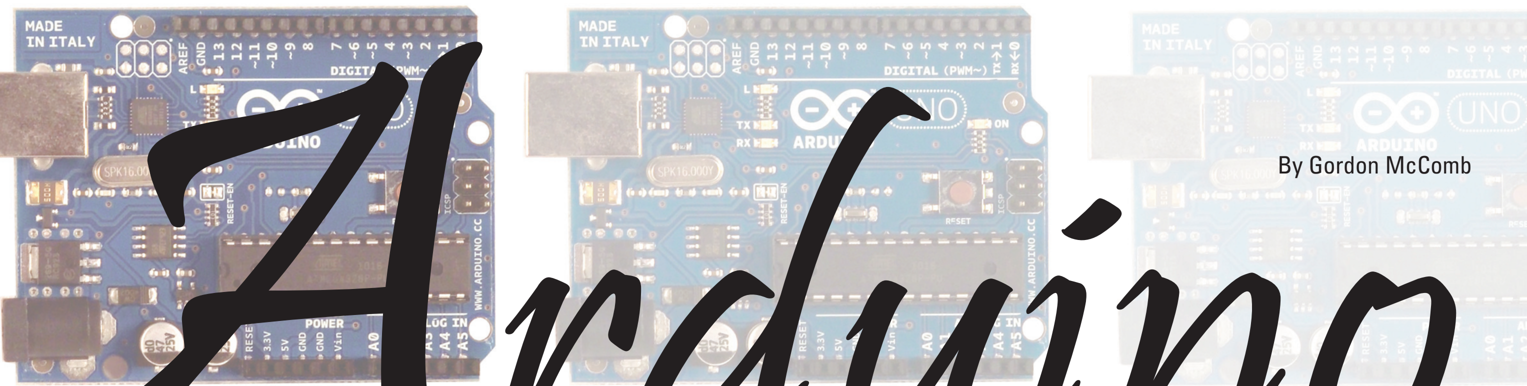
Making Robots With The Arduino

Part 1



By Gordon McComb

Twenty years ago, I began work on my ultimate home robot. Its brain was an Intel 80286-based PC motherboard, running at a whopping 8 MHz. The robot used a floppy disc drive to load the operating system and programs, and custom prototype boards for external interfacing.

The beast needed a hefty battery for power, and with the battery alone weighing some 15 pounds, I needed a sturdy frame to keep everything together. Constructed of aluminum, the robot measured 18 inches square by almost three feet high, and required heavy duty and expensive gear motors — all this just to meander down the hallway and scare the &@%! out of my cat.

Five years and over $1,500 later, I put “Maximillian” to rest, pulling its parts to use in other projects. Robot electronics were shrinking, and that meant robots themselves were getting smaller. Innovations like the BASIC Stamp made it much easier to experiment with low cost, self-contained microcontrollers — perhaps the ideal robotic brain. Microcontrollers are now so commonplace that you have your pick of hundreds of makes and models; from the super simple, to the confoundedly complex. Somewhere in the middle is the Arduino — a small and affordable microcontroller development board that’s fast becoming something of a superstar.

Why the Popularity?

Sure, the Arduino is a capable little critter able to handle the most common things microcontrollers can do. And let’s not forget that some of its fame has to do with price: the standard Arduino costs about $30, assembled and tested. Even less if you want to build it from a kit.

Then there’s its free programming software. Using a standard USB cable, it lets you easily connect the Arduino to your computer — Windows, Mac, or Linux — and begin working in minutes. The programming editor is simple to use and comes with several dozen examples to get you started.

What’s really made the Arduino a darling of geeks the world over is this: Both its hardware design and software are open source. That means others are able to take the best ideas and improve on them, all without paying licensing fees. This has created something of a cottage industry of fans and third-party support.

Though the most popular version of the Arduino is made by a company in Italy (where the board was originally developed), many others offer compatible designs in one form or another. Add to this a growing body of add-ons that maximize the Arduino, and free resources for programming examples, code libraries, and step-by-step tutorials.

Introducing Arduino Robotics

So, it makes sense to look at ways to leverage the Arduino to build robots. That's exactly what we'll be doing in this article and several more to follow in the months ahead. I'll show you how to build, program, and use an economical and expandable autonomous desktop robot — the ArdBot — that's powered by an Arduino. Cost of the project is under $85 — even less if you already have some basic components like a solderless breadboard and hookup wire.

