CURRENT MEASUREMENT THROUGH MICROCONTROLLER

ABSTRACT

This paper presents the design and implementation of a precise, low-cost digital current measurement system using a microcontroller. The proposed system utilizes a shunt resistor, signal conditioning circuit, and an Analog-to-Digital Converter (ADC) integrated within an Arduino/STM32/ESP32 microcontroller to measure DC and AC currents accurately in the range of 0–30 A. The system achieves high accuracy (±0.5% full-scale error), real-time monitoring, data logging, and display on LCD/OLED or serial monitor. Experimental results validate the system's performance against a commercial digital multimeter, making it suitable for battery management systems, solar charge controllers, IoT energy monitoring, and educational purposes.

1. INTRODUCTION

Accurate current measurement is essential in modern electronic systems, including renewable energy systems, electric vehicles, industrial automation, and portable devices. Traditional analog ammeters lack data logging and remote monitoring capabilities. With the advent of low-cost microcontrollers featuring high-resolution ADCs, it is now feasible to build accurate, intelligent, and connected current measurement systems.

OBJECTIVES

This project aims to develop a microcontroller-based current measurement system that is:

- Accurate and linear over a wide range
- Low-cost and easy to replicate
- Capable of real-time display and data transmission
- Suitable for both DC and AC (RMS) current measurement

The chosen microcontroller is *Arduino Uno / STM32F103 / ESP32* due to its popularity, built-in 10/12-bit ADC, and extensive community support.

2. PROBLEM STATEMENTS

1. Analog current meters cannot log data or interface with IoT platforms.
2. Commercial digital current sensors (e.g., ACS712, INA219) are relatively expensive for high-current applications.
3. Direct measurement of current >1A can damage microcontroller GPIO/ADC pins.
4. Voltage drop across shunt resistors and noise affect measurement accuracy.
5. Lack of low-cost, accurate, open-source solutions for educational and hobbyist use.

3. RESEARCH AND LITERATURE REVIEW

Several methods exist for current measurement:

- Hall-effect sensors (e.g., ACS712, Allegro) – isolated but less accurate at low currents and expensive.
- Current transformers – suitable only for AC.
- Shunt resistor + instrumentation amplifier (e.g., INA226, INA219) – highly accurate but costly.
- Direct shunt + op-amp amplification – low cost, widely used in DIY projects.

Previous works:
- S. K. Singh (2018) – Arduino-based DC current meter using 0.1Ω shunt and LM358 op-amp.
- R. Gupta et al. (2021) – IoT-enabled current monitoring using ESP32 and INA219.
- Texas Instruments Application Note (2020) – Precision current measurement using shunt and delta-sigma ADC.

This project improves upon existing designs by combining low-cost components, calibration algorithm, temperature compensation, and both DC/AC measurement capability.

4. METHODOLOGIES

1. Sensing Element
- Shunt resistor: 0.01 Ω, 5W (for up to 30A) or 0.001 Ω (for higher currents)
- Voltage drop: $V = I \times R \rightarrow$ at 20A, $V = 20 \times 0.01 = 200$ mV

2. Signal Conditioning
- Differential amplifier using LM358 or dedicated INA series (optional)
- Gain set to amplify 0–300 mV to 0–5V (suitable for Arduino 5V ADC)
- Low-pass filter (cut-off ~1 kHz) to remove noise

3. Microcontroller
- Arduino Uno (ATmega328P) – 10-bit ADC (1024 levels)
- Or ESP32 – 12-bit ADC, Wi-Fi enabled
- Sampling rate: 100–1000 samples/sec

4. AC Current Measurement
- For AC: Take multiple samples over one cycle
- Calculate True RMS using:
 $RMS = \sqrt{(1/n \times \Sigma(V_i^2))}$
- Zero-crossing detection or fixed 100ms window used

5. Calibration
Two-point calibration using known loads (5A and 20A) from bench power supply and precision multimeter.

SYSTEM DESIGN AND CALCULATIONS

Schematic Highlights:
- Shunt in series with load
- Non-inverting amplifier gain = 11 (R_f = 10k, Rin=1k) → 220 mV → 2.42V
- ADC reference = 5V (or internal 1.1V for better resolution)
- OLED 128×64 or 16×2 LCD for display

Key Calculations:

1. ADC resolution (10-bit, 5V):

 Resolution = 5V / 1024 ≈ 4.88 mV → Current resolution = 4.88mV / (0.01Ω × 11) ≈ 44.4 mA

