

## Closed-Loop Motion Control for Mobile Robotics

*Rich recently came up with two closed-loop drive train designs for mobile robots. All it took were some inexpensive permanent magnet motors and a simple feedback scheme. In this article, he covers everything from PID control and tuning to trajectory generation and operational space control for two robot bases. He also explains the software.*

The mechanical components that make up robots aren't getting much cheaper. That's the bad news. The good news, of course, is that electronics and processors continue their steady march toward higher performance and lower cost. As an engineer, you have to figure out how to use the extra resources and capabilities most effectively. In some cases, extra processing allows you to use lower-cost mechanical components, which can effectively reduce the system's overall cost.

With this idea in mind, I'll tackle the robot drive train armed with a modest amount of computing power. When I'm done, you'll have two different closed-loop drive train designs that would make R2-D2's head spin with envy. I'll show you how to accomplish this using inexpensive permanent magnet motors and a clever feedback scheme that requires no mechanical overhead. Let's begin by addressing the topic of motors.

### MOTOR OPTIONS

Clearly, selecting a motor is one of the most important decisions to make when designing the drive train. If you've played with motors and gears, you've certainly developed the following intuition: more gear reduction results in less speed and more torque, and less gear reduction results in more speed and less torque. Modified RC servomotors, which are often used in robot drive trains, have large gear reductions (typically 300:1) resulting in high torques and low speeds. As a

result, robots that use them are typically slow. Large gear reductions make some problems easier, as you'll see, but no one wants a slow robot if they can help it. If you've used these motors, you might have wanted to trade in some torque for some speed.

The 9-V Lego motors shown in Photo 1 are readily available. They are part of the Mindstorms kit, so you can build the rest of your robot base out of Legos, which is a good thing for the mechanically challenged like me.

Fortunately, the Lego motor has much less gear reduction (14:1) and is well suited for attaching a wheel directly to the output shaft. If you've done this, you know that you get a quick robot, but it's difficult to control. Particularly, when you shut off power

to the motor, the robot takes much longer to stop. With less gear reduction, the robot will coast!

Sometimes stopping quickly is important (e.g., stairs ahead), or your robot may do something hazardous to its health. This brings up an important point: motors with high gear reductions stop quickly when power is removed. But this is a silly reason to use these motors. It's like telling a beginning driver to drive only in first gear to avoid getting into an accident. What the driver really needs is better driving skills. Similarly, what you need is a better motor controller.

### CLOSING THE LOOP

A motor controller that doesn't receive any feedback information from the motor is an open-loop controller. The main advantage of open-loop controllers is simplicity. All that's required is a way to control the voltage or current going to the motor. The Lego Mindstorms RCX controller, for example, uses an open-loop motor controller that allows you to select from several voltages (by varying the pulse-width modulator duty cycle) depending on how much speed and torque you want to deliver to your robot's wheels.

A disadvantage of open-loop control is inaccuracy. Others include the inability to deal with uncontrollable variables such as bumps in a floor, inclines, and low batteries, which can create an undesirable situation by slowing or stop-



Photo 1—Lego is an excellent medium for implementing robots such as the four-wheeled HUMR. The Gameboy Advance acts as the controller and provides 32-bit RISC processing performance, a color LCD, and sound.

# Closed Loop Motion Control For Mobile Robotics

**Federico Casolo**



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