

# Design & Fabrication of an Automated Mechanical Stir Casting and Heating System for the development of Aluminium Metal Matrix Composites (AMMC)

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**Abstract**— This paper presents the design and implementation of an automated temperature monitoring and control system for molten metal processing, based on an embedded microcontroller. The system integrates a high-temperature thermocouple sensor (MAX6675), an ATmega328 microcontroller, a solid-state relay (SSR) for heating control, and a DC motor-driven stirring mechanism. Temperature data is transmitted to MATLAB via serial communication, where a graphical user interface (GUI) enables real-time monitoring, visualization, and parameter control. The SSR provides reliable, spark-free switching of the heating element. Stirring motor speed is managed through pulse width modulation (PWM) signals from the microcontroller and adjusted via the MATLAB GUI. Safety features include thermal limits, grounding protection, and electrical isolation. The system is compact, cost-effective, and suitable for laboratory and small-scale industrial applications. Experimental results confirm accurate temperature measurement, stable heating control, and effective stirring. Future enhancements may include PID control algorithms and wireless communication.

**Keywords**—ATmega328; Molten metal processing; Temperature control; Solid State Relay; MATLAB GUI; PWM; Thermocouple; MAX6675; Embedded systems

## 1. Introduction

Accurate temperature control and efficient material processing have become increasingly important in modern thermal systems. In molten metal processing, maintaining stable temperatures and uniform composition is critical for achieving desired material properties. This project presents the development of a microcontroller-based system that integrates temperature sensing, heating control, and mechanical stirring within a unified platform. A high-temperature sensor measures furnace temperature, with data processed by the ATmega328 microcontroller. The processed data is transmitted to MATLAB, where a graphical user interface (GUI) provides real-time monitoring and visualization. This interface allows users to observe temperature variations and interact with the system efficiently. The system employs a Solid-State Relay (SSR) to control the electric heating element, offering advantages

such as rapid switching, absence of mechanical wear, and high reliability, which are suitable for resistive heating loads. Heating can be managed through the MATLAB GUI, enabling users to activate or deactivate the system as needed. Additionally, a motor-driven stirrer mixes the molten metal to ensure uniform heat and reinforcement material distribution. The motor is controlled via pulse-width modulation (PWM) signals from the ATmega328, with speed adjustments made through a MATLAB slider interface, providing precise, real-time stirring control. Serial communication between the embedded hardware and MATLAB environment enables continuous data exchange and system control. Safety features, including proper grounding, electrical isolation, and noise reduction, are incorporated to ensure reliable operation. The system is compact, cost-effective, and straightforward to implement, making it suitable for educational and industrial prototype applications. Replacing a full development board with the ATmega328 microcontroller improves system efficiency and reduces hardware complexity. The system architecture also supports future enhancements, such as automatic temperature control using proportional-integral-derivative (PID) algorithms, data logging, and remote monitoring. Overall, this project offers a practical and scalable solution for automated thermal processing and molten metal handling

## 2. Literature Review

Several studies have investigated the influence of process parameters and automation in stir casting and furnace control systems.

Ramnath et al. (2019) examined the effect of SiC and Al<sub>2</sub>O<sub>3</sub> reinforcement on the mechanical properties of AA6061 composites produced by stir casting. The study reported improved tensile strength and hardness with increased SiC content but highlighted that manual temperature control caused porosity defects due to temperature fluctuations.

Kumar and Dhiman (2019) analyzed the influence of stirring speed and time on the particle distribution of AA7075/B4C composites. Their results showed that a stirring speed of 500 rpm for 10 minutes produced uniform reinforcement distribution. However, the stirrer speed was manually controlled, limiting process repeatability.

Prabu and Rajabathar (2020) developed a microcontroller-based furnace temperature monitoring system using an Arduino and K-type thermocouple. The system enabled temperature display and wireless data transmission, but it lacked automated heater control and advanced data visualization.

Nguyen et al. (2021) implemented a microcontroller-based PID temperature control system for an electric resistance furnace and achieved temperature regulation within  $\pm 2^{\circ}\text{C}$ . Although the system demonstrated high accuracy, the use of advanced hardware increased system cost.

