Indonesian Journal of Interdisciplinary Research in Science and Technology (MARCOPOLO)
Vol. 4, No. 7, 2026 : 481-488

Arduino-Based Automated Control and Multi-Sensor Data Acquisition System for Coffee Grinder

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A R T I C L E I N F O

Keywords: Coffee Grinder, Automated Control, Arduino Uno, Relay Module, Data Acquisition, TCS34725, Gas Sensor Array

Received: 5 May
Revised: 24 June
Accepted: 27 July

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A B S T R A C T

Abstract — Post- roast coffee processing and quality evaluation require consistent mechanical grinding and reliable acquisition of physical bean characteristics. This study presents the design and implementation of an automated control and multi-sensor data acquisition system for a coffee grinder based on the Arduino Uno microcontroller. The electromechanical subsystem automates a 220 VAC electric motor using an active-low optocoupled relay connected to digital pin D13, operating under a precise 45-second timed grinding cycle. The integrated testing chamber incorporates a stabilized four-point LED illumination array governed via digital pin D5 through a 220 Ω current-limiting resistor to ensure consistent measurement conditions. Physical characteristic acquisition combines a TCS34725 digital color sensor operating over an I2C communication bus (pins A4 and A5) and a metal-oxide semiconductor gas sensor array (TGS2602, TGS2620, and MQ-135) interfaced with 10-bit analog-to-digital converter channels (pins A0, A1, and A2). The custom power distribution circuit steps down 12 VDC input into two isolated +5 VDC rails using dual LM7805 linear regulators with diode 1N5408 reverse-polarity protection and a 5×20 mm fuse, effectively isolating microcontroller logic from actuator inrush noise. Experimental test-point measurements confirmed supply rail stability at 4.97 V and idle I2C bus levels at 4.94 V (SDA) and 4.96 V (SCL). Baseline gas sensor characterization under ambient clean air yielded stable median voltages of 1.698 V (TGS2602), 1.058 V (MQ-135), and 0.210 V (TGS2620). Sensor telemetry is structured and streamed via UART serial communication at 500 ms intervals without packet loss. The developed platform demonstrates robust electromechanical sequencing and synchronized multi-sensor telemetry, establishing an objective hardware foundation for post-grind coffee evaluation.

DOI: https://doi.org/10.55927/marcopolo.v4i7.54
E-ISSN: 2986-8009
https://journal.formosapublisher.org/index.php/marcopolo

INTRODUCTION

Post-harvest processing of coffee beans involves roasting and grinding stages that directly determine the final physical and sensory quality of the brew. During ground coffee preparation, manual grinder operation often introduces particle size variations and inconsistent batch properties due to subjective timing. In addition, assessing post-roast ground coffee beans requires responsive instrumentation to capture physical characteristics objectively, reducing human observer bias caused by ambient illumination and fatigue.

Embedded microcontroller automation provides an effective approach for standardizing grinding cycles and streamlining multi-sensor data acquisition. The Arduino Uno board, based on the ATmega328P 8-bit RISC microcontroller, features 14 digital input/output pins, a 6-channel 10-bit analog-to-digital converter (ADC), and dedicated serial interfaces including I2C and UART. These hardware capabilities make it particularly suitable for controlling high-power electromechanical actuators and interfacing multi-modal sensor arrays.

This paper focuses exclusively on the engineering design, hardware implementation, and experimental evaluation of the Arduino-based control and multi-sensor acquisition system for a coffee grinder. The control subsystem coordinates a 220 VAC motor through an optocoupled relay with precise 45-second operational cycles. Simultaneously, the acquisition subsystem integrates a TCS34725 digital color sensor and a metal-oxide semiconductor gas sensor array (TGS2602, TGS2620, and MQ-135) to measure physical ground coffee attributes, streaming structured telemetry via USB UART at 500 ms intervals.

