International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 04 , April - 2026

Design and Development of Robotic Arm for Spot Welding

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Abstract This paper presents the design and development of a 3-degree-of-freedom (3-DOF) robotic arm for automated spot welding applications in small-scale manufacturing environments. The system integrates a mechanically structured robotic arm with a microcontroller-based control unit to achieve precise positioning and consistent welding performance. Servo/DC motors are employed for controlled joint movement, while a motor driver interface ensures stable power delivery and accurate actuation. The welding operation is executed through programmed logic that synchronizes arm positioning with controlled pressure and current application at the electrode tips. Limit switches are incorporated to enhance operational safety and prevent mechanical overtravel. The developed prototype demonstrates reliable, repeatable, and uniform weld quality while reducing human effort and exposure to hazardous conditions. The proposed system offers a cost-effective and compact solution suitable for educational purposes and small industrial automation, contributing toward the advancement of smart manufacturing and Industry 4.0 practices.

Keywords - Robotic arm, Spot welding, Automation, Microcontroller, Servo motor, Stepper motor, Industrial robotics, Manufacturing automation, Semi-automated system, Precision welding.

I. INTRODUCTION

A robotic arm is a programmable mechanical device that performs tasks similar to a human arm. It typically consists of joints, actuators, and a control system that enables precise movement and manipulation. In industrial environments, robotic arms are extensively used for material handling, assembly, painting, and welding. Spot welding involves joining two or more metal sheets by applying pressure and heat generated by an electric current through electrodes. Automating this process ensures consistent weld strength, faster production, and improved safety. With advances in microcontrollers and affordable automation components, it has become possible to design low-cost robotic systems suitable for educational and small-scale industrial applications. This project builds upon these technologies to design and develop a robotic arm capable of performing spot welding operations automatically.

The primary motivation behind this project is to reduce human effort and risk in welding operations while enhancing working conditions such as electric shock, burns, and fumes. By a robotic arm, repetitive and hazardous tasks can be automated, improving workplace safety. Additionally, the project aims to demonstrate the integration of mechanical design, electronics, and control systems in building a practical automation prototype. It serves as a foundation for students and researchers to explore industrial robotics, automation techniques, and intelligent control systems. Ultimately, this project contributes to the vision of Industry 4.0, where smart, automated systems drive modern manufacturing processes.

II. LITERATURE REVIEW

Robotic arms have been widely studied for automation and industrial manufacturing processes. The study in **[14]** presented the design of a robotic arm equipped with a gripper and end-effector for performing spot welding operations. The system utilized motor-driven mechanisms to achieve controlled movement and effective welding performance.

Research in **[17]** discussed advanced robotic welding and automation technologies that improve welding efficiency, safety, and productivity. The study highlighted the role of intelligent control systems and modern automation techniques in improving welding accuracy and operational reliability.

A robotic welding arm designed using a microcontroller-based control system was proposed in **[18]**. The system demonstrated improved precision and reduced human error by automating the welding process through programmed motion control.

The work presented in **[16]** focused on the design and fabrication of a six-degree-of-freedom (6-DOF) robotic arm for spot welding applications. The study showed that increased degrees of freedom improve flexibility and positioning accuracy in industrial tasks.

Material selection and structural analysis for welding robotic arms were examined in **[13]**, where different materials were compared using finite element analysis. The results indicated that material properties significantly influence

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thermal behavior, deformation, and durability of robotic welding systems.

In addition, research in **[15]** developed a multi-degree-of-freedom robotic arm using servo motors for welding applications. The system demonstrated reliable motion control and consistent welding results while maintaining a relatively low system cost.

Although several robotic welding systems have been developed with different control techniques and structural designs, there is still a need for **compact, low-cost, and semi-automated robotic arms** suitable for small-scale industrial and educational applications.

III. SYSTEM DESCRIPTION

The proposed Spot Welding Robotic Arm system is a semi-automated electromechanical platform developed to perform precise, consistent, and repeatable spot welding operations, particularly suited for small-scale and medium-scale industrial applications. The primary objective of the system is to reduce manual intervention, improve weld quality, and enhance operational safety while maintaining cost-effectiveness. Unlike fully manual welding processes that depend heavily on operator skill, the robotic system ensures uniform weld strength and positioning accuracy through programmed control.

The system combines a robust mechanical arm structure with an embedded microcontroller-based control unit to coordinate motion and welding actions. The mechanical assembly consists of multiple joints and links that provide several degrees of freedom, enabling flexible movement similar to a human arm. Motor actuation is achieved using servo or DC motors, which allow accurate angular positioning and controlled speed regulation. These motors are driven through a motor driver interface that ensures adequate current supply and stable operation.

The embedded control system plays a crucial role in synchronizing arm movement and welding timing. It executes predefined motion sequences and activates the welding mechanism only after the desired position is accurately reached. The welding mechanism applies controlled pressure and electrical current for a specific duration to form strong and reliable weld joints. Through this integration of mechanical design, electronic control, and actuation systems, the proposed robotic arm achieves precise motion control, consistent welding performance, reduced human error, and improved production efficiency.