The robot base is simple to build and can be constructed out of a variety of materials; no special tools are required. I'll demonstrate a version made of expanded PVC plastic, but you can use heavy cardboard, foam board, picture frame mat board, or most any other material you like. (For your convenience, you can get the robot chassis precut with all the hardware; see the **Sources** box for more information.)

I believe in robot designs that let you explore and experiment, and the ArdBot leaves plenty of room for expansion and independent discovery. You can use the robot for line or wall following, maze solving, or general meandering around in a room. (Cat scaring optional.) You can also take the concepts presented here and design your own version of the ArdBot — bigger or smaller, wheels or tracks — your choice.

In this installment, you'll learn all about the Arduino: what it's made of, how to connect it to your computer, and how to start developing robot projects for it. You'll also be introduced to the ArdBot chassis, including where to get its main parts. In coming installments to this series, you'll explore programming the robot to do interesting things, and extending its features with sensors and other add-ins.

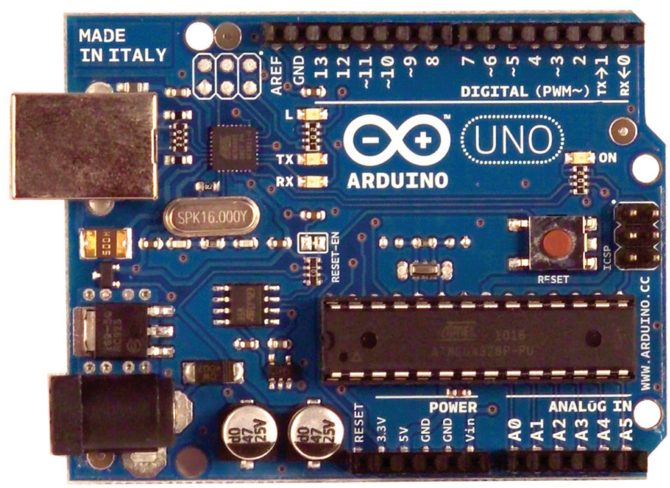


FIGURE 1. The Arduino Duo is a compact microcontroller board based on the Atmel ATmega328 chip. It's available from a number of sources at about $30 average retail.

Arduino Under the Hood

First introduced in 2005, the Arduino has gone through numerous iterations, revisions, and improvements. As I'm writing this, the Arduino team just released their newest version: the Arduino Uno (see **Figure 1**). Like its predecessors, the Uno is an all-in-one development board. It contains an Atmel AVR microcontroller — specifically the ATmega328 — a USB-to-serial interface, five volt voltage regulator, and various support electronics.

Previous iterations of the Arduino have included the Duemilanove (which means 2009 in Italian) and the Diecimila which means 10,000 (a reference to the number of Arduino boards that had been manufactured by that time; many more have been made since).

The Uno, Duemilanove, and Diecimila are what might be called main or core board designs. These all share a common form factor which is a PCB that measures 2-1/8" by 2-3/4". All contain a power jack for a 2.1 mm (center positive) barrel connector, as well as a USB Type B jack for hooking up to a host computer.

A series of 28 female pin headers allow connection of external devices to the Arduino. The headers are separated into three groups as shown in **Figure 2**. The groups are: power, analog input, and digital input/output. Of the 28 pins, 20 are devoted to input and output. There are six analog input pins which can also serve as general-purpose digital I/O. The 14 digital input/output pins include six that can be used to generate PWM (pulse width modulated) signals; these are useful for such things as controlling the

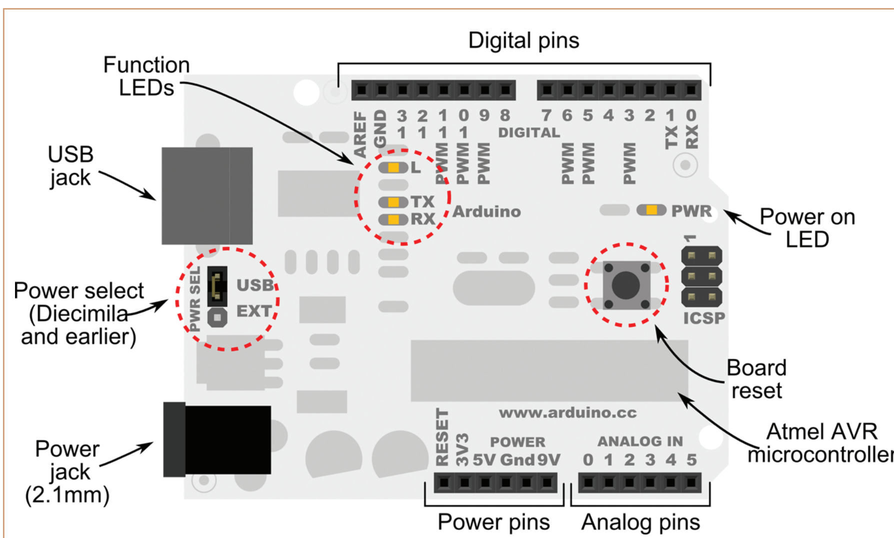


FIGURE 2. Points of interest on the Arduino board include the USB and power jacks, function and power LEDs, and rows of connection headers.