LITERATURE REVIEW

Microcontrollers serve as dedicated embedded control units in industrial automation and precision instrumentation. Operating at 16 MHz with integrated flash memory, SRAM, and EEPROM, single-chip microcontrollers reliably execute deterministic control algorithms without the operating system overhead typical of personal computers.

Electromechanical relay modules provide robust galvanic isolation between low-voltage digital control circuits (5 VDC) and high-voltage AC mains (220 VAC). Utilizing an optocoupled trigger with an active-low switching configuration prevents spurious gate triggering during microcontroller power-up transitions, ensuring reliable motor engagement and disengagement.

Multi-sensor integration for coffee analysis requires stable physical measurement environments. Digital color sensing using the TCS34725 provides red, green, blue (RGB), and unfiltered clear (C) light intensity data through an integrated infrared-blocking filter and internal 16-bit ADCs over an I2C bus. Concurrently, Taguchi gas sensors (TGS series) and MQ series metal-oxide sensors exhibit conductivity shifts when reacting with volatile organic compounds and thermal degradation products from roasted coffee grounds. Stabilizing supply rails and capturing baseline voltages under clean air are essential for accurate analog telemetry.

METHODOLOGY

The system architecture comprises three primary functional layers: the sensor acquisition layer, the embedded control core (Arduino Uno), and the actuation and serial communication interface. The mechanical platform utilizes a heavy-duty coffee grinder driven by a 220 VAC electric motor, coupled with an enclosed sample inspection chamber containing the optical and gas sensing modules.

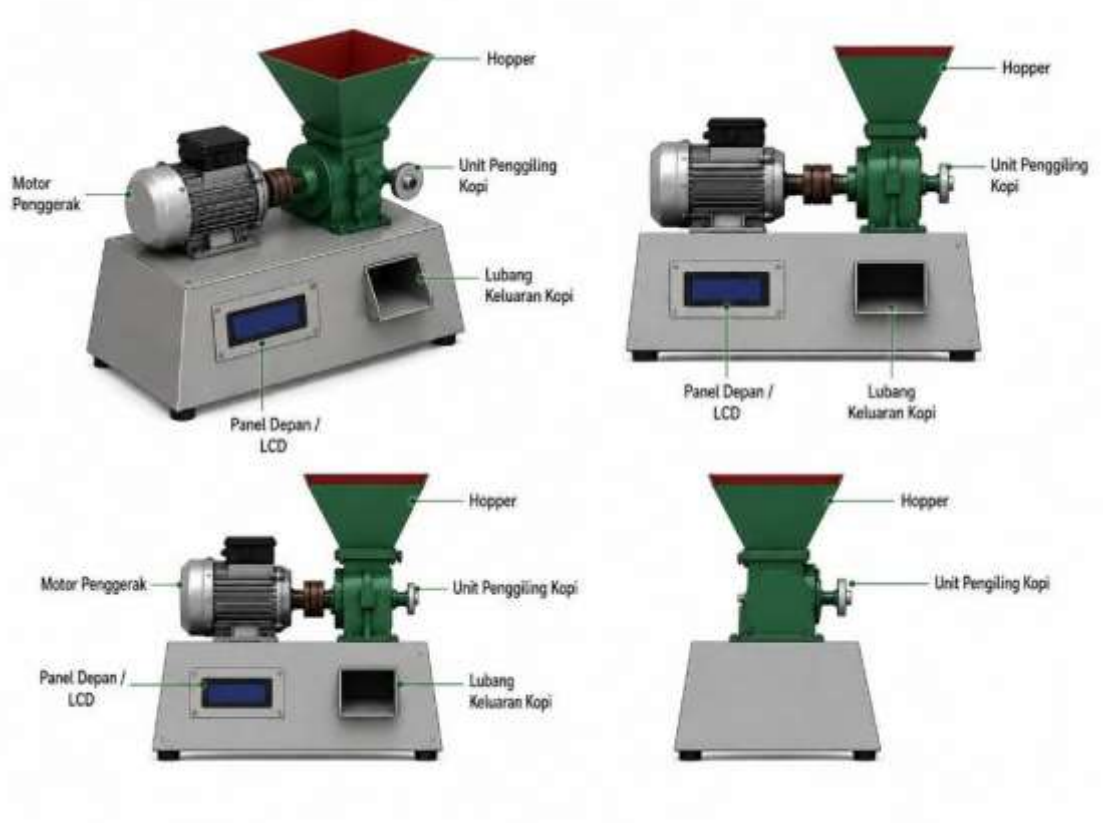


Figure 1. Mechanical Assembly and Physical Construction of the Automated Coffee Grinder System

