Wireless robotics: Fast robot prototyping

Build a prototype robot quickly and easily

Level: Introductory

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Learn about the different materials and techniques you can use to physically build a robotic prototype. Rather than constructing a solid finished robot, see how to build a fast and easy prototype that can be disassembled, reconfigured, and reassembled quickly and easily.

Introduction

The previous article, "How to drive your wireless robot," covered the use of servo controllers and how to modify a servo motor for continuous rotation. This gives you a good starting point for actually building a "base" robotic system. I want to continue the "bottom-up" approach of creating integrated subsystems and assembling them together without any real idea of what the final product will look like, which was described in my inaugural article, "A recipe for success in wireless robotics."

In this article I want to show you how to actually prototype a wireless robot. I'm going to take you through an initial prototype I developed in a couple of hours, and then show how I took this prototype to the next level using sturdier building materials.

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Materials for fast prototyping

When you build a robot, one of the critical questions you face early on is what materials to use. I want to spend some time on this question because there are so many options, and there's no reason that you can't get started right away with materials that you probably already have around the house or that you can easily obtain at your local hardware, arts and crafts, or toy and hobby stores. (I exclude from this statement the PDA, servo controller, and perhaps the servo motors that were described in the last article.)

Building toys

My children use a variety of different building toys on a daily basis, and I think that many of them are appropriate for robot prototyping. This has become an issue in my family, because I'm often buying toys for myself that they aren't allowed to use until I'm done with them. Or, I'm commandeering their toys for use in a project. My oldest son (age 6) has quite correctly pointed out that I should practice the same level of fairness that I'm trying to instill in him. Fortunately, however, he is easily distracted by hand-me-downs and these are in constant supply.

I am especially fond of *erector sets*. I like the high-quality metal ones with a large number of pieces. There are robotics kit systems that are available commercially that use erector set components that are well-adapted to robot body building. However, it's only worth the price if you also intend to use the robotic electronic components.

Some erector set kits are geared toward building a specific kind of model (such as cars or airplanes), while the most expensive ones are for general use. You're better off getting a general kit than a set designed to build a specific model (unless the model looks a lot like a robot you're hoping to build.) By screwing the pieces together using small nuts and bolts they're much sturdier than LEGOs, but still very reconfigurable.

Figure 1. Erector set screws: Use your fingers first

As shown in Figure 1, I use my fingers to start the screw into the nut. I'm often assembling delicate things in a tight space, so the use of my fingers helps me to get maximum control. If you're assembling things in a very tight space, consider holding the nut in place with needle-nosed pliers or the wrench that came with the erector set.

Note: If you engage in robot prototyping, you are probably going to have to disassemble and reassemble your work numerous times before you're done. It's an iterative process where the lessons learned from each mistake provide valuable information to make the next try work correctly. (How many times do you hit the "undo" button or make changes to your text when editing a large program or a complex document? With hardware prototyping, the equivalent operation is disassembly and reassembly.)

Figure 2. Sometimes you need three (or four) hands

Sometimes you wish you had more than two hands. I encountered this situation in Figure 2. Don't forget that you can use many available tools. (You don't have to confine yourself to the ones that came with the set.) Clamps, screwdrivers, and needle-nosed pliers are useful. In this case, I'm using alligator clips that are part of a soldering set intended for electronics work. It lets me hold two erector set pieces at just the right angle while I focus on tightening the nut and the bolt.

Of course, if you have a friend or co-worker who's willing to help, then you can use an actual extra pair of human hands. This is theoretically the ideal support system: flexible, nimble, and agile. However, people have this annoying habit of saying things like "just a minute" or "What, again?," which tends to slow the development cycle down to a crawl.

The nuts and bolts that come with an erector set are also useful for other purposes. I like to drill holes in other items such as acrylic Plexiglas sheets and aluminum sheets. I've identified a drill bit that is the optimal width for this purpose. In this way, I can cut sheets of acrylic and aluminum and make them interchangeable with the erector set. This is a great solution to the problem of never having the right erector set piece.

LEGOs are another good example. They can easily be reconfigured, and there are now a lot of specialty pieces that can be quite invaluable. The wheels are especially noteworthy. A problem with LEGOs is that they fall apart, and often the pieces aren't quite right. Many people glue them together with various adhesives. Tape is an alternative: you can add strength without sacrificing re-configurability.

Many people also modify LEGOs with all sorts of hardware. You can drill holes in them, remove the connector nubs to create a smooth surface, clamp metal sleeves onto them, or whatever else you can think of. I did something similar in my cardboard prototype discussed below.

Figure 3. LEGO caster wheel

This photo is from the bottom of my cardboard prototype. I've fashioned a caster wheel out of LEGOs and used a glue gun to attach it to the bottom of the bot. This wheel kept falling apart, so I glued some of the pieces together with the glue gun. I know they'll stick securely, but I can probably disassemble them later with a little elbow grease. I also used a drill to alter the gray sleeve that holds the wheel axle. This piece was designed to hold the axle firmly so it wouldn't turn. Drilling allows the wheels to turn freely.

The bottom piece, the one glued to the box, is a useful "spinner" piece that allows the entire caster wheel assembly to spin as well. So it has two degrees of freedom.

This design was implemented flawlessly, but it completely failed to work in practice. The wheels didn't spin when the robot turned. Instead they continued to point in the wrong direction and got dragged along sideways. I therefore decided not to carry this part of the design forward in the next phase of the prototype; instead, I tried to make a caster wheel out of erector set parts.

