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Design and Development of a Low-Cost Arduino-Based Automated Welding Table Using Linear Actuators

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Abstract: *Industrial automation plays a vital role in improving productivity, precision, and safety in modern manufacturing industries. This paper presents the design and development of a low-cost automated welding table prototype using an Arduino Uno microcontroller, two linear actuators, and a servo motor. The developed system integrates mechanical and electronic components to achieve sequential motion control for simulating automated welding operations. An Arduino Uno controls the movement of the linear actuators and servo motor through an L298N motor driver, while an LM2596 buck converter ensures stable voltage regulation. The prototype incorporates start and stop push-button controls for user operation and safety. Experimental validation confirmed reliable sequential operation, smooth motion coordination, and consistent performance under repeated operating cycles. The developed system serves as an economical educational platform for demonstrating industrial automation concepts and provides a foundation for future enhancements such as PLC control, sensor integration, Human-Machine Interface (HMI), and actual welding equipment. The proposed prototype offers a simple, cost-effective, and scalable solution for mechatronics education and automation research*

Keywords: Industrial Automation, Arduino Uno, Linear Actuator, Servo Motor, Welding Table, Mechatronics System, Motion Control.

I. INTRODUCTION

Automation has significantly transformed manufacturing industries by increasing production efficiency, reducing human effort, and improving product quality. In the modern industrial landscape, competitive pressures necessitate the adoption of automated systems to satisfy stringent quality control standards and elevate manufacturing throughput. Welding is one of the most widely used manufacturing processes where automation can play a critical role in improving repeatability, ensuring uniform structural integrity, and drastically reducing operator fatigue and exposure to hazardous environments [1], [2].

Traditional welding operations often depend heavily on manual positioning and human movement coordination, which inevitably introduces human error and significant variations in weld quality. Factors such as unsteady hand movement, varying travel speeds, fluctuating torch angles, and fatigue-induced inconsistencies directly affect the mechanical properties and aesthetic characteristics of the completed weld pool. Industrial robotic welding systems, while highly effective, address these limitations but require substantial initial capital investment, sophisticated programming expertise, specialized facility layouts, and advanced high-maintenance sensing systems [3], [4]. Consequently, such heavy-scale commercial systems are completely unsuitable for educational institutions, vocational training centers, and small-scale or micro-scale industries operating under strict budgetary constraints [5], [6].

To alleviate these challenges, there is an urgent socio-economic and pedagogical need for the design and realization of accessible, modular, and low-cost automated positioning frameworks. By leveraging modern embedded platforms, open-source microcontrollers, and standardized electromechanical actuators, it is entirely feasible to synthesize functional prototypes that emulate the kinematic precision of high-end industrial systems without their associated prohibitive financial overheads. Such systems allow students, researchers, and small businesses to conduct experimental validations, validate trajectory control algorithms, and explore automated sequencing principles in a highly affordable, transparent manner.

The primary objective of this comprehensive research work is to design, implement, and validate a highly accessible, low-cost automated welding table prototype utilizing the versatile Arduino Uno microcontroller platform [7], [8]. The developed system exemplifies the principles of sequential motion control through the seamless integration of two high-torque linear actuators and a precise angular positioning servo motor. By coordinating translational and rotational degrees of freedom, the system provides a structured mechanism capable of orchestrating complex welding profiles. The prototype not only functions as an economical educational platform for clarifying advanced mechatronics and control systems concepts but also establishes a reliable technological foundation for future, large-scale industrial adaptations tailored specifically for emerging markets and cost-sensitive production applications.

II. LITERATURE SURVEY

Automation in welding applications has received significant attention from researchers worldwide due to its direct impact on enhancing production quality, structural reliability, and throughput metrics. Over the past few decades, the transition from manual execution to automated systems has evolved from hard-wired relays to flexible microcontroller-based arrangements, open-source architectures, and sophisticated multi-axis robotic platforms [1], [3].

Marwoto et al. [1] developed an automated welding machine specifically optimized for Metal Inert Gas (MIG) applications, capable of performing straight and circular welding using an Arduino-based control system. Their work demonstrated noticeable improvements in path accuracy and repeatability through basic programmable motion profiles. Similarly, Khuyen and Phuoc [2] designed a 2D profile generation system applied to laser welding technology, emphasizing the mathematical mapping of trajectories to ensure uniform energy density distribution. Kah et al. [3] conducted a comprehensive investigation into robotic arc welding sensors and programming methodologies within complex industrial environments, highlighting that while advanced seam tracking significantly enhances productivity, it fundamentally inflates system complexity and cost beyond the reach of smaller companies. Biber et al. [4] explored an adaptive process control mechanism for robotic welding, utilizing real-time feedback loop adjustments to regulate wire feed rate and voltage parameters dynamically.

