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Arduino Nano-Based Control System for Temperature Monitoring and Fuel Flow Regulation in a Bioethanol Stove

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A R T I C L E I N F O

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A B S T R A C T

Abstract — Stable bioethanol stove operation requires coordinated temperature acquisition and fuel delivery. This study presents an Arduino Nano control platform for a wickless stove. Two K-type thermocouples are digitized by independent MAX6675 modules and averaged every 2 s. A 4×4 keypad and 20×4 I2C LCD provide input and status, while D11 supplies PWM through an L298N driver to a 12 V pump. Thermocouple tests from 100 to 200 °C produced 1.63% mean error. L298N tests at PWM 140–160 produced 2.00% mean voltage error. Sixteen-point pump calibration increased flow from 0.045 to 0.964 mL/s and yielded $Q = 0.012574(PWM) - 1.3794$ with $R^2 = 0.9585$. The results verify the embedded sensing and fuel-flow actuation chain

INTRODUCTION

Bioethanol can be produced from sugar- and starch-containing biomass, including sugarcane molasses, and used as a renewable liquid fuel [1], [2]. In a wickless bioethanol stove, the rate at which fuel reaches the burner affects evaporation, flame intensity, and the resulting temperature. Previous stove experiments have also shown that bioethanol grade and burner configuration influence temperature distribution and thermal performance [3]. A practical stove therefore needs an embedded platform that can acquire high-temperature measurements and regulate fuel delivery consistently.

K-type thermocouples are suitable for combustion measurements because they tolerate a wide temperature range and respond directly to changes at the hot junction. The MAX6675 provides cold-junction compensation and converts a K-type thermocouple signal into a 12-bit, 0.25 °C digital reading through an SPI-compatible interface [5]. An Arduino Nano can coordinate several such interfaces while also scanning a keypad, updating a display, and producing an 8-bit PWM command [4]. Because a pump requires more current than a microcontroller pin can supply, the PWM command must be applied through a motor driver such as the L298 [7].

This study develops and validates the Arduino-side control chain of a bioethanol stove. The contribution is an integrated embedded platform that averages two independent temperature channels, accepts operating commands through a 4×4 keypad, presents status on a 20×4 I2C LCD, and controls a 12 V mini pump through PWM. Evaluation covers the thermocouple measurement circuit, L298N output response, and the empirical relationship between PWM and bioethanol flow. These component-level tests establish whether the sensing and actuation hardware can support repeatable stove operation.

LITERATURE REVIEW

Sugarcane processing produces molasses that retains fermentable sugars. Fermentation and distillation can convert this material into bioethanol [1], [2]. When bioethanol is supplied to a wickless burner, fuel delivery and vaporization determine how much vapor is available for combustion. Pratama, Sanata, and Sutjahjono reported that bioethanol grade affects flame-temperature distribution and stove performance, confirming that fuel-side operating conditions must be controlled during thermal tests [3].

The MAX6675 is designed specifically for K-type thermocouples. It performs cold-junction compensation, detects an open thermocouple, and returns temperature data at 0.25 °C resolution [5]. Septiana et al. demonstrated that a K-type thermocouple and MAX6675 can be integrated with Arduino-based data acquisition, while also emphasizing the need for calibration before quantitative use [6]. Using two channels in the present system provides measurements at two burner locations; their arithmetic mean is used as the representative stove temperature.

PWM changes the average electrical power delivered to a DC actuator by changing the ratio of active time to one switching period. Lubis and Yanie used Arduino-generated PWM to regulate a DC pump in a liquid-transfer system [8].

The L298 dual full-bridge driver accepts TTL-level control signals and can drive inductive loads, including DC motors [7]. Actual pump flow nevertheless depends on the motor, supply, tubing, and hydraulic load, so a measured PWM-to-flow relationship is required for the assembled stove rather than assuming a purely theoretical proportional response.

METHODOLOGY

System Architecture

The prototype is a wickless stove with a separate bioethanol tank, a mini DC pump, a burner, two K-type thermocouples, and a front control panel. The controller enclosure contains an Arduino Nano, two MAX6675 modules, a 4×4 keypad, a 20×4 LCD with an I2C backpack, an L298N driver, and the required power distribution. The control electronics operate at 5 V, whereas the driver and pump use a 12 V rail. The mechanical arrangement is shown in Figure 1.

