Making Robots With The Arduino

Part 2

By Gordon McComb

The ArdBot is a low-cost, 7" diameter servo-driven robot base, ready for expansion. It's called ArdBot because it's based on the popular and inexpensive Arduino microcontroller board. The ArdBot costs under $80 to build; even less if you already have some of the components, like the breadboard, jumper wires, and battery holder.

In the last installment, we introduced the ArdBot and its central Arduino brain. This month, we'll continue the discussion with full construction plans for the ArdBot. I built the reference design using 1/4" expanded PVC plastic, but you can use wood, acrylic, foam board, picture frame mat, or most anything else that is rigid enough for the components.

ArdBot Basic Design

The ArdBot uses two "decks" for mounting a pair of servo motors, batteries, microcontroller, small prototyping board, and other components you'd like to experiment with. The bottom deck is basically a 7" diameter circle with cutouts for the wheels. The top deck is the same 7" diameter circle with the side lobes cut off.

The decks are separated by a set of four 1-3/4" long standoffs. The actual length of the standoffs is not really important. You can make them shorter or longer — 1-1/2" is the practical minimum and 3" the maximum.

While it's a bit more challenging to cut circles to make a robot base, it's the best overall shape for navigating tight places like mazes or the corner of a living room. The concept of the ArdBot is flexibility, however. There's no reason your version must be circular. You can make a square bot if you'd like, or cut off the corners of the square to make an octagon.

If you don't want to construct the mechanical pieces of the ArdBot at all, you can get them precut with all the hardware; see the **Sources** box. ArdBot is designed for expandability. If the twin decks do not provide enough space for all your experiments, you can add more decks. I don't recommend any more than three decks total, as any more may pose a weight problem for the drive system.

The brain of the ArdBot is an Arduino Uno — the latest of the all-in-one core designs of the Arduino. If you already own an earlier version of the board — a Diecimila or Duemilanove — those will work, too. The only requirement is that you have version 0017 or later of the Arduino programming environment. The ArdBot project was created and tested using version 0019 — the latest as of this writing. Complementing the Arduino microcontroller board is a mini solderless breadboard. It has 170 tie points —

In preparing Part 1 of this series, I made a last-minute change to include the new Ardunio board that's just been released. Only I got the name wrong — in several places in the article, I referred to the new board as the Duo. The correct name for the board is the Uno.

enough for the basic experiments we'll be doing in this series of articles. Don't let the small size of the breadboard limit you. The ArdBot is large enough for bigger breadboards, even multiple boards, should you need them. You might want to start with the mini breadboard, then as you use the ArdBot for further experiments you can add more prototyping space.

About the Servo Drive

The ArdBot uses differential steering where the base is propelled by two motors and wheels on opposite sides. To keep costs down and minimize construction complexity, the robot uses a pair of skids placed in the front and rear to provide balance. With this arrangement, the ArdBot is able to move forward and back, turn left and right, and spin in place. The skids are smooth and polished metal, so they present little drag on whatever surface the robot is rolling over. Even so, the ArdBot is best suited for travel on hard surfaces or carpet with a short nap.

The two drive motors run off their own battery supply which is a set of four AA rechargeable or non-rechargeable cells. The motors are standard size radio control airplane servos that have been modified for continuous rotation.

The ArdBot reference design uses servos that come from the factory already modified so you don't have to hack them. I used a pair of GWS S-35 servos, but there are others available (see **Sources**) for under $15 each. I won't provide instructions here on how to modify a servo for continuous rotation. That subject has been tackled in past issues of *SERVO* and *Nuts & Volts*, so I'll leave it at that.

Making the ArdBot Base

The ArdBot is constructed with four body pieces held together with hardware fasteners. **Table 1** provides a full list of mechanical parts. **Tables 2** through **5** specify the other components to complete the ArdBot.

All body pieces assume 1/4" thick material. For your reference, **Figure 1** shows a completed ArdBot, ready to be programmed and played with. The body pieces include:

- *Bottom deck* measuring 7" diameter with cutouts for the wheels (see **Figure 2**). The deck includes a number of holes, of which only six are required. Any other holes are up to you. I've included several additional holes at the front and back of the deck for mounting bumper switches and other sensors. The wheel cutouts measure 2-5/8" x 7-5/8"; sized for commonly available 2-1/2" or 2-5/8" diameter robotic wheels for R/C servo motors.
- *Top deck* measuring 7" x 5" (see **Figure 3**). Only four of its holes are critical; these mate with matching holes in the bottom deck using a set of four standoffs. A 1/2" diameter hole in the center (or thereabouts) provides a throughway for wires from the bottom deck. The other holes as shown are optional, and are for attaching sensors and other accessories.
- *Pair of servo mounts* (see **Figure 4**) for attaching the servos to the bottom deck. You can make these

Table 1. Mechanical Parts.

Qty	Description
1	7" diameter bottom deck with wheel well cutouts for the drive wheels.
1	7" × 5" top deck.
2	Servo mounts.
4	90° plastic L brackets for attaching the servo mounts to the bottom deck. These brackets measure 3/4" × 3/4" with hole centers at 3/8", and are made to work with the two servo mounts.
16	4-40 x 1/2" machine screws and nuts for attaching the servos and servo mounts to the bottom deck.
4	Deck risers consisting of: (4) 1-3/4" aluminum (or plastic) risers with 4-40 threads; (4) 4-40 × 1/2" pan head machine screws; and (4) 4-40 × 1/2" flat head machine screws.
2	Skids consisting of: (2) 8-32 × 3/4" machine screws; (2) 8-32 hex nuts; and (2) 8-32 acorn (cap) nuts.
3	Sets of mounting hardware for Arduino Uno, consisting of (3) 4-40 × 1/2" machine screws; (3) 4-40 nuts; and (3) plastic washers.