Loukas et al. [5] proposed an automated defect-free multi-pass welding strategy that combined robotic path programming with specialized thermal monitoring systems. While their approach eliminated internal voids, it required extensive computational clusters to process sensory data. Thompson et al. [6] implemented an early knowledge-based system for welding automation, proving that programmatic rules could guide path adjustments, though their implementation was constrained by the legacy hardware of the era. Ngo et al. [7] tackled the challenges of non-linear dynamics by developing a robust control scheme for multi-axis welding robots, utilizing sophisticated adaptive algorithms to compensate for external load disturbances and inertia shifts during operation.

Gaonkar and Sharma [8] investigated the viability of using low-cost open-source hardware, specifically focusing on industrial automation using Arduino-based embedded systems. They concluded that for sub-millimeter applications, cheap microcontrollers offer sufficient processing bandwidth when coupled with dedicated hardware drivers. Prabowo and Irwanto [9] analyzed the expanding role of Arduino applications in modern engineering education, validating its utility as a bridging tool that converts complex control theories into tangible mechanical actions. Salazar-Serrano et al. [10] designed an array of modular Arduino-based automation systems for laboratory applications, verifying that these microcontrollers provide excellent long-term reliability under continuous operational cycles. Nugroho et al. [11] specialized in precision angular control, detailing servo motor applications in multi-axis robotic arms and analyzing how

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Pulse Width Modulation (PWM) resolution limits angular step fidelity. Joshi et al. [12] introduced a force control system for servo-driven welding guns, demonstrating that precise mechanical pressure regulation is critical for optimizing spot-welding uniformity.

Groover [13] provided the classic baseline theoretical frameworks for modern manufacturing automation, defining the discrete state-machine logic required to orchestrate sequential processing lines safely. Siciliano and Khatib [14] expanded on these kinematic paradigms in their seminal handbook, providing the absolute mathematical framework for rigid-body transformations, forward kinematics, and angular positioning controls that govern multi-axis systems. Craig [15] provided deep analytical methodologies for coordinate system definitions and actuator spatial mappings, which form the core of current trajectory tracking algorithms. Ogata [16] established the foundations of classical control engineering, defining the transient response, steady-state error analysis, and stability criteria essential for analyzing electromechanical actuator behaviors.

A. Research Gap

Existing welding automation systems primarily focus on industrial applications using robotic manipulators, advanced sensors, and machine vision technologies. Although these systems provide high precision and productivity, they are expensive, complex, and unsuitable for educational institutions and small-scale industries. Limited research has been reported on low-cost, educational-scale welding automation platforms using embedded controllers and basic automation components. Therefore, there is a need to develop an affordable, modular, and scalable automated welding table that demonstrates industrial automation concepts while serving as an effective learning and research platform.

B. Proposed Solution

The present study proposes the design and development of a low-cost automated welding table prototype based on the Arduino platform. The proposed system integrates linear actuators and a servo motor to provide precise linear and angular motion required for automated welding operations. An Arduino microcontroller is employed to implement sequential control, ensuring coordinated movement of the actuators and the welding table according to predefined operational parameters. The prototype is designed to demonstrate the fundamental concepts of welding automation using readily available and cost-effective components, making it suitable for educational institutions, laboratory demonstrations, and prototype validation. The developed system aims to provide an affordable alternative to conventional industrial welding automation systems while facilitating hands-on learning and experimental research in automation and mechatronics.

C. Objectives

This research aims to design, develop, and experimentally validate a low-cost automated welding table employing a microcontroller-based motion control system. The proposed prototype is intended to facilitate the demonstration of fundamental welding automation principles while providing a practical platform for experimental studies and educational applications.

The specific objectives of this research are:

1. To design and develop a compact automated welding table prototype.
2. To implement a microcontroller-based sequential control strategy for automated operation.
3. To achieve synchronized linear and angular motion through the integration of linear actuators and a servo motor.
4. To experimentally evaluate the functionality and performance of the proposed system.
5. To provide a scalable and economical platform for education, laboratory experimentation, and prototype development in welding automation.