Power Supply and Distribution Circuit

The electronic subsystem is powered by an external 12 VDC / 3 A regulated power source. To eliminate electrical transients and voltage dips caused by motor inrush current, the power distribution circuit incorporates two independent LM7805 voltage regulators (TO-220 package), providing isolated +5VDC1 and +5VDC2 rails. Reverse polarity protection is implemented via a 1N5408 diode, and an inline 5×20 mm fuse protects against overcurrent conditions. Electrolytic filtering capacitors (1000 µF on the input, 470 µF on the output) suppress low-frequency ripple.

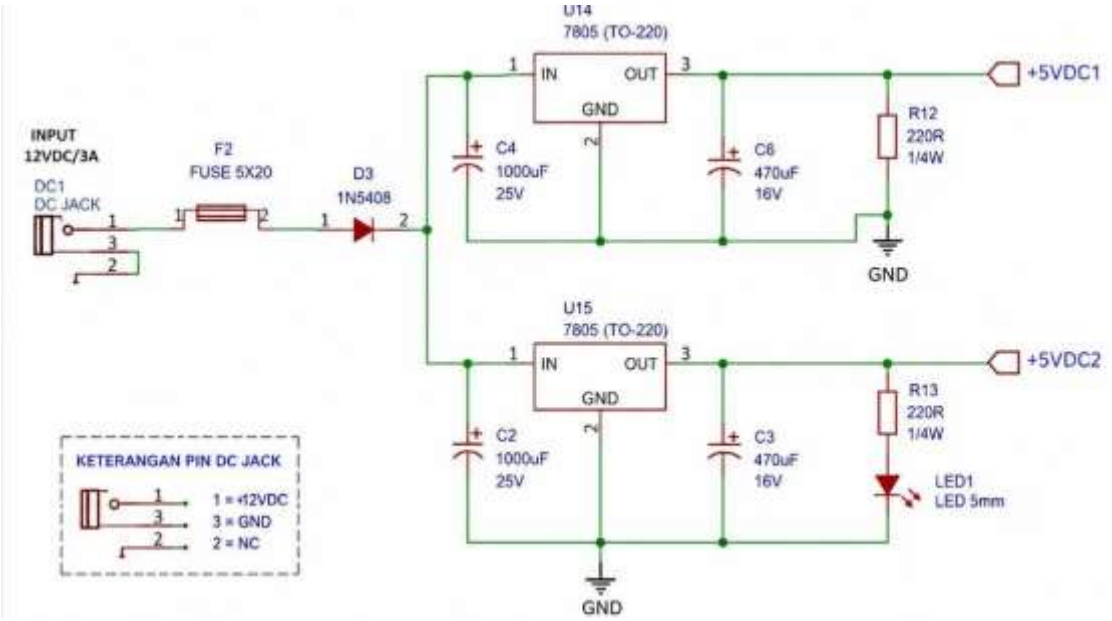


Figure 2. Dual-Rail Regulated 5 VDC Power Supply Schematic with Reverse-Polarity and Overcurrent Protection

Relay Control and Actuator Interfacing

The 220 VAC grinder motor is governed by a Songle SRD-05VDC-SL-C single-channel relay module featuring optocoupler isolation. The control signal connects to digital pin D13 of the Arduino Uno. The firmware employs active-low logic: asserting a LOW state energizes the relay coil, closing the Normally Open (NO) contact and powering the motor. After an elapsed grinding interval of exactly 45,000 ms (tracked using the non-blocking millis() timer), digital pin D13 is set HIGH, de-energizing the relay and halting the motor.