Cardboard

This has been used by a few people in the past, but it's a surprisingly rare building material for robotic prototyping. Maybe this is because of its obvious flaws: it's rather flimsy and your robot is going to look like a piece of junk. It's an insulator when it is dry, but it turns into a conductor (not to mention a soggy mess) as soon as it gets wet. It's not very sturdy, and you're going to break your prototype many times before it is finished.

Despite these limitations, I've used cardboard as a prototyping material and I highly recommend it. With nothing more than some old boxes, a cutting knife, pair of scissors, and a glue gun, you can quickly create your own robotic prototype in a couple of hours. I have also found a hole punch and rubber bands to be useful. Don't laugh, this is an extremely powerful technique!

The basic approach is to cut some pieces of regular paper and form them into the shape you'd like to see for your prototype component. Then trace the paper onto cardboard and use sturdy scissors or a cutting tool to cut it into place. To adhere multiple pieces of cardboard together, I generally go for my glue gun or some duct tape. The tape is good for a hinge, but you are going to damage the cardboard when you remove it, so keep that in mind. The glue from the glue gun dries quickly and holds tight. It's my preferred cardboard adhesive. Because of the small amount of glue used, you can generally rip the pieces back apart without doing that much damage. A word of caution: glue guns are very hot and you can get a nasty burn if you're not careful. Also, the glue drips out of the tip when you're not using it. Place it in a shallow cardboard box such as a shoebox lid when not in use, and remember to unplug it if you're not going to use it for the next 10 minutes or longer.

I created a cardboard prototype robot for this article, and it's covered in some detail below.

Foamcore board

Figure 4. Cutting foamcore board

Figure 4 illustrates the technique for working with foamcore board. You can easily cut it into virtually any shape. This material is available at arts and crafts shops. It's structurally similar to cardboard, except that instead of corrugated card paper it has foam in the middle. Just use a cutting tool to score the paper, and snap it along the cut line. You can then cut the paper on the other side with fine scissors or a cutting tool. Or you can just cut it all the way through the first time. Another use for this material is to strip off a bit of the paper on one side. You then get foam on one side and paper on the other. This is useful if you want a soft cushion.

Plastic

Ah, but what kind of plastic? There are a number of different kinds. Many plastics that you'll find around the house have softeners in them to make them more flexible and less brittle. This makes them more useful to the manufacturers. Unfortunately, it also makes them adhesive-resistant.

Without getting into all the technical details of the different kinds of plastics, let me just say that you will know a useful building material when you see it. I got some sheets of clear acrylic from my local hardware store and was immediately able to put them to good use. I also found that disposable plastic sandwich boxes from the grocery store could be cut with sturdy scissors and reshaped into useful forms. Narrow PVC piping (intended for plumbing) can also be very useful.

I got a little frustrated with plastic adhesives. There are many different kinds of plastic out there, and most of the adhesives only work on a certain subset of them. There's no substitute for testing, and you'll need a little persistence and patience. Follow instructions meticulously, and test it on a small piece in advance to make sure it's going to stick.

The biggest problem with adhesives for prototyping is that they tend to *stick*! (Of course that's the point.) During the prototyping process, you may find yourself repeatedly disassembling and re-assembling something in an effort to get it just right. So gluing some pieces together might not be appropriate during the early iterations of prototyping.

I have had good luck with screwing and taping. Electrical tape can temporarily hold some pieces together. If the plastic is clean and dry, then you may be able to untape and retape it a couple of times before needing to change the tape. I've also been able to drill holes and use small nuts and bolts as a temporary fastener. (As described earlier, I use the ones from my erector set.)

Of course, you can always create your own plastic objects in exactly the right shapes and sizes using techniques such as plastic injection molding. I haven't done this myself yet, and I regard it as much too advanced for this article. It also represents a big commitment to a design idea; probably not the right choice for the early stages of prototyping. Even so, I'm strongly considering plastic molding in the future, for the later stages of the design process. I'm presently researching cheap and easy techniques.

Metals

My favorite metal for prototyping is 1- to 2-mm aluminum sheets. You can get aluminum in a lot of different thickness widths, and other metals are also available. If it's thin enough, you can cut it with a sturdy pair of scissors. Using this technique, you can create sheets of aluminum in exactly the shapes you need. I'll also drill holes in them as illustrated below.

Metal rods and pipes can be widely used. They can be soldered together if needed. It's not exactly the same as the solder you'd use for electronics, but the skill set should transfer without too much alteration. Of course, you could try something advanced like welding. I don't consider it to be the right choice for this article because it's too advanced. However, welding is certainly an incredibly useful thing to do. You'll probably wind up trying it out if you get far enough along in robotics.

There's another issue to keep in mind with welding and soldering: you tend to sacrifice reconfigurability. In the early stages of prototyping, I find myself constantly pulling apart my work, making some change, and reassembling it. It's harder to do this if you've welded everything together. For this reason, I think it would be better to start with a different approach for the early stages of prototyping.

Reusing other items

Many people have items lying around that would be very useful in a robotics project. Consider that empty baby wipe tub, that old computer case, that toy car. I have two toy "grippers" that might make useful robotic arms in the future.

It's difficult to generalize about this issue, because it's basically a matter of what you have lying around the house.

It's becoming very popular to "hack" existing products and make them do things that were never intended by the manufacturer. This is an attractive approach in robotics. Perhaps instead of building a robot body, you can get a cheap toy robot that suits your needs. You could remove all the internal components and replace them with a wireless computer, servo controller, and some small servo motors. There's no limit to this approach except for your ingenuity.