* For your convenience, all mechanical pieces — including precut decks and servo mounts — at are available through Budget Robotics. See the **Sources** box for details.

Table 2. Motors and Wheels.

Qty	Description
2	Standard size R/C servo motors, modified for continuous rotation.
2	2-1/2" or 2-5/8 diameter wheels with hubs to attach to the servo motors.

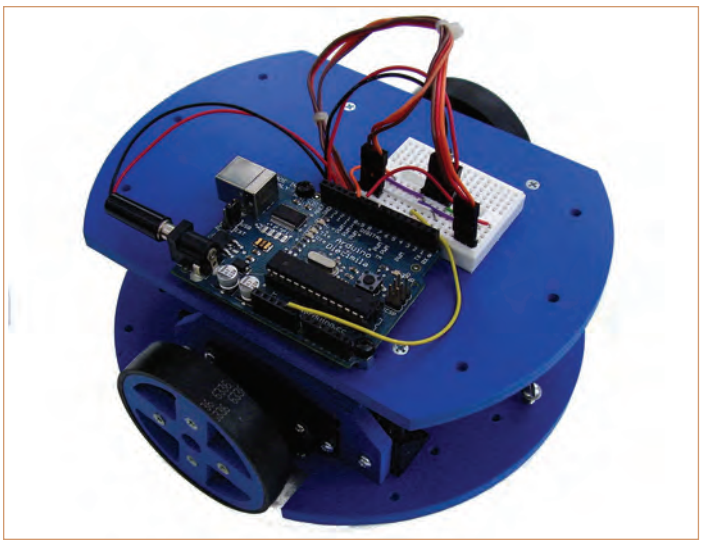

FIGURE 1. The completed ArdBot with Arduino microcontroller board, solderless breadboard, servos, wheels, and all body parts.

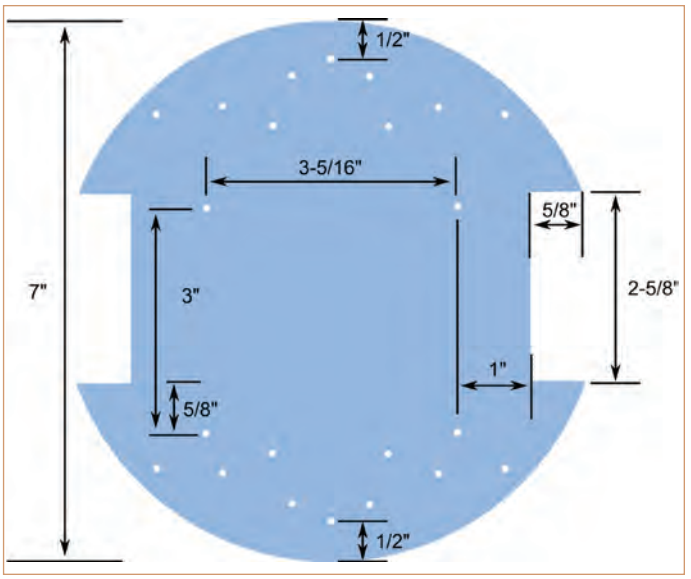

FIGURE 2. Layout pattern for cutting and drilling the bottom deck of the ArdBot. The only truly critical dimensions are the cutouts for the wheels and the placement of the two sets of holes immediately beside the wheel cutouts. These holes are for the servo mounts. See **Figure 5** for a description of all holes.

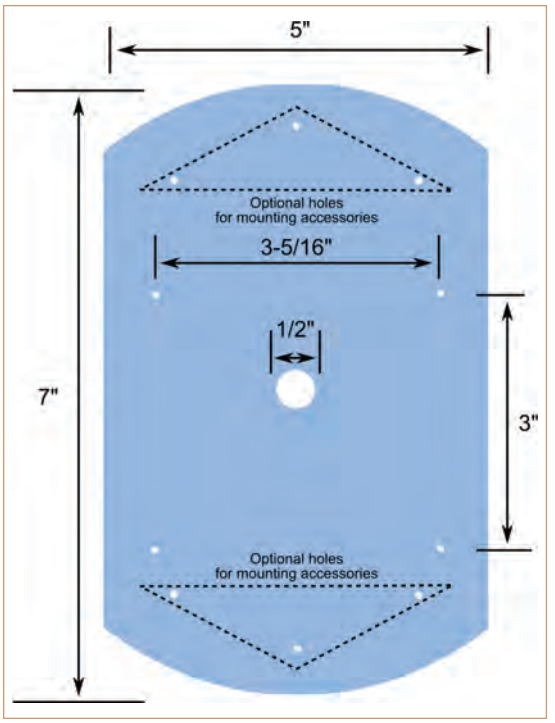

FIGURE 3. Layout pattern for cutting and drilling the top deck of the ArdBot. Critical holes are the four small ones nearest the center. These must match the four servo mounting holes in the bottom deck.

yourself or, if you choose, purchase them separately. If you make the mounts, be aware that sizing is critical. The two holes on either side of the mount must be spaced 3" apart to accommodate the same hole spacing in the bottom deck.

The base parts may be cut from stock measuring 12" x 12" which is a common size for expanded PVC or other plastic purchased through mail order. A motorized scroll saw is the perfect tool for cutting out the ArdBot base components, but if you don't have one handy, a coping saw also works. Use a wood blade; it'll work whether you're making the base with aircraft-grade plywood (available at the hobby store), PVC, or other plastic.