Table 1. Arduino at a Glance.

Arduino Version	Microcontroller	Supports Standard Expansion Shields
Uno and Duemilanove (2009b)	ATmega328	Yes
Duemilanove (pre-2009b) and Diecimila	ATmega168	Yes
Mega 2560	ATmega2560	No
Nano, Mini, LilyPad, others	ATmega168 or ATmega328	No

Table 2. Microcontroller Specifications.

	ATmega168	ATmega328	ATmega2560
Flash memory	16 KB; 2 KB used by bootloader	32 KB; 0.5 KB used by bootloader	256 KB; 8 KB used by bootloader
SRAM	1 KB	2 KB	8 KB
EEPROM	512 bytes	1 KB	4 KB
Clock speed	16 MHz	16 MHz	16 MHz

speed of motors. Through its I/O pins, the Arduino supports the basic inter-communications standards: TTL serial, SPI, 1-Wire, and I²C. Two of its pins (digital I/O lines 2 and 3) support hardware interrupts that via software trigger on a LOW value, a rising or falling edge, or a change in value.

Like any microcontroller, the Arduino is basically a small single-board computer designed to interface to external hardware like switches, motors, lights, relays, sensors, and LEDs. At the heart of the Arduino is an Atmel AVR microcontroller. The exact version of AVR controller depends on the version of the Arduino. For example, the older Diecimila and the first Duemilanove versions used an AVR ATmega168; the second generation Duemilanove (referred to as 2009b) as well as the Uno, use the AVR ATmega328. The '328 is physically identical to the '168 but it contains more memory space. See **Tables 1** and **2** for details on variations between the controller chips used.

The bulk of the components on the Arduino are surface-mount, but on most Arduino boards the AVR microcontroller is provided in a dual inline pin (DIP) package. This permits easy replacement should that ever be needed. A new AVR chip costs maybe $5 or $6; that's a lot cheaper than replacing the entire Arduino board.

Keep in mind that the AVR provided in commercially manufactured Arduino boards comes with a bootloader program pre-installed in its Flash memory. This bootloader allows you to program the Arduino by using a USB connection to your PC. When replacing the AVR microcontroller of an Arduino, you need to either purchase a chip with the bootloader software pre-installed, or if you have the proper hardware setup — like an Atmel STK500 programmer — you can do it yourself. Instructions for downloading bootloader software into an AVR chip are provided on the main Arduino information page.

Table 3. Arduino Pin Resources.

Arduino Uno, Duemilanove, and Diecimila	
Digital I/O Pins	14 (of which six provide PWM output)
Analog Input Pins	6
Nano	
Digital I/O Pins	14 (of which six provide PWM output)
Analog Input Pins	8
Mega 2560	
Digital I/O Pins	54 (of which 14 provide PWM output)
Analog Input Pins	16

Many Variations on a Theme

The core board designs of the Uno, Duemilanove, and Diecimila are perhaps the most common and popular of the Arduinos, but there are numerous other variations. Here are just some of the standardized Arduino boards you'll encounter. The Arduino BT and Fio are intended for wireless applications. The BT contains a Bluetooth module; the Fio has a built-in Zigbee radio. (You can also readily add Bluetooth and Zigbee to an Uno or other core board using "shields" detailed below.)

The Nano is a compact stick-shaped board made for breadboard use. It has all the main features of the Uno and others (including built-in USB jack), but measures only 0.73" x 1.7". It uses only surface-mount parts.

The Mini is even smaller, and is ideal for very small bots with limited space. The Mini lacks its own USB jack, and requires the use of a USB adapter or serial TTL connection to the host PC for programming. The Mini has four analog input pins instead of the six or eight of the other versions.

The Mega2560 is based on a larger AVR chip, and it offers over three times the number of analog and digital I/O lines (see **Table 3**). Memory and program space are bigger, too. The Arduino Mega2560 contains 256 KB of Flash (by comparison, the Uno has 32 KB), as well as more RAM and EEPROM space. Use this for the bigger jobs.

