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Welding Automation Design using Metal Inert Gas for Straight and Circular Welding

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Abstract

An automatic welding machine is a tool used to carry out welding semi-automatically. The welding process is carried out using an Arduino as a microcontroller and a TB6560 driver as a Nema 23 stepper motor driver. Operation of the tool is carried out using Candle software. The tool movement system uses a lead screw and nut block on the Z axis as well as a timing belt and timing pulley to drive the X and Y axes. This machine has dimensions of 1200 mm long, 800 mm wide and 1250 mm high. The research model used is RnD. Tool testing is carried out by giving movement commands in the form of straight lines and circles to determine the accuracy of the movement, then testing is carried out using a welding machine to determine the welding results. Testing was carried out with variations of straight lines with variations of 18 mm, 24 mm, 25 mm, 30 mm, 36 mm, 42 mm, 50 mm, 75 mm, 100 mm, 125 mm and circle variations of 50 mm, 75 mm and 100 mm. Each variation was tested 3 times to produce an average backlash of 0.250 mm. Automatic welding machine can produce neat and even welds on straight welding, but there are still shortcomings in the results of circular and square welding. Adjustment of welding parameters and settings on the welding machine used needs to be done to improve the quality of the weld results.

Keywords: Arduino microcontroller, candle software, lead screw mechanism, stepper motors, welding accuracy.

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INTRODUCTION

Welding methods are widely used in connecting rods in machine and steel building construction. Such method is to connect materials by heating them to a certain temperature with or without pressure, with the application of pressure only, with or without using filler materials (Nugroho & Setiawan, 2018). The use of this technique is widely used as a substitute for bolts and rivets in designing machine construction or others. The use of welding joint techniques certainly does not only have advantages, there are also several disadvantages both in the process and the results of the welding. Manual welding can only be done by certain people who already have high working hours experiences. This is because manual welding requires high technique and precision to get maximum results, so it cannot be done by just anyone (Kah et al., 2016). Welding done manually has a low level of consistency, so the welding results can vary if done repeatedly.

The welding automation and improving welding results, stating that there are several problems that arise in welding carried out manually, either differences in the level of expertise of the welding operator or changes in physical and psychological conditions that occur in the welding operator (Triwibowo et al., 2015). This causes the welding results not only to be less than optimal and not meet welding regulation standards but also produce inconsistent quality. These problems will be felt more in the field of welding research which requires consistency in the quality of welding results. Metal inert gas (MIG) welding is one technology to improve the welding results. The use of electrodes in MIG welding is in the form of welding wire which has a gas arc welding and also uses the gas as a shield when the arc and metal melt in the environment. The application MIG welding is usually used for welding in industries that make tools or goods (Cahyadiatma et al., 2019). MIG welding offers enhanced efficiency and reduced spatter compared to traditional methods, making it suitable for high-precision industrial applications (Zhang et al., 2017). The use of welding that has efficient, practical, and economical properties is also often used in various industries. The advantages of using MIG welding, for example, this welding does not produce crust like shield metal arc welding.

An automatic welding robot system, namely a technical and economic analysis of the combination of robotic welding with conventional welding on offshore building structure pipe joints (Purnomo & Pribadi, 2017). The purpose of such study is to conduct a technical and economic analysis of the use of welding robots in the manufacture of building structures. The robotic welding systems significantly improve productivity and cost-effectiveness in large-scale industrial projects (Pan et al., 2020). The study began with an observation of the use of conventional welding, then a technical and economic comparative analysis was carried out with the use of welding robots covering costs, quality, productivity, and flexibility. The research on robotics and computer-integrated manufacturing (Geng et al., 2023). The study discusses the path planning method for robotic welding of structures on medium-thick plates based on three-dimensional depictions. The experimental results show that the method can run well, producing good weld seams with welding paths that are in accordance with the program being run.

In addition, developing an automatic welding tool, namely the design and construction of a MIG welding automation system to improve the quality of welded joint (Triwibowo et al., 2015). The steps in the study are to identify user needs, tool specifications, design, manufacturing, assembly, calibration and testing. The modular design approaches in automated welding systems enhance adaptability and reduce operational complexity (Chen et al., 2019). This welding robot has a design and operation that tends to be easy. The motion path can be a straight line or zigzag, but in testing the motion path can be a circle, square or other shape according to the command being executed.

