

Optimization of Spot Welding Performance Through Microcontroller- Solenoid Drive and Ultrasonic Sensing

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ABSTRACT

This research discusses the design and testing of an Arduino microcontroller-based spot welder control system with solenoid drive and ultrasonic sensor as the main input. The system is designed to improve efficiency, precision, and consistency of welding results by automating the electrode clamping process as well as voltage regulation according to material specifications. The combination of a relay and voltage regulator module allows the current to be optimally adjusted based on the thickness of the work plate, thereby reducing welding defects. Tests show that the system is capable of detecting objects within 10 cm, and a welding time setting of 3 seconds proves sufficient to produce an optimal weld point. On plates with a thickness of 1.44 mm, the best results were achieved at voltages of 4V and 6V; for thicknesses of 1.8 mm and 2.2 mm, the optimal voltage was 8V. The pressure from the solenoid proved to be sufficient in joining the materials well. These results show that the microcontroller-based welding system is effective in adaptively managing the welding time and voltage, and provides consistent and robust results. These findings support the potential application of the system in smarter and more automated production processes in accordance with industry 4.0 principles.



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1. INTRODUCTION

In the era of the Industrial Revolution 4.0, the need for smart, automated and efficient manufacturing systems is increasing. One process that undergoes continuous innovation is welding, especially the resistance spot welding (RSW) method. This method utilizes heat from electrical resistance to join two or more metal plates together. The process is fast, energy-efficient and suitable for mass production, making it widely used in the automotive, electronics and light metal industries [1]. In the context of production technology development, spot welding continues to be refined to meet the quality and efficiency standards of modern production [2]. As highlighted by Chinn et al. [10], effective control strategies in resistance spot welding are crucial to ensure joint consistency and high-quality results, which emphasizes the importance of developing innovative control methods. In order for the spot welding process to produce strong and consistent joints, a fast and accurate control system is required. Pneumatic technology is still widely used as an electrode drive, but this system has several disadvantages such as large size, dependence on air pressure, and response that is not always precise. Therefore, this research proposes the use of linear solenoids as a replacement for pneumatic systems.

Solenoids are more compact, have a fast response time, and are capable of providing sufficient pressure for light metal welding [5].

This system is controlled by an Arduino microcontroller which is in charge of regulating the working logic and duration of the active solenoid. Arduino was chosen because it is flexible, easy to program, and has proven effective in various automation control projects [3]. To improve the system's work efficiency, an ultrasonic sensor is used as the initial detection input. This sensor is capable of detecting workpiece distances of up to 10 cm with high accuracy [4]. When the sensor detects the presence of a workpiece, it will send a signal to the Arduino which then triggers the activation of the relay to deliver electric current to the solenoid [6]. The use of a layered relay system allows the control of large currents to the solenoid to remain stable and safe. The MY2N 12V DC relay is used to activate the MY4-GS relay, which functions as a voltage regulator control module. This voltage can be set according to the thickness and type of material to be welded. With the right voltage setting, the welding results can be more optimal and minimal defects [9]. This welding process is fully controlled by a semi-automatic system, which combines sensors, microcontrollers, relays, and actuators in a single system.

Similar research has been conducted by M. A. Wahab who explained the importance of current and time parameters in determining weld quality [7]. In addition, a study from A. A. Al-Fadhli showed that the use of microcontrollers in welding systems provides increased accuracy and flexibility in welding control [8]. Research by M. A. M. Yusof also proved that the Arduino-based automatic welding system is able to improve time efficiency and joint quality [11]. Meanwhile, Hon et al. [12] emphasized that technological innovation such as rapid prototyping has accelerated advancements in manufacturing systems. This perspective supports the idea that integrating microcontrollers, solenoid drives, and ultrasonic sensors into spot welding is part of a broader trend toward smarter and more efficient production technologies. The methods to be used in this research include the design of mechanical and electronic systems of spot welding machines, integration of ultrasonic sensors for workpiece detection, programming Arduino microcontrollers to set the working time of the solenoid and logic control, testing welding performance on metal plates with varying thicknesses, and analyzing welding results based on the influence of voltage and time on weld quality. Through this approach, a semi-automatic spot welding system that is efficient, precise, and easy to implement in small to medium scale industries is expected to be created.