Possible drawbacks to "hacking" an existing robot design include the limitations of the robot you're hacking. The case may provide extremely limited space, or the wrong shape. You may want to go with the existing motors, in which case you'll probably need to find a different way to control them. So while your level of effort in building the body is much smaller, your level of expertise may need to be higher to make this approach work. (Maybe one way around these problems is to create a larger cardboard prototype of the design you're trying to modify, and then miniaturize it later.)

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A cardboard prototype

Figure 5. Cardboard prototype body

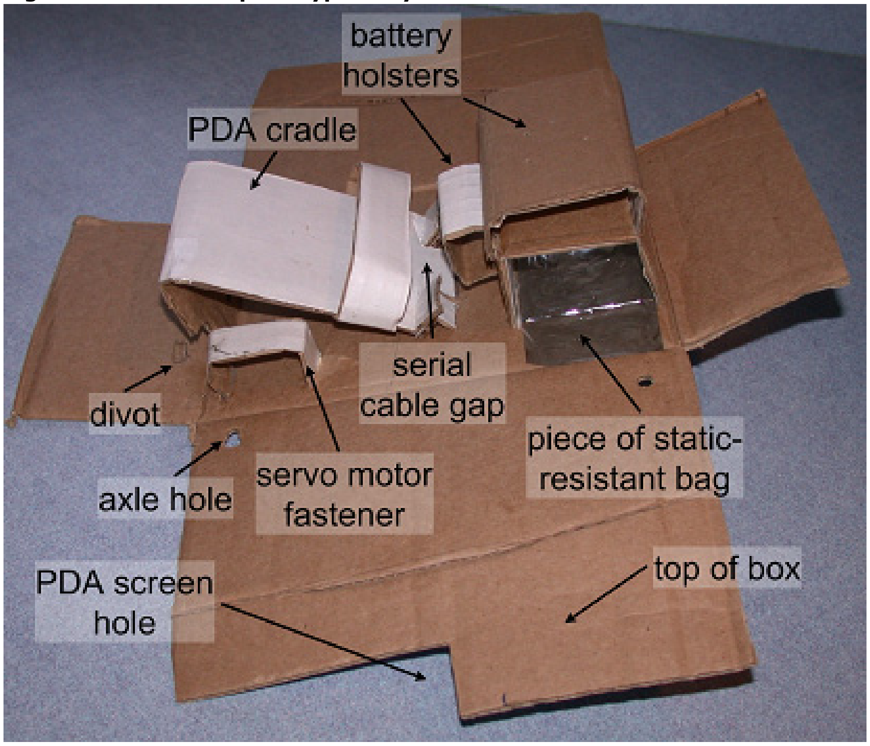

Figure 5 shows a cardboard prototype that has been disassembled and opened up. I've removed all the electronic components to focus attention on the cardboard. The main piece is a sheet of cardboard that can be folded up into a box. You'll notice a cradle for my PDA. I put a strap to hold the PDA in place, and some "feet" to keep it from sliding down to the bottom of the box. There's a gap between the feet to accommodate a serial cable. Also notice that the top of the box has a notch in it on both ends, so that I can see (and interact with) the PDA.

There is a servo motor on this side of the box, and another one behind the PDA cradle. There's a fastener strap to hold each servo motor in place. This strap is always ripping off when I open the robot, so I have taken out my glue gun to re-attach it on many occasions. I don't mind this with cardboard, but I want to avoid this problem when I switch to sturdier building materials. I used a hole punch to create a hole for the neck of the servo motor. A wheel is attached to the neck on the outside of the box.

Note the divot at left. Sometimes a piece comes close to the edge and there's not enough room for the cord. In this case, the problem is caused by the fact that my hole punch couldn't reach far enough from the edge to give enough clearance to the servo motor's cord. I cut a divot in the cardboard to accommodate the cord. Obviously this is a design flaw that I would want to correct in the next version of the prototype.

Finally, there's a subsystem on the right that contains the batteries and the servo motor controller. Because the controller is a circuit board, I glued on a rectangle of static-resistant plastic underneath it. This was part of the plastic bag that held the controller when it arrived in the mail. Fortunately, I have a number of these bags left over from previous purchases, so I still have a place to keep the controller when it's not in use.

Figure 6. Cardboard prototype wheel assembly

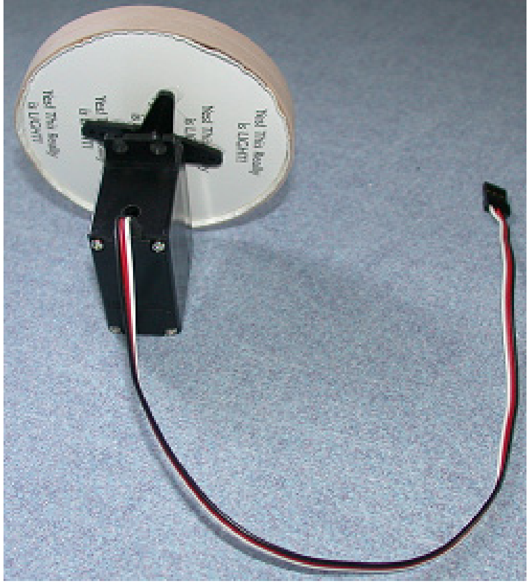

Figure 6 shows a wheel assembly. Basically, this just involved attaching the wheel to the servo motor. I made two wheels for this prototype. Both wheels are made from the bottoms of ice cream cups that I happened to have around the house. Unfortunately, these are rather slick and waxy, so they spin uselessly on my wood floor. I put two wide rubber bands around the circumference of each wheel for traction.