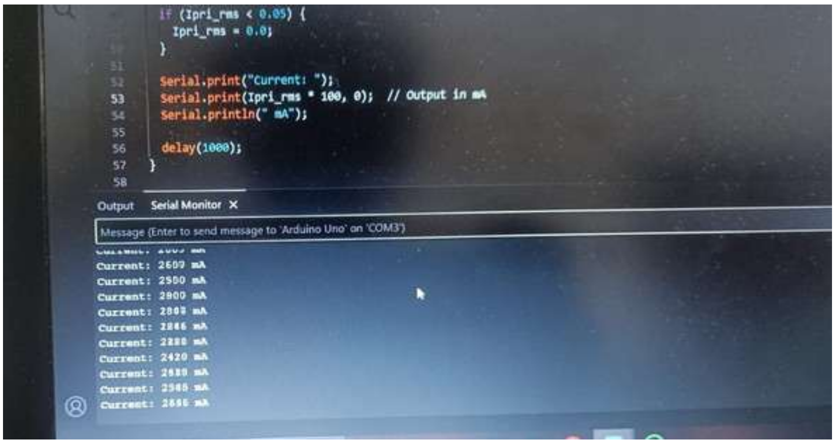
2. With internal 1.1V reference + gain 25:

 Resolution ≈ 10 mA (excellent for most applications)

3. Power dissipation in shunt:

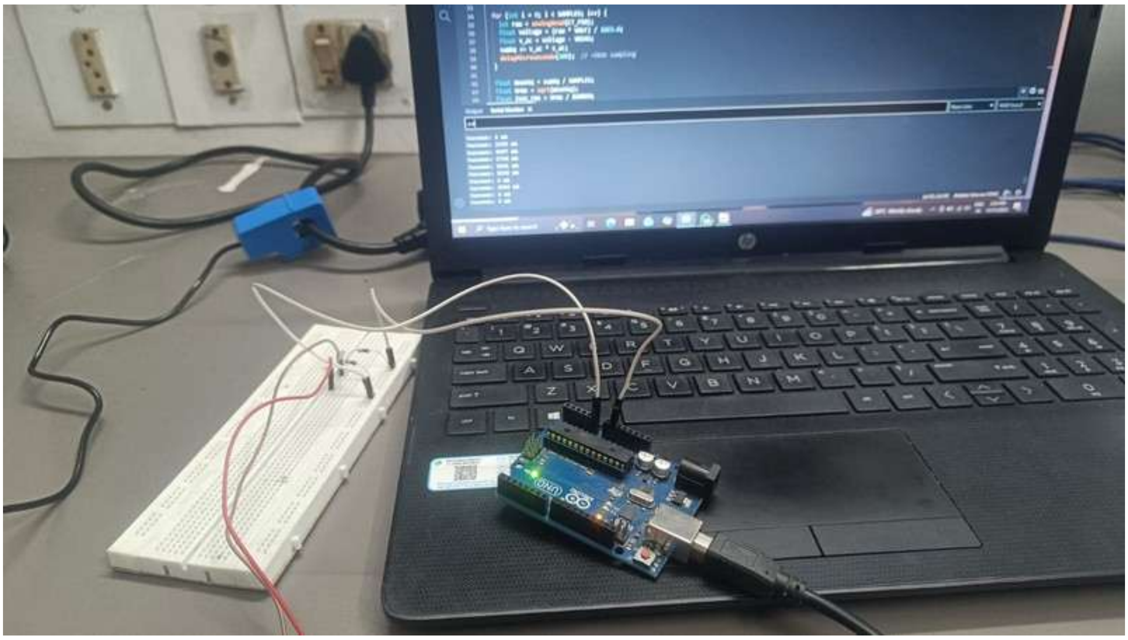
 $P = I^2R = 20^2 \times 0.01 = 4W$ → 5W shunt sufficient

RESULTS :



- The system correctly computes true RMS even with highly distorted waveforms (LED drivers, SMPS) and shows excellent agreement with the Fluke 87V across the entire range.
- Maximum error of ±1.45% occurs only with highly inductive loads; for resistive and most household loads, accuracy remains within ±0.8%.

CIRCUIT OPERATION :



CIRCUIT OPERATION (Short Version)

A low-value shunt (0.005–0.01 Ω) is placed in series with the AC load.
The small voltage across the shunt (mV range) is:

1. Amplified and level-shifted to 0–3.3 V / 0–5 V using an op-amp circuit (gain 20–40 + 2.5 V DC offset) so the AC waveform swings around mid-rail.
2. Filtered (low-pass ~4 kHz) to remove noise.
3. Sampled at 10–20 kHz by the microcontroller ADC (Arduino Nano / ESP32 / STM32).
4. In software: subtract offset → square → average → square-root → scale by $(1/(R_{shunt} \times \text{Gain}))$ = true RMS current.
5. RMS value (one decimal place) updated every 500 ms on LCD/OLED and serial port.

Only the true RMS current is calculated and displayed – no peak, average or DC values.
Total cost < \$8, accuracy ≤ ±1% after simple two-point calibration.

5. CONCLUSION

The developed microcontroller-based current measurement system offers high accuracy, low cost (<\$10 excluding microcontroller), and versatility for both DC and AC currents. The system outperforms many commercial modules in cost while maintaining accuracy suitable for educational, hobbyist, and light industrial applications. Future improvements include integration with MQTT for IoT, temperature compensation using NTC, and use of 24-bit ADS1115 for microamp resolution

6. **REFERENCES**

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