2. RESEARCH METHOD

This This spot welding machine is designed using an Arduino microcontroller-based automatic control system interface. This system uses a linear solenoid as the main actuator to move the welding electrode vertically to the workpiece surface. Specifically, the solenoid used is a Solenoid Fuel Pump 1751, which operates at 12 VDC with a current of about 2–3 A. It is wound with enamel-coated copper wire (diameter ± 0.35 –0.40 mm) and capable of producing a magnetic field of around 450–600 Gauss, with a stroke length of 10–15 mm and a pressing force of 15–20 N. These characteristics make it suitable to replace pneumatic drives in providing consistent pressure and precision movement during the welding process.

To detect the presence of the workpiece, an ultrasonic sensor is mounted at the bottom of the electrode. The system employs the HC-SR04 ultrasonic sensor, which operates at 5 VDC, with a measurement range of 2–400 cm and an accuracy of about 3 mm. In this design, the sensor is programmed to detect objects within 10 cm to ensure accurate electrode positioning before the welding process begins. The signal from the ultrasonic sensor is sent to the Arduino when the workpiece is within the programmed detection distance. After receiving the signal, the Arduino introduces a short delay to confirm the position and then activates the MY2N 12VDC relay, which works in parallel with a 12VDC automotive relay. The contacts on the MY2N relay are used to drive the MY4-GS relay, which is connected to the voltage regulator module.

The welding process lasts for 3 seconds, according to the programming on the Arduino, which has been adjusted based on the results of trials on various plate thicknesses (1.44 mm, 1.8 mm, and 2.2 mm) and voltage variations (4V to 8V). Once the duration is over, the system automatically cuts off the current to the solenoid and the electrodes return to their initial position. The entire system is

designed to work repetitively with high precision, efficiently, and easily operated to support automation in spot welding processes on an industrial scale.

This research begins with the creation of an operation process flowchart developed to describe the system workflow from initialization to decision making and actions taken. Figure 1. The flowchart describes the process of controlling the system based on distance measurements using ultrasonic sensors. The process starts with the initialization of the ultrasonic sensor, LCD, and relay. After that, the ultrasonic sensor measures the distance of the workpiece.

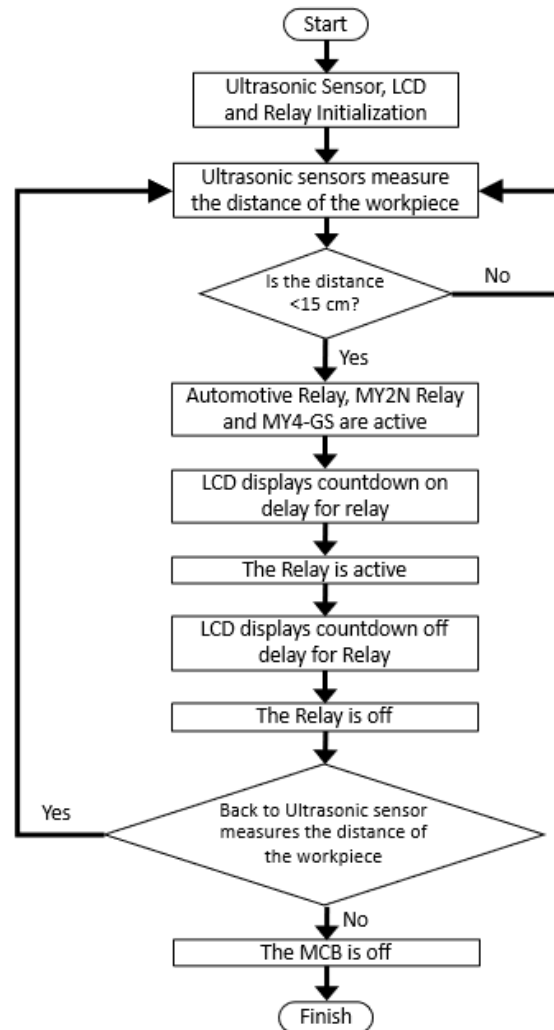


Figure 1. Flowchart proses Spot Welding

2.1. Mechanical Design

The mechanical design of the tool includes structural design and arrangement of mechanical components to support the stability and efficiency of the tool. Figure 2 which is the front view shows the main arrangement such as the position of the electrode, solenoid, and ultrasonic sensor which are installed in line to maximize the accuracy of detecting the workpiece.