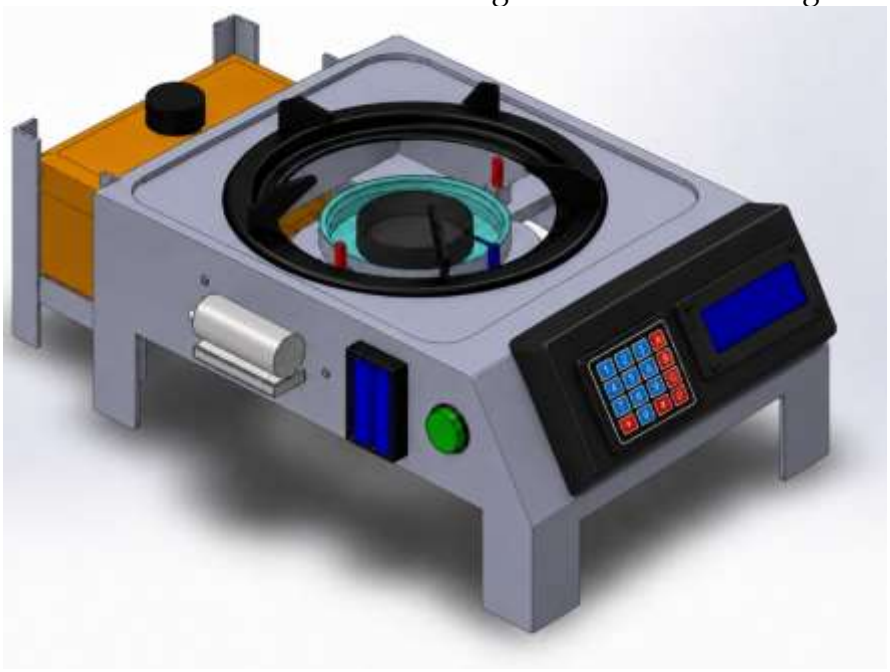


Figure 1. Mechanical Design of the Arduino-Controlled Bioethanol Stove

Electrical Integration

Each thermocouple has a dedicated MAX6675 channel. Sensor 1 uses D5 for SO, D6 for CS, and D7 for SCK; Sensor 2 uses D8, D9, and D10 for the same functions. The keypad occupies D2-D4, D12, and A0-A3. The LCD uses A4 for SDA and A5 for SCL at address 0x27. Pin D11 is connected to the ENA input of the L298N and supplies the pump PWM command. IN1 is held at 5 V and IN2 at ground so the pump rotates in one fixed direction. The complete wiring and pin allocation are shown in Figure 2 and Table 1.