The most tricky part was attaching the wheels to the servo motor. I noticed that the servo horns had small holes in them, so I tried to run a wire through those holes without much success. My wires were too thick. I could have stripped off the insulation or used a thinner wire however. Then I used a needle and thread. This worked well, except I forgot to trim off the excess thread before turning on the servo motor and it got all tangled up. When I trimmed off the thread, the wheel worked perfectly. I also tried using a glue gun to attach the wheel to the servo horn. This worked fine as well. The horns are much cheaper than the motors, and can be purchased separately in a variety of shapes. Therefore, I wasn't concerned about the possibility that I might not be able to get the wheel off the servo horn later, as a result of gluing.

Figure 7. Completed cardboard prototype

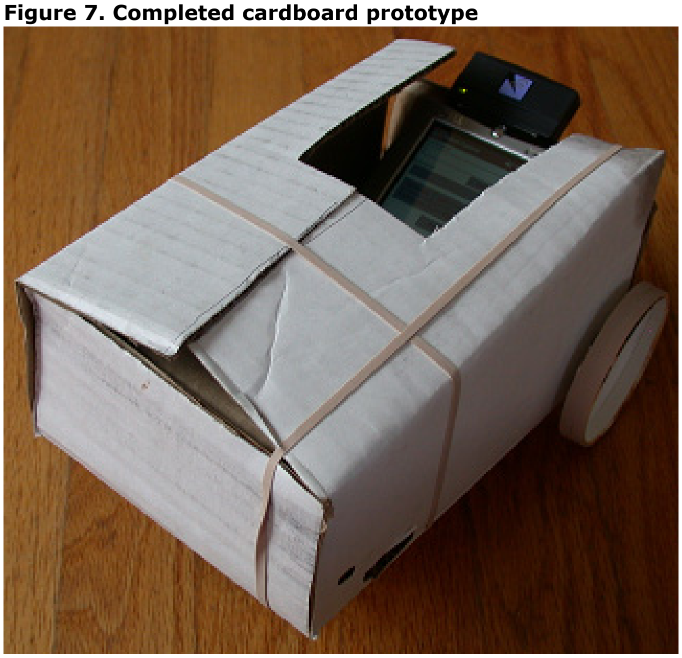

Figure 7 shows the completed cardboard prototype. You can see the wheels and the PDA sticking out of the top with the wireless card attached. It's all held together by two rubber bands. I had initially experimented with sturdier materials to hold it together, but I found that I kept opening it so often that rubber bands made more sense. This isn't perfect, however, and in a future prototype I might create some kind of a fastener that will open and close while holding its shape when needed.

A serious drawback of this design is the fact that I needed to remove the wheels from the servo motor every time I opened up the box. If I forgot to unscrew the horn and wheels from the servo motor, I would end up ripping the servo fastener straps off the bottom of the box. I would want to take this into account in future designs: opening the box to get inside should be easy and low-risk.

Obviously, it's not a very sturdy prototype, but I don't consider this to be a flaw or a problem. Actually, it's an advantage in some ways because I found myself constantly ripping out parts to replace them with slightly improved alternatives. Whenever something broke, I could easily repair it with the glue gun.

Summary: hooray for cardboard.

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Creating a bracket

I want to show you the next prototype I created with sturdier materials. However, I want to start by illustrating a basic technique that I used throughout the process. I create an "L" bracket using a drill, some sheet aluminum, some sheet acrylic, and some very small nuts and bolts from the erector set.

Figure 8. Scoring an acrylic sheet with a cutting tool

In Figure 8 I'm scoring an acrylic sheet using a cutting tool and a straightedge. Any straightedge will do, but it's a good idea to score it along the full length of the sheet. If you have a very large acrylic sheet, then you may find yourself cutting a long, narrow strip off it and trimming that strip into a number of smaller pieces.

Note: If you try to cut a square piece out of a sheet of acrylic, you're likely to create a fault line that will crack the entire piece of acrylic in two. In general, you should cut all the way across the sheet.

After you've got the groove started, you may be able to lay aside the straightedge and deepen it freehand. But, be careful because the scoring tool likes to jump out of the groove and create a new groove in a completely different direction. You want to create a groove that's at least 1 mm deep.

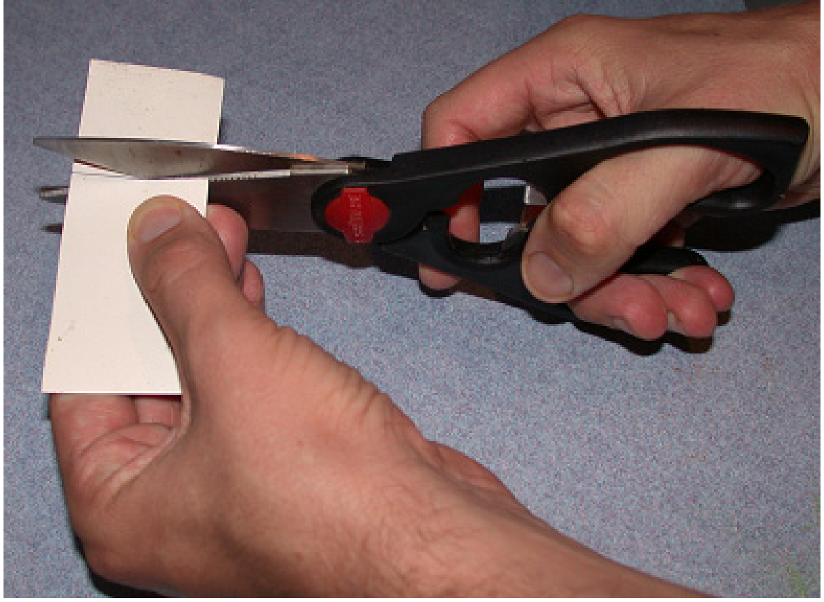
Figure 9. Snapping acrylic in two

After you've got a deep enough groove, it's easy to snap the sheet along the groove as shown in Figure 9.