Hiremath et al. (2022) emphasized the importance of maintaining consistent melt temperature and stirring speed during stir casting to achieve reliable mechanical properties in aluminium metal matrix composites. The study identified the absence of automated control systems as a major source of variability in experimental results.

These studies highlight the importance of **accurate temperature monitoring and controlled stirring conditions**, indicating the need for a **low-cost automated monitoring and control system for stir casting processes**.

### 3. Objectives

i) We want to measure the furnace temperature. We are using a K-Type thermocouple sensor and the ATmega328 microcontroller for this.

ii) We need to control the electric heating element. A Solid-State Relay (SSR) with ON/OFF switching will be used based on set temperature limits.

iii) The stirring motor speed needs to be regulated. This will be done using PWM signals from the ATmega328 via the L298 motor driver.

iv) We have to send real-time temperature data from the ATmega328 to MATLAB. This will be done through communication for live monitoring and control using a GUI.

v) We must evaluate how well our system works. We will check the temperature accuracy, control reliability and safe operation, under high-temperature conditions.

### 4. Proposed System Architecture

The system we are talking about is made up of four parts: temperature sensing and signal conditioning, embedded

processing and control actuator interfaces and real-time monitoring and visualization.

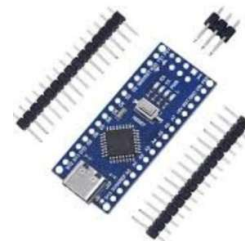
#### A. Temperature Sensing Module

We use a K-type thermocouple to measure the temperature. This thermocouple is connected to a MAX6675 converter. The MAX6675 talks to the ATmega328 using SPI. It sends 12-bit temperature data to the ATmega328. This data is very accurate with a resolution of  $0.25^{\circ}\text{C}$ . It can measure temperatures from  $0^{\circ}\text{C}$  to  $+1024^{\circ}\text{C}$ .



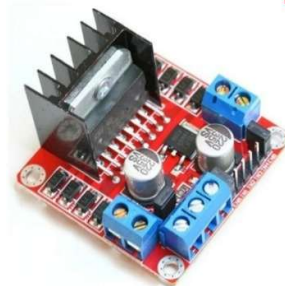
#### B. Embedded Processing Unit

The ATmega328 is the brain of the system. It constantly reads the temperature data from the MAX6675. Then it makes the adjustments and sends the data to MATLAB using UART serial communication at 9600 baud. The ATmega328 also generates signals to control the motor speed. Tells the heater when to turn on and off.



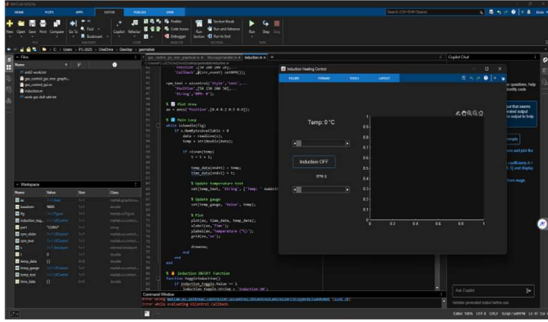
#### C. Actuator Interface Module

We use a Solid-State Relay or SSR to turn the heating element on and off. The SSR is controlled by a signal from the microcontroller. It can handle a lot of power from 10 to 40 amps. It works with voltages from 24 to 380 volts. The SSR is very reliable and quiet. We also use an L298 H-bridge motor driver to control the DC motor that stirs the mixture. The motor driver gets its instructions, from the microcontroller.



D. MATLAB GUI and Visualization

We made an interface using MATLAB that lets people interact with the system. This interface shows the temperature plots graphs of the temperature over time and lets people turn the heater on and off. It also has a slider to adjust the motor speed. The interface talks to the ATmega328 using communication so it can get the latest data and send commands to the system.



5. Hardware Components

A. ATmega328 Microcontroller

The ATmega328 is an 8-bit AVR RISC microcontroller featuring 32 KB Flash, 2 KB SRAM, and 1 KB EEPROM. It operates at up to 16 MHz with a supply voltage of 1.8–5.5 V. It includes a 10-bit ADC, hardware UART, SPI and I2C interfaces, and six PWM channels.

