Design and Fabrication of a 3-axis Semi-Automated Welding Setup to Improve Joint Strength

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Abstract. This paper presents a design for a 3-axis semi-automated Tungsten Inert Gas (TIG) welding setup utilizing a PIC microcontroller and actuators to enhance welding efficiency and accuracy. Incorporating screw actuators offers advantages over traditional systems, including improved positional control, repeatability, and energy efficiency. The design phase involves mechanical structure development, microcontroller integration, and welding component assembly. Modern control algorithms enable dynamic adjustment of welding parameters for optimal weld quality. The three-axis configuration allows precise welding of various geometries, with ball screw actuators ensuring smooth motion control. The machine features a user-friendly interface suitable for both experienced welders and beginners. Experiment results demonstrate high-quality welds on materials like stainless steel, aluminium, and steel, contributing to reduced waste and increased productivity.

Keywords: Design, Fabrication, Precision, Repeatability; Semi-automated Tungsten Inert Gas welding (TIG).

1 Introduction

Welding is the act of joining materials together by melting and fusing their edges to form a solid and long-lasting bond. The underlying aim of all welding processes is to form a solid and reliable connection between materials. Vural et al. Observed that Welding is the process of putting materials together in a welding zone using force, heat, and/or filler metal. Shielding gases, welding pastes, or powders, for instance, can make it easier. [1]. Welding procedures differ in their techniques, tools, and applications. Welding holds immense importance across numerous industries and applications due to its core function in uniting materials, which are crucial for construction, manufacturing, and maintenance, welding is highly valued across a variety of sectors and applications.

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Welding is essential for erecting strong bridges, buildings, and pipelines in the construction and infrastructure development industries, assuring structural integrity and safety. It makes it possible to put together complex parts for industrial, and consumer items, cars, and airplanes. The construction of power plants, pipelines, and oil facilities in the energy industry depends on welding, ensuring the safe transmission of energy resources. Turan et al. Welding is very important in the shipbuilding industry. During this operation, which should be overseen by quality control experts and carried out by competent and professional welders, the ship's structure should be protected [2]. Brazing and soldering are lower-temperature techniques that do not melt the base metal, whereas welding does. The base metal is normally melted first, followed by the addition of a filler material to create a molten metal (the weld pool). To create a weld, pressure can either be applied alone, in combination with heat, or both. A shield is also required during welding to avoid contaminating or oxidizing the molten metals or filler metals. Two primary types of welding are used to fuse metal fusion welding and non-fusion welding. Melting to strips of metal at a high temperature to produce one piece is called fusion welding. MIG and TIG are common fusion welders that use electrical arcs and consumable electrode wires.

AL-Qenaei et al. noticed increasing their temperature to the point of fusion, causing them to create a sort of molten metal pool at the junction's ends. At times, a filler metal is added to the pool to create a homogenous mixture that, when allowed to harden, forms a permanent connection [3]. Non fusion welding employs pressure to fuse metals like magnesium, copper, aluminium, and stainless steel that have low melting points. Although fusion welding delivers more strength and longevity than non-fusion welding, it does need more skill.

Conventional welding is the most used joining technique used in construction, manufacturing, and maintenance industries to create durable connections between materials. It requires skilled welders with precision, importance to the data, and a thorough understanding of welding processes for high-quality welds. However, one of the challenges the welders face in a conventional welding setup is maintaining consistent welding parameters. When examining the quality and integrity of the weld joint, parameters including electrode angle, welding speed, and arc duration are important considerations. Inconsistencies in these parameters can lead to welding defects such as porosity, undercutting, and incomplete fusion. James et al. reviewed weld defects, caused by incorrect welding parameters, procedures, or filler metal combinations, which significantly impact weld performance and longevity. Understanding these defects and their causes can ensure higher-quality, longer-lasting welds. Common defects include penetration, lack of fusion, porosity, cracking, undercut, and lamellar tearing. These defects can lead to unexpected failure below the design load or after fewer load cycles than predicted [4]. To address these challenges and improve welding consistency, unconventional welding robots have been introduced. Robots are used to control devices in various fields such as mechanical assembly, paints, weldments, and surgical procedures. They are frequently employed in welding processes. To provide the limited mobility needed for welding, Jaspreet et al. constructed a robotic welding arm that included a variety of components, their roles, connecting, and programming. [5]. Mao et al. fabricated an automatic moveable welding robot system that tracks seams with the help of a revolving arc sensor. The system consists of an ultrasonic obstacle avoidance sensor, a two-dimensional motion platform, and a wheeled body. Results from experiments demonstrate automated tracking of big fillet welding seams in confined places. [6].