Novelty in the welding process is needed to improve the process and consistent welding results. The advancements in automation and adaptive control systems are critical to addressing variability in welding outcomes (Lee et al., 2021). In this study, improvement on testing with circular welding is being conducted. Welding equipment with automatic or semi-automatic movement is needed to replace the role of the welding operator. Welding automation is expected to produce consistent welding quality. Welding automation can be applied more widely in the industrial sector and will support research in the field of welding.

METHODS

The research method in this study uses the RnD method. This method has several main stages, namely problem formulation, data collection, product design, tool making and tool testing. The systematic RnD frameworks are critical for developing reliable automated systems, particularly in industrial applications (Sommerville et al., 2015). The research flow can be seen in Figure 1. This procedure outlines the steps involved in designing and testing an automatic welding machine using MIG. The problem is identified to understand the challenges in the automatic welding system. A literature study is conducted, and the tool specifications are determined based on references and design requirements. The machine is designed by considering technical and functional parameters. The importance of integrating modular design principles is to ensure adaptability and scalability in automated machinery (Chen et al., 2018). Component preparation and manufacturing are carried out according to the design plan. Component assembly, electronics, and control systems are installed to ensure the machine functions properly. Motion trajectory calibration is performed to verify that movements align with expectations. If the calibration fails, adjustments are made. The iterative calibration processes are essential for achieving precision in robotic welding systems (Zhang et al., 2019). The testing process is conducted after successful calibration. Result analysis is carried out based on the data obtained from the testing process. A conclusion is drawn based on the analysis to evaluate the machine's performance. The process is completed once the conclusion has been established.

The electronic components of the automatic welding machine control system are shown in Figure 2. The image illustrates the wiring diagram based on an Arduino Uno, which acts as the microcontroller sending movement commands to the stepper motor drivers. Arduino-based systems are known for being cost-effective and flexible for industrial automation prototyping (Budiharto et al., 2020). The system utilizes four TB6560 stepper motor drivers to control four Nema 23 stepper motors, each responsible for motion along the X, Y1, Y2, and Z axes. The X-axis motor handles left-right movement, the Y1 and Y2-axis motors manage forward and backward motion, and the Z-axis motor controls vertical movement of the welding torch.

The setup is powered by a 24V power supply, which energizes the stepper motor drivers and motors. An adjustable step-down converter is included to regulate voltage for specific components. A main on/off switch controls the overall power to the system. To maintain thermal stability, a cooling fan (kipas) is installed to dissipate heat from the stepper motor drivers and other components, which is crucial for ensuring the longevity and reliability of high-power electronic systems (Astarloa et al., 2017). Power is supplied via a 220V AC input, which is then converted to 24V DC. This wiring configuration allows the stepper motors to receive precise movement commands from the Arduino Uno, enabling accurate and automated welding operations.

Details about the components used in the automatic welding machine, listing their specifications and functions, are shown in Table 1. The following is the relationship of the table to the wiring diagram. The table provides a list of mechanical, electrical, and software components, while the wiring diagram shows how the electronic components are connected to control the welding machine. The Arduino, stepper motors, TB6560 drivers, power supply, and fan in the diagram directly correspond to the "Electronics" section in the table. The frame, base plate, and moving components from the table provide the physical structure and movement system needed for operation, though they are not explicitly shown in the wiring diagram.

Furthermore, the components listed under the software section in the table—such as Arduino IDE and GRBL firmware—play an essential role in defining the motor control logic and command execution. The integration of hardware and software components ensures that the system operates in a synchronized and programmable manner, which is critical for achieving precision in automated welding processes.