If using foam board or picture mat, you can cut the pieces using a sharp hobby knife or mat cutter. The usual safety precautions apply. A circle cutting jig makes perfect circles when using these materials. If you don't own a circular jig yourself, see if the local picture frame store will make the cuts for you. When using picture mat material, cut two of everything, and double-up the pieces for extra stiffness. Except for the large center hole in the top deck, all holes are drilled with a 9/64" bit.

Assembling the ArdBot

With the body pieces constructed (or purchased) and all other parts in hand, you're ready to build your ArdBot. Here's how.

Step 0

Before assembly, you may want to use 150 grit sandpaper to smooth the edges of the base parts. Orient the bottom deck so that the holes are aligned as shown in **Figure 5**. Note that the holes for each servo are not symmetrically placed on the deck. This is to accommodate

Table 3. Electronic Parts.

Qty	Description
1	Arduino Uno (or compatible) microcontroller board with USB programming cable.
1	Mini solderless breadboard; 170 tie points.
1	Set of solderless breadboard wire jumpers (or make your own using 22 gauge solid conductor wire).
1	AA x four battery holder, with female header connector; see text.
1	Nine volt battery clip, with 2.1 mm polarized barrel plug; see text.
1	Length of 12 (or more) breakaway 0.100" male header pins, double-sided (long) pins; see text.

Table 4. Power.

Qty	Description
4	AA alkaline or nickel metal hybride rechargable batteries.
1	Nine volt battery.

Table 5. Optional (but nice to have) Parts.

Qty	Description
1	Nine volt metal or plastic battery holder.
1	Hook-and-loop (Velcro) strips for mounting battery holders and solderless breadboard; small pieces of double-sided foam tape.

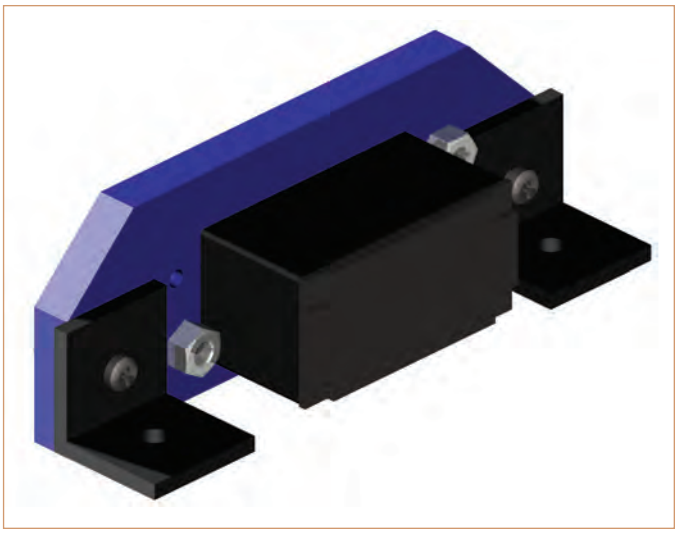

FIGURE 7. Attach two L brackets to the servo mount. The L brackets should be flush with the bottom of the servo mount.

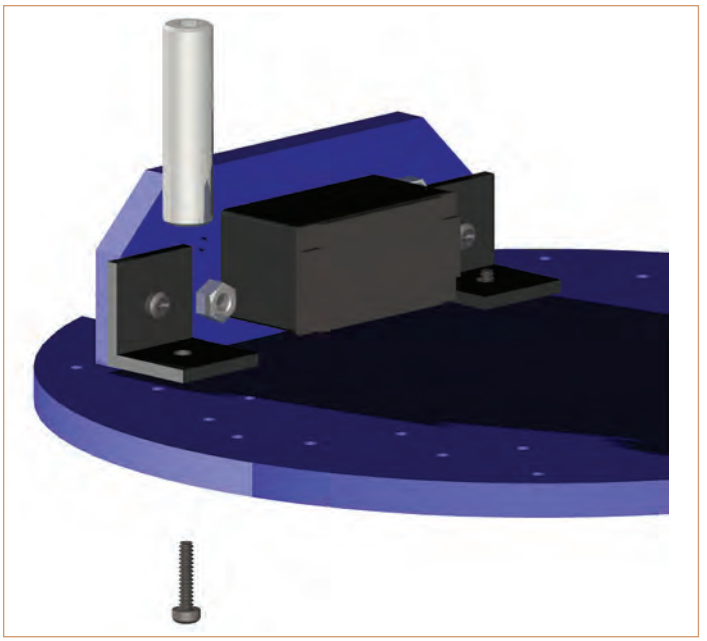

FIGURE 8. Secure the servo mounts to the bottom deck using machine screws and threaded standoffs. The standoffs serve to separate the decks.

the L bracket, and then into the standoff as shown in **Figure 8**. When orienting the mount assembly, be sure that the servo shaft is centered in the wheel well cutout. Align the assembly so they are parallel with the wheel well cutout, then tighten all the screws. **Figure 9** shows how the completed servo, mount, and standoffs should look. Repeat the same procedure for the right mount assembly.

Step 4

Attach the front and rear skids as shown in **Figure 10**. Each skid uses an 8-32" machine screw, hex nut, and acorn (cap) nut.

