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LOW-POWER MULTI-SENSOR EXTENSION FOR WEMOS CONTROLLERS USING MULTIPLEXED ANALOG INPUTS

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Abstract

The increasing demand for low-cost, compact, and energy-efficient IoT systems has highlighted the limitations of microcontroller units (MCUs) such as the WeMOS D1 Mini, which are constrained by a single analog input pin. This is a major challenge for applications that require multiple analog sensors, such as environmental monitoring or smart agriculture. This paper presents a hardware-based solution using the CD74HC4067 16-channel analog multiplexer to expand the analog input capacity of the WeMOS controller. The system architecture allows multiple sensors to share a single analog input managed by digital control lines. The experimental implementation used six Light Dependent Resistor (LDR) sensors to evaluate accuracy, latency, and power efficiency. The results show that sensor reading accuracy remains within ±2% deviation, with an average channel switching latency of 42 milliseconds and only a 5% increase in total power consumption compared to a single sensor system. These results confirm that the multiplexing strategy maintains reliable performance while significantly improving scalability without compromising power constraints. The proposed approach provides a robust, low-power, and low-cost method for multi-sensor deployment on constrained MCUs, enabling broader application in resource-constrained IoT systems. Future developments may include cascading multiple multiplexers and integrating wireless data transmission for remote sensing applications.

Keywords: WeMOS D1, analog multiplexer, low-power IoT, sensor expansion, embedded systems

Abstrak

Kebutuhan yang terus meningkat terhadap sistem IoT yang hemat biaya, ringkas, dan efisien energi telah menyoroti keterbatasan mikrokontroler seperti WeMOS D1 Mini, khususnya jumlah pin input analog yang sangat terbatas. Hal ini menjadi tantangan besar bagi aplikasi yang memerlukan banyak sensor analog seperti pemantauan lingkungan dan pertanian cerdas. Penelitian ini mengusulkan solusi berbasis perangkat keras dengan menggunakan multiplexer analog 16-kanal CD74HC4067 untuk memperluas jumlah input analog pada mikrokontroler WeMOS. Arsitektur sistem memungkinkan banyak sensor berbagi satu pin analog, dikendalikan oleh beberapa pin digital sebagai pengendali kanal. Implementasi eksperimental dilakukan dengan enam sensor cahaya LDR untuk mengukur akurasi, latensi, dan efisiensi daya. Hasil eksperimen menunjukkan bahwa akurasi pembacaan sensor tetap dalam kisaran deviasi ±2%, dengan rata-rata latensi perpindahan kanal sebesar 42 milidetik, dan peningkatan konsumsi daya sistem hanya sebesar 5% dibandingkan dengan sistem satu sensor. Temuan ini menegaskan bahwa pendekatan multiplex ini memberikan performa yang andal dan efisien untuk pengembangan sistem sensor berskala besar. Pendekatan yang diajukan memberikan metode yang tangguh, hemat daya, dan efisien biaya untuk memperluas kapasitas sensor pada mikrokontroler terbatas, sehingga dapat memperluas penerapan sistem IoT dalam berbagai kondisi dengan sumber daya terbatas. Pengembangan selanjutnya dapat diarahkan pada integrasi multiplexer bertingkat dan transmisi data nirkabel untuk aplikasi pemantauan jarak jauh.

Kata Kunci: WeMOS D1, multiplexer analog, IoT hemat daya, ekspansi sensor, sistem tertanam