TABLE I: ATmega328 Key Specifications	
Operating Voltage	1.8 V – 5.5 V
Clock Speed	16 MHz (external crystal)
Flash Memory	32 KB
SRAM	2 KB
EEPROM	1 KB
PWM Channels	6
Communication	UART, SPI, I2C

B. MAX6675 Thermocouple Interface

The MAX6675 performs cold-junction compensation and digitizes the thermocouple signal using the Seebeck effect. It communicates over SPI and eliminates the need for external analog signal conditioning circuits. The CS, SCK, and SO lines connect to PB2, PB5, and PB4 of the ATmega328, respectively.

TABLE II: MAX6675 Key Specifications	
Temperature Range	0°C to +1024°C
Resolution	0.25°C (12-bit)
Communication	SPI (read-only)
Supply Voltage	3.0 V – 5.5 V
Conversion Time	0.17 s (max)

C. Solid State Relay (SSR)

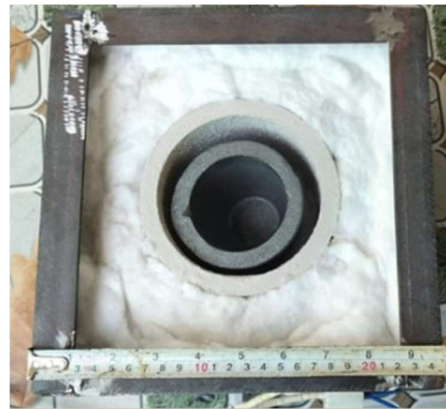
The SSR is an electronic switching device that replaces mechanical contactors for heater control. It uses opto-isolation to separate the control circuit from the load circuit, improving safety. The output side handles AC loads up to 380 V and 40 A, while the input side accepts DC control signals of 3–32 V from the microcontroller output pin PD7.

D. L298 Motor Driver

The L298 is a dual H-bridge motor driver capable of driving two DC motors simultaneously. It accepts PWM on ENA pin for speed control and direction logic on IN1/IN2. The device supports motor supply voltages up to 46 V and output currents of up to 2 A per channel, protecting the microcontroller from high motor currents.

E. Power Supply

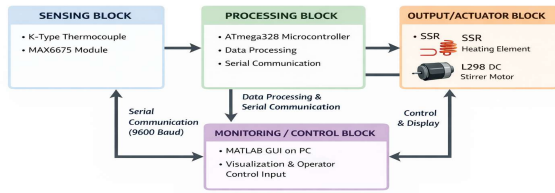
A linear power supply comprising a step-down transformer (230 V to 12 V), bridge rectifier, filter capacitor, and 7805 voltage regulator provides a stable 5 V DC supply for the microcontroller and sensor circuits. The 7805 includes internal thermal shutdown and current limiting protection, ensuring reliable supply under variable loads.



6. Methodology And Implementation

A. System Development Approach

The system was developed following a modular bottom-up approach. Each functional module—sensing, processing, actuation, and visualization—was developed, tested, and validated independently before system-level integration. This approach facilitated efficient debugging and ensured component-level reliability prior to full assembly.



**B. Firmware Development**

The ATmega328 firmware was written in embedded C using the AVR-GCC toolchain. The firmware initializes SPI for MAX6675 communication, configures Timer0 for PWM generation on PD5 (ENA of L298), sets PD7 as digital output for SSR control, and initializes UART at 9600 baud for MATLAB communication. The main loop continuously reads temperature every 250 ms, transmits the value via UART, and processes any incoming command bytes from MATLAB (heater ON/OFF, PWM duty cycle updates).