Several Arduino resellers (such as Solarbotics and Adafruit) offer their own custom offshoots of the Arduino — these typically go by different names such as Boarduino or Freeduino to differentiate them from the original Arduino designs. The Adafruit Boarduino (available in kit form for under $18) is like the Arduino Nano. It uses thru-hole components for ease of soldering.

Some variations of the Arduino depart from the standard form-factor of the Uno, and are not designed for use with expansion shields (discussed below). A good example is the LilyPad — a special Arduino layout engineered for making (among other things) wearable microcontroller projects. Think Borg implants, only more friendly looking. The flower-shaped LilyPad has a flat profile and can be sewn into fabric. It has connection points on the ends of its 22 petals.

With so many variations of the Arduino floating around, it's easy to get confused. For the ArdBot, we'll be using an Arduino Duo, but you can readily substitute just about any of the other versions. If you already have an earlier Duemilanove or even Diecimila, you can use it with the ArdBot. The only catch is that you'll need to make sure you have an up-to-date Arduino programming environment installed on your computer. I've tested everything with version 0019 of the Arduino programming IDE (discussed later), so with that version or anything later you should be good to go.

Ready Expansion Via Shields

The Arduino is an example of the KISS principle. Its simple design helps keep costs down, and makes the Arduino a universal development board adaptable to just about anything. While there are more expensive specialty versions of the Arduino made for robotics applications, the basic board lacks connectors to directly attach to motors, sensors, or other devices.

The Arduino itself has no breadboard area, but it's easy enough to connect any of the inputs or outputs to a small breadboard via wires. For an application like robotics, you'll want to expand the Arduino I/O headers to make it easier to plug in things like motors, switches, and ultrasonic or infrared sensors.

One method is to use an add-on expansion board known as a shield. These stick directly on top of the core board designs (Uno, Duemilanove, and Diecimila). Pins on the underside of the shield insert directly into the Arduino's I/O headers. Two popular expansion shields are the solderless breadboard and the proto shield; both provide prototyping areas for expanding your circuit designs.

Of course, you don't absolutely need a shield to expand the Arduino. You can place a breadboard — solderless or otherwise — beside the Arduino, and use ribbon cables or hookup wire to connect the two together. This is the approach we'll be using with the ArdBot described in this series of articles.

USB Connection and Power

To allow the easiest possible means of programming, the Arduino Duo and related core boards support on-board USB. You merely need to connect a suitable USB cable between the Arduino and your computer. The cable even provides the power to the board. The necessary USB drivers are provided with the Arduino software. In most cases, installation of the drivers is not fully automatic, but the steps are straightforward and the Arduino support pages provide a walk-through example.

The Arduino accepts a standard USB Type B connector. Your PC probably uses the larger Type A connector, so you need a Type A to Type B USB cable. Keep in mind that some PCs and laptops may use Mini-A or Mini-B connectors, so check first before purchasing a cable for use with the Arduino.

Operating voltage of the Arduino circuitry is five volts which is supplied either by the USB cable when it's plugged into a USB port on your computer, or by a built-in linear regulator when the board is powered externally. The regulator is intended to be powered by 7-12 VDC; a nine

Main Components

This is a *selected* list of North American sources for the main components for the ArdBot.

Arduino Duo or Duemilanove

Source	Item or SKU
Adafruit	50
HVW Tech	28920 (Freeduino SB)
RobotShop	RB-Ard-03
SparkFun	DEV-09950

Solderless breadboard, 170 tie-points

Source	Item or SKU
Adafruit	65
HVW Tech	21380
Parallax	700-00012
RobotShop	RB-Spa-139

Continuous rotation servo (Futaba spline)

Source	Item or SKU
Parallax	900-00008
Pololu	1248
RobotShop	RB-Gws-23
Solarbotics	36000
SparkFun	ROB-09347

2-1/2" or 2-5/8" rubber wheels (Futaba spline)

Source	Item or SKU
Adafruit	167
HVW Tech,	
Solarbotics	SW
Parallax	28109
Pololu	226
RobotShop	RB-Sbo-86