INTRODUCTION

The rapid evolution of Internet of Things (IoT) technology has driven an increasing demand for efficient, low-cost, and scalable sensor networks (Dwivedi et al. 2021; Garg and Jailia 2020; Rashid, Pecorella, and Chiti 2020). Microcontroller-based platforms such as the WeMOS D1 Mini, which is built on the ESP8266 chipset, are widely used in prototyping and deployment of such systems due to their compact size, built-in Wi-Fi capability, and energy efficiency (Ance et al. 2023). Despite these advantages, WeMOS devices suffer from a critical limitation: a restricted number of analog input pins, typically only one, which poses a significant bottleneck for applications requiring multiple analog sensors. Environmental monitoring (Kishorebabu and Sravanthi 2020; Ouni and Saleem 2022), precision agriculture (Kalpana et al. 2024), smart buildings (Al-Talb et al. 2023; Santos et al. 2021), and real-time health diagnostics (Valsalan et al. 2022) often rely on dense networks of analog sensors such as temperature (Pezeshki, Mazinani, and Omidvar 2022), humidity (Fletcher and Fisher 2018), light intensity (LDR), gas detection (Praveenchandar et al. 2022), and soil moisture sensors. To support these applications, designers are compelled to either adopt more complex microcontroller units (MCUs) with additional analog inputs, or employ external expansion strategies to multiplex analog signals into a single pin. The former adds cost and power consumption, while the latter offers a more compact and efficient alternative. Analog multiplexers, particularly the CD74HC4067, a 16-channel analog/digital multiplexer, have emerged as effective tools for expanding sensor input channels without increasing the microcontroller's pin count. Through dynamic channel switching controlled by digital pins, this method enables multiple sensors to be read sequentially through one analog input, significantly reducing hardware complexity and power usage. Prior research has explored the use of analog multiplexing in various contexts, including wearable electronics (Al-Atawi et al. 2023; De Giovanni et al. 2021; Jung and Lee 2022), smart agriculture systems (Kethineni and Gera 2023; Siddiquee et al. 2022; Simo et al. 2023), and air quality monitoring (Rastogi and Lohani 2022; Samal et al. 2023; Zivelonghi and Giuseppi 2024).

However, few studies have addressed the performance trade-offs between input expansion and system latency (Rathi and Borkotoky 2024; Shao et al. 2023), energy consumption (Dos Anjos et al. 2021), or signal accuracy in the context of compact (Płaczek 2024), low-power IoT nodes based on WeMOS microcontrollers. This study aims to fill this gap by developing and analyzing a low-power sensor expansion framework using the WeMOS D1 Mini and CD74HC4067 multiplexer. The system integrates up to eight light sensors (LDRs) connected to a single analog input, and evaluates key performance parameters including switching latency, power efficiency, and reading accuracy. The primary contributions of this paper are:

- A validated hardware-software architecture for low-cost multi-sensor expansion using WeMOS and CD74HC4067.
- Quantitative performance evaluation of the proposed multiplexing system, focusing on power overhead and latency.
- Demonstration of scalability and efficiency suitable for deployment in low-power IoT monitoring systems.

RESEARCH METHODS

The proposed system aims to augment the analog input capacity of the WeMOS D1 Mini by integrating a CD74HC4067 16-channel analog multiplexer, thereby facilitating the serial reading of multiple analog sensors (LDRs) through a singular analog input. This section delineates the hardware architecture, sensor configuration, switching control algorithm, and software implementation utilized in the experimental setup.

The system has been meticulously engineered to achieve the following objectives:

- The objective is to expand the analog input capability of a single-channel microcontroller.
- It is imperative to ensure that the device under consideration exhibits minimal power consumption, a trait that is well-suited for implementation within the confines of IoT environments.
- It is imperative to ensure the accuracy and low latency of sensor readings for non-time-critical applications.

Hardware Components

The following Table 1 shows the hardware that supports the prototype.

Table 1. Prototype hardware specifications

Component	Description
WeMOS D1 Mini	Microcontroller with ESP8266 (1 analog input)
CD74HC4067 Multiplexer	16-channel analog switch

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LDR Sensors × 6	Light-dependent resistors (for light detection)
10kΩ Resistors	For voltage divider configuration with LDRs
Breadboard, Jumpers	For prototyping
Power Supply (5V)	USB or external source

The sensors are connected to channels C0–C5 on the multiplexer, with the multiplexer's SIG pin routed to the A0 analog input of the WeMOS. The control pins S0–S3 are connected to four digital GPIOs on the WeMOS (e.g., D1–D4), which are used to select the active channel, as seen in Figure 1.

Circuit Design

The LDRs are wired in a voltage divider configuration, thereby producing a variable voltage output depending on the ambient light. The CD74HC4067 sequentially routes the output of each LDR to the WeMOS's A0 pin. The control logic employs a 4-bit binary selector to address one of the 16 available channels, as seen in Figure 1.

