Technical Article

6 Situations Where Small Amplifiers Solve Big Challenges in Vacuum Robots

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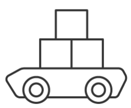
After a busy week, cleaning is the last thing people want to do with their downtime. The vacuum robot, which has been around for about 23 years, is getting more intelligent and automatic, enabling consumers to focus on what's really important.

Reference designs and products for vacuum robots



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The inclusion of more features in vacuum robots, such as new mopping capabilities and automatic dust disposal, means more challenges when designing a reliable system. Small amplifiers can help solve many big challenges quickly. Here are 6 ways small amps can solve big challenges:

Challenge No. 1: Reduced Motor Life Due to Delayed Detection of Stall Conditions.

The power of a vacuum robot's wheels determines its obstacle-crossing ability. In order to navigate thick carpet and climb thresholds, the motor power needs to be at least 30 W or more. If a stall or overload event occurs, such as a wheel getting caught on an electric cord, the motor winding current will ramp up immediately. Delayed detection of such an event results in the motor overheating and reduces its lifetime.

Solution No. 1: Fast Transient Response Current Sensing in a Motor Control System.

To reduce the chance of overheating, you can use a low-side current-sensing circuit to monitor the motor's current; see Figure 1.

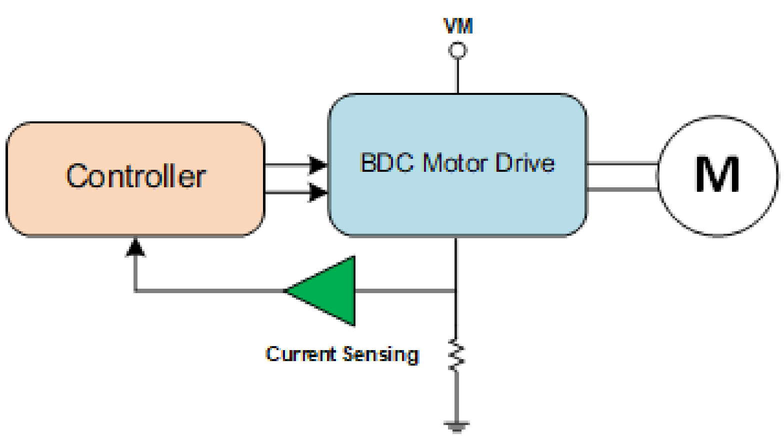

Figure 1. Current-sensing Circuit in a Motor Control System

The key parameter used as a current sensing circuit in motor control systems for operational amplifiers (op amps) in this application is the slew rate. For example, When a stall event occurs, the winding current ramps up from 0.5 A to 3.5 A, and the corresponding output of the op amp is 0.5 V to 3.5 V (with 50-mΩ shunt resistor and 20-V/V gain). The step change's settling time is about 6 μs using an op amp with a 0.5 V/μs slew rate, while the same step change's settling time is only 0.2 μs using an op amp like TI's TLV905x with a 15 V/μs slew rate. Thus, using TLV905x with 30 times faster transient response will increase the margin for controllers to execute overcurrent protection.

Challenge No. 2: Low Battery Duration Due to an Inaccurate Charging Voltage.

Maximizing battery capacity is an important design challenge in vacuum robots. There is an expectation that robots should be able to do a full cleaning cycle before needing to charge again.

A high output voltage ripple using low-quality current sensing will create a nonutilizable battery capacity. For example, ±3.5% accuracy at 4.2 V will reduce the usable battery capacity to 40% after 250 charging cycles, whereas ±0.5 accuracy at 4.2 V keeps the usable battery capacity at 85%.

Solution No. 2: High-accuracy Voltage/current Sensing in a Constant-current/constant-voltage Loop.

One common way to charge the battery is with a discrete charging solution like that shown in Figure 2. The voltage- and current-sensing circuits generate the feedback voltage and current signal in the control loop. In order to achieve high accuracy, stability, offset voltage and temperature drift are key parameters for op amps used here.