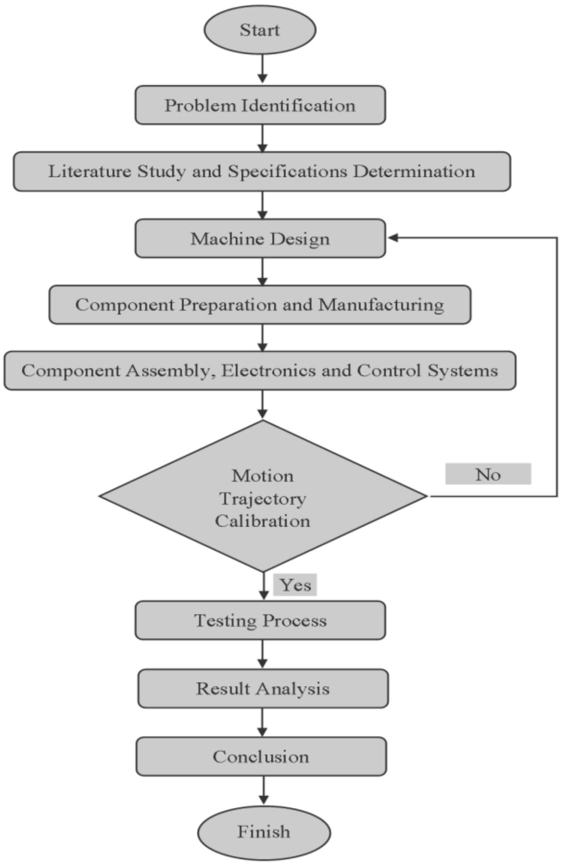

Figure 1. Research flow diagram

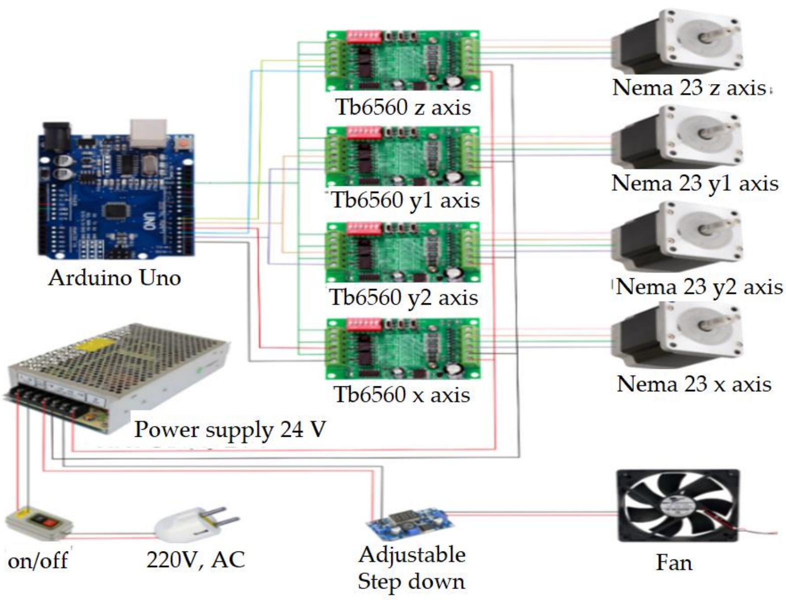

Figure 2. Electrical Schematic.

Table 1. Component Specifications

Main Part	Component Name	Description
1. Frame	Aluminum Profile	Material: Aluminum Size: 30 mm x 30 mm x 1200 mm 30 mm x 30 mm x 800 mm 40 mm x 80 mm x 250 mm
2. Base Plate	Iron Plate ST37	Material: Iron Plate ST37, Thickness: 3 mm
3. Movers	Motor stepper	Nema 23 2A
	Timing Belt	Material: Rubber, Width: 10 mm, Pitch: 2 mm
	Timing Pulley	Material: Aluminum, Inside diameter: 8 mm Width: 10 mm, Pitch: 2 mm, No. teeth: 20
	Screw	Material: Stainless steel, Diameter: 8 mm Pitch: 2 mm, Start: 4
	Nut	Material: Polycarbonate, Inside diameter: 8 mm Pitch: 2 mm, Start: 4
	Bearing F608ZZ	Bearing F608ZZ, Inside diameter: 8 mm Outside diameter: 22 mm
4. Electronics	Arduino	Arduino Uno R3
	Driver motor stepper	TB6560
	Power supply	24 Volt, 10 A
	Fan	Klop 8025HS DC 12 V
	Step down	Adjustable step down
5. Application	Laptop	ThinkPad T450s, Intel® Core™ i5-5200U CPU @ 2.20GHz 2.19 GHz
	Software	GRBL Plotter, Candle

RESULTS AND DISCUSSION

Safety factor simulation was performed using Autodesk Inventor 2024 software. The load on the x, y and z axes was 12.7 kg. The load was rounded to 15 kg and then multiplied by two to ensure the frame was strong enough to withstand the load to be given. The load was 30 kg or 66.139 lbf. The importance of conservative load estimation in structural simulations is to account for dynamic operational stresses (Kim et al., 2020). The simulation results can be seen in Figure 3 as safety factor.