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III. PROPOSED METHODOLOGY

The automated welding table was developed using a systematic engineering approach that integrated mechanical design, electronic hardware, embedded programming, and system testing. The development process comprised six major stages: (1) requirement analysis, (2) system design, (3) hardware selection and mechanical fabrication, (4) circuit development, (5) Arduino-based programming, and (6) system integration and experimental validation. This methodology ensured proper coordination between hardware and software, resulting in reliable sequential motion control and stable system operation.

A. System Architecture

The proposed automated welding table is organized using a deeply layered, decoupled architecture to ensure functional independence, ease of diagnostic troubleshooting, and modular component interchangeability. The layout comprises six highly distinct functional layers: the Input Layer, the Control Layer, the Driver Layer, the Motion Layer, the Power Management Layer, and the Mechanical Structure Layer. Each layer operates as an autonomous module, passing well-defined signals across strict hardware boundaries to guarantee smooth operation.

1. Input Layer: Comprises physical human-machine interaction elements including debounced industrial Start and Stop push buttons that transmit clear state-change triggers to the control hardware.
2. Control Layer: Anchored by the Arduino Uno (ATmega328P), executing the primary state machine, processing input signals, and regulating pulse widths and logic levels.Driver Layer: Employs an L298N dual H-bridge module with integrated flyback diodes to supply up to 2A per channel to the linear actuators, buffering the delicate control electronics from inductive spikes.
3. Motion Layer: Integrates two high-precision linear actuators and an MG996R servo motor, providing the necessary mechanical degrees of freedom to execute translational and rotational positioning profiles.
4. Power Management Layer: Converts raw 230V AC mains into a regulated 12V DC bus via a high-current switching adapter, which is subsequently stepped down to 5V DC via an LM2596 buck converter to drive the digital logic circuitry cleanly.
5. Mechanical Structure Layer: The physical chassis fabricated from 5mm optically clear acrylic sheets and rigid nylon standoffs, ensuring high dielectric isolation and substantial mechanical damping properties.

B. Hardware Component Analysis

A technical assessment of the specific hardware modules highlights their electromechanical matching and functional contributions to the overall automation assembly:

Linear Actuators: Operating at 12V DC, these actuators feature a built-in lead screw mechanism that transforms rotational motor torque into linear thrust, providing stable holding torque when powered down.

Fig. 1 Linear Actuator

Arduino Uno: Operates at a clock speed of 16 MHz, utilizing 32 KB of flash memory. It interprets input pins via internal pull-up configurations and translates them into output states using high-speed hardware timers.

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Fig 2 Arduino UNO

Servo Motor (MG996R): A high-torque, metal-geared rotary actuator operating at 5V DC. It interprets a 50 Hz PWM signal to determine its exact angular holding position between 0° and 180°.

Fig. 3 Servo Motor (MG996R)

L298N Driver: Incorporates an internal multi-watt package containing two full H-bridge circuits, enabling bidirectional DC motor steering via direction pins and speed regulation via pulse-width duty cycles.

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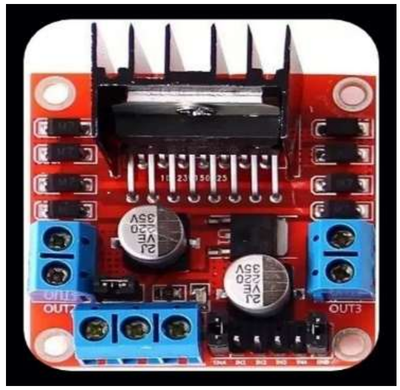

Fig. 4 L298N Driver

Power Supply and Voltage Regulation: Electrical power is supplied through a regulated 12 V, 5 A DC power source. An LM2596 DC–DC buck converter provides regulated voltage for the Arduino Uno and associated electronic components, ensuring stable operation and improving overall system reliability.

Fig. 5 Power Supply and Voltage Regulation

Buck Converter (LM2596 Step-Down Module): The LM2596 buck converter regulates the 12 V DC input supply to provide a stable voltage for the Arduino Uno and other low-power components, ensuring reliable operation and protecting the system from voltage fluctuations.

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Fig. 6 Buck Converter (LM2596 Step-Down Module)

Ball Bearings: Ball bearings are incorporated into the mechanical assembly to minimize friction and ensure smooth movement of the rotating and sliding components.

Fig. 7 Ball Bearings

Structural Materials (Acrylic and Nylon): The mechanical structure is fabricated using acrylic sheets and nylon components to provide a lightweight, rigid, and electrically insulated framework.