The first time I tried this, I made the mistake of not cutting a groove the full length of the sheet. I sent a long irregular split along the rest of the sheet, and I haven't tried that approach again. (I know I already said that, but I've made this mistake enough times that it bears repeating.)

Unfortunately, you're restricted to straight lines rather than curves using this technique.

Figure 10. Cutting an aluminum sheet with scissors



If you look at Figure 10, it appears that I'm cutting paper rather than aluminum! Actually the aluminum is painted white. I'd be just as happy with unpainted aluminum sheets, but I got this stuff for free from a contractor, so I'm certainly not complaining.

It's easy to cut sheet aluminum with scissors if it's thin enough. (It may not be very good for the scissors, but personally I consider them to be a disposable item when I consider the amount of money I occasionally spend on electronics!) If it's thicker, then try scoring it with a cutting knife and bending it back and forth along the score line. It should then snap fairly easily. Scissors are a much simpler choice if you want to create any kind of a curve.

Obviously you should draw a cut line on the aluminum first, before cutting.

For a bracket, the idea is to cut a piece of aluminum that's wide enough to overlap each piece of acrylic on either side, and a little shorter than the acrylic so it doesn't hang over the edges.

Figure 11. Careful when scoring and bending aluminum

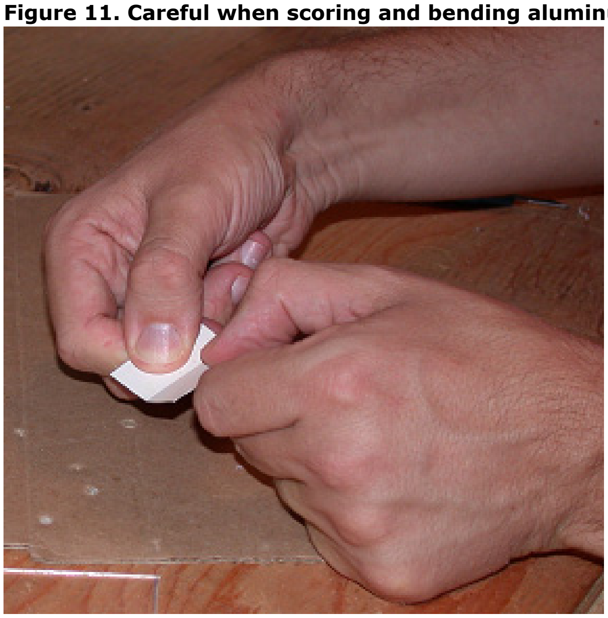


Figure 11 shows me bending a piece of aluminum. When you bend aluminum, you'll generally get a gentle curve rather than a tight folded edge. One way to create a sharper angle is to score it slightly with a cutting tool before bending. This technique can also be used to snap the aluminum, so you should be careful not to score it too deeply. After you have scored it in this way, avoid unbending and rebending it again because it will snap easily.

I present an alternative kind of bracket below that doesn't involve any scoring and still yields a good angle.

Figure 12. Drilling holes in acrylic

Figure 12 shows how easy it is to drill holes in acrylic. Many people would use a drill stand, but freehand is also fine for prototyping. I marked the acrylic in two spots where I'm going to make a hole, and then I started drilling. I strongly urge you to use safety goggles when doing this. If you wear glasses, then get the kind of safety goggles that can fit over the glasses. You don't want shards of acrylic shrapnel getting in your eyes. There are some kinds of wisdom that you don't need to learn from personal experience.

After I've completed all my acrylic drill holes, I put the aluminum in place underneath the acrylic and get it set up just the way I want it. A good idea is to clamp the two materials together. I then place the drill back into the acrylic drill hole and use it to drill a hole in the aluminum. This ensures that the two holes line up exactly.

Note: When drilling aluminum it's also important to wear safety goggles. If you're not convinced, then just consider how a tiny razor-sharp shard of aluminum would feel lodged in your eye. Ouch! Did I mention the safety goggles?

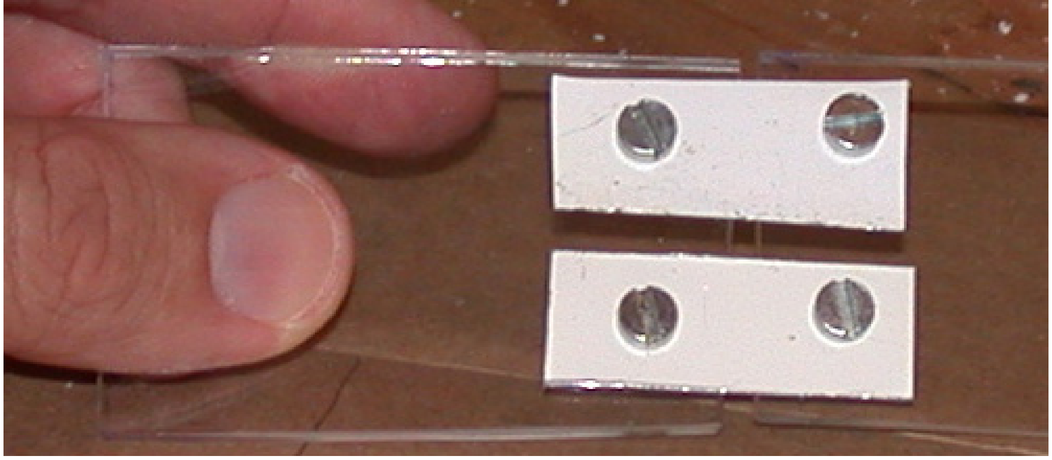
Figure 13. Completing the hinge

After I've got the holes just right, I'll put a screw in it and bolt the other side to hold it firmly in place. That way I know they'll stay lined up perfectly. Only at this point do I go on and drill the next aluminum hole. In figure 13 above, I've already drilled three out of four holes, and there are three nuts in place. I'm currently drilling the fourth and final hole.