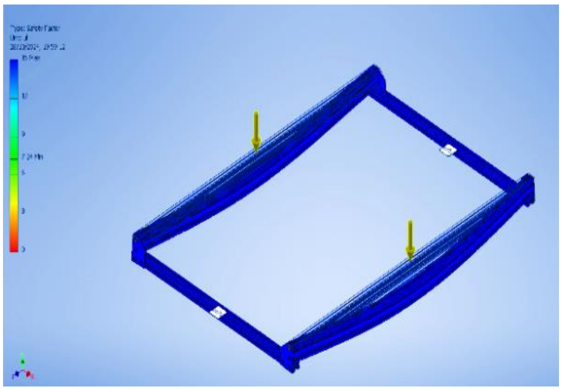

Figure 3. Safety factor

Based on the simulation the blue color is the highest safety factor. The lowest safety factor is 7.24 which is found in the green part. The lowest safety factor is what makes it easy for damage to occur later, namely in the connection part of the frame. The localized stress concentrations in welded joints require careful design validation to prevent structural compromise (Zhang et al., 2018). The machine frame can be categorized as safe because the safety factor is not less than 1.

The calculation of the component mass is calculated by weighing. The load on the x-axis is 9.022 kg, the load on the y-axis is 12.713 kg using 2 motors and the load on the z-axis is 5.945 kg. The necessity of precise mass distribution analysis for multi-axis systems is to optimize dynamic performance (Li et al., 2019). The tension on the lead screw is calculated as follows in Equation 1-4. A validated methodology for lead screw load analysis in automated machinery is needed (Chen & Kuo,

2021) and aligned with the equations applied here.

Stress

$$\tau_t = \frac{F}{A} \quad (1)$$

Bending stress

$$\sigma_b = \frac{3WH}{(\pi d_r n)H^2} \quad (2)$$

Shear stress

$$\sigma_g = \frac{16T}{\pi {d_r}^3} \quad (3)$$

Maximum shear stress

$$\sigma_{gmax} = \frac{1}{2}\sqrt{{\tau_t}^2 + 4.{\sigma_g}^2} \quad (4)$$

Designing an automatic welding machine requires motor power planning to suit the needs. Torque can be calculated using the following Equation 5-8

$$F = m.a \quad (5)$$

substituted,

$$T = F.r \quad (6)$$

Power can be calculated as follows,

$$\omega = \frac{2\pi n}{60} \quad (7)$$

substituted,

$$P = T.\omega \quad (8)$$

The role of torque optimization in stepper motor-driven systems is to balance energy efficiency and mechanical output (Pratomo et al., 2022). The calculation results can be seen in Table 2. That provides a list of mechanical, electrical, and software components, while the wiring diagram shows how the electronic components are connected to control the welding machine. The Arduino, stepper motors, TB6560 drivers, power supply, and fan in the diagram directly correspond to the "Electronics" section in the table. The integration of modular control systems is to enhance welding automation reliability (Budynko et al., 2023). The frame, base plate, and moving components from the table provide the physical structure and movement system needed for operation, though they are not explicitly shown in the wiring diagram.

Table 2. Calculation results

No	Calculation	Results
1	Stress (τ_t)	$1.16\ x\ 10^6\ N/m^2$
2	Bending stress (σ_b)	$0.483\ x\ 10^4\ N/m^2$
3	Shear stress (σ_g)	$3.183\ x\ 10^6 N/m^2$
4	Max. shear stress $\sigma_{gmax)}$	$3.235\ x\ 10^6\ N/m^2$
5	X-axis torque (T)	0.53 $N.m$
6	X-axis power (P)	16.642 $Watt$
7	Y-axis torque (T)	0.374 $N.m$
8	Y-axis power (P)	11.744 $Watt$
9	Z-axis torque (T)	0.233 $N.m$
10	Z-axis power (P)	7.316 $Watt$

The realized tool is an automatic welding machine featuring an aluminum and iron frame with a stepper motor-based drive system, as shown in Figure 4. The aluminum profiles offer an optimal balance of strength and weight for industrial automation frames (Geng et al., 2021). Designed for MIG welding on straight or circular paths, the machine consists of several key components. The frame, made of aluminum profiles and iron, ensures structural stability, while linear rails and stands support the movement of the X, Y, and Z axes. The drive system utilizes stepper motors mounted on both sides, connected to a timing belt and screw drive for precise and smooth movement. The welding head, centrally mounted, operates based on a programmed Arduino or CNC controller. The use of timing belts and screw drives are for high-repeatability motion in welding applications (Lee & Ahn, 2020). Positioned in a workshop or engineering laboratory, the machine is surrounded by other equipment used for experiments or testing. Its primary function is to perform automatic welding without requiring manual electrode direction, ensuring neater, more uniform welds across different welding paths and materials, depending on the welding parameters used.

