Application Brief

Optimizing Sensor Integration in Robots with Analog Multiplexers

TEXAS INSTRUMENTS

Introduction

Modern robots must integrate an ever-growing set of analog sensors for navigation and system monitoring into a single MCU. The resulting I/O bottleneck limits channel count and drives up bill-of-materials cost, forcing a trade-off between capability and price. This brief presents an engineering solution: using TI analog multiplexers to expand the MCU's analog inputs, delivering a sensor-rich design while meeting consumer-grade cost targets. Reference designs and evaluation modules are available on ti.com to accelerate development.

Design Challenges

1. Limited MCU I/O Capacity Consumer robot microcontrollers are selected to balance performance and cost, typically resulting in constraining GPIO and ADC channel counts. Modern robots often require more sensors than available MCU pins, creating a fundamental design constraint.
2. Bill of Materials Impact Upgrading to a higher pin-count MCU to accommodate additional sensors cascades into multiple cost increases:
   - Cost of MCU increases when moving from a 48-pin to a 100-pin package
   - Power delivery components require upgrades to support higher current demands
   - Passive component count increases substantially with additional decoupling capacitors and pull-up/down resistors
3. PCB Space and Complexity Larger MCUs fundamentally alter PCB design requirements:
   - A 100-pin LQFP package (14x14mm) consumes approximately two times the board area of a 48-pin LQFP (9x9mm)
   - Increased routing complexity may require additional PCB layers or more expensive manufacturing processes

Example of Multiplexer Design: Mid-Tier Robotic Vacuum Sensor Array

A typical robotic vacuum integrates a comprehensive array of analog sensors that enable effective navigation and system monitoring. These sensors work in concert to provide complete awareness of both the surrounding environment of the robot and the internal operational state.

Traditional Approach (Without Multiplexers): Direct MCU Connection

In direct-connection architecture, every analog sensor requires a dedicated ADC channel on the microcontroller. This leads to a rapid consumption of available I/O.

- 4 IR Proximity Sensors connect to four dedicated ADC inputs
- 2 Cliff Sensors connect to two dedicated ADC inputs
- 2 Motor Current Sensors connect to two dedicated ADC inputs
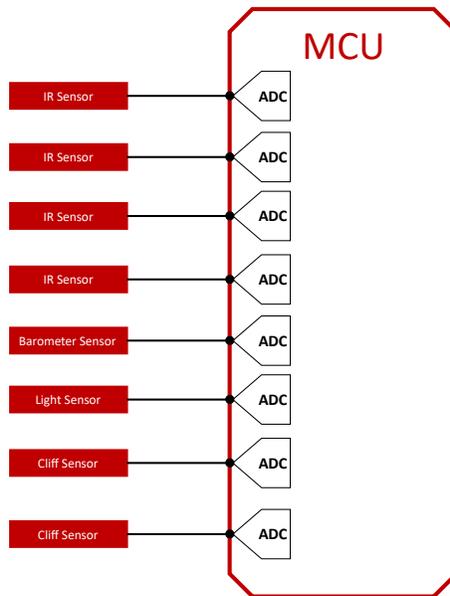
Total ADC Channels Required: Eight

Figure 1. Before Multiplexer implementation

Result: MCU's ADC resources are being consumed, leaving no headroom for future sensor expansion.

Multiplexer Approach: Consolidated Signal Path

Goal: Reduce ADC channel count while preserving sensor fidelity.

By inserting a single 8:1 multiplexer, the entire sensor suite can be consolidated and managed by a small subset of the MCU's pins.