Li et al. constructed a welding robot with six degrees of freedom and nine motion joints for large-scale workpiece welding. It uses two macro and micro motion motors for precision. To guarantee precision and stability, seam tracking makes use of the robot's kinematics model. [7]. Mohammad et al controlled the ideal welding parameters voltage, current, and arc length using the arc voltage, which resulted in no change in arc energy during the TIG welding process. [8]. Hong et al. developed a new method for arc welding for real-time trajectory tracking, called the Welded Line Tangent Method. This method creates kinematics models for robots and mobile machines, ensuring satisfactory control characteristics and accuracy [9]. Taewon et al. developed mobile welding robots with vision sensors and automatic control systems, validated using Hough transform image processing, and confirmed for precise and stable welding [10]. Ario et al. used microcontroller control to adjust the back bead width. A neural network system was trained and constructed using machine vision, welding speed, and current data [11].

However, one drawback of these unconventional welding robots is their high cost. The initial investment required to acquire and set up such robotic systems can be substantial, making them less accessible for small-scale operations or companies with budget constraints. This cost factor limits the widespread adoption of unconventional welding robots, despite their potential benefits in terms of improved welding quality and productivity. So robotic welding is replaced by CNC welding. Robotic welding is advantageous in that it may be used for activities requiring continuous production, complicated trajectories, and more comprehensive automation. It is also more cost-effective.

Seayon et al. designed a machine that can weld 2D profiles and joints, and electronic devices like motors and drivers are interfaced with a microcontroller board. The report focuses on design calculation and structural analysis of an L-section base frame and bridge [12]. Yong-Ak et al termed Gas metal arc welding (GMA) as a technology used in the hybrid approach known as "3D welding". This is the most cost-effective form of welding [13]. Santhoshi et al developed a CNC welding setup with a Y-axis roller. This portable machine has 3 degrees of freedom and uses Arduino shields. The Y-axis roller rotates at a set speed, allowing linear and circumferential welding. This automation reduces health risks, improves welding precision, and boosts productivity [14]. Ai-min Li et al. presented a robotic welding setup for carbon dioxide gas welding, designed using the PLC control system method. The system's control circuit diagram, I/O address assignment table, hardware and software design, and Human Machine Interface (HMI) are also detailed. Experimental results show improved welding quality and efficiency [15].

Venkata et al. designed and implemented low-cost three-dimensional computerized numerical control (CNC) machines for industrial applications [16]. Oladebeye et al. developed a predictive model to identify the welding speed and time of an established welding robot and to study Surface Methodology to optimize welding parameters, including voltage, current, material thickness, and arc length [17]. Liguo Huo et al. combining condition number and manipulability, a new kinetostatic performance index is generated. The optimal welding solution is achieved using the twist decomposition strategy, with limits and singularity avoidance as a secondary goal [18].

After analyzing these numerous advancements, it is clear that there is an unmatched increase in demand for high-precision welding solutions. Still, there is a demand for a proper welding process, and there is a need to develop a proper welding setup to improve the weld quality. So, our research work is to offer a superior interest in the fabrication and development of a "3-axis Semi-Automated Welding Setup" to improve joint strength.