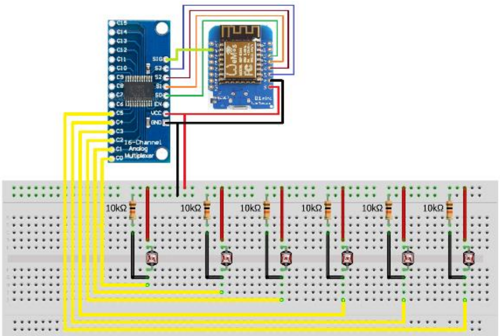

Figure 1. Circuit board design

The following is a simplified representation of the control logic, as seen in Figure 2:

- The value of C0 is equivalent to 0000.
- The sequence C1 is equivalent to the binary digit 0001.
- The sequence C2 is equivalent to the binary digit 0010.
- ...
- The binary value 0101 is equivalent to C5.

It is imperative to note that a switching delay of 30–50 milliseconds (ms) is introduced subsequent to each selection in order to stabilize the signal.

Software Implementation

The firmware is developed in Arduino IDE using the following logic, as seen in Figure 2:

- The initialization of the multiplexer control pins (S0–S3) as digital outputs is required.
- The following definition is to be provided: a loop that cycles through selected channels (C0 to C5).
- The initial step entails the configuration of the pertinent binary value on S0–S3, a prerequisite for the subsequent activation of each channel.
- It is imperative to wait 42 milliseconds for signal stabilization.
- The analog value from A0 must be read.
- The storage or transmission of sensor data can be facilitated through the utilization of serial or Wi-Fi connections.

Excerpt of control logic in Arduino code

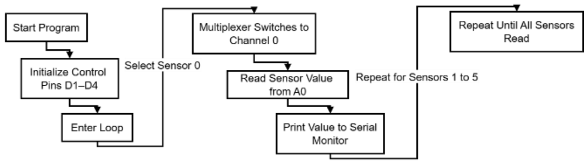

Figure 2. Control logic flowchart

Figure 3 shows the code execution activity and program algorithms, as seen Figure 2, in the screen capture view.

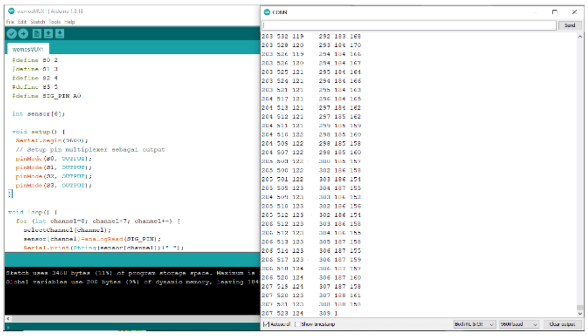
Figure 3. Code execution view

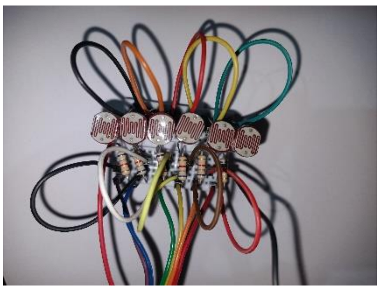
Figure 4. Sensors module

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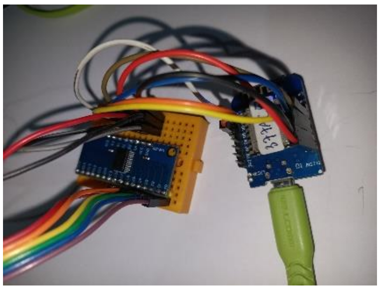

Figure 5. WeMOS and multiplexer module

RESULTS AND DISCUSSION

Sensor Reading Accuracy

The accuracy of the sensor readings acquired via the multiplexed channel was assessed by subjecting the system to controlled lighting conditions, with six LDR sensors connected to channels C0–C5 of the CD74HC4067. The voltage output of each sensor was meticulously measured using a calibrated multimeter and then compared against the analog values read by the WeMOS via the A0 pin, as seen in Figure 4 and Figure 5. The findings indicated that the discrepancy between the measured (WeMOS) and actual (multimeter) readings remained within ±2%, thereby substantiating the reliability of the multiplexing approach for low-resolution analog sensing. This margin of error is deemed acceptable for environmental monitoring applications where high precision is not a prerequisite, as seen in Table 2.

Table 2. A comparison of sensor voltages was conducted under medium light intensity.