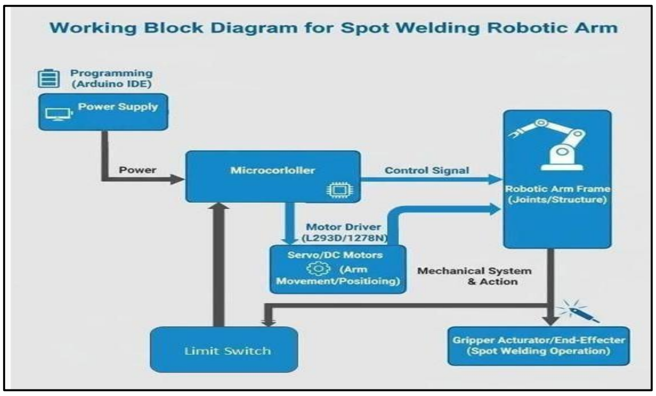

Fig.1.Block Diagram of Working for Spot Welding Robotic Arm

1. Power Supply Unit

The power supply provides regulated DC voltage to the microcontroller, motor driver, and actuators. It ensures stable operation of electronic components and sufficient power for motor actuation during welding tasks.

2. Microcontroller Unit

The microcontroller acts as the central control unit of the system. It is programmed using Arduino IDE and controls the movement, positioning, and timing of the welding operation. Based on the programmed logic, the microcontroller sends control signals to the motor driver to achieve accurate arm motion and welding coordination.

3. Motor Driver (L293D/L298N)

The motor driver circuit acts as an interface between the microcontroller and motors. Since the microcontroller cannot supply sufficient current directly to drive motors, the motor driver amplifies control signals and provides the required current to servo or DC motors.

4. Servo/DC Motors

Servo or DC motors are used for arm movement and positioning. These motors provide controlled rotational motion to achieve multiple degrees of freedom, enabling the robotic arm to simulate human arm movements. Accurate positioning ensures proper alignment during spot welding.

5. Robotic Arm Structure

The mechanical structure consists of joints and links forming the robotic arm frame. The design provides flexibility and controlled movement across multiple axes. The structure ensures stability during welding operations.

6. Limit Switch

Limit switches are used as safety and positioning feedback devices. They prevent over-rotation of joints and ensure safe operation by restricting motion beyond predefined limits.

7. Gripper Actuator / End-Effector

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The end-effector performs the actual spot welding operation. It applies controlled pressure and current at specific points to create strong welded joints. The welding process is activated based on programmed timing and positional accuracy.

Working Principle

When power is supplied, the microcontroller initializes the system and executes the programmed welding sequence. Based on input conditions, control signals are sent to the motor driver, which drives the motors to position the robotic arm at the required welding point. Once the correct position is achieved, the end-effector activates the welding operation for a predefined duration. Limit switches ensure safe movement and prevent mechanical damage. This coordinated control ensures precise, repeatable, and automated spot welding with reduced human error.

IV. DEGREE OF FREEDOM (DOF)

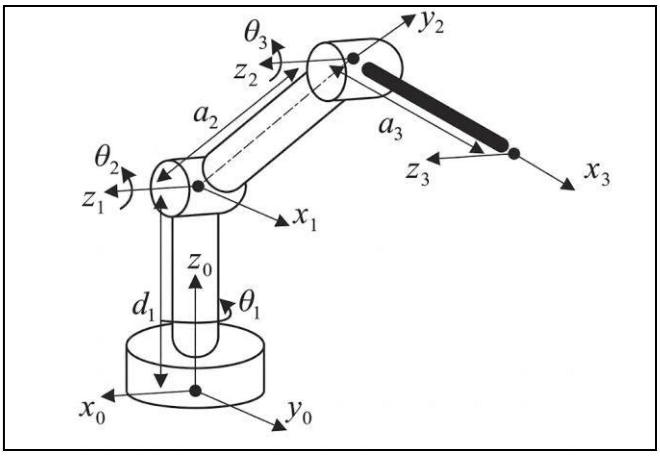

Fig.2. 3-DOF Structure

In robotics, a Degree of Freedom (DOF) refers to a single, independent direction in which a robot or one of its joints can move. You can think of it as the number of independent variables or parameters required to completely define the position and orientation of the robot's end-effector (tool) in space.

To understand how this applies to robotic arms, it helps to break down how objects move in a three-dimensional world.

The 6 Fundamental Degrees of Freedom

Any unconstrained rigid body in 3D space has exactly six degrees of freedom. They are divided into two categories:

Translation (Positioning): Moving linearly along the three spatial axes.

1. Moving forward and backward (along the x-axis).

2. Moving left and right (along the y-axis).

3. Moving up and down (along the z-axis).

Rotation (Orientation): Turning around those three spatial axes.

4. Roll: Tilting side to side (rotating around the x-axis).

5. Pitch: Tilting forward and backward (rotating around the y-axis).

6. Yaw: Turning left and right (rotating around the z-axis).

V. ADVANTAGES OF PROPOSED SYSTEM

- Increased productivity
- Improved weld consistency
- Reduced human risk
- High repeatability
- Programmable flexibility
- Adaptable for small industries

VI. Applications

- Automobile body assembly
- Sheet metal fabrication
- Appliance manufacturing
- Structural steel fabrication
- Hazardous industrial environments

VII. RESULTS

The robotic arm for spot welding was successfully designed, developed, and tested. • The arm performed accurate and repeatable movements to reach the desired welding positions. • The microcontroller-based control system effectively synchronized arm motion and welding operation. • The spotwelding process was carried out smoothly with proper timing and pressure between the electrodes. • The weld joints produced were uniform, strong, and consistent in quality

VIII. CONCLUSION

The project “Design and Development of Robotic Arm for Spot Welding” was successfully designed and implemented. The 3-degree-of-freedom robotic arm was able to perform accurate and repeatable spot welding operations using a microcontroller-based control system. The integration of servo motors and programmed logic ensured proper electrode positioning and consistent welding performance.

The developed prototype improves safety, reduces human effort, and enhances weld quality compared to manual welding. Although limited in flexibility compared to industrial robots, the system proves that low-cost robotic automation can effectively support small-scale

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 04 , April - 2026

manufacturing and educational applications.

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