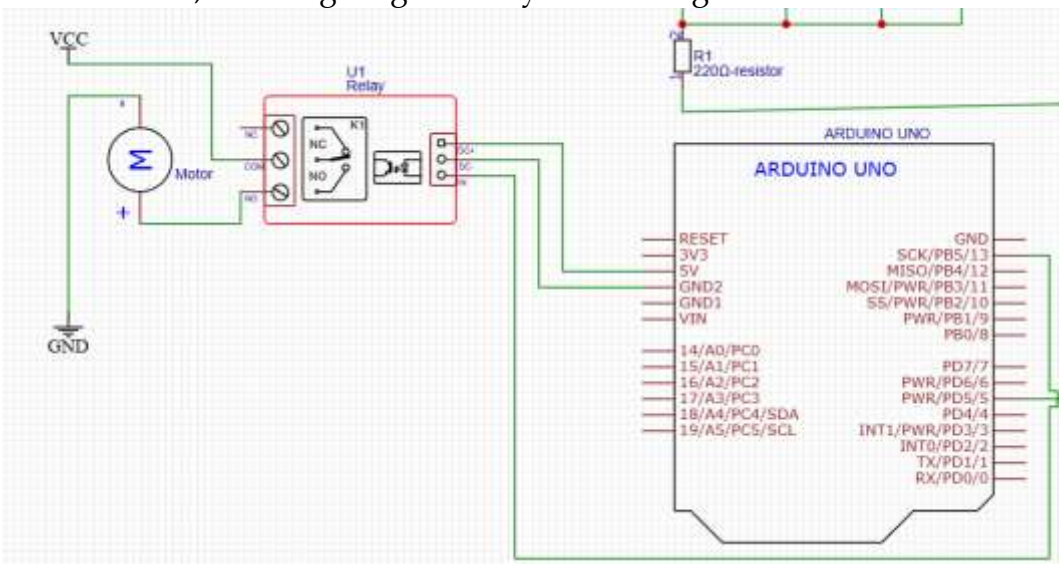


Figure 3. Optocoupled Relay Interfacing Circuit for 220 Vac Electric Grinder Motor Control

Multi-Sensor Hardware Wiring and Chamber Illumination

The inspection chamber features four white LEDs wired in parallel through a 220 Ω current-limiting resistor, controlled via digital pin D5 to supply stable illumination during optical measurement. The TCS34725 color sensor interfaces via I2C using pin A4 (SDA) and pin A5 (SCL). The gas sensor array consists of three metal-oxide sensors (TGS2602, TGS2620, and MQ-135) with their analog output pins connected directly to 10-bit ADC channels A0, A1, and A2.