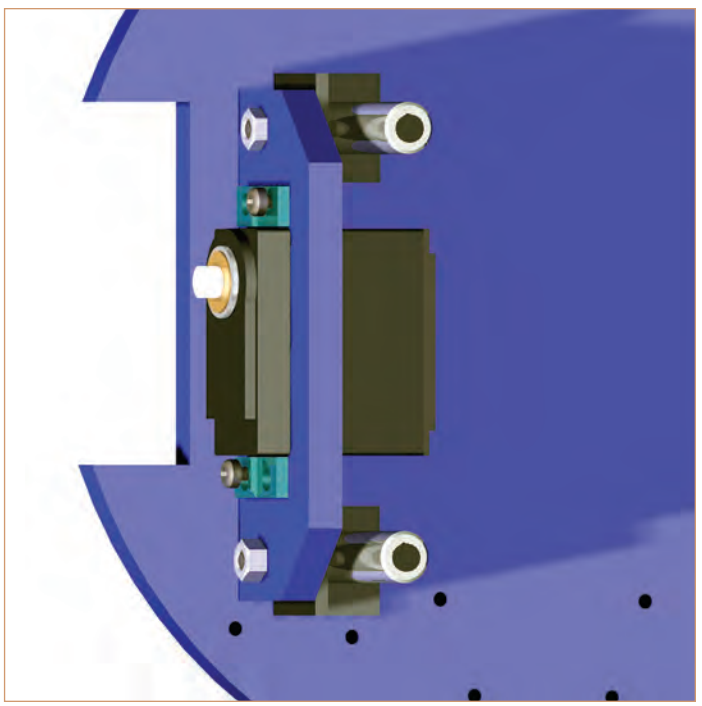

FIGURE 9. Here's how the completed servo mount should look with standoffs in place.

1. Using a screwdriver, thread a machine screw into the hole at the front and back of the deck (refer to **Figure 5** for the location of these holes). The screw is inserted from the top of the deck (the side with the servos). The holes for the skids are undersized for 8-32 machine screws. When using a soft material like wood or PVC plastic, the fastener will tap the hole as you screw it in. Continue threading the screw into the hole until the head is about 1/4" from the deck, as indicated in the picture.

2. Put the hex nut onto the screw, followed by the acorn nut. Tighten the acorn nut against the hex nut.

Repeat these steps for the other skid. You may adjust the height of the skid by loosening or tightening the machine screw in the hole. If you need greater height adjustment or the hole for the skid is too large to self-tap,

FIGURE 10. ArdBot uses static skids (made with 8-32 metal fasteners) for front and back balance. You can adjust the height of each skid to compensate for the diameter of wheels you use.

the offset of the servo drive shaft. While there is technically no "front" or "rear" of the ArdBot, for the purposes of assembly, the top of the illustration in **Figure 5** is the front and the bottom is the rear.

Step 1

Insert a servo into a servo mount by sliding it back-end first through the mount. The fit may be tight, depending on the make and model of the servo. (As necessary, enlarge the rectangle for the servo using a file or coarse sandpaper.) Do not force the servo into the mount or the mount may be damaged.

Secure the servo to the mount with 4-40 x 1/2" screws and hex nuts (**Figure 6**). You can use four screws for each servo, or only two. When using two screws position them on opposite corners of the servo mounting flange, as shown.

Repeat for the opposite servo and mount. *Be sure to construct the second servo and mount in a mirror image to the first!* Refer to **Figure 9** in Step 3 to see how the motors should be inserted into the mounts. For reference, also see **Figure 12** for an aerial view of the ArdBot and its completed bottom deck.

Step 2

Using 4-40 x 1/2" machine screws and nuts, attach two plastic L brackets to each of the servo mounts (**Figure 7**). You'll be make a "left" and a "right" mount assembly.

For the left mount assembly, the motor shaft should face to the left and toward the "top" of the deck (as referenced in **Figure 5**). Attach the L brackets to the right side of the mount. For the right mount assembly, the motor shaft should face to the right, also toward the top of the deck. Attach the L brackets to the left side of the mount.

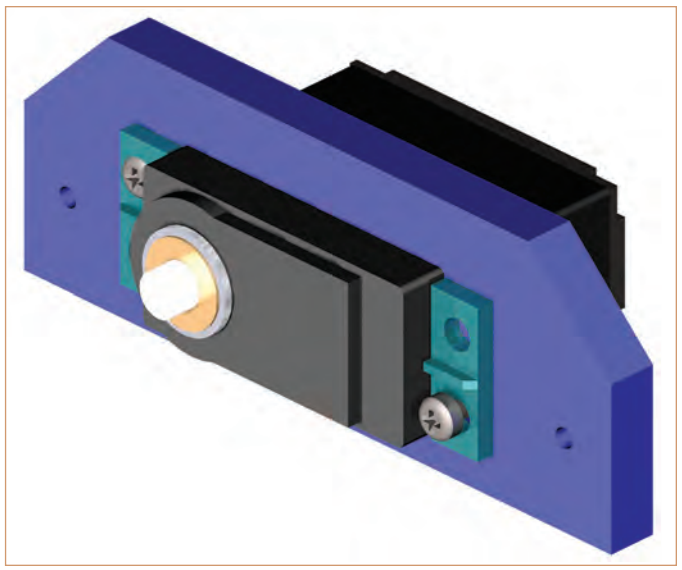

FIGURE 6. Servo motor secured into one of the servo mounts. You need two of these.

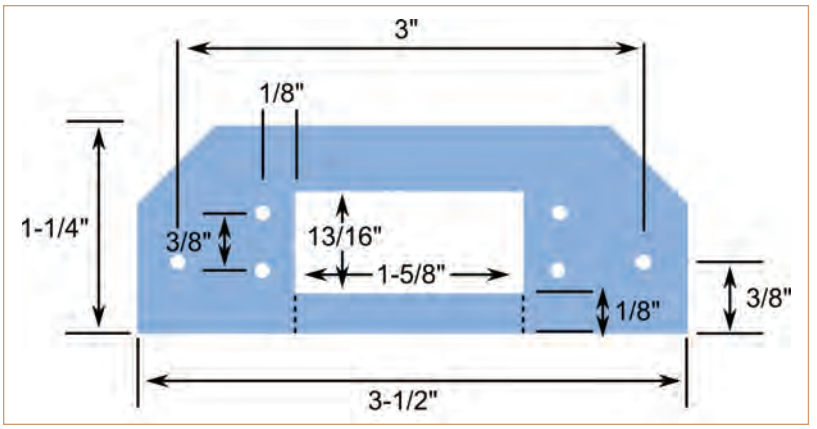

FIGURE 4. Layout pattern for cutting and drilling the servo mount. You'll need two of these. If cutting the inside rectangle proves difficult, you can instead make the mounts by cutting through at the dotted line. The mount will be a little more fragile, so handle it carefully. Use all four screws to secure the servo in the mount, rather than just two.