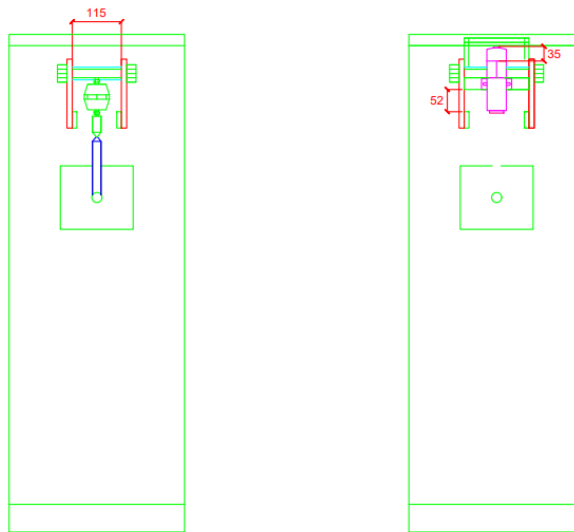


Figure 2. The Front View

While Figure 3, a side view, shows how the components are arranged vertically, including the swing arm mechanism and control system layout, to provide a clearer understanding of the direction of electrode movement during the welding process.

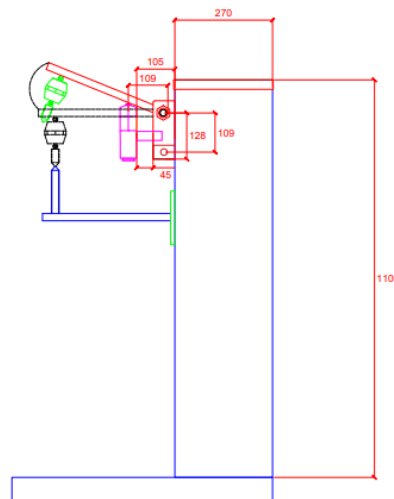


Figure 3. A Side View

Figure X shows the comparison of the spot welding machine before and after the integration of the microcontroller, solenoid actuator, and ultrasonic sensor. The initial design still relied on conventional control without precise automation, while the modified design demonstrates the application of Arduino-based control, Solenoid Fuel Pump 1751 as the electrode driver, and HC-SR04 ultrasonic sensor for accurate workpiece detection. This comparison highlights the improvement in automation and precision achieved through the proposed system.



Figure 4. Before and After

The input component in this system is an ultrasonic sensor, which functions as a workpiece distance detector and sends signals to the Arduino. Arduino acts as the main processing and control center in this welding machine control system. Meanwhile, the output component consists of LCD and relay. In the relay output section, there are three relays connected to each other, where the third relay is connected to a potensio module that functions as a voltage regulator for the welding transformer. This stage is followed by the creation of an electronic circuit scheme that illustrates how all electronic components will be connected as shown in Figure 5.

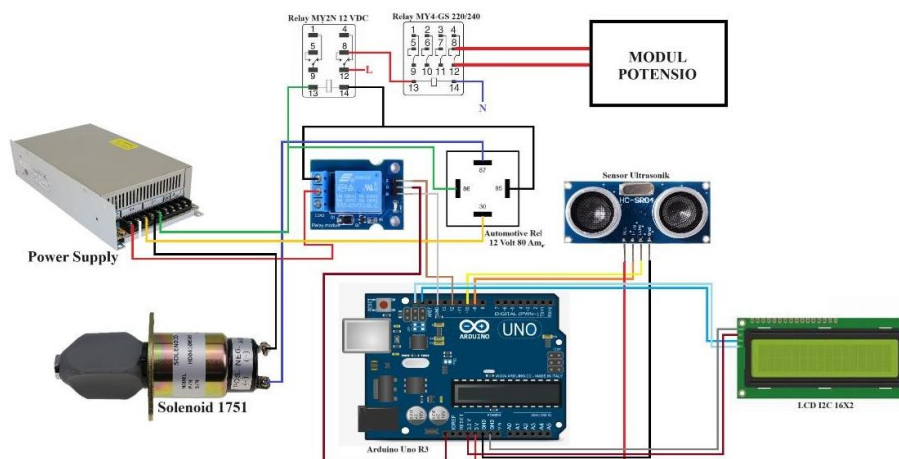


Figure 5. Component Circuit

2.2. Software Design

Software design includes the creation and development of software used to operate the tool. The program uses Arduino which is designed to control an automatic welding system based on ultrasonic sensors and relays. The ultrasonic sensor works by sending a signal through the trig pin and receiving its reflection through the echo pin, then calculating the distance of the workpiece based on the duration of the reflection. If the object is detected to be within a distance of less than or equal to 10 cm, the system will wait for 3 seconds to confirm the position, then activate the relay connected to the solenoid to press the electrode for 3 seconds. After that, the relay will be turned off automatically and the system returns to the initial state for the next cycle. The whole process is repeated periodically every 2 seconds, and displayed in real-time via Serial Monitor for debugging or monitoring distance

and relay status. This program is the core of a simple yet effective microcontroller-based spot welding control system.