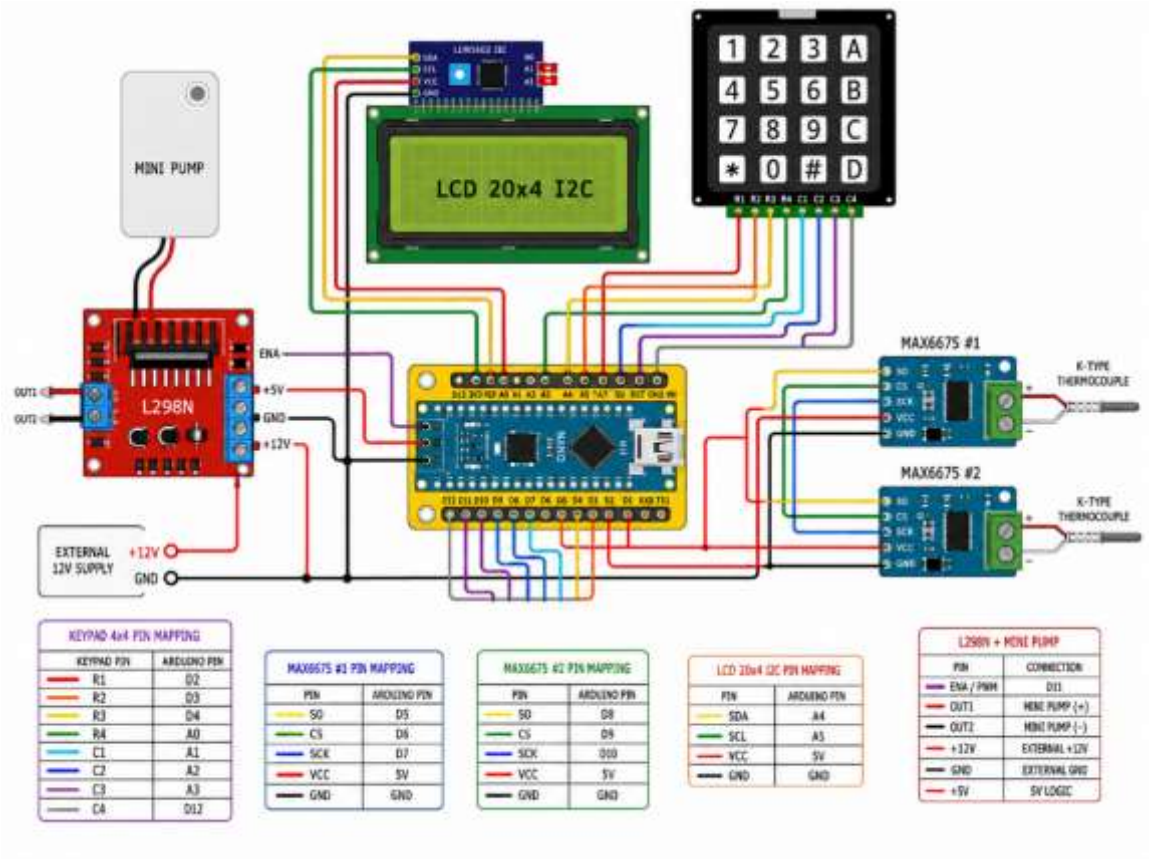


Figure 2. Complete Arduino Nano Controller, Sensing, Display, Keypad, and Pump Wiring

Table 1. Arduino Nano Interface Allocation

Subsystem	Signal	Arduino Nano pin	Function
MAX6675 channel 1	SO / CS / SCK	D5 / D6 / D7	Temperature channel 1
MAX6675 channel 2	SO / CS / SCK	D8 / D9 / D10	Temperature channel 2
Keypad rows	R1 / R2 / R3 / R4	D2 / D3 / D4 / A0	Matrix row scanning
Keypad columns	C1 / C2 / C3 / C4	A1 / A2 / A3 / D12	Matrix column scanning
LCD 20×4 I2C	SDA / SCL	A4 / A5	User display
L298N	ENA	D11 (PWM)	Pump power command
L298N	IN1 / IN2	5 V / GND	Fixed pump direction

Embedded Firmware Sequence

During setup, the firmware starts serial communication at 9600 bit/s, initializes the LCD, configures D11 as an output, and forces the pump command to zero. The main loop scans the keypad continuously. In the flame-stabilization path, key B opens the flame-size menu and keys 1, 2, or 3 select small, medium, or large delivery. The Arduino first applies PWM 110 for 200 ms to prime the pump. It then produces 30 ms pump pulses at PWM 110, separated by 950, 850, or 750 ms according to the selected level. Timing uses millis() so keypad and display handling remain responsive between pulses. Key D immediately sets PWM to zero and returns the system to standby.

The Arduino reads both MAX6675 channels every 2 s and calculates their arithmetic mean. The LCD displays the operating state, mean temperature, and selected delivery interval. The firmware states and outputs are summarized in Table 2. This article evaluates the embedded sensing and actuation implementation; it does not evaluate a higher-level command-generation model.

Table 2. Firmware States For Arduino-Based Fuel Delivery

State	User command	Pump output	Displayed information
Standby	Power-up or D	PWM 0	Menu, temperature, stopped status
Flame selection	B	PWM 0	Small, medium, or large option
Small flame	1	PWM 110 for 30 ms; 950 ms off	Temperature and 950 ms interval
Medium flame	2	PWM 110 for 30 ms; 850 ms off	Temperature and 850 ms interval
Large flame	3	PWM 110 for 30 ms; 750 ms off	Temperature and 750 ms interval

Experimental Procedures

Thermocouple output was measured at six setpoints from 100 to 200 °C. The two channel voltages were averaged and compared with the report's 41 μV/°C reference approximation. The reference voltage and percentage error were calculated using Equations (1) and (2), where T is the temperature setpoint, Vavg is the average of the two measured channel voltages, and Vref is the reference voltage.

$$Vref\,(mV) = 0.041\,T \quad (1)$$

$$Error\,(\%) = |Vavg - Vref| / Vref \times 100 \quad (2)$$

The L298N output was measured with a 12 V supply at PWM commands of 140, 145, 150, 155, and 160. The theoretical average voltage was calculated with