Insert the machine screws through the L bracket, then through the servo mount. Secure on the other end with a nut. Before tightening, be sure the bottom of the L bracket is flush with the bottom edge of the servo mount.

Step 3

Attach the left mount assembly to the bottom deck using two 4-40 x 1/2" screws and standoffs. The screws should come up from the underside of the deck, through

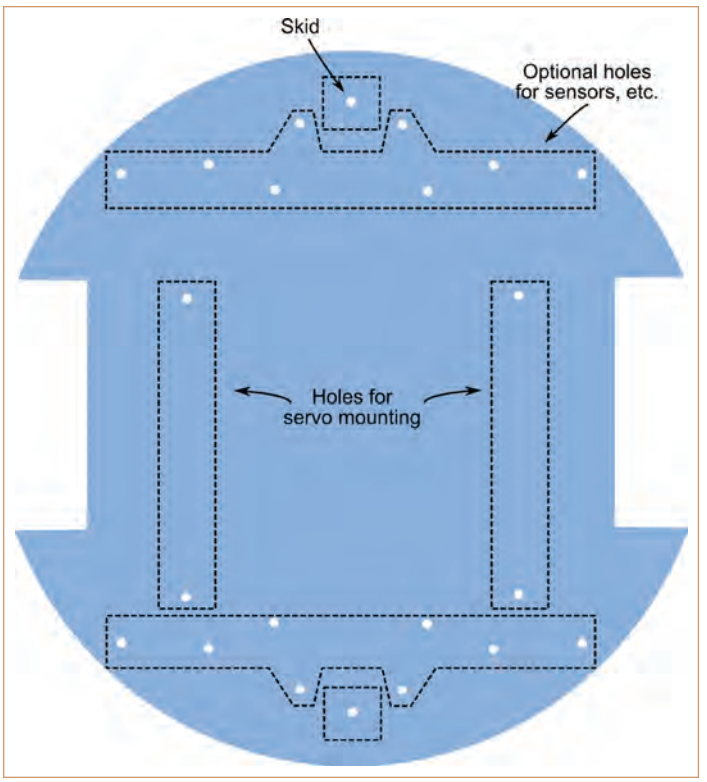

FIGURE 5. Only four holes are critical for the bottom deck: the two sets marked Holes for servo mounting, and the front and rear Skid. The rest are optional for sensors and other accessories you may want to add later.

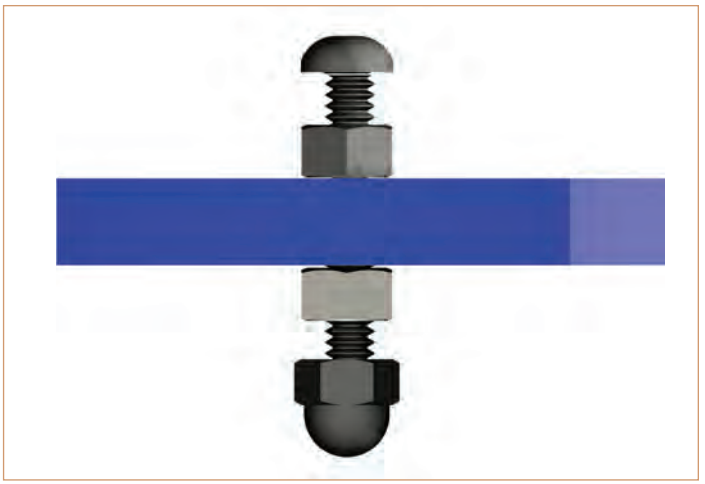

FIGURE 11. If you need additional height control for the skids or the hole for the skid cannot be threaded, use a longer 8-32 screw with hex nuts above and below the deck.

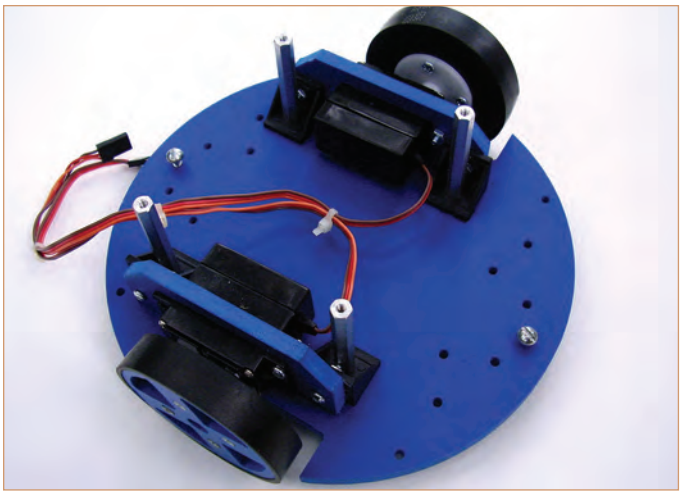

FIGURE 12. The completed bottom deck of the ArdBot. Note the orientation of the servos in the mounts.

merely use a longer machine screw and tighten into place using nuts on both the top and bottom of the deck, as shown in **Figure 11**.