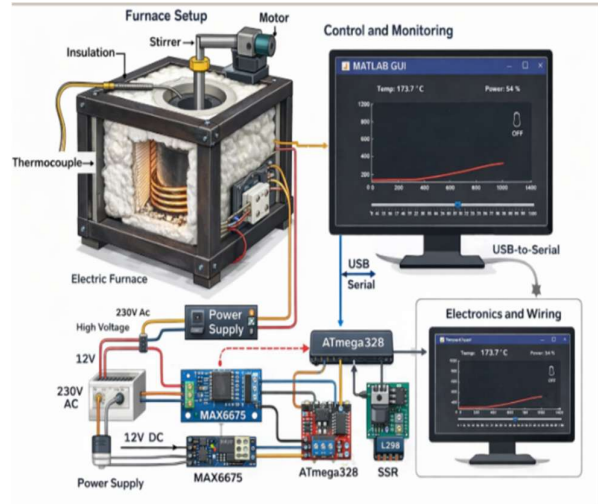
**C. MATLAB GUI Development**

The MATLAB GUI was designed using the App Designer tool. It includes a live temperature display, a scrolling real-time graph, a toggle button for SSR ON/OFF control, and a slider (0–100%) mapped to PWM duty cycle (0–255) for motor speed adjustment. Serial object communication is established using MATLAB's serialport function. Incoming temperature strings are parsed, plotted, and checked against configurable upper and lower limits, triggering automatic heater shutoff if thresholds are exceeded.

**D. Safety and Noise Mitigation**

Proper grounding of all circuit elements, star-point topology for ground connections, ferrite beads on signal lines near the SSR, and physical separation of power and signal wiring are implemented to minimize electromagnetic interference. Software-level debouncing and median filtering over three consecutive temperature readings further improve measurement stability.

- 06 Software Development**
- 07 Integration & Testing**
- 08 Results & Conclusion**



**7. Results And Discussion**

The system was tested under controlled conditions across a range of temperatures. The MAX6675 showed consistent accuracy within  $\pm 1^\circ\text{C}$  when compared against a calibrated reference thermometer at multiple set points. Serial communication between the ATmega328 and MATLAB was stable with no data loss observed over extended test periods.

The SSR demonstrated reliable ON/OFF switching with response times below 10 ms, significantly faster than equivalent mechanical relay systems. No sparking or contact degradation was observed. The MATLAB GUI correctly reflected temperature updates in real time with a refresh latency of approximately 300 ms. Motor speed control via the PWM-driven L298 provided smooth and proportional stirring speed adjustment, with the motor responding linearly to slider input from 10% to 100% duty cycle.

The automatic thermal cutoff feature successfully deactivated the heater when the temperature exceeded the preset upper threshold, and re-enabled it when the temperature fell below the lower threshold, demonstrating effective on/off hysteresis control. The overall system cost was significantly lower than equivalent PLC-based solutions, validating its suitability for educational and laboratory contexts.

Noise from the SSR switching was measurable on the thermocouple signal but reduced to acceptable levels through software median filtering and proper shielding, confirming the effectiveness of the implemented mitigation strategies.

- 01 Requirement Analysis**
- 02 Literature Review**
- 03 Component Selection**
- 04 System Design**
- 05 Hardware Implementation**

## 8. Conclusion

This paper describes the design, implementation, and testing of an automated temperature monitoring and control system for molten metal processing. The system combines an ATmega328 microcontroller, a MAX6675 thermocouple interface, a Solid-State Relay, an L298 motor driver, and a MATLAB GUI into a single embedded platform. This solution solves key problems with manual and PLC-based systems by providing precise temperature measurement, safe heater switching, adjustable stirring speed, and real-time visualization. It achieves all of this at a much lower cost and with simpler hardware.

The experimental results indicate that the system is accurate, stable, and safe throughout its intended operating range. The modular design and open communication protocol allow for future improvements. These could include PID-based closed-loop temperature control, data logging to external storage, wireless communication using ESP8266 or similar modules, and integration with cloud-based monitoring dashboards. The system is a practical and scalable solution for thermal processing in both research and educational settings.

## 9. References

- [1] G. Gulden Jr. et al., "System and method for monitoring operating parameters of an electric arc furnace," U.S. Patent US20020136260A1, Sep. 26, 2002.
- [4] Anonymous, "Hybrid furnace with fuel and/or electricity," U.S. Patent US20240352338A1, 2024.
- [5] Anonymous, "Electric arc furnace monitoring system and method," U.S. Patent US7991039B2, Aug. 2, 2011.
- [6] Atmel Corporation, "ATmega328/P Datasheet," Rev. 8161D-AVR-10/09, 2009.
- [7] Maxim Integrated, "MAX6675 Cold-Junction-Compensated K-Thermocouple-to-Digital Converter Datasheet," 2002.
- [8] STMicroelectronics, "L298 Dual Full-Bridge Driver Datasheet," 2000.
- [9] MathWorks, "MATLAB App Designer Documentation," The MathWorks Inc., Natick, MA, 2023.