2.3. Hardware Design

Hardware design involves the creation of electronic circuits and the selection and arrangement of sensors, actuators and other components needed to function according to the device specifications. This stage begins with the creation of a system block diagram showing the main components and how they are interconnected. The system block diagram can be seen in Figure 6.

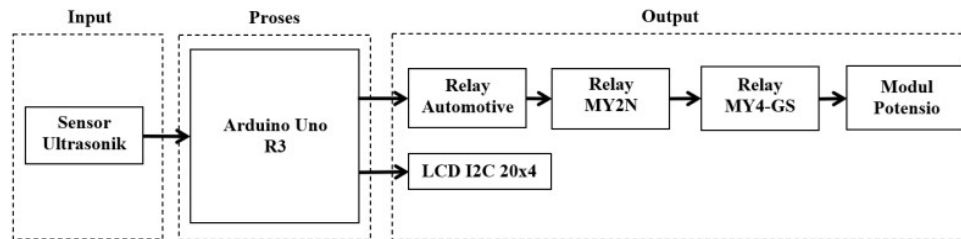


Figure 6. Blok diagram Hardware

The method of data collection in this study was carried out through the design and testing of a microcontroller-based spot welder welding system. This system consists of main components such as solenoid as electrode driver, Arduino as control center, and ultrasonic sensor as input to detect the presence of workpiece. In addition, a combination of 5V, 12V 80A relays, MY2N 12VDC relays, and MY4-GS relays are used to regulate the electric current to the solenoid and voltage regulator module. This voltage regulator module allows adjustment of the voltage level according to the type and thickness of the material being tested, so that welding defects can be minimized.

Testing is executed by operating the system in stages. The MCB is turned on first to activate the control and power circuits. Next, the switch on the voltage module is activated and the voltage is manually adjusted based on the test material. The test starts from the lowest voltage to prevent early damage to the material. Each change in voltage was tested on materials of different thicknesses, and the welding results were observed to assess the quality of the resulting weld points. This process is repeated to obtain accurate and consistent data.

During the test, the ultrasonic sensor detects the presence of a workpiece within a maximum distance of 15 cm from the electrode. When the workpiece is detected, the sensor sends a signal to the Arduino to activate the relay, which then flows current to the solenoid. The solenoid will pull the swing arm of the electrode to clamp the workpiece. Once the time is up, the relay cuts off the current and the solenoid returns to its original position. Each time this process is completed, data related to voltage, material thickness, and weld quality is recorded as part of data collection.

3. RESULTS AND DISCUSSION

In the first experiment, a plate with a thickness of 1.4 mm was used. Experiments were carried out using varying voltages. Testing using a voltage of 2 and 4 volts the filter and plate stick very well, testing using a voltage of 6 volts the filter and plate stick but the filter is damaged, testing using tegangan 8 and 10 volts the filter and plate do not stick and the filter is damaged.

In the second experiment, a plate with a thickness of 1.8 mm was used. Experiments were carried out using a voltage of 2 and 4 volts, the filter and plate did not stick, testing using a voltage of 6 and 8 volts, the filter and plate stuck well, testing using a voltage of 10 volts, the filter and plate stuck but the filter was damaged.

In the third experiment, a plate with a thickness of 2 mm was used. Experiments were carried out using voltages of 2, 4, and 6 filters and plates did not stick, testing using voltages of 8 and 10 volts filters and plates stuck well.

This test is carried out by welding on workpieces with plate thicknesses of 1.4mm, 1.8mm, and 2mm. The following data results taken from the welding results can be seen in Table 1.

Table 1. Welding Testing

Thickness of Plate (mm)	(V)	(A)	(Watt)	(s)	Welding Result
1,4	2	55	110	3	Plate and filter are attached but not strong
	4	354	1416	3	Plate and filter are strong attached
	6	691	4146	3	
	8	1149	9192	3	The filter is attached to the plate, but the filter is slightly damaged
	10	OL	OL	3	The filter is melted and there are holes in the plate
1,8	2	35	70	3	Plate and filter are not attached
	4	306	1224	3	Plate and filter are attached but not strong
	6	535	3210	3	The filter is attached to the plate, but the filter is slightly damaged
	8	850	6800	3	Plate and filter are strongly attached
	10	1558	15580	3	Strainer melted but plate remains good
2,2	2	46	92	3	Plate and filter are strongly attached
	4	263	1052	3	
	6	716	4296	3	Plate and filter are strongly attached
	8	1005	8040	3	
	10	1718	17180	3	The filter is still good but there is a hole in the plate

The experiment can be seen in Figure 7, which presents the documentation evidence that supports the explanation and data shown in Table 1. The figure illustrates the actual implementation of the system under different voltage levels and plate thicknesses. This visual documentation validates the experimental setup and confirms the results summarized in the table, providing a clear comparison of welding outcomes based on the tested parameters.