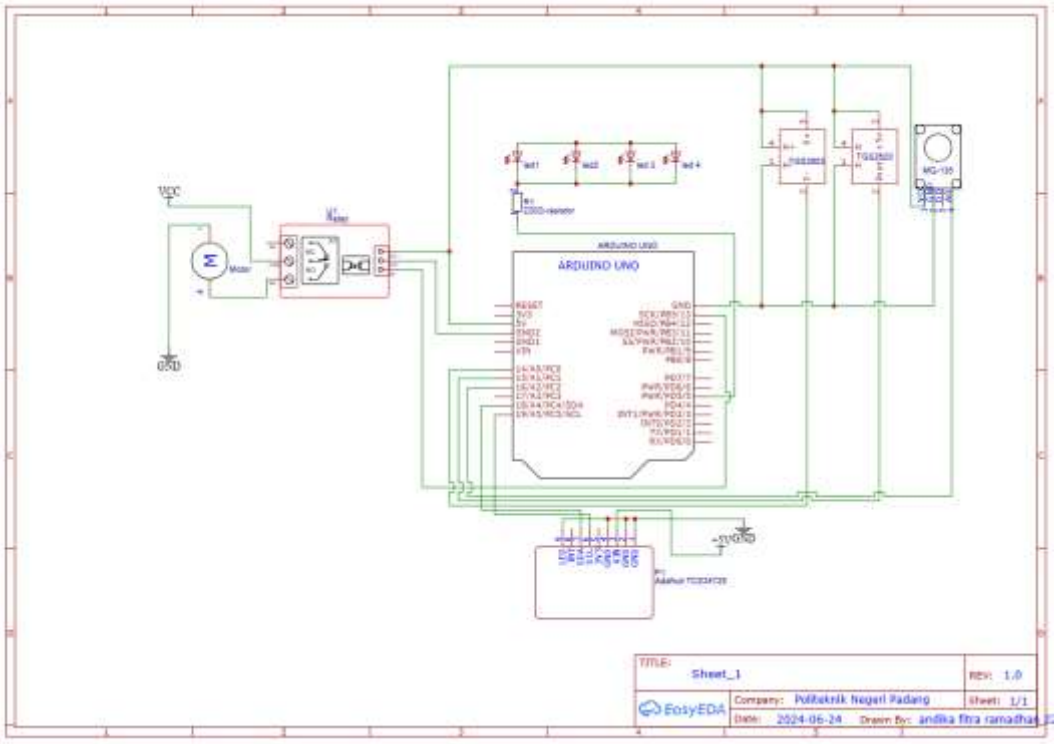


Figure 4. Complete Electrical Schematic Diagram of the Arduino Uno Controller and Sensor Wiring

Table 1. Pin Interfacing and Hardware Wiring Allocation on Arduino Uno

Module / Sensor	Module Pin	Pin Function	Arduino Uno Pin	Power Rail
Relay Module 5 V	IN	Relay Control (Active-LOW)	Digital Pin D13	+5 VDC (Rail 2)
Chamber LED Array	Anode (+)	Illumination Supply	Digital Pin D5 (via 220 Ω)	Arduino Board
TCS34725 Color Sensor	SDA	I2C Serial Data	Analog Pin A4	+5 VDC (Rail 1)
TCS34725 Color Sensor	SCL	I2C Serial Clock	Analog Pin A5	+5 VDC (Rail 1)
TGS2602 Gas Sensor	OUT / AO	Analog Sensor Output	Analog Pin A0	+5 VDC (Rail 2)
TGS2620 Gas Sensor	OUT / AO	Analog Sensor Output	Analog Pin A1	+5 VDC (Rail 2)

MQ-135 Gas Sensor	OUT / AO	Analog Sensor Output	Analog Pin A2	+5 VDC (Rail 2)
Common Ground	GND	System Ground Reference	GND Bus	GND

RESULTS AND DISCUSSION

Electrical Test-Point Verification

Electrical validation was conducted across four critical test points (TP1 to TP4) using a calibrated digital multimeter during active system operation. As detailed in Table 2, the module supply voltage at TP1 remained steady at 4.97 V, well within the allowable operating range of the ATmega328P and peripheral modules. Internal regulation within the TCS34725 module maintained a 3.28 V core voltage, matching its 3.3 V IC specification. Idle I2C communication lines measured 4.94 V on SDA (TP3) and 4.96 V on SCL (TP4), confirming that pull-up resistors maintain stable logic-HIGH states during inactive bus phases.