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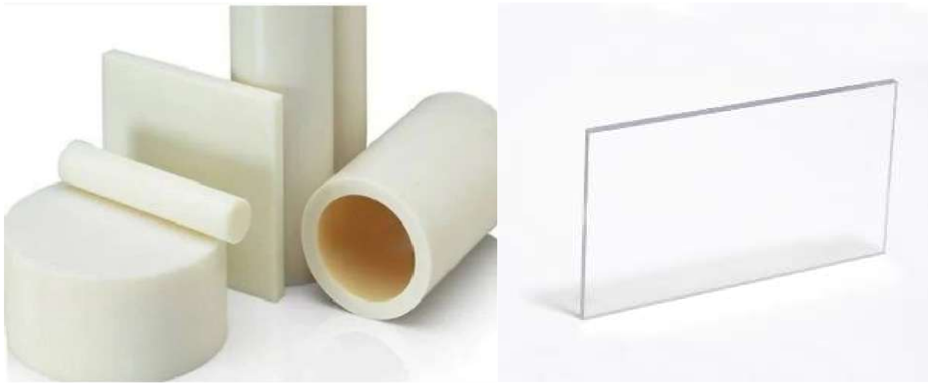

Fig. 8 Structural Materials (Acrylic and Nylon)

Circuit Design

The circuit architecture integrates the power supply, Arduino Uno microcontroller, L298N motor driver, linear actuators, servo motor, and user interface into a unified control system. A **12 V DC power supply** serves as the primary power source, while an **LM2596 DC–DC buck converter** provides regulated voltage for the Arduino Uno and other low-power electronic components, ensuring stable and reliable operation.

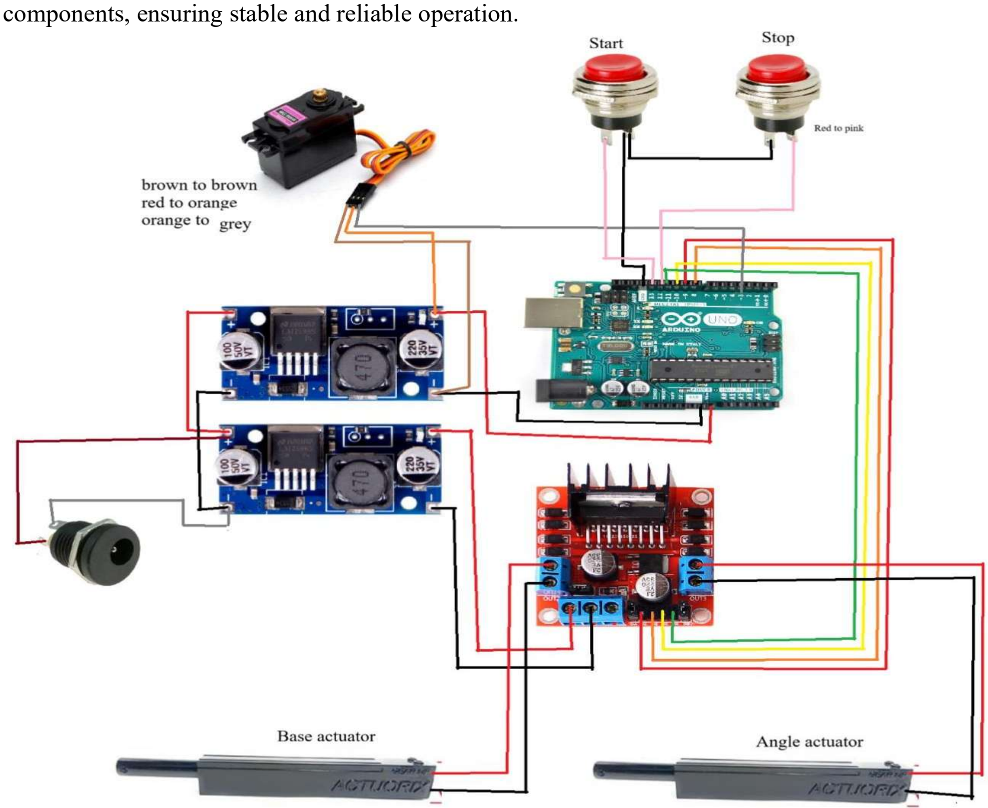

Fig. 9 Circuit Design

The **Arduino Uno** functions as the central controller, receiving input signals from the Start and Stop push buttons and executing the embedded control algorithm. Based on the programmed sequence, the Arduino generates digital control

