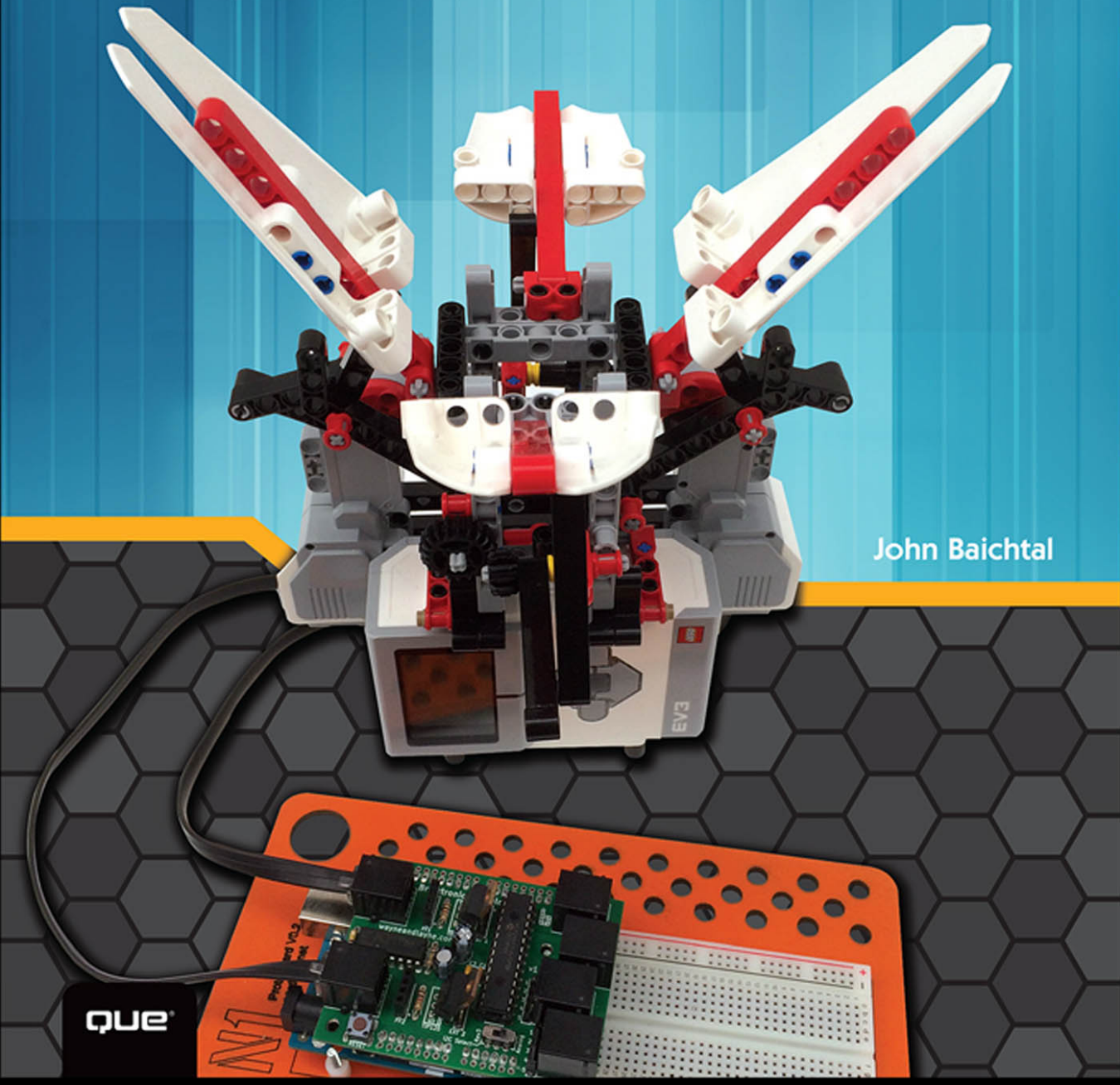
HACKING

YOUR LEGO® MINDSTORMS® EV3 KIT



John Baichtal

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HACKING YOUR LEGO® MINDSTORMS® EV3 KIT

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800 East 96th Street,
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Hacking Your LEGO® Mindstorms® EV3 Kit

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Contents at a Glance

Table of Contents

About the Author

John Baichtal has written or edited more than a dozen books, including the award-winning *Cult of Lego* (2011, No Starch Press), *Make: LEGO and Arduino Projects* (2012, Maker Media) with Adam Wolf and Matthew Beckler, *Robot Builder* (2014, Que), and *Basic Robot Building with LEGO Mindstorms NXT 2.0* (2012, Que), as well as *Building Your Own Drones* (2015, Que). His most recent book is *Maker Pro* (2014, Maker Media), a collection of essays and interviews describing life as a professional maker. John lives in Minneapolis, Minnesota with his wife and three children.