Step 5

Attach the wheels to the servos. Each wheel is secured with a small self-tapping screw that is supplied with the servo. Note that the servo shaft is splined; this spline matches the wheel hub. Be sure to press the wheel onto the shaft firmly while tightening the screw. Do not over-tighten the wheel mounting screw, but be sure the wheel is on snugly. **Figure 12** shows the completed bottom deck of the ArdBot, with motors, mounts, and wheels attached. (I've bound the wire leads for the servos using cable ties to keep things neat. You can do the same if you wish.)

Step 6

Secure the side of the nine volt battery holder against the side of the AA battery holder using a small piece of double-sided foam tape or hook-and-loop (Velcro). Next, secure the AA battery holder to the approximate center of the bottom deck using a square or two of hook-and-loop to keep it in place. Note the electrical connections for both the nine volt battery and the AA battery holder:

- The nine volt battery uses the traditional two-prong battery clip, terminated on the other end with a 2.1 mm barrel plug. This plug inserts into the power jack of the Arduino. You can make this power lead yourself by soldering a barrel plug onto a standard two-prong battery clip, or purchase one ready-made (see the **Sources** box). When constructing your own, be absolutely sure the + (positive) connection is the center of the plug; the – (negative) connection is the outside of the barrel.
- The AA battery holder uses a female 0.100" pin header connector. You can use a connector with two or more pins; the additional pins can be used to help assure proper polarity. With just two pins, you must be VERY careful to never (and I mean NEVER, EVER!) reverse the polarity of the connector. If you do, your servos will be instantaneously and permanently damaged. By using (for example) a four pin connector, you can block up one of the unused terminals. This helps prevent you from reversing the connector when you plug it in. (Of course, still be careful, no matter what system you use!) Insert fresh batteries into the holders and attach the clip to the nine volt battery. The holders with batteries are shown in **Figure 13**.

Step 7

Find a favored spot on the top deck for your Arduino, and mark three holes for mounting the board. Be sure not

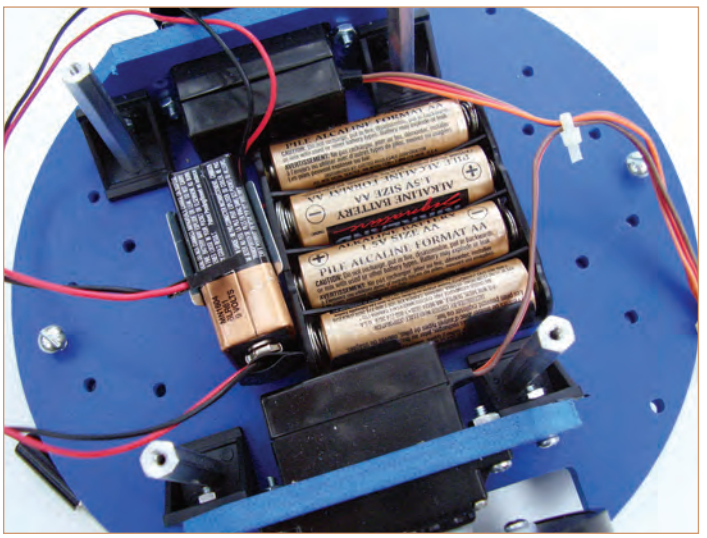

FIGURE 13. The bottom deck is large enough for several battery packs, and they can be neatly placed in the center. The reference design uses a nine volt battery to power the Arduino, and a holder with four AA cells to power the servo motors.

Listing 1

```
/*
 ArdBot ServoTest
 Tests servos of robot by moving them in
 different directions
 Requires Arduino IDE version 0017 or later
  (0019 or later preferred)
*/

#include <Servo.h>

Servo servoLeft;            // Define left servo
Servo servoRight;           // Define right
servo

void setup()
{
  servoLeft.attach(10);     // Set left servo to
                            // digital pin 10
  servoRight.attach(9);     // Set right servo
to
                            // digital pin 9
}

void loop()                 // Loop through
                            // motion tests
{
  forward();                // Example: move
                            // forward
  delay(2000);              // Wait 2000
                            // milliseconds
                            // (2 seconds)
  reverse();
  delay(2000);
  turnRight();
  delay(2000);
  turnLeft();
  delay(2000);
  stopRobot();
  delay(2000);
}

// Motion routines for forward, reverse, turns,
// and stop
void forward()
{
  servoLeft.write(0);
  servoRight.write(180);
}

void reverse()
{
  servoLeft.write(180);
  servoRight.write(0);
}

void turnRight()
{
  servoLeft.write(180);
  servoRight.write(180);
}

void turnLeft()
{
  servoLeft.write(0);
  servoRight.write(0);
}

void stopRobot()
{
  servoLeft.write(90);
  servoRight.write(90);
}
```

to cover up any of the four holes used for securing the top deck in place. Otherwise, you'll have to remove the Arduino in order to take off the top deck

Drill the three holes using a 9/64" bit. Secure the Arduino board to the top deck using 4-40 machine screws, nuts, and plastic washers. The washers go between the heads of the screws and the board, and minimize the possibility of a short circuit.

Mount the mini solderless breadboard so that it's close to the Arduino, but doesn't block the 1/2" wiring access hole in the top deck. Though most mini breadboards come with double-sided self-adhesive tape, I recommend that you don't use the tape. Instead, mount the board using a square or two of hook-and-loop. This allows you to easily remove the board when you need to.