- Four IR Proximity Sensors
- Two Cliff Sensors
- Two Motor Current Sensors

The system routes all eight sensors through a single 8:1 TMUX1308A Multiplexer. This multiplexed signal is then directed to a single MCU ADC input. The entire multiplexer operation is controlled by three standard GPIO pins from the microcontroller.
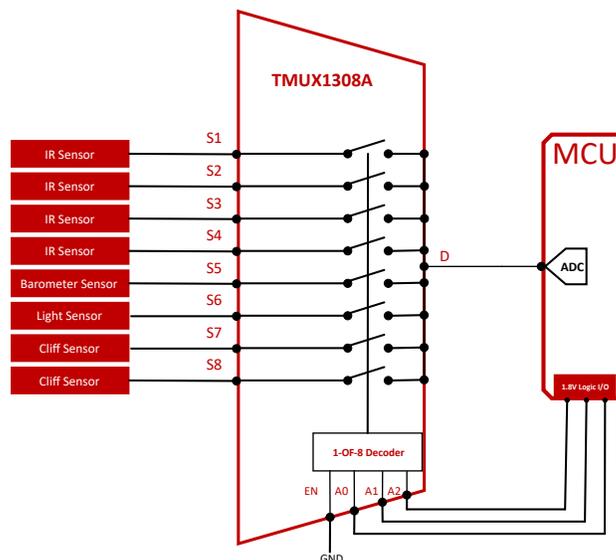

Figure 2. With Multiplexer Implementation

Results: This architecture not only fits within the I/O budget of the original target MCU but also frees up the remaining ADC channels for future feature expansion. The overall size savings with this implementation are significant, reducing the required MCU input pins from eight analog inputs to just one analog input plus three digital control pins, resulting in a net reduction of four pins and potentially allowing for a smaller MCU package to be used.

Key MUX Parameters for Robotics Applications

When selecting an analog multiplexer for robotics, focus on these critical datasheet parameters that directly impact sensor accuracy, power consumption, and signal integrity. All values shown are typical; consult the *Typical Characteristics* section of each datasheet for detailed performance curves.

Key design considerations include matching the supply voltage range to the system rails, verifying adequate bandwidth for sensor sampling rates, and verifying that on-resistance does not compromise measurement accuracy for high-impedance sensors. Small improvements in these parameters can translate into measurable gains in battery life, signal integrity, and system reliability.

Parameter	Typical Range	Robotic Impact
Supply Voltage Range	1.8V–5.5V (LV) 5.5-100V (HV)	Eliminates level-shifters between sensor rails and MCU domains
Supply Current	2µA–15µA (LV) 45µA–200µA (HV) (typ/max at VDD)	Static power draw: $P = VDD \times ICC$
On-Resistance	30Ω–150Ω (at specified test current)	Signal attenuation: $Verror = RON/(RON + Rsensor)$
Source Off-Leakage	±1nA (typ), ±25nA (max)	Leakage from unselected inputs to output
Drain Off-Leakage	±1nA (typ), ±50nA (max)	Leakage from output to unselected inputs
Bandwidth (-3dB)	1MHz–500MHz	Supports fast IMU sampling and control loops
Propagation Delay	5ns–50ns (typ)	Signal delay through the switch
Break-Before-Make Time	10ns–50ns (typ)	Prevents momentary short between channels
Charge Injection	2pC–8pC	Critical for capacitive sensors
ESD Protection	2kV–4kV HBM	Protects exposed sensor connectors in field environments
Maximum Power Dissipation	250mW–500mW	Thermal design limit for total power

**LV means Low Voltage, HV means High Voltage

Recommended TI Parts

Table 1. Recommended TI Parts

Part Number	Channels	VDD Range (V)	Package	Features
TMUX1308A TMUX1309A	8:1, 1-channel 4:1, 2-channel	1.62V - 5.5V	TSSOP, 16 BQB (WQFN), 16	Low voltage, short-to-battery
TMUX1208 TMUX1209	8:1, 1-channel 4:1, 2-channel	1.8V - 5.5V	TSSOP, 16 QFN, 16	Low-RON and smallest package option
TMUX4051	8:1, 1-Channel	5V – 24V	TSSOP, 16	High voltage, 1.8V compatible control inputs
MUX508	8:1	10V – 36V	TSSOP, 16 SOIC, 16	High voltage, break-before-make
TMUX8108	8:1	10V – 100V	TSSOP, 16	Integrated pulldown resistor on logic pin

Conclusion

Selecting a multiplexer influences the performance, reliability, and power consumption of the robot. Designers must evaluate supply-voltage range, supply current, bandwidth, on-resistance, propagation delay, and ESD protection to balance these trade-offs for the specific system. This applies whether designing a compact drone, a precision robotic arm, or an autonomous vehicle. For these diverse applications, TMUX1308A, TMUX1208, and TMUX4051 provide different channel configurations and performance characteristics to match varying robotics requirements.

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