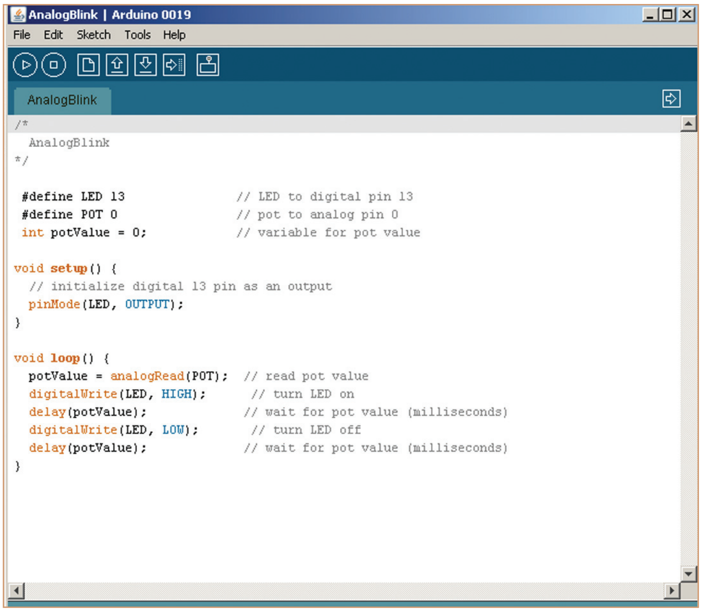


FIGURE 3. The Arduino integrated development environment (IDE) provides a centralized place to write, compile, and download programs to the Arduino board.

volt battery is ideal. Anything higher than 12 volts is not recommended as it could cause the regulator to overheat.

For robotics, I think it's best to power the Arduino from its own battery. The ArdBot uses a split supply where the Arduino is powered by a nine volt transistor battery; a separate four-cell AA battery holder is used for servo motors and other components that don't require voltage regulation.

Indicator LEDs are provided on the Arduino for testing and verification. A small green LED shows power; two other LEDs show serial transmit and receive activity and should flash when the board is being programmed from your computer. A fourth LED is connected in parallel with digital I/O line 13 and serves as a simple way to test the Arduino and make sure it is working properly. We'll use this feature in a simple example later on in this article.

Programming the Arduino

Microcontrollers depend on a host computer for developing and compiling programs. The software used on the host computer is known as an integrated development environment, or IDE. For the Arduino, the development environment is based on the open source Processing platform (**www.processing.org**) which is described by its creators as a "programming language and environment for people who want to program images, animation, and interactions."

The Arduino programming language leverages an open source project known as Wiring (**wiring.org.co**). The Arduino language is based on good old-fashioned C. If you are unfamiliar with this language, don't worry; it's not hard to learn, and the Arduino IDE provides some feedback when you make mistakes in your programs.

Sources

Adafruit Industries
www.adafruit.com
Arduino resellers and custom shield projects. Convenient premade nine volt battery clip and 2.1 mm barrel connector (see product #80), and nine volt battery holder with switch (product #67).

Arduino
www.arduino.cc
The main Arduino site provides downloads, tutorials, references, design schematics, and other information useful for learning about and using the Arduino family of boards.

Atmel
www.atmel.com/products/AVR
Manufacturers of the AVR microcontrollers used in the Arduino. See their site for datasheets (in PDF format).

Budget Robotics
www.budgetrobotics.com
Custom machined decks, servo mounting hardware, and assembly hardware for the ArdBot.

Freeduino
www.freeduino.org
Home of the Freeduino collaborative project.

HVW Technologies
www.hvwtech.com
Reseller of Arduino products and manufacturer (with Solarbotics) of the *Freeduino SB*.

Parallax
www.parallax.com
Not resellers of Arduino, but they offer continuous rotation servos, wheels, and sensors.

Pololu
www.pololu.com
Wheels, continuous rotation servo motors.

RobotShop
www.robotshop.ca (Canada); *www.robotshop.us* (US)
Full service retailer carrying most all of the official Arduino lineup, plus servo motors, solderless breadboards, and sensors.

Solarbotics
www.solarbotics.com
Continuous rotation servos, five-cell AA battery packs with attached 2.1 mm barrel connector, Arduino, and Arduino-clone boards.

SparkFun Electronics
www.sparkfun.com
Reseller of the Arduino and manufacturer of custom Arduino-like hardware.

If you've dabbled in Basic, you just need to remember that in C, keywords and variables are case sensitive. Instead of using If/End If, in C, code blocks are grouped together using the { and } (brace) characters. Statements are terminated with a ; (semi-colon) character, rather than just a simple line break. Any other differences, you'll pick up quickly.

To get started with programming your Arduino, first go to: **http://arduino.cc** and then click on the Download tab. Find the platform link (PC, Mac, Linux) for your computer and download the installation file. Step-by-step instructions are provided in the Getting Started section of the Arduino website. Be sure to read through the entire instructions.