Table 2. Multimeter Voltage Measurements across Electrical Test Points

Test Point	Measurement Location	Nominal Reference	Measured Voltage	Operational Status
TP1	VIN / VCC Module Pin	5.00 V	4.97 V	Normal (Within ±1% Tolerance)
TP2	Circuit Ground (GND)	0.00 V	0.00 V	Normal (Common Reference)
TP3	SDA (I2C Data Line)	5.00 V	4.94 V	Normal (Logic HIGH Pull-up)
TP4	SCL (I2C Clock Line)	5.00 V	4.96 V	Normal (Logic HIGH Pull-up)

Relay Timing and Grinding Motor Control Evaluation

The relay control subsystem underwent 10 consecutive automated grinding trials. In each trial, receiving the start command over serial UART successfully triggered the relay, energizing the 220 VAC motor. Motor run times recorded via external digital chronometer averaged 45.012 ± 0.015 seconds. The dual LM7805 regulator topology prevented electrical reset events (brownouts) on the Arduino Uno during both motor start inrush and inductive turn-off transient spikes.

TCS34725 Color Sensor Response across Coffee Samples

The optical response of ground coffee samples was evaluated under constant LED chamber lighting across three roast degrees (Light, Medium, and Dark Roast). The Arduino converted 16-bit photodiode readings into standardized 8-bit RGB channels. As shown in Table 3, the unfiltered Clear Raw channel exhibited a distinct downward progression from 44.50 (Light Roast) and 46.50 (Medium Roast) to 16.00 (Dark Roast). This significant attenuation reflects the increased light absorption characteristic of darker roast particles.

Table 3. TCS34725 Mean Color Channel Measurements Across Ground Coffee Roast Levels

Roast Degree	Red Channel (R)	Green Channel (G)	Blue Channel (B)	Clear Raw Value	Mean RGB
Light Roast	14.60	16.50	13.50	44.50	14.87
Medium Roast	13.50	17.20	14.20	46.50	14.97
Dark Roast	4.50	6.40	5.40	16.00	5.43

Gas Sensor Array Baseline and Sample Characterization

Baseline voltage characterization was established under ambient clean air conditions for 10 seconds prior to coffee exposure. Voltage outputs were derived from 10-bit ADC readings according to Vout = (ADC / 1023) × 5.0 V. As recorded in Table 4, clean air baseline voltages averaged 1.698 V (347.5 ADC) for TGS2602, 1.058 V (216.5 ADC) for MQ-135, and 0.210 V (43.0 ADC) for TGS2620.

Table 4. Clean Air Baseline Voltage and ADC Measurements for the Gas Sensor Array

Sensor Model	Analog ADC Pin	10 s ADC Reading Range	Median Baseline ADC	Baseline Voltage (Vout)
TGS2602	Pin A0	343 – 354	347.5	1.698 V
MQ-135	Pin A2	207 – 228	216.5	1.058 V
TGS2620	Pin A1	41 – 45	43.0	0.210 V

Upon introducing coffee samples into the chamber, sensor conductivity shifted due to surface chemical interactions. The MQ-135 sensor exhibited the strongest sensitivity to roast intensity, rising from 148.08 ADC (Light Roast) to 160.33 ADC (Medium Roast) and reaching 240.28 ADC (Dark Roast). This 62.3% surge reflects the release of pyrolytic volatile compounds during intense roasting. Sensor telemetry was transmitted continuously via serial UART at 500 ms intervals without data corruption or buffer overflow.

CONCLUSIONS AND RECOMMENDATIONS

An automated control and multi-sensor data acquisition system for a coffee grinder was successfully developed using an Arduino Uno microcontroller. The optocoupled relay circuit reliably commanded a 220 VAC electric motor over repeatable 45-second operational intervals. The isolated dual LM7805 regulator circuit effectively prevented electrical reset transients during motor switching. Multi-sensor data acquisition captured clear optical distinctions via the TCS34725 color sensor and gas concentration shifts across the TGS2602, TGS2620, and MQ-135 array, streaming synchronized telemetry over USB UART at 500 ms intervals. Future enhancements will focus on implementing closed-loop rotational speed

control and automated active purging in the gas sensor chamber to improve sensor recovery times.

ACKNOWLEDGMENT

The authors express their sincere gratitude to the Department of Electrical Engineering, Politeknik Negeri Padang, for providing laboratory facilities, instrumentation support, and academic guidance throughout the development and evaluation of this coffee grinder control and acquisition system.

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