Step 8

To complete the ArdBot, secure the top deck to the standoffs using 4-40 x 1/2" flat head screws. Assuming you are using a soft material (wood, PVC plastic, foam board, etc.), the heads of the screws should countersink by themselves as you tighten them and lay flush against the deck. Thread the battery and servo leads through the center hole of the top deck. To keep down cost and complexity, there are no power switches for the batteries, so leave the battery leads unattached until you're ready to program and use the ArdBot. (When you're done playing, be sure to unplug the batteries to keep them from draining.)

Two-Servo Wiring Plan

The Arduino lacks direct connections for attaching the servo motors. Instead, the mini breadboard provides prototyping space for connecting up both servos, as well as the AA battery holder that powers the servos. Refer to **Figure 14** (schematic) and **Figure 15** (pictorial) for wiring the solderless breadboard. Using a strip of 0.100" double-sided (long) male header pins, break off two sets of three pins, and one set of pins for the AA battery connection.

Note that you want the version of male header pins that are "double-sided" — they're long on both sides. If you use the standard header pins, the length of pins on one side is shorter. These don't make good contact when used with solderless breadboard designs. See the **Sources** box for a couple of mail order companies offering double-sided long header pins. In a pinch, you can use right-angle header pins instead and straighten them out so that all the pins are flat. The reference design uses a AA battery holder with a four-pin female connector. The + and – leads are on the two outside positions of the connector. I've broken off the pin right next to the + connection of the male header, then used a short piece of solid conductor hookup wire to fill in its corresponding hole in the connector. This prevents the connector from being reversed when plugged in.

When wiring the solderless breadboard, be especially careful not to mix positive and negative leads to the servo. Reversing the power leads to a servo will permanently

damage it. *Here's an important note*: The ArdBot uses separate battery supplies for the Arduino and the two servos. In order for everything to function properly, the ground connections for the Arduino and the servo battery supply must be connected together. This is shown in both the schematic and pictorial circuit views.

Make sure to also properly orient the connectors for the servos when you plug them into the board. Servo power leads are color-coded, but the colors aren't universal.

- Ground (–) is typically black or brown.
- Power (+) is most often red, and with modern servos is always in the middle.
- Signal is white, yellow, or sometimes orange (but take care — on some servos the power wire is orange!).

When in doubt, check the spec sheet that comes with your servos. Don't guess!

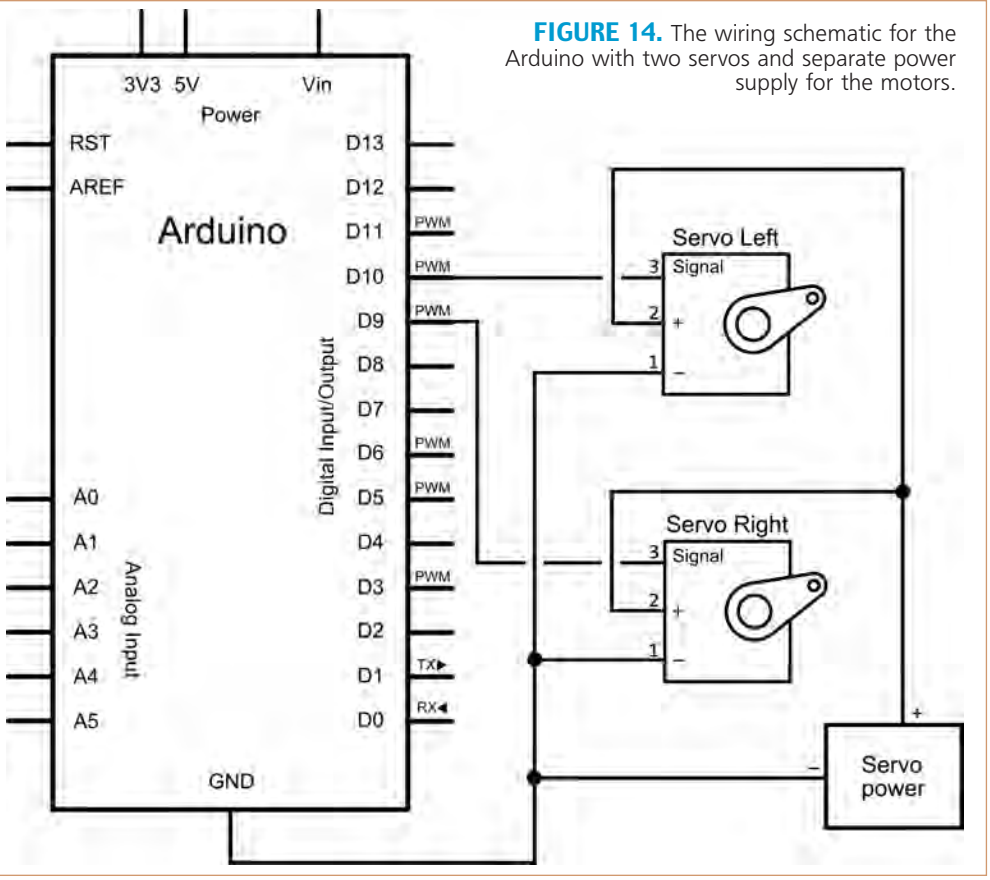

FIGURE 14. The wiring schematic for the Arduino with two servos and separate power supply for the motors.

Servo Test Sketch

With the ArdBot constructed and the breadboard wired, you're ready to test the robot and put it through its paces. Refer to **Listing 1** for a quick servo test sketch.

Start the Arduino IDE, connect a USB cable between your computer and the Arduino (as noted on the Getting Started pages of the Arduino website), and type the program as shown. When done, Verify (compile) the sketch and look for any syntax errors. If there are none, download the sketch to your Arduino.