After completing all the drilling, I then remove all the screws and clean everything off to get rid of the shrapnel. Then I reassemble and I'm good to go.

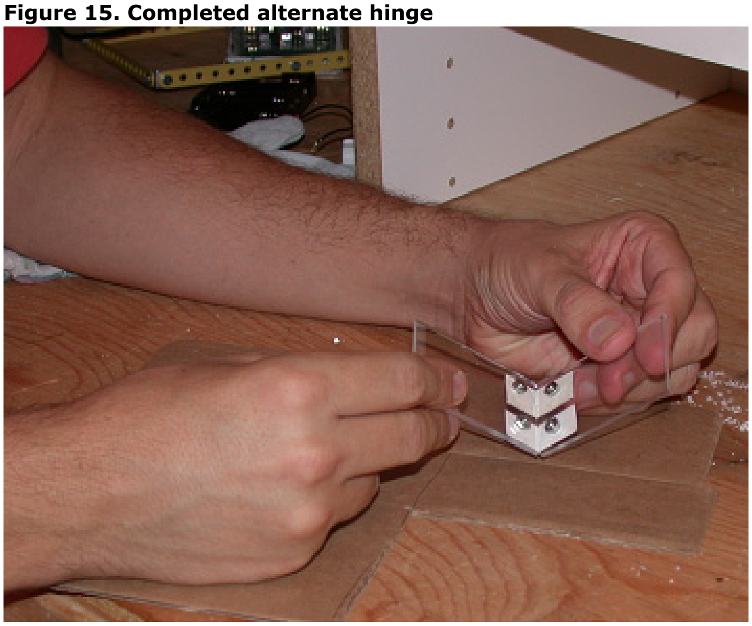
An advantage of this technique is that your drill holes are interchangeable with the ones from your erector set. This makes it easy to mix and match acrylic, aluminum, and erector set pieces. There are certainly an unlimited number of other things that can be fastened together in this way: foamcore board, wood, leather, you name it.

Figure 14. Alternate hinge design



Here's a variation on the hinge design just shown. It doesn't involve scoring so it may produce a stronger result. In Figure 14, I've simply fastened the aluminum to the acrylic without bending. I used two strips, but I could have used one. Note that I left a small gap between the two acrylic sheets. This is critical. If you're going to use this technique then you should determine the right size gap, which should be approximately equal to the thickness of your acrylic. Create a small insert to go between the two pieces to keep them the right distance apart while you're drilling the aluminum holes. This is one of those cases where an extra hand or two is helpful.

Figure 15. Completed alternate hinge



In Figure 15 I've simply bent the hinge into place. (Before bending it, I flipped it over from the previous diagram so that the aluminum is on the outside and the acrylic is on the inside.) Because I didn't score it, I think it will be stronger and more resilient. Even so, I would still avoid unbending and rebending it. It will weaken the metal, and will soon result in breakage. However, my experience with this technique shows that it's much more tolerant to a little bending and rebending if you're trying to get the angle or the position just right.

If you're not connecting two pieces of acrylic together, then you can't use this technique. To avoid scoring, try bending the aluminum with two pairs of pliers (not needlenose), one in each hand. It's a bit tricky and more time consuming, but it works.

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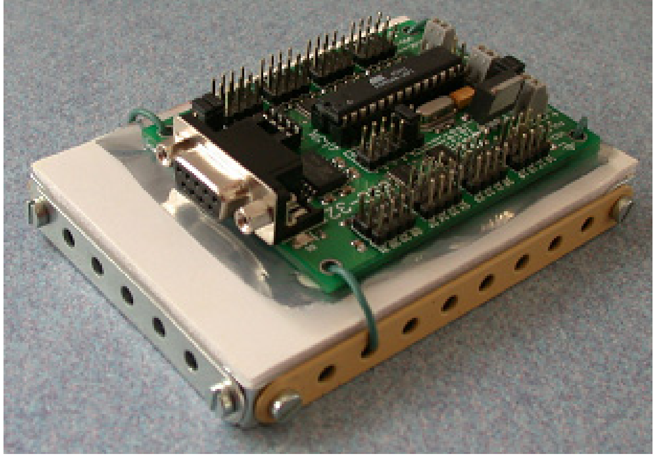
Main prototype robot

After completing the cardboard prototype, I felt I was ready to continue with a copy of the same robot using some of the other materials I've already covered. I wanted to create a sturdier base to work on, because I have a lot of other ideas I'd like to add to this robot as time goes on.

From here on in, we're using the construction techniques we've covered above, plus some other minor ones that occurred to me naturally in the course of making the prototype. I'm not going to give you explicit assembly instructions for creating exactly the same robot that I built. The point of this article is to get you to invent your own robot using creativity and the materials and tools you choose, plus anything you already have on hand. Your background, goals, and needs will be different, so you'll wind up with a different result.