Be aware that the main Getting Started section assumes you're using an Arduino Uno, Duemilanove, Nano, or Diecimila board. If you're using another version of the Arduino, be sure to check out its corresponding page on the site.

Once installation is complete, you're ready to try out your Arduino. Start by connecting the board to your PC via a USB cable. If this is the first time you've used an Arduino on your PC, you must install the USB communications drivers, as detailed in the Getting Started guide.

Using the Arduino programming environment is simple. First-time use of the environment requires you to specify the Arduino board you are using, and as necessary, the serial port that is connected to the board (the Arduino's USB connection looks like a serial port to your computer). You may then open an existing example program which is called a sketch in Arduino parlance, and download the program to your board. Or, you may write your own sketch in the IDE editor. **Figure 3** shows the Arduino IDE with a short sketch in the main window.

After writing or opening an existing sketch, you need to compile it which prepares the code for downloading to the Arduino. The Arduino IDE calls compiling a program verifying. At the bottom of the text editor is a status window which shows you the progress of compiling (verifying). If the sketch is successfully compiled, it can then be downloaded to the Arduino where it will automatically run once the download is complete.

Programming for Robots

As you go through the list of programming statements available in the Arduino IDE (choose Help->Reference), you might think there isn't much power for doing things like running servos, operating stepper motors, reading potentiometers, or displaying text on an LCD.

Like most any language based on C, the Arduino supports the notion of "libraries" — code repositories that extend core programming functionality. Libraries let you re-use code without having to physically copy and paste it into all your programs. The standard Arduino software installation comes with several libraries you may use, and you can download others from the Arduino support pages and from third-party websites that publish

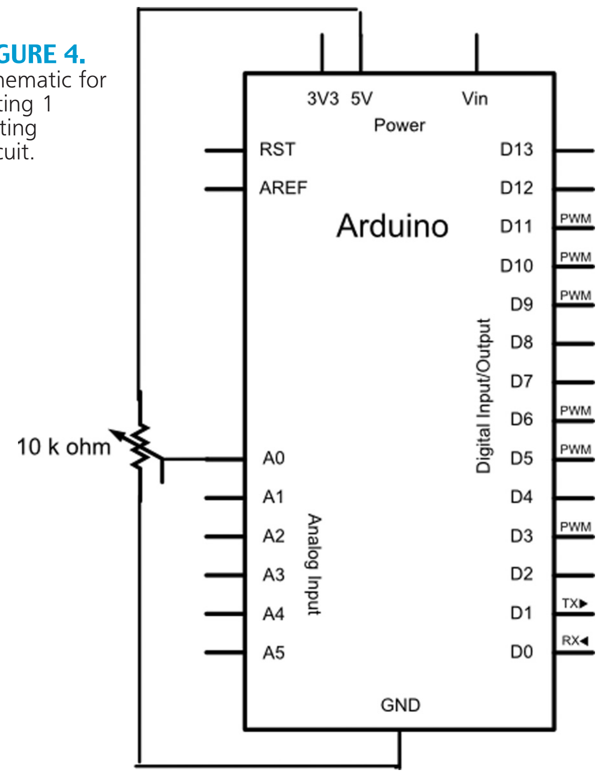


FIGURE 4. Schematic for Listing 1 testing circuit.

Arduino library code.

A good example of a library you'll use with the ArdBot — and likely many other robot projects — is Servo. This library allows you to connect one or more hobby R/C servos to the Arduino's digital I/O pins. The Servo library comes with the standard Arduino installation package, so adding it to your sketch is as simple as choosing Sketch->Import Library->Servo. This adds the line

```
#include <Servo.h>
```

which tells the Arduino IDE that you wish to include the Servo library in your sketch. With the functionality of the library now available to you, you can use its various functions to control one or more servos. For example, you can use the write function to rotate a servo to a specific position, from 0 to 180 degrees. The following code

```
myServo.write(90);
```

moves a servo to its midpoint, or 90 degree position.

Structurally, Arduino sketches are very straightforward and are pretty easy to read and understand. The Arduino program contains two main parts: setup() and loop(). These are programming functions that do what their names suggest: setup() sets up the Arduino hardware, such as specifying which I/O lines you plan to use, and whether they are inputs or outputs. The loop() function is repeated endlessly when the Arduino is operating.