Once downloaded, put a small book under your ArdBot to lift its wheels off the ground. Disconnect the USB cable, and — in this order — plug the AA battery connector into the breadboard, then plug in the nine volt power to the Arduino power jack. (If you are using an Arduino Diecimila, be sure to switch over the power selection jumper from USB to EXTernal.) If everything is connected properly, the servo motors should go through a test pattern.

Assuming the motors are working as they should, depress the Reset switch on the Arduino board and place the ArdBot on the ground. Release the switch and the robot should perform its self-test maneuvers. If the motors aren't moving, double-check your wiring, making sure the servo connectors are properly oriented. They won't work if the connectors are reversed on the breadboard.

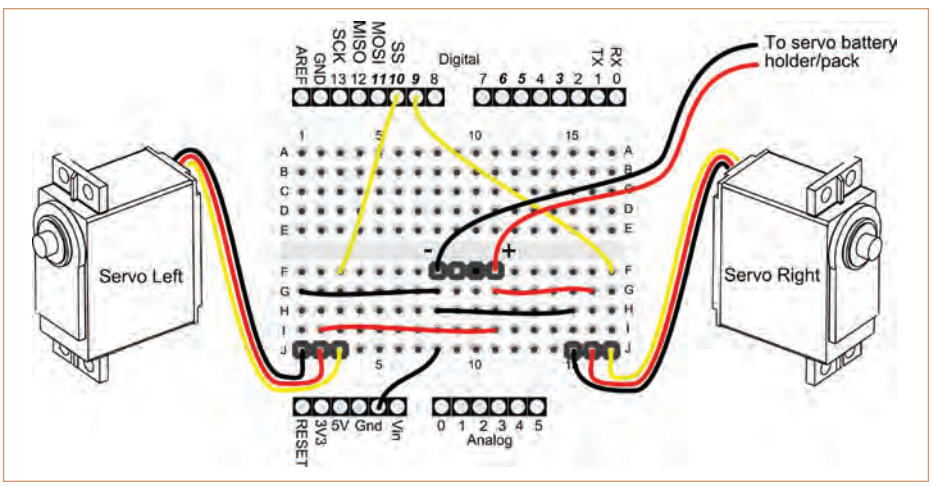

FIGURE 15. Pictorial view of how to connect the Arduino to the two servo motors. Note that the Arduino ground connection is shared with the power for the servos. This is very important.

Sources

Arduino
www.arduino.cc
Prefabricated ArdBot body pieces with all construction hardware.

Budget Robotics
www.budgetrobotics.com

AdaFruit
www.adafruit.com

HVW Tech
www.hvwtech.com

Jameco
www.jameco.com

Parallax
www.parallax.com

Pololu
www.pololu.com

Robotshop
www.robotshop.com

Solarbotics
www.solarbotics.com

SparkFun
www.sparkfun.com

Please note! The list of sources is not exhaustive, and is merely designed to get you started in the right direction. There are other companies who sell these items, and not all sources are listed. Common parts like battery holders and breadboard jumper wires are not included here, as they are readily available at RadioShack and hundreds of online electronics supply stores.

Check out ***www.fritzing.com*** for a user-to-user Arduino project community, including an Arduino development library that allows you to create virtual breadboard designs of your projects. You may then turn your projects into schematics and even etchable circuit boards. We've used Fritzing to prepare some of the illustrations for this series of articles.

Closer Look at the Test Sketch

Before closing out this month's installment of the ArdBot, let's quickly review how the test sketch works. First off is an *include* statement to the *Servo.h* library header file which is provided with the Arduino IDE installation. This file and its corresponding C language program, provide all the actual coding to make the servos function.

Next comes two statements that create, or *instantiate*, two *Servo* objects for use in the remainder of the sketch. Each object represents a physical servo attached to the Arduino. Methods of these objects include things like specifying which digital pin is used to connect from the Arduino to the servo, and the position of the servo. Note I've given the two *Servo* objects descriptive names: *servoLeft* and *servoRight*. It's easier to keep track of things this way.

In the *setup* function, the *servoLeft* and *servoRight* objects are "wired" to their respective pins on the Arduino; in this case, pin 10 for *servoLeft* and pin 9 for *servoRight*.

Now comes the main body of the program, provided in the *loop* function. It contains a series of user-defined functions for *forward*, *backward*, and so on, plus a delay of 2,000 milliseconds (two seconds) between each function. You can see that the robot repeats the same demonstration steps over and over:

- Goes forward for two seconds.
- Reverses for two seconds.
- Turns right for two seconds.
- Turns left for two seconds.
- Stops for two seconds.

Finally, each user-defined function specifies the specific motion to apply to the servos. With the *Servo* object, servos are commanded to move one direction or another by (among other ways) specifying an angle between 0 and 180. The servo then moves to that angle in response.

When using servos that have been modified for continuous rotation, 0 makes the servo rotate one direction; 180 makes the servo rotate in the opposite direction; and 90 makes it stop. Pretty easy, isn't it?!

In our next installment, we'll look at servo programming in depth, as well as connecting some sensors to the ArdBot for reactive control, getting feedback from the robot, and more! SV

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Main Components Sources

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)
Jameco	2121105
RobotShop	RB-Ard-03
Pololu	1616
SparkFun	DEV-09950

Solderless Breadboard; 170 tie-points

Source	Item or SKU
Adafruit	65
HVW Tech	21380
Jameco	2109801
Parallax	700-00012
RobotShop	RB-Spa-139

Nine volt to 2.1 mm Barrel Plug Cable

Source	Item or SKU
Adafruit	80
SparkFun	PRT-09518

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

Double-sided (long) Male Header Pins

Source	Item or SKU
Parallax	451-00303
Pololu	1065