Dedication

This book is dedicated to my wife Elise, my kids Arden, Rosemary, and Jack, my mom Barbara, and to all those who strive to make an item or platform work better for them by hacking it!

Acknowledgments

Thanks for the inspiration and assistance (in no particular order) to Miguel Valenzuela, Pete McKenna, Steve Norris, Steven Anderson, MakerBeam, Jude Dornisch, SparkFun Engineering, Adam Wolf, Michael Freiert, Sophi Kravitz, Christina Zhang, Lenore Edman, Rick Kughen, Sean Michael Ragan, John Wilson, Susan Solarz, Akiba, Mark Frauenfelder, Chris Berger, Michael Krumpus, Alex Dyba, Brian Jepson, Becca Steffen, Dave Bryan, Actobotics, Mike Hord, Makeblock, Pat Arneson, Erin Kennedy, Mindsensors, Windell H. Oskay, Johngineer, Matthew Beckler, Riley Harrison, David Lang, Trammell Hudson, Kristina Durivage, AnnMarie Thomas, Pete Prodoehl, Bruce Shapiro, Alex Allmont, John Edgar Park, and Dexter Industries. Apologies to anyone I forgot!

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3

Hacking LEGO I: Connections

Mindstorms' components consist of modules linked together. The motors connect to the Intelligent Brick but not directly—they use wires to link the power and data of both modules together. Those linkages are themselves fascinating. This chapter explores what's up with those Mindstorms wires and demonstrates how to hack them into different configurations. Then, I describe some of the common methods Mindstorms hackers employ to control and connect components without using wires.

Mindstorms Wires Explained

Let's begin by exploring all the nitty-gritty details of the standard Mindstorms wire. LEGO uses semiproprietary wires in its Mindstorms variants. I call them semiproprietary because they're just a standard configuration (known in the business as RJ12) but with the tab off to one side, as shown in Figure 3.1. You literally could use RJ12s if those tabs were off-center. Since LEGO has seen fit to do it this way, however, we have to use our creativity to overcome this inconvenience.

First, however, let's check out what you get in the EV3 set:

- Four—250mm/10-inch
- Two—350mm/13.75-inch
- One—500mm/20-inch

So to recap, the EV3 set includes four short cords, one long cord, and two in the middle. The cords can be swapped end-to-end and can be used with everything from motors to sensors. They're truly universal in the Mindstorms world, meaning you only have to worry about length when you grab a wire.

FIGURE 3.1 Mindstorms cables' off-center tabs are all that differentiate them from RJ12s.

Not surprisingly, these three sizes aren't good for everyone, so some established suppliers have come up with different wire sets:

- HiTechnic's NXT Extended Connector Cable Set (P/M NWS1000) includes six cables, ranging in length from 120mm (4.7-inch) to 900mm (35.4-inch). You can buy the set at hitechnic.com.
- Mindsensors' Flexi-Cable pack (P/N FLEX-Nx) includes four cables: 200mm, 350mm, and 500mm just like regular LEGO cables. However, Mindsensors' cables have thinner and more flexible insulation, allowing them to move around and bend more readily than LEGO's stiffer wires. You can buy the Flexi-Cables at mindsensors.com.

Inside the Mindstorms Wire

So, what's going on inside that black plastic insulation? It turns out there are six smaller wires inside, as shown in Figure 3.2.

1. The blue wire is the SDA (serial data) wire, one-half of a two-wire data transfer protocol called I^2C. EV3 can transmit sensor data and commands through the I^2C bus.
2. Yellow is the SCL (serial clock) wire, the other half of the protocol.
3. Green is power, typically delivering either 3.3 or 5V from the EV3's battery pack. You can use this wire to power electronic circuitry and add-on modules.
4. Red is ground. Creating a circuit with the power pin and this ground yields 5V.
5. Black is also ground. A circuit with this ground and the power pin yields 3.3V.
6. White is analog, transmitting analog sensor signals back to the EV3 Intelligent Brick.