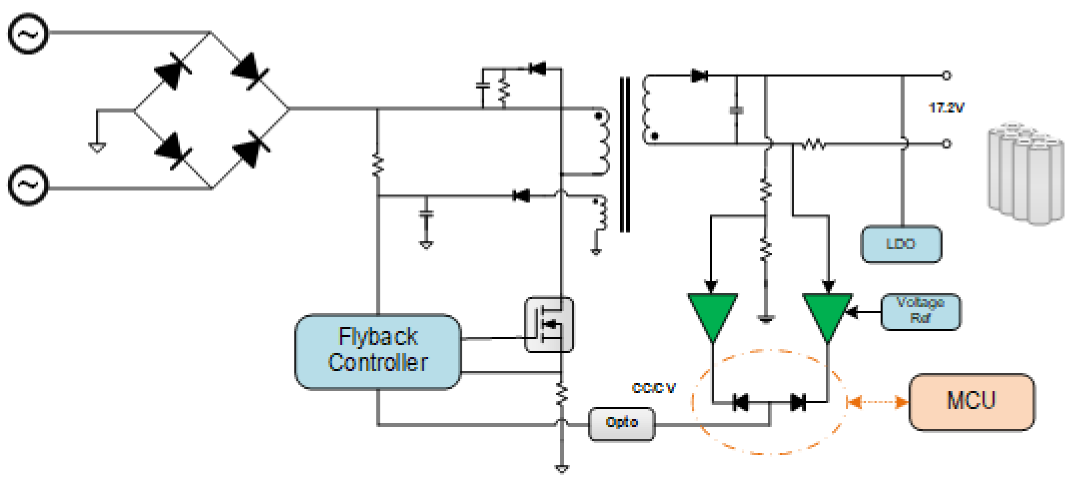

Figure 2. A Discrete Battery Charger Circuit

Challenge No. 3: an Overheated Battery Due to Negative Temperature Coefficient (NTC) Thermistor Error.

Monitoring the temperature of the battery pack is a primary safety concern in vacuum robots. Compared to the solution of temperatures sensors, the cost-effective way of monitoring the temperature of a battery pack is to use an NTC thermistor sensing circuit. Inaccurate temperature sensing may cause the battery pack to overheat or burn out.

Solution No. 3: High-accuracy Temperature Sensing with NTC.

One way to sense temperature is to use a resistor and thermistor to divide the power supply, and directly connect the divider output with an analog-to-digital converter (ADC) pin inside system controller. The output impedance of the divider is low and the output voltage range is non-ideal for ADC, so this way is not efficient or accurate.

Figure 3 uses an op amp as a buffer to condition the temperature output signal, offering a high impedance node for the divider and low impedance node to drive the ADC, and conditioning the output range to optimal ADC resolution The influencing parameters of the op amp are DC accuracy (offset voltage, voltage drift) and stability.

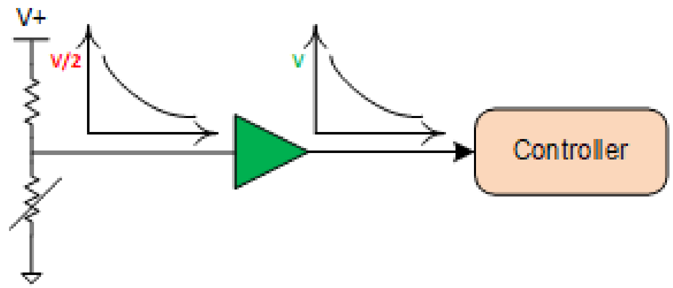

Figure 3. NTC Thermistor Sensing Circuit

Challenge No. 4

: **Low-precision location and navigation system due to an inaccurate odometer.**

When a vacuum robot's is reconstructing its environment, the odometer should provide accurate traveled distance that is used for mapping. An inaccurate odometer measurement will cause low-precision location and navigation for the robot.

Solution No. 4: a Robust Odometer Signal-enhancing Circuit.

A common way to measure the mileage is by using a photoelectric decoder or a Hall-effect sensor and counting the pulses to obtain mileage information. Usually the odometer is installed inside the wheel so the printed circuit board traces are long and are easier to be affected by switching noise, thus the output signal is distorted at the input port of MCU. A buffer circuit as shown in Figure 4 can produce a standard logic signal with no jitter and glitch.