Figure 16. Completed servo controller assembly



In Figure 16 I've built a servo controller assembly to hold the controller board. The construction technique consists simply of building a rectangular frame with the erector set, and cutting a matching piece of foamcore board. I then cut a piece of static-resistant plastic from the bag that contained the motor controller board. I attach these together by poking holes in the plastic and the foam board, and running short pieces of wire through the holes to attach them all together. My servo controller board happens to have mounting holes in the corners that can be used for this purpose.

It's not clear to me how the design would be impacted if I had used a smaller servo controller. This one is at the large end of the spectrum.

Figure 17. Power assembly

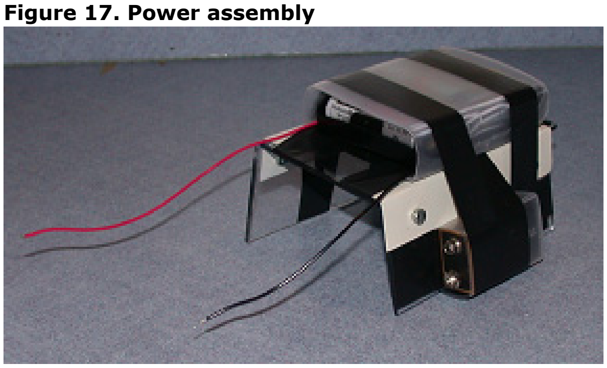


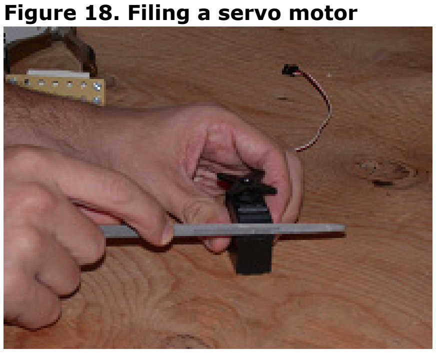
Figure 17 shows the power assembly, which consists of the servo controller board assembly, a cover, and the battery packs.

I created a cover to fit over the servo controller board. I made it pretty high to leave plenty of room for plugs. I used acrylic Plexiglas and strips of aluminum, together with screws as described above. In the cardboard prototype I had attached these pieces firmly together, which unfortunately made it harder to plug and unplug things as I was making improvements. In this prototype, I decided to not to attach the controller assembly to the cover, allowing it to slide freely back and forth for plugging and unplugging purposes.

There are also battery holders for two different voltage batteries. I used little plastic strips from some disposable plastic sandwich boxes my wife bought at the grocery store to create the battery holders. I simply cut a sandwich box into strips with strong shears and refolded them with pliers. I then tried to use various plastic adhesives to glue the battery holders in place, but without much success. Eventually I gave up and resorted to electrical tape. Not very aesthetically pleasing, but it did the trick and it's *still reconfigurable*.

I needed 9 volts to power the motor controller, so I simply bought an alkaline "transistor" battery. I needed 6 volts to power the motors, and I was concerned about this battery running down so I wanted to use rechargeable batteries. Alkaline AA batteries are 1.5 volts, so four of them in serial will provide 6 volts. Rechargeable AA batteries only provide about 1.2 volts, so I would need five. I searched high and low for a five-battery clip, and came up empty. I did find both a four-battery and one-battery AA clip at my local electronics store. I wired them together in serial by connecting the red wire from one battery clip to the black wire from the other. I attached the two clips together with a glue gun, plus electrical tape to keep everything firmly in place.

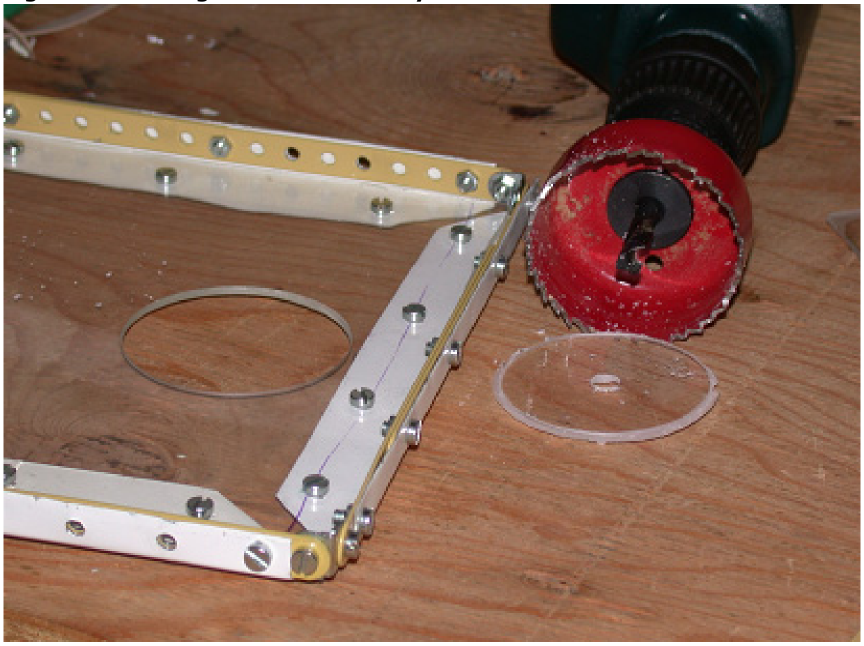
Figure 18. Filing a servo motor



It's a fortuitous coincidence that the servo motor has mounting holes that are compatible with my erector set. The holes are ample size for an erector set screw and are set about a centimeter apart. A small tab is in the way and prevents the erector set piece from lying flat against the servo mounting holes however. Because the tab is made of plastic, it's a simple matter to remove it with a fine file or sandpaper. This is shown in Figure 18. You could use a dremel or other tools for this purpose as well.