Knowing the purpose of each wire helps you hack them, and it never hurts to understand what's going on under the insulation.

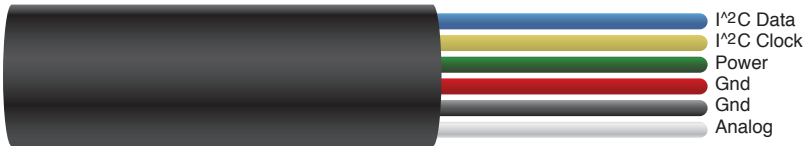

FIGURE 3.2 The Mindstorms wire actually consists of six smaller wires.

Hacking Mindstorms Wires

Not unexpectedly, LEGO hackers have explored the wires and created their own variants to suit the needs of their projects. The following are a sampling of techniques you could employ.

Changing the Length of a Mindstorms Wire

This is an obvious one. How do you change the length of a Mindstorms wire? The following takes you through the steps, with Figure 3.3 guiding you along the process.

1. Make a shorter wire: Cut the plug off one end, making sure to leave yourself a couple of inches of wire, and trim the remaining length down to the size you want. To make a longer wire, cut an end off two wires, so that their combined length equals the size you want.
2. Carefully remove the outer black insulation and pull apart the six inner wires.
3. Solder together each wire to its same-colored mate on the other side. (If you need to polish up your soldering skills, there's a helpful how-to here: http://mightyohm.com/files/soldercomic/FullSolderComic_EN.pdf.)
4. Insulate the individual wires with heat-shrink tubing, such as SparkFun P/N 9353. Then the combined wires should get a larger piece of tubing to keep them in check.

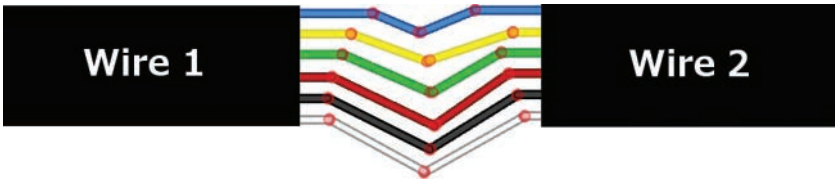

FIGURE 3.3 To alter a Mindstorms wire, just cut it apart and solder it back together.

Using a Breakout Board

Another way to access the inner workings of a Mindstorms wire is to use a breakout board. These are little circuit boards with Mindstorms-compatible plugs on them, allowing you to break out the six inner wires as separate pins.

A couple of variants are floating around; I like the Bricktronics Breakout Board, selling for only $4 from wayneandlayne.com. In Figure 3.4 I demonstrate how to light up an LED, connecting from the power pin to the red ground (5V) with a 470-ohm resistor protecting the LED from too much voltage.

FIGURE 3.4 To access the inner wires individually, use a breakout board.

Breadboard-to-PF Hybrid Wire

PF refers to Power Functions, a mostly compatible motorized set put out by LEGO and marketed alongside Mindstorms. In fact, the beams and other building elements in the EV3 set are identical to the parts sold with PF sets, making the two remarkably compatible. Not completely, however, because there is no way to control PF's awesome DC motors using your EV3 brick. Two of PF's four wires are 9V and GND, and the other two control the speed of the motor.

You still need a way to trigger the voltage—the 9V the Power Functions motors are expecting is more than the EV3 brick can handle. In Chapter 5, "Hacking LEGO II: Alternate Microcontrollers," I show you how to use an Arduino microcontroller that not only can control those great PF motors, but also Mindstorms servos as well.

In the meantime, here's how to make your own hybrid wire:

1. Cut off one end of a Power Functions extension cable (LEGO P/N 8886). It has a male end and a female end, with the male end looking like a regular 2x2 LEGO brick, and the female end looking like the underside of a similar brick, allowing you to attach them together just like they were regular bricks.
2. Strip the four individual wires on the female end. They consist of Power, Control 1, Control 2, and Ground. Solder each wire to a male header pin (SparkFun P/N 12693) or a Molex plug like you see in Figure 3.5, which you can crimp on yourself, or buy a pigtail such as the SparkFun P/N 9920. Use heat shrink to cover all conductive surfaces.