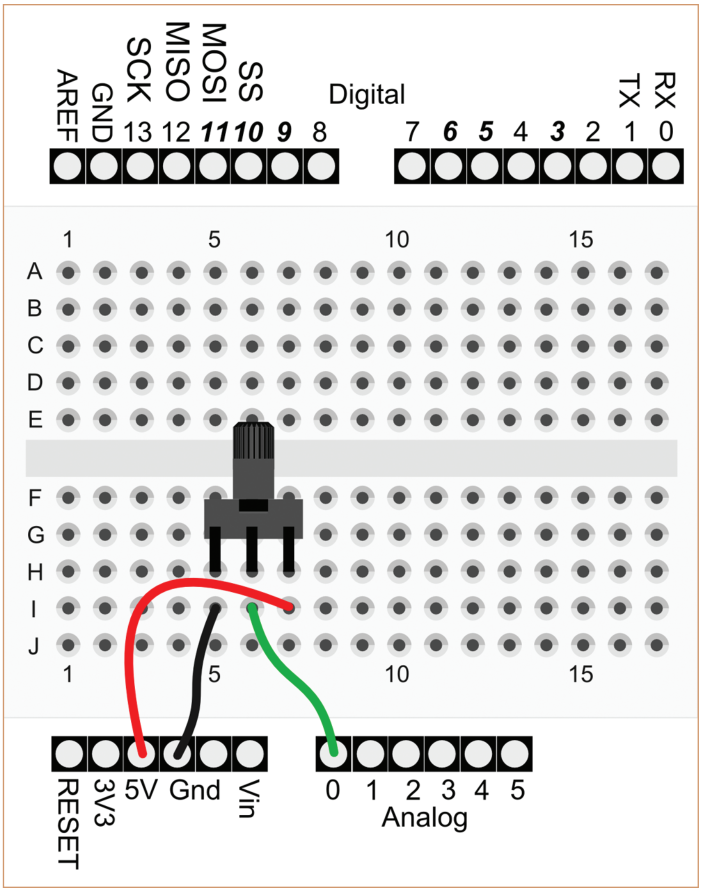


FIGURE 5. Breadboard layout for Listing 1 testing circuit. The potentiometer is 10 kW, linear taper.

Experiment By Doing

Listing 1 demonstrates a few fundamental Arduino concepts useful in any robotics development — that is, reading an analog sensor and providing visual feedback. I've taken one of the examples that comes with the Arduino IDE and modified it slightly to conform to the style we'll be using throughout this series of ArdBot articles. It uses a 10 kΩ potentiometer to alter how fast Arduino's built-in LED flashes.

Check out **Figure 4** for a schematic of the circuit used for the program listing; **Figure 5** shows a pictorial breadboard view of connecting the potentiometer to the Arduino hardware. The potentiometer is connected to the board as a common voltage divider. That way, the Arduino detects the value of the pot as a variable voltage from zero volts (ground) to five volts.

Note that I'm using a standard mini solderless breadboard with 170 tie-points. The breadboard serves as a prototyping area for connecting to various hardware, and is part of the ArdBot. You can use any other size of solderless breadboard, but none of the circuits for the ArdBot will require anything bigger.

Here's how the program works:

The first two lines set variable constants, so hardware connected to the various I/O pins can be referred to by name and not pin number. This is merely for our convenience. The built-in LED is connected to pin 13, and the potentiometer — named POT in our program — is connected to analog pin 0.

Another variable is defined to hold the current value of the potentiometer which will be a number from 0 to 1023. This number is derived from the Arduino's integrated 10-bit analog-to-digital (ADC) converter, and it represents a voltage level from zero volts to five volts.

The setup() section gets the Arduino hardware ready for the rest of the program. When first powered on, all the I/O lines are automatically defined as inputs. The LED pin needs to be an output, however, so that distinction is defined here. The programming statement that changes the function of an I/O line is pinMode. It expects two values (called arguments): the number of the I/O pin — in this case, it's 13 as defined by the LED variable — and whether the pin is an OUTPUT or an INPUT.

The loop() section is automatically started the moment the program has been downloaded to the Arduino. The looping continues until the board is either unplugged, the reset button on the Arduino is pushed, or a new program is loaded into memory. The loop begins by reading the voltage on analog pin 0 — remember, it's defined in the POT variable at the top of the program. The program then turns the LED on, and waits for a period of time defined by the current position of the potentiometer before turning the LED off again.

The waiting period is in milliseconds (thousandths of a second), from 0 to 1023, the range of values from the Arduino's ADC. Very fast delays of about 100 milliseconds or less will appear as a steady light. You'll be able to see the LED flash with longer delays.

