ручним операцијама, задовољавајући потребе индустрије за прецизношћу, безбедношћу и продуктивношћу у понављајућим производним окружењима заснованим на ласерима.