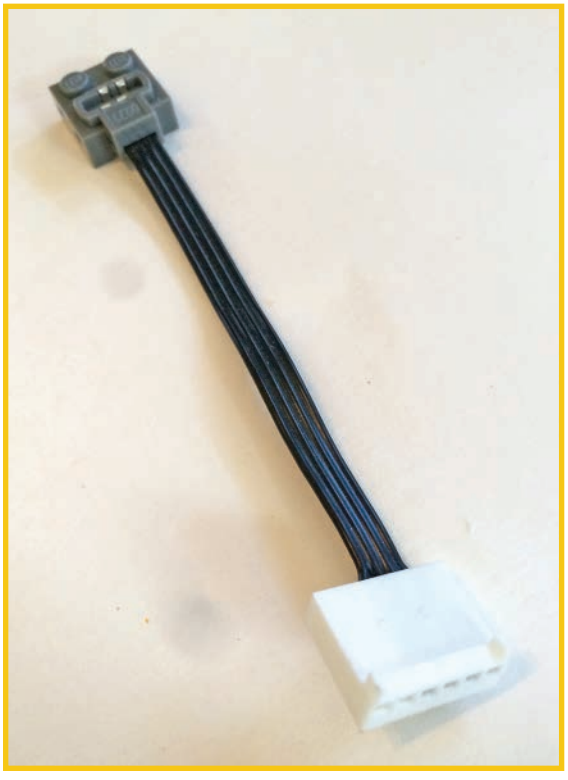

FIGURE 3.5 A cable that connects LEGO's proprietary PF connector to a breadboard.

Exploring Wireless Options

Mindstorms wires are a given—but what about wireless communication? The EV3 kit comes with two ways to communicate wirelessly with your Intelligent Brick.

Infrared Sensor and Beacon

The EV3 set includes a dirt-simple infrared remote (IR) control and receiver that allow you to control two motors on your model, both forward and backward (see Figure 3.6). In addition, you can opt between two channels, so theoretically you could control four motors with two remotes and two receivers. Another option would be to have four motors connected to your robot—for instance, two for propulsion and two to control a robot arm—and you simply switch channels when you want to do one task or the other.

The sensor has one added feature that most IR receivers lack: It can be used as a proximity sensor, beaming out infrared light and sensing as it bounces back. This feature has a short range compared to other proximity sensors (for example, ultrasonic), and can detect proximity only within 50cm to 70cm, or around 2 to 3 inches.

The beacon is what LEGO calls its remote control, and this is not just for fun: One of the projects described in the EV3 set is an IR-homing robot that wanders around until it senses the infrared signal from the beacon and rolls toward it. The controller's range is only about 2 meters, unfortunately.

FIGURE 3.6 The infrared sensor and beacon give you simple wireless control of your robot.

Bluetooth

Another intriguing option is the EV3 brick's Bluetooth capabilities. The Intelligent Brick has a Bluetooth chip on-board, allowing it to connect to other EV3 bricks as well as take commands from smartphones using an application called the Commander, which includes preset control configurations for the five sample robots that are part of the EV3 set (see Figure 3.7). You can also create an interface for a custom robot, pulling out sliders and buttons from a library to match what you're building.

EV3's Bluetooth capability also allows you to control the Intelligent Brick from your PC or Mac wirelessly, just as if you had it plugged in with a Bluetooth cable.

Finally, one cool aspect of the robot, both in terms of Bluetooth and regular wiring, is you can link up to four EV3 bricks together if you want to build a gloriously complicated robot.