Equation (3). Fuel-flow calibration used a fixed 17 mL collection volume. For each PWM command from 105 to 180 in steps of five, the collection time was recorded and flow Q was calculated with Equation (4). A least-squares linear regression was then fitted to all 16 measurements.

$$VPWM = PWM / 255 \times 12\ V \quad (3)$$

$$Q\ (mL/s) = 17\ mL / collection\ time\ (s) \quad (4)$$

RESULTS AND DISCUSSION

Thermocouple Measurement Verification

Table 3 presents the two measured voltages, their average, and the 41 µV/°C reference. The individual errors ranged from 0.70% to 4.67%, with a mean of 1.63%. The largest deviation occurred at 120 °C, where the average measured voltage was 5.15 mV compared with the 4.92 mV reference. Across the remaining setpoints, the error did not exceed 1.22%. The response remained monotonic over the full 100-200 °C interval, as shown in Figure 3.

Table 3. K-Type Thermocouple Voltage Verification

Setpoint (°C)	Sensor 1 (mV)	Sensor 2 (mV)	Average (mV)	Reference (mV)	Error (%)
100	3.9	4.2	4.05	4.10	1.22
120	5.1	5.2	5.15	4.92	4.67
140	5.6	5.8	5.70	5.74	0.70
160	6.4	6.6	6.50	6.56	0.91
180	7.2	7.4	7.30	7.38	1.08
200	8.0	8.2	8.10	8.20	1.22

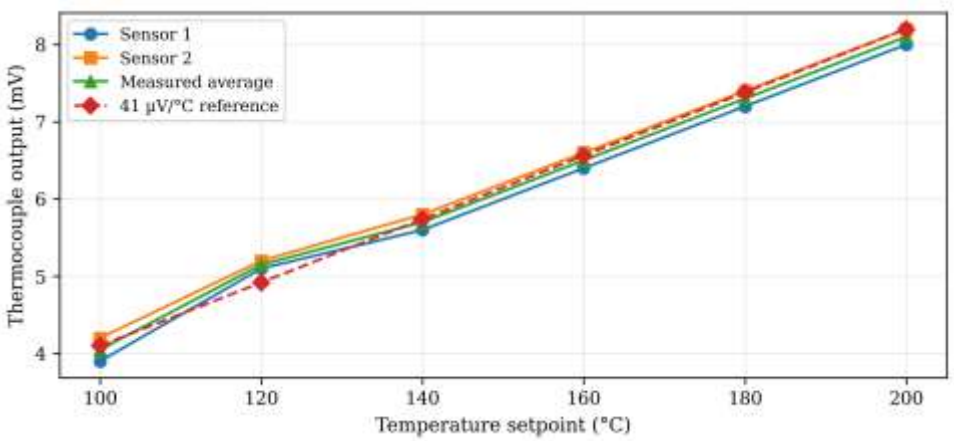


Figure 3. Measured Thermocouple Outputs and the 41 µv/°C Reference

The close agreement supports use of the dual-channel circuit for embedded monitoring, but the test compares voltage with a linear datasheet approximation

rather than a traceable temperature standard. Septiana et al. similarly note that MAX6675-based acquisition should be calibrated for quantitative measurements [6]. A reference thermometer or calibrated dry-block source would therefore be required before reporting metrological accuracy for the complete temperature channel.

L298N Output Verification

Increasing the PWM command from 140 to 160 raised the measured L298N output from 6.44 to 7.39 V. The corresponding theoretical values were 6.59 and 7.53 V. Table 4 shows that the measured output was consistently 0.13-0.15 V below the simple PWM average, and the mean percentage error was 2.00%. This monotonic response confirms that D11 and ENA form a usable electrical control path for the pump, while the small voltage difference reflects losses in the assembled driver circuit.

Table 4. L298N Output with a 12 V Supply

PWM	Measured (V)	Theoretical (V)	Difference (V)	Error (%)
140	6.44	6.59	0.15	2.25
145	6.68	6.82	0.14	2.10
150	6.92	7.06	0.14	1.97
155	7.16	7.29	0.13	1.84
160	7.39	7.53	0.14	1.85

PWM-to-Flow Calibration

The 16-point calibration results are listed in Table 5. With the collection volume fixed at 17 mL, the measured time decreased from 380.13 s at PWM 105 to 17.63 s at PWM 180. The corresponding flow increased from 0.045 to 0.964 mL/s. The least-squares fit produced Equation (5) with $R^2 = 0.9585$.