Listing 1

```
 #define LED 13        // LED to digital pin 13
 #define POT 0         // pot to analog pin 0
 int potValue = 0;     // variable for pot value

void setup() {
  // initialize digital 13 pin as an output
  pinMode(LED, OUTPUT);
}

void loop() {
  potValue = analogRead(POT);        // read pot
                                     // value
  digitalWrite(LED, HIGH);   // turn LED on
  delay(potValue);           // wait for pot
value
                             // (milliseconds)
  digitalWrite(LED, LOW);    // turn LED off
  delay(potValue);           // wait for pot
value (milliseconds)
}
```

Quick View of the ArdBot

Figure 6 shows the prototype ArdBot, made of 6 mm (about 1/4") expanded PVC. In the next installment, I'll provide detailed construction plans, but here's the robot in a nutshell:

- Two 7" "decks" provide generous room for motors, batteries, Arduino, and mini solderless breadboard, as well as future expansion. The top deck is secured by four machine screws to a set of 1-3/4" long aluminum hex standoffs.
- Two standard size continuous rotation servos drive the robot using the differential steering technique where the speed and direction of each motor determines where the robot travels.
- Half-inch wide tires provide traction indoors and out. The wheels measure 2-1/2" in diameter, and directly connect to the servo shafts.
- To keep costs down the ArdBot doesn't use wheel casters or ball transfers. Instead is uses two height-adjustable skids fore and aft which keep the robot level. The skids have rounded bottoms and act just like small rollers.

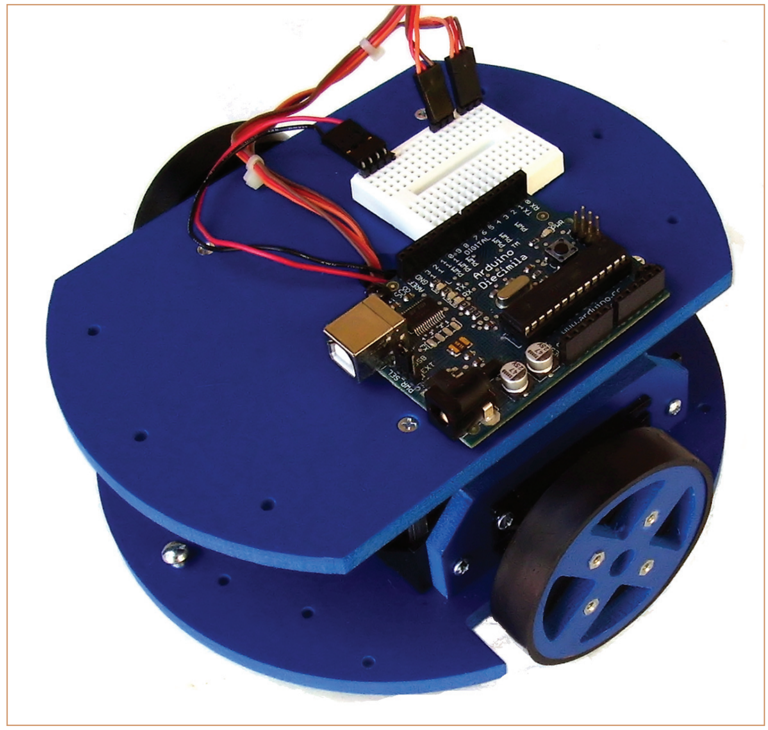


FIGURE 6. Prototype ArdBot, a double-decker desktop robot using the Arduino Duo or similar controller board. It's designed for easy expansion and experimentation. Construction will be covered in Part 2.

The bottom deck is used for mounting the servos and battery packs. The deck is large enough for several four- or five-cell AA battery holders, plus a nine volt cell or custom battery packs. There's room in the corners of the deck for mounting infrared, bump switch, or other sensors.

The top deck provides open access to the Arduino and solderless breadboard, both of which you can place anywhere you want. This way, you can program and reconfigure the board without any disassembly of the robot. There's room for servo turrets, accelerometers, GPS receivers, sensor modules, and more. In the event you need even more room for your experiments, you can add a third deck for an additional 35 square inches of space.

The ArdBot is a universal design with components you can get from a variety of suppliers. See the **Sources** box for a list of online retailers that sell the Arduino and other parts. You can build the ArdBot platform yourself, or if you don't like mechanical construction, as a convenience to *SERVO* readers, you can get the two body decks and all mounting hardware from my Internet company, Budget Robotics.

So much for the basics. See you next time for detailed constructions plans of the ArdBot and more. **SV**

About the Author

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