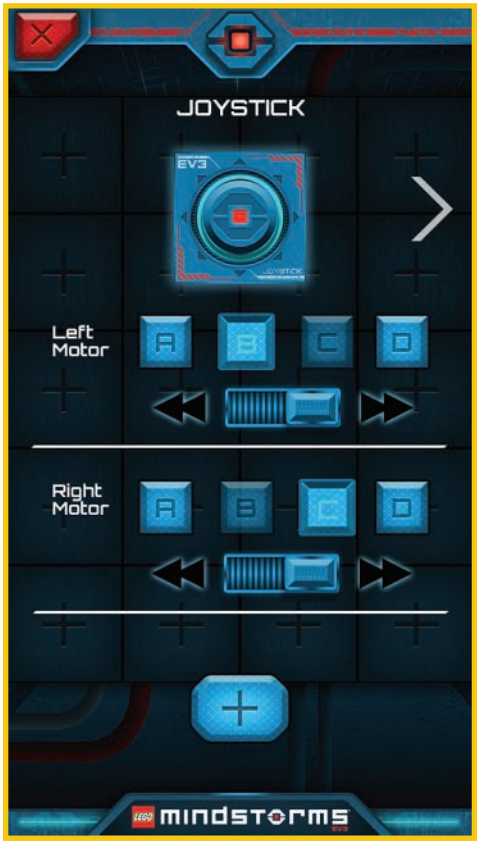

FIGURE 3.7 LEGO's Bluetooth app allows you to control robots wirelessly.

Hacking Wireless

It almost goes without saying that Mindstorms fans have figured out how to control their robots in ways not officially supported by LEGO. Here are just a few ways to wirelessly control your Mindstorms robot.

XBee

A common hobbyist and professional wireless specification is called Zigbee, and XBee is a brand of wireless modules built to that spec. Dexter Industries (dexterindustries.com) sells a

Mindstorms-compatible XBee breakout called the NXTBee, though I'm not sure whether it's compatible with EV3 yet. Another technique is to ditch the EV3 brick altogether and use an Arduino: Check out the cool LEGO bracer shown in Figure 3.8. It has an Arduino, battery pack, XBee, and Wii nunchuk, allowing me to operate a robot with a wearable controller. SparkFun sells XBee radios (P/N 8665) as well as its own flavor of breakout board.

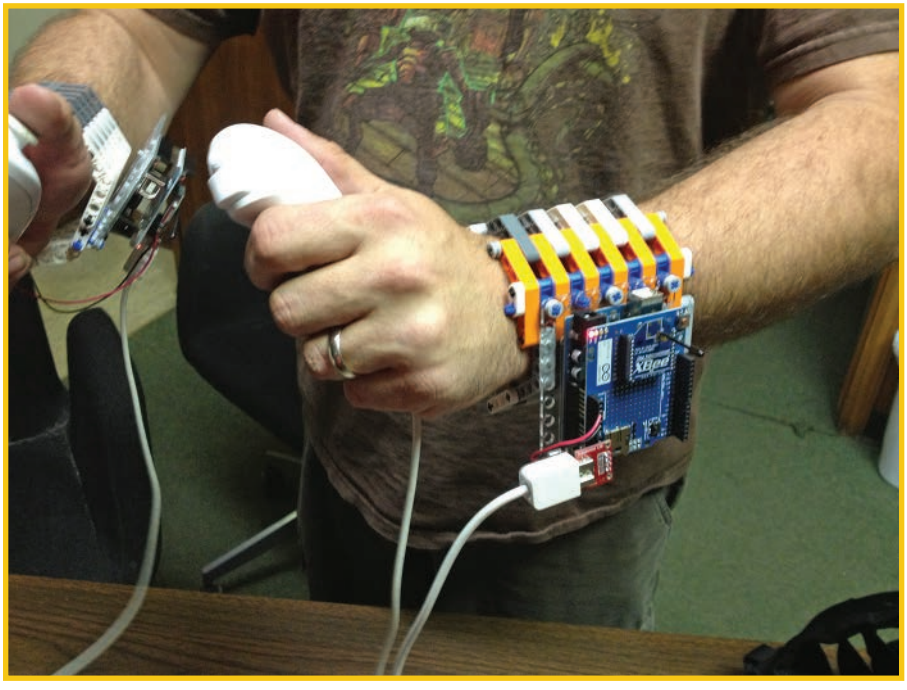

FIGURE 3.8 This wireless controller combines LEGO, Wii, and Arduino.

Radio Control

Normal radio control (RC) technology doesn't mesh well with Mindstorms, but it can be made to work. RC flight electronics consist (in their most basic configuration) of a radio, shown in Figure 3.9, as well as a receiver. The receiver interprets the data from the transmitter and triggers pins that tell the motors what to do. Not surprisingly, those same pins can trigger Arduino actions or could be used to bump Mindstorms touch sensors with a servo.