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signals for the **L298N motor driver**, which controls the bidirectional operation of the two linear actuators. Pulse Width Modulation (PWM) signals generated by the Arduino are used to achieve precise angular positioning of the servo motor. The two linear actuators are independently controlled through the dual H-bridge outputs of the motor driver, enabling coordinated extension and retraction during the welding sequence. The servo motor is directly interfaced with the Arduino through a dedicated PWM output, providing synchronized rotational motion. A common ground is maintained across all modules to ensure signal integrity and reliable communication between the control and power circuits.

WORKING PRINCIPLE

The operation of the developed automated welding table is governed by an Arduino Uno microcontroller executing a predefined sequential control algorithm. Initially, a regulated **12 V DC power supply** energizes the system, while the **LM2596 buck converter** provides the required operating voltage to the low-power electronic components. Upon pressing the **Start** push button, the Arduino initiates the programmed sequence by generating digital control signals for the **L298N motor driver** and PWM signals for the **servo motor**.

The motor driver controls the bidirectional operation of the two linear actuators, enabling their sequential extension and retraction to achieve the required linear motion. Simultaneously, the servo motor performs the programmed angular movement, thereby synchronizing rotational and translational motions. Upon completion of the operating cycle, the Arduino commands all actuators to return to their initial positions, after which the system enters the standby state, ready for the next operating cycle. The **Stop** push button can be activated at any stage to immediately terminate the operation, ensuring safe and reliable system control.

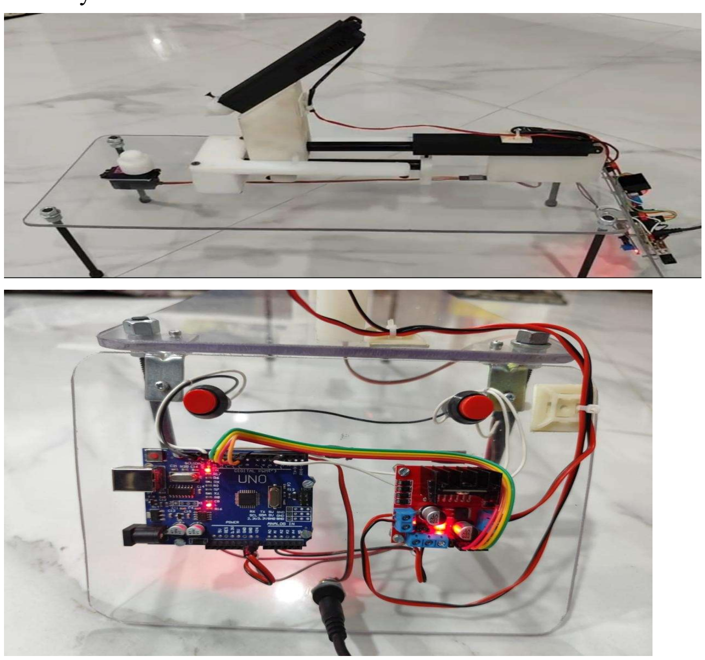

Fig. 10 Developed System

The operational sequence of the developed system is summarized as follows:

1. Power ON and system initialization.
2. Start button activation to initiate the control sequence.
3. Sequential operation of the linear actuators through the L298N motor driver.
4. Angular positioning using the servo motor.
5. Return of all actuators to the home position and system reset.

A. Features of the Developed System

The developed automated welding table integrates embedded control, electromechanical actuation, and power management to demonstrate the fundamental principles of welding automation. The system is designed to provide reliable operation, modularity, and ease of implementation, making it suitable for educational, laboratory, and prototype-level automation applications. The key features of the developed system are summarized as follows:

- **Microcontroller-based control** using the Arduino Uno for sequential execution of the welding operation.
- **Coordinated linear and angular motion** through the integration of two linear actuators and a servo motor.
- **Bidirectional actuator control** using the L298N dual H-bridge motor driver.
- **Regulated power management** using a 12 V DC power supply and an LM2596 buck converter for stable system operation.
- **User-friendly operation** through Start and Stop push buttons for manual control of the automation sequence.
- **Modular and low-cost design**, allowing easy component replacement, maintenance, and future system upgrades.
- **Compact and lightweight mechanical structure** fabricated using acrylic sheets and nylon spacers for laboratory and educational applications.
- **Repeatable and reliable operation** through a predefined embedded control algorithm for consistent system performance.