Figure 7. Spot Welding Test

4. CONCLUSION

The experimental results show that welding efficiency is strongly influenced by the thickness of the material and the voltage used. For plates with a thickness of 1.44 mm, optimal results were achieved at a voltage of 4V-6V, while at thicknesses of 1.8 mm and 2.2 mm, efficient welding was obtained at a voltage of 8V. The microcontroller-based control system proved to be effective in managing sensors, relays, and solenoids, so as to regulate welding time and pressure precisely according to material characteristics. This modification improved welding quality, consistency, and efficiency. In addition, the automated system was able to detect material position, regulate pressure, and execute the welding process more reliably than the manual method. A series of independent trials were conducted prior to industrial deployment, and the results show that the system has great potential for wider application in a smart manufacturing environment in line with Industry 4.0 standards.

REFERENCES

- [1] Ma. Sahrevy, "Analisa Pengaruh Kuat Arus dan Waktu Las pada Proses Las Titik (Resistensi Spot Welding) terhadap Kekuatan Tarik pada Hasil Sambungan Las Pelat SS 400". L. Burlion, *et al.*, "Keeping a ground point in the camera field of view of a landing UAV," *IEEE International Conference on Robotics and Automation, Vols 1*, pp. 5763-5768, 2013.
- [2] R. Siswanto and M. Eng, *Buku Ajar Teknologi Pengelasan HMKB791*, 2018.
- [3] S. Agus Setiawan and M. Hidayat, "Prototype Lampu Penerangan Jalan Otomatis Menggunakan Sensor LDR Berbasis Arduino Uno", [Online]. Available: <https://www.offapedia.com/2021/04/pengertian->
- [4] Galih Wsk, "Cara Kerja Sensor Ultrasonik: Teknologi Mendeteksi Jarak Akurat," *wikielektronika.com*. Accessed: Aug. 06, 2024. [Online]. Available: <https://wikielektronika.com/cara-kerja-sensor-ultrasonik/>
- [5] Risky Abadi, "Solenoida: Pengertian, Fungsi, Cara Kerja, Penggunaan Sehari-Hari." Accessed: Aug. 12, 2024. [Online]. Available: <https://thecityfoundry.com/solenoida/>
- [6] Dickson Kho, "Pengertian Relay dan Fungsinya," *teknikelektronika.com*. Accessed: Aug. 12, 2024. [Online]. Available: <https://teknikelektronika.com/pengertian-relay-fungsi-relay/>
- [7] M. A. Wahab, *Welding: Principles and Applications*, 8th ed. Boston, MA: Cengage Learning, 2020.
- [8] A. A. Al-Fadhli and M. T. Abed, "Design and implementation of microcontroller-based resistance spot welding machine," *Int. J. Eng. Res. Technol. (IJERT)*, vol. 9, no. 2, pp. 213–218, Feb. 2020.
- [9] D. G. Chinn, R. A. Matula, and A. H. Titus, "Control strategies for resistance spot welding systems," *IEEE Trans. Ind. Appl.*, vol. 44, no. 6, pp. 1672–1678, Nov.–Dec. 2008.
- [10] D. G. Chinn, R. A. Matula, and A. H. Titus, "Control strategies for resistance spot welding systems," *IEEE Trans. Ind. Appl.*, vol. 44, no. 6, pp. 1672–1678, Nov.–Dec. 2008.
- [11] M. A. M. Yusof, M. F. Roslan, and R. A. Bakar, "Automated welding control system using Arduino microcontroller," in *Proc. 2018 IEEE Int. Conf. on Smart Instrumentation, Measurement and Applications (ICSIMA)*, Kuala Lumpur, Malaysia, 2018, pp. 1–5.
- [12] K. K. B. Hon, Y. Ma, and J. Y. H. Fuh, "An overview of rapid prototyping technologies in manufacturing," *Int. J. Adv. Manuf. Technol.*, vol. 15, no. 1, pp. 25–33, Jan. 1999.