FIGURE 3.9 An RC transmitter and receiver can control Mindstorms models.

PlayStation Controller

Mindsensors.com and a couple of other places sell a wireless controller that consists of a PlayStation 2 (PS2) interface card that plugs into the EV3 Intelligent Brick—onto which a wired PS2 controller may connect (see Figure 3.10). Mindsensors also sells a 2.4Ghz wireless PS2 controller and a matching dongle that plugs into that interface card, allowing you to wirelessly control your robot.

FIGURE 3.10 Mindsensors' PS2 adapter lets you control your model with a game controller.

Wi-Fi Dongle in EV3

There is no native Wi-Fi capability in EV3 bricks, but you can add it with a USB dongle, such as the NetGear WNA1100 shown in Figure 3.11. As a matter of fact, the WNA1100 is currently the *only* wireless dongle that the EV3 works with out of the box. It may be that other models can be made to work with the EV3, but so far just this one works.

FIGURE 3.11 The NetGear WNA1100 is the only Wi-Fi dongle that works with the EV3.

BrickPi and a Wi-Fi Module

Here's another example of a Wi-Fi add-on module allowing wireless communication of a Mindstorms robot. The BrickPi shield allows you to control Mindstorms by doing away with the EV3 brick and using a Raspberry Pi minicomputer, with the BrickPi mounted on top (see Figure 3.12). A Wi-Fi module from Adafruit (P/N 814) provides connectivity, though the Pi's built-in Ethernet port is always an option.

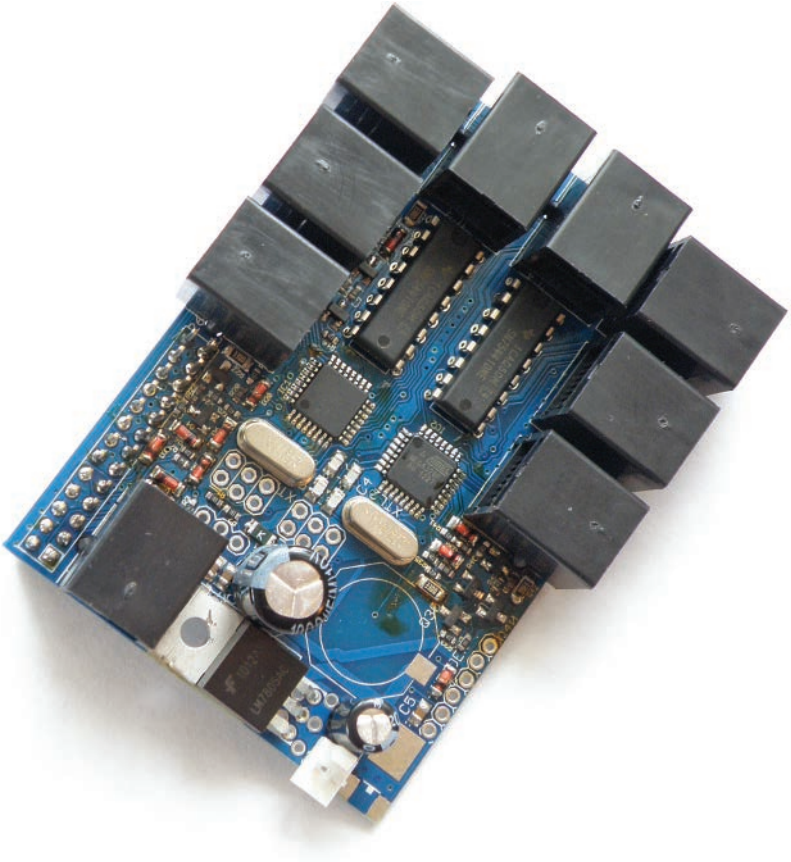

FIGURE 3.12 The BrickPi shield helps control Mindstorms robots.

Summary

This chapter is all about connections: hacking Mindstorms wires and playing around with wireless options such as infrared, radio control, and Wi-Fi. In Chapter 4, "Project: Remote-Controlled Crane," you put this knowledge to good use, making a rolling crane that responds to a variety of wireless control methods.

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Index

C

D

N

O

P-Q

R

S

T

U-V

W

X-Z