2 Design For The 3-Axis Semiautomatic Welding Setup

The down frame was designed to support the welding equipment and the workpiece to be welded securely. The lead screw actuators are used for linear movements of axes. Complete control over the movement of the welding flame can be made achievable by the 3-axis setup (X, Y, and Z axes). The X-axis controls horizontal movement along the workpiece while the Y-axis manages the vertical height adjustment and the Z-axis regulates the welding arc length for quality weld. Seayon et al. designed Automatic welding machines using electronic parts like motors and drivers connected to an Arduino microcontroller board. Engineering concepts like material strength, manufacturability, and simplicity were applied for efficient design. Theoretical assessment of the apparatus requires knowledge of engineering concepts and structural components [19].

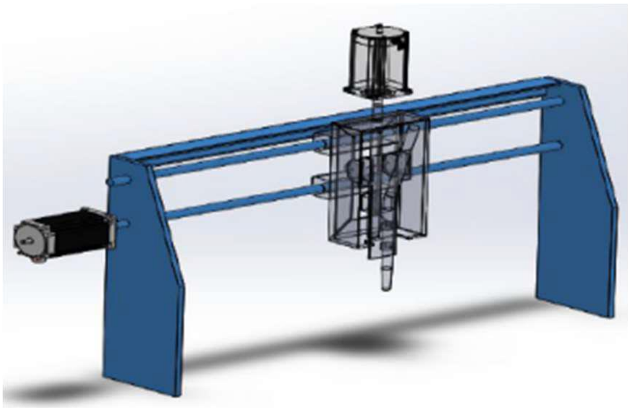

Fig. 1. The design of the bridge setup (Seayon [12])

Christopher Ehrmann et al. Emphasized existing linear drive system condition monitoring techniques the significance of condition monitoring for rack and pinion drives and the necessity of a customized system suited to their needs. A dependable PIC microcontroller is attached to DC motors that include sensors for increased precision to obtain precise control [20]. Pratheep et al. developed a 3-axis welding robot that has been constructed to improve welding quality and production in industrial settings. The robot uses the AT Mega 2560 to teach welding at target points incrementally, with an embedded program and stepper motor for less accuracy [21]. Bayindir et al created an APIC-based control unit for a friction welding machine. It was assessed for low-carbon steel joining operations and offered flexible utilization, cheap cost, low programmability, and adjustable software. [22].

Michal et al. examined the experimental analysis of a bipolar stepper motor, SY28STH32-0674A, using a dual full-bridge driver L298 and a microcontroller ATmega8-16PU. The motor's angular velocities increased in full-step mode, but issues arose when using half-step mode between 1400 and 1900 s. Heavy loads can cause increased torque and power consumption, making stepper motors unsuitable for high-speed applications [23]. Minghai et al. observed that siemens PLC is used in a welding control system for automobile dashboard brackets, enabling real-time control through touch screens. This system reduces costs, improves efficiency, and meets the production process requirements, accelerating the automobile manufacturing industry's rapid development [24].

Fatinah et al. constructed a DC motor in order to manage speed and direction, that was powered by a PIC 18F4550 microcontroller that generated PWM signals. The direction of the motor is managed by the DC drive. The project uses programmable timers, ports, and interrupts to show low-cost motor speed control while analysing drive performance [25]. Katke et al. created a DC motor speed control system by utilising a PIC 16F877A microprocessor. The technology makes use of pulse width modulation (PWM) and an optical encoder in a closed-loop control system. The microcontroller's adaptability to a range of applications is demonstrated by its ability to maintain the intended motor speed even in the presence of load changes. [26]. Jia et al. introduced a single-loop DC speed feedback control system. The system, which analyzed the mathematical model in the situation of adjusting the voltage to reach the speed correction, proposed a speed control method based on PWM and has given the hardware and software implementation based on PIC18F258, IGBT, EXB841, and so on [27].

A welding torch mounting system is used to accommodate the TIG welding machine torch. This welding torch system helps to change the arc angle and ensure a quick and secure change when required. Safety features such as emergency, protective enclosures, and interlocking systems are provided. These components were used to provide the semi-automatic features for the welding setup.