Channel	Multimeter (V)	WeMOS Reading (scaled)	Error (%)
C0	1.98	1.96	1.01
C1	2.02	2.04	0.99
C2	1.95	1.94	0.51
C3	2.10	2.07	1.42
C4	1.89	1.91	1.06
C5	2.00	1.98	1.00

Power Consumption Efficiency

Power consumption is a critical parameter for IoT devices, particularly in battery-powered scenarios. The total current draw of the system was measured using a USB power monitor while sequentially reading all six sensors, as seen in Table 3.

Table 3. The total current draw

Configuration	Average Current (mA)
Single Sensor Only	72
Multiplexer + 6 LDR	76

The findings suggest that the incorporation of the multiplexer and multiple sensors led to an increase in power consumption by approximately 5.5%, thereby substantiating the energy efficiency of the design. Given that only one sensor is actively read at a time, the additional load from the CD74HC4067 remains minimal, thereby confirming that the system remains well-suited for low-power IoT deployments.

Latency and System Responsiveness

Each sensor reading cycle entails the selection of a new channel via the 4-bit control lines and a brief stabilization delay prior to analog acquisition. The mean switching time per channel was measured to be approximately 42 milliseconds, which includes logic transition and signal settling. This latency is deemed acceptable for environmental sensing applications, where readings are typically separated by intervals of seconds or minutes. However, for high-frequency real-time monitoring, further optimization may be necessary, such as the use of interrupt-driven acquisition or faster ADCs, as seen in Figure 6.

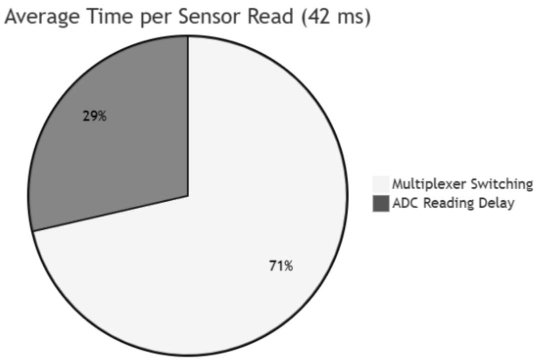

Figure 6. System Response Time per Sensor (ms)

Stability and Crosstalk

Repeated measurements over an extended period demonstrated minimal signal crosstalk between channels, a phenomenon attributed to the internal channel isolation of the CD74HC4067. The implementation of proper grounding and shielded wiring has been demonstrated to further enhance signal integrity. Furthermore, the system demonstrated stability under typical indoor conditions, as no significant temperature drift or voltage instability was observed during prolonged operation.

Scalability and Deployment Readiness

While the initial prototype utilized six sensors, the system has the capacity to accommodate up to 16 analog inputs through the use of a single multiplexer. In the case of larger sensor arrays, it is possible to cascade multiple CD74HC4067 units; however, this approach entails the additional cost of greater control logic and latency. Additionally, the modular design of the WeMOS platform facilitates seamless integration with cloud-based platforms (e.g., Blynk, Thingspeak) for remote monitoring. Subsequent augmentations may encompass wireless transmission, power-saving modes, and event-driven acquisition logic.

CONCLUSIONS AND SUGGESTIONS

This research confirms the viability and efficiency of a multiplexed analog input strategy to overcome the hardware limitations of the WeMOS D1 Mini microcontroller in IoT-based environmental sensing applications. By integrating the CD74HC4067 16-channel analog multiplexer, the system successfully reads up to six analog sensors using a single analog pin, while maintaining measurement accuracy within ±2% and incurring only a marginal power increase of approximately 5%. The average channel switching latency of 42 milliseconds is acceptable for most environmental monitoring applications, which do not require hard real-time responsiveness.

The proposed system demonstrates several key strengths: a compact hardware design, low power consumption, and a modular architecture that supports straightforward scalability. These advantages make the solution particularly suitable for IoT implementations in constrained environments such as smart agriculture, greenhouse automation, and distributed environmental monitoring networks. Furthermore, the method eliminates the need for more powerful or costly microcontrollers by maximizing the efficiency of existing hardware.

Future work will focus on the following directions:

- Enhancing the multiplexing architecture to support dynamic sensor allocation and error-tolerant communication protocols.
- Integrating wireless transmission and edge computing capabilities to enable distributed and low-latency sensor networks.
- Exploring sensor fusion algorithms and cloud-based analytics for improved data quality and automated decision-making in real-time applications.

In conclusion, this study lays a strong foundation for scalable, energy-efficient, and cost-effective sensing architectures that can be adapted across various IoT domains.

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