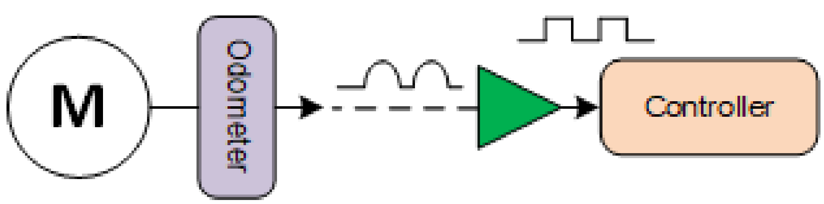

Figure 4. Buffer for a Robust Logic Output Circuit

Challenge No. 5: Noisy/distorted Motor-drive Signals Cause the Motor Running Unexpectedly.

The system controller is usually placed at the center of the control board, while the motors are installed at the edges of the board. So the drive signals directly connected to the port of MCU are easier to be noisy or distorted, causing the motor running unexpectedly.

Solution No. 5: a Pulse-width-modulation (PWM) Enhancer Circuit in the Motor-drive Path.

Instead of the circuit connecting drive signal with an MCU pin, the solution here is to add an op amp as an enhancer. Figure 5 shows a discrete motor-drive solution for a brushed DC motor. The controller generates PWM signals to drive H-bridge power transistors through a totem-pole field-effect transistor driver. The PWM enhancer circuit helps minimize latency and enhances PWM signals, with lower noise and distortion.

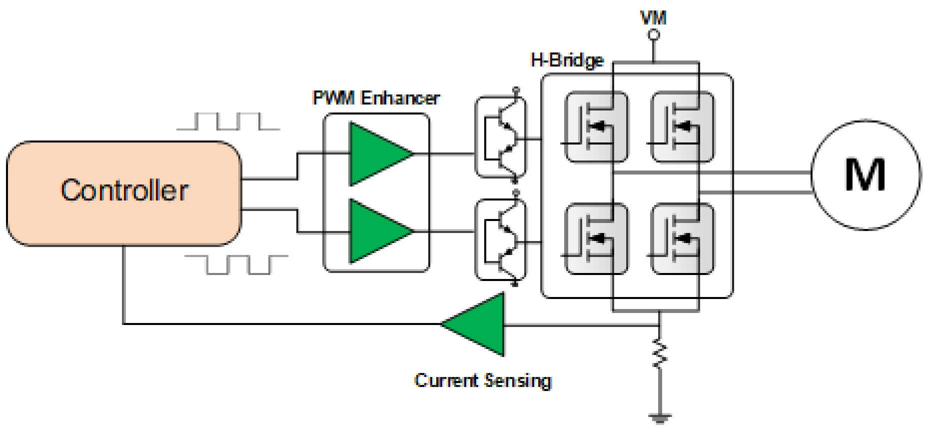

Figure 5. Enhanced PWM Circuit

Challenge No. 6: Vacuum Robot Collisions or Falls Due to Erroneous Distance Detection.

Cliff sensors are used to detect the height of stairs, while collision sensors are used to detect obstacles around a vacuum robot. Erroneous distance detection will cause inaccurate sensor performance, causing collision or fall event occurs and damaging the robot.

Solution No. 6: High-accuracy Infrared Output Signal Conditioning.

Infrared LEDs and phototransistors are widely used as a low-cost solution for detecting distance, as shown in Figure 6. The distance information correlates to the amplitude of an echo wave, which is carried by a fixed-frequency modulated wave.

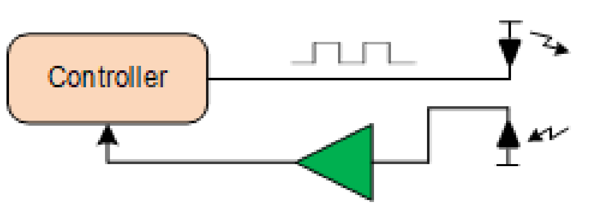

Figure 6. A Signal Conditioning Circuit for an Infrared LED Receiver

The transimpedance op amp amplification circuit is widely used here with a low-input bias current. The reference circuit is shown in SBOA268A.

TI's TLV906x, TLV905x and TLV900x general-purpose amplifiers are a good fit for many of these situations in vacuum robots, helping reduce time to market and solve common design challenges.

Additional Resource

- Download the "Analog Engineer's Circuit Cookbook: Amplifiers."

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