VI. EXPERIMENTAL RESULTS AND DISCUSSION

The developed automated welding table was successfully designed, fabricated, and experimentally evaluated under laboratory conditions. The experimental results demonstrate that the proposed system performs the predefined sequence of operations accurately and reliably. Upon activation of the **Start** push button, the Arduino Uno executed the embedded control algorithm, resulting in the coordinated operation of the linear actuators and servo motor. The linear actuators achieved smooth bidirectional motion, while the servo motor provided accurate angular positioning, thereby validating the effectiveness of the proposed control strategy.

The integration of the Arduino Uno, L298N motor driver, linear actuators, servo motor, and power management circuit ensured stable system operation throughout the experimental trials. The regulated power supply provided reliable voltage to all electronic components, and no significant operational failures or voltage fluctuations were observed during testing. The developed prototype successfully demonstrates the feasibility of implementing a low-cost automated welding platform for educational and laboratory applications.

The experimental investigation confirms that the proposed system:

- Successfully performs coordinated linear and angular motion through sequential control.
- Achieves reliable synchronization between the embedded controller and electromechanical actuators.
- Demonstrates stable operation with effective power management.
- Provides a modular and cost-effective platform for automation education and prototype development.

TABLE I Functional Validation of the Developed Prototype

Sr. No.	Function Tested	Expected Outcome	Observed Outcome
1	Power Supply	Stable power to all components	Stable operation observed
2	Arduino Program	Execute programmed sequence	Executed successfully
3	Linear Actuator-1	Extension and retraction	Smooth movement observed
4	Linear Actuator-2	Extension and retraction	Smooth movement observed
5	Servo Motor	Rotation from 0° to 180°	Accurate rotation observed
6	Sequential Operation	Automatic sequence execution	Successfully completed
7	Start Push Button	Start operation	Responded correctly

8	Stop Push Button	Stop operation	Successfully stopped system
9	Complete Automation Cycle	Continuous operation	Successfully completed

TABLE II Hardware Integration Result

S. NO.	Hardware Component	Performance	Remark
1	Arduino Uno	Excellent	Stable controller operation
2	L298N Motor Driver	Excellent	Reliable actuator control
3	Servo Motor	Good	Accurate positioning
4	Linear Actuator-1	Excellent	Smooth motion
5	Linear Actuator-2	Excellent	Smooth motion
6	LM2596 Buck Converter	Excellent	Stable voltage regulation
7	Power Supply	Good	Continuous operation

VII. FUTURE SCOPE

The developed automated welding table demonstrates the feasibility of implementing a low-cost microcontroller-based automation system for educational and laboratory applications. Although the proposed prototype successfully performs the intended sequential motion control, its functionality can be further enhanced to meet the requirements of industrial welding applications. Future research may focus on improving the system by incorporating advanced control strategies, intelligent sensing, and real-time monitoring technologies. Such enhancements would improve the accuracy, reliability, flexibility, and industrial applicability of the proposed system while extending its potential for use in smart manufacturing and Industry 4.0 environments. Future developments may include:

1. Integration of PLC and HMI to improve industrial compatibility, real-time monitoring, and operator interaction.
2. Implementation of sensor-based closed-loop control and machine vision for accurate positioning, seam tracking, and weld quality inspection.
3. Incorporation of IoT-enabled monitoring and an automated welding torch to facilitate remote diagnostics, process optimization, and validation under practical industrial operating conditions.

VIII. CONCLUSION

An Arduino-based automated welding table prototype has been designed, developed, and experimentally evaluated to demonstrate the fundamental principles of welding automation. The developed system integrates an Arduino Uno microcontroller, linear actuators, a servo motor, and an L298N motor driver to achieve coordinated linear and angular motion through a predefined sequential control algorithm. Experimental results confirm that the prototype performs the desired motion sequence with satisfactory accuracy, repeatability, and operational reliability.

The proposed system provides a simple, modular, and cost-effective alternative for demonstrating automation concepts in educational institutions and research laboratories. Owing to its low implementation cost and ease of integration, the developed prototype can serve as an effective platform for teaching embedded systems, motion control, and industrial automation.

Future work will focus on incorporating closed-loop feedback control, position sensors, machine vision, and welding process monitoring to improve positioning accuracy, process adaptability, and suitability for advanced industrial applications.

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