3 Fabrication Of A 3-Axis Semiautomatic Welding Setup

Precision welding is an important process in various workstations and industries, demanding accuracy, efficiency, and consistency. To meet these requirements, we are fabricating a 3-axis semiautomated welding setup. This advanced system blends human expertise with automation, enabling precise control and repeatability, offering significant improvements in welding quality and productivity.

3.1 Down Frame

The workpiece and actuators are fixed at the base of the setup. They chose the aluminium material with the v-slot profile, as seen in Fig. 2, for the frame material to maximize its strength. There is no significant load operating on the frame since the foundation material does not exceed the maximum load where the actuators are the only ones located.

Fig.2 Aluminium Extrusions (Santhoshi[14])

3.2 Actuators

It is an assembly of the lead screw, DC motor, shaft, and driver as shown in Fig.3.Where the screw nut is attached to the lead screw when the lead screw is applied the rotational motion screw nut moves in the longitudinal direction so the torch can be in the desired direction. The lead screw is constructed from EN8 carbon steel and has a double start thread. Its dimensions are 12 mm in diameter, 500 mm in travel length, 3 mm pitch, and a 30^{o} angle. This parameter produces an efficiency of52.4%. The motor requires a voltage range of 12 Vand RPM is 500.

Fig.3 Lead screw(Santhoshi[14])

3.3 Microcontroller

In this experiment the PIC controller as shown in Fig.4. is used to move the torch in the desired direction. Embedded C language or assembly language is used for programming it provides us with easy control over the movement of the torch.

Fig.4 PIC microcontroller

4 Welding Process For Dissimilar Joint

In industries where the demand for joining different materials is prevalent, such as aerospace, automotive, and construction, welding of different joints plays a pivotal role in creating strong, durable, and dependable connections. This welding technique exemplifies the fusion of expertise in metallurgy, welding techniques, and material compatibility to produce superior and enduring welded joints between materials with diverse properties. Welding dissimilar joints with TIG requires the expertise of a skilled welder who can execute the process with precision. Proper torch angle, travel speed, and filler metal deposition techniques must be applied to achieve a consistent and high-quality weld. Kohyama et al. examined the microstructural alterations caused by dual-ion irradiation in 316 SS welded joints. Three distinct factors were used to weld the specimens: current, voltage, and flow rate. They employed a 500 x 300 x 15 welding specimen, and in the end, they stressed how sensitive the microstructure evolution in welded connections is, particularly in hazardous areas. Therefore, it is imperative to thoroughly assess any changes in the mechanical and corrosion properties of welded joints inside a fusion environment. Additionally, the HAZ's least swelling-resistant zone may result from the I-butt welding of a plate with a thickness of 15 mm [28].

P. Liu et al. used the wire feed and welding velocity parameters, as well as the welding plate specification, which measured 100Lx40Wx3thk mm, to study the microstructure attributes of TIG welded connections constructed of Mg/Al dissimilar materials. After examining the microstructure, hardness, and fracture, they came to the conclusion that the magnesium substrate and the weld metal fused. Columnar crystals form in the vicinity of the weld metal and develop into it. The welding temperature cycle had a major effect on the magnesium substrate in the fusion zone, and the crystals were tiny. Dendritic crystal constituted the majority of the weld metal component. [29]. Ahmad et al. used X-ray diffraction to investigate the phase characterisation and microstructure of zircaloy-4 and stainless steel 304L TIG-welded joints. They found in the molten zone of Zr (Cr, Fe)2 intermetallic compounds and Zr2Fe–Zr2Ni eutectic phases, which had greater hardness and density.[30].

5 Conclusion

Semi-automatic welding machines are designed. The simplicity of the design for the setup is maintained for the low cost of the fabrication of the setup of the welding machine. The design can be implemented to manufacture working models. To carry out effective designing, knowledge from a variety of technical disciplines, including strength material machine design, was employed. Manufacturability of the design was taken into consideration when designing. To build a cost-effective automated welding machine, the design's simplicity was preserved to the greatest extent possible.

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