Table 5. Fuel-Flow Measurements Using A 17 Ml Collection Volume

No.	PWM	Collection time (s)	Flow Q (mL/s)
1	105	380.13	0.045
2	110	285.22	0.060
3	115	179.75	0.095
4	120	125.72	0.135
5	125	97.88	0.174
6	130	77.05	0.221
7	135	69.04	0.246

No.	PWM	Collection time (s)	Flow Q (mL/s)
8	140	55.96	0.304
9	145	42.92	0.396
10	150	40.39	0.421
11	155	30.72	0.553
12	160	28.53	0.596
13	165	25.02	0.679
14	170	21.91	0.776
15	175	18.23	0.933
16	180	17.63	0.964

$$Q\ (mL/s) = 0.012574(PWM) - 1.3794 \quad (5)$$

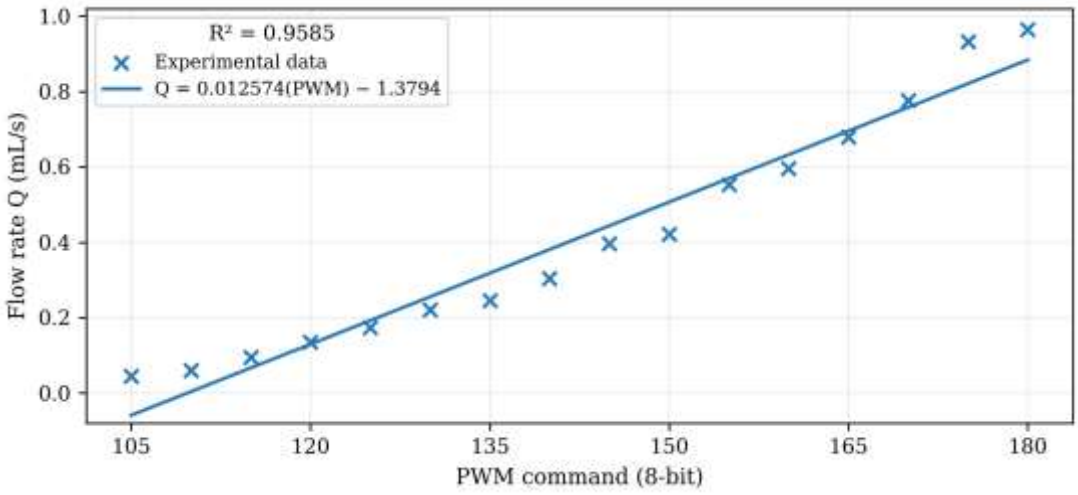


Figure 4. Experimental Pwm-To-Flow Data and Linear Regression

The high R^2 indicates a strong overall linear association within the tested hardware configuration. However, the low-PWM points deviate from the fitted line, and the negative intercept has no physical meaning for a stopped pump. Equation (5) should therefore be used only as an empirical description of the tested range and must not be extrapolated below it. The firmware's 30 ms pulse mode also requires separate pulse-volume validation because the calibration used continuous operation; pump startup dynamics may affect very short delivery events.

CONCLUSIONS AND RECOMMENDATIONS

An Arduino Nano-based temperature acquisition and fuel-flow control platform was implemented for a wickless bioethanol stove. The controller acquires two MAX6675 temperature channels, scans a 4×4 keypad, updates a

20×4 I2C LCD, and drives a 12 V mini pump through the D11 PWM output and an L298N driver. Thermocouple voltage verification from 100 to 200 °C produced a mean error of 1.63% against the 41 μV/°C reference approximation. L298N testing at PWM 140-160 produced a mean voltage error of 2.00%. Pump calibration from PWM 105 to 180 increased measured flow from 0.045 to 0.964 mL/s and yielded $Q = 0.012574(PWM) - 1.3794$ with $R^2 = 0.9585$.

The results verify the complete Arduino sensing and actuation path at component level. Before deployment, the temperature channels should be calibrated against a traceable reference, and the delivered volume of the 30 ms pump pulses should be measured directly. Further development should add flame and fuel-leak detection, current monitoring, and a fail-safe cutoff independent of the main program.

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