Figure 4. Realization of the Tool

Table 3 presents the test results of the welding machine's motion accuracy, specifically evaluating the precision of its movement along the X-axis, Y-axis, and circular paths. The average error for the X-axis straight motion is recorded at 0.233 mm, while the Y-axis straight motion shows a slightly lower error of 0.229 mm. Meanwhile, the circular motion exhibits a higher average error of 0.289 mm, indicating a slight decrease in precision when following curved paths. The overall average error across all tested movements is 0.250 mm, demonstrating the machine's capability to maintain a relatively high level of accuracy in automated welding operations. The curved-path errors to inertial effects in stepper motor systems suggest dynamic compensation strategies (Wang et al., 2019). These results highlight the effectiveness of the drive system and control mechanisms in achieving precise motion control, although further refinements may be necessary to enhance performance, particularly in circular welding paths.

Table 3. Test Results

No	Test name	Average error
1	X-axis straight motion	0.233 mm
2	Y-axis straight motion	0.229 mm
3	Circular motion	0.289 mm
Overall average error		0.250 mm

Welding testing was carried out using a welding machine with the Lakoni MIG160i type as show in Figure 5. The type of welding used is the flux type without additional CO_2 or Argon gas. The media used for welding testing is ST37 iron plate with a thickness of 3 mm. The flux-cored arc welding's suitability for automated systems is due to reduced spatter and stable arcs (Sproesser et al., 2021). Testing was carried out by straight and circular welding. An automatic welding machine in operation, utilizing the MIG welding method. The welding head, mounted on a CNC-controlled system, is actively generating sparks as it fuses metal components. The machine moves along a predefined path with the help of stepper motors, timing belts, and screw drives, ensuring precise and consistent welding results. The aluminum and iron frame provides structural stability, while linear rails support the movement along the X, Y, and Z axes.

The surrounding environment suggests an engineering workshop or laboratory setting, with various tools and equipment visible in the background. This automated system enhances efficiency by reducing the need for manual intervention and improving weld quality across different metal surfaces.

Figure 5. Welding process

Figure 6 illustrates the results of two different types of welding performed by the automatic welding machine. Image (a) shows a straight welding pattern, demonstrating the machine's ability to maintain a consistent and uniform weld along a linear path. Image (b) presents joint welding, where two metal pieces are fused together along their seam. The weld bead in both images indicates the quality and consistency of the welding process, highlighting the machine's capability in executing precise and stable welds.

Figure 7 displays welding results for two geometric patterns. Image (a) shows circular welding, where the machine follows a curved path to create a continuous weld along a circular shape. Image (b) depicts square welding, where the machine precisely forms a welded square. These images emphasize the machine's ability to perform complex welding paths with accuracy, essential for applications requiring specific geometric patterns. Thus, the role of parameter optimization in achieving uniform welds across diverse geometries are necessary (Kah et al., 2018).

(a) (b)

Figure 6 (a) straight and (b) joints welding

(a) (b)

Figure 7. (a) Circular and (b) square welding

CONCLUSION

This study produces a mechanical design of welding automation using MIG for straight and circular welding. The machine is designed using Autodesk Inventor 2024 software, and simulations have been carried out with the lowest safety factor of 7.24. The dimensions of the tool are 1200 mm long, 800 mm wide and 1250mm high. The Z-axis drive uses a lead screw and nut block, while the X and Y axes use a timing belt and timing pulley. The results of the motion accuracy test show a relatively small average backlash, namely on the X axis of 0.233mm, on the Y axis of 0.229 mm and the Z axis of 0.289mm. So that the average overall backlash is 0.250 mm.

The suggestions that can be given in this study are the need for a study on optimizing the use of welding settings on the welding machine used so that the welding results are more optimal.

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