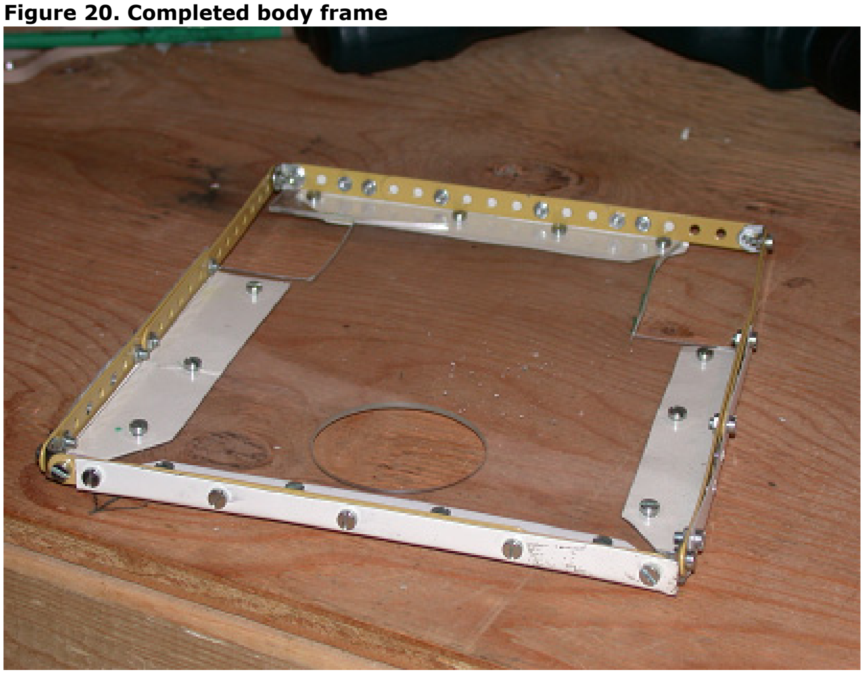
This step is certainly optional. You could attach the servo to a piece from the erector set without filing away this little tab. However, it wouldn't be quite as snug a fit.

Figure 19. Making a circle cut in acrylic



A weakness of working with acrylic sheets is that it's not easy to make a cut in the center of the sheet. If you try to score the Plexiglas and pop out a piece, you're likely to get a split that extends across the entire sheet, breaking it in two. However if you want to cut a round hole, then it's possible to use an attachment like the one shown in Figure 19. I find it's easiest to start with a smaller drill bit and then switch to the circle-making attachment. I also like to work from both sides, starting on one side, then switching to the other. That way the two circles meet in the middle. It produces a cleaner hole as a result. Even so, you still might want to file or sand the interior of the hole after cutting it out.

Figure 20. Completed body frame



The piece shown in Figure 20 was the last one I made for this prototype. It is based on careful measurements of all the other pieces. Like most of the work of this prototype, it had to be built and rebuilt, assembled, taken apart, and reassembled many times in development. Finally, it appeared to be just the right size to hold all the other parts of the robot.

You'll notice the round hole in front, which is for a caster wheel that will turn freely when the two back wheels turn the robot. The caster wheel is not powered. The circular shape of the hole will allow the caster wheel to spin in any direction. It's just the right size to fit my rather large caster wheel. (It's not easy to make a small one with erector set pieces.) I should point out that all my attempts to make caster wheels out of LEGOs or erector sets have met with poor results. In future I'll probably just buy a ready-made caster wheel instead.

There are also two rectangular holes in the back of the frame to accommodate the servo motors. These holes are just the right size for the servo itself, as well as the servo frame and mounting pieces that hold it in place.

If you examine Figure 20 carefully, you may notice a few places where the acrylic split due to careless work on my part. One of them is at a screw hole; the other is at a servo hole. I got a little over-confident during a moment when things seemed to be going smoothly.

Figure 21. Drive frame bottom view

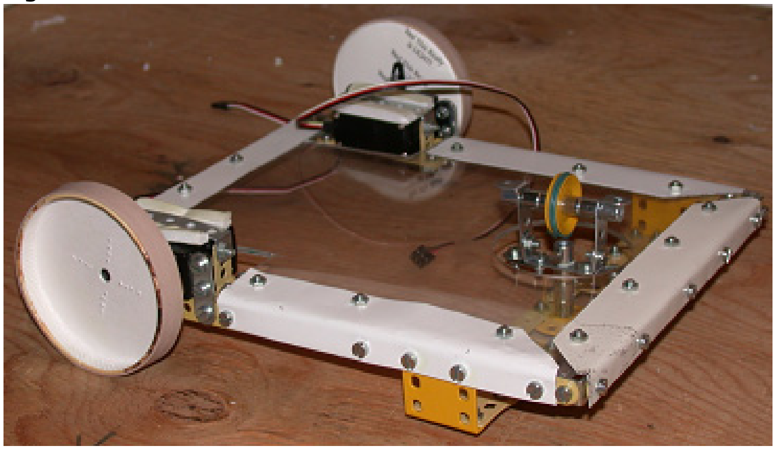


Figure 21 shows the bottom view of the entire drive frame. I turned it upside down to take the photo. The servos have been mounted in place with the wheels attached to them. I've retained the wheels from the cardboard prototype for now. They'll be one of the first things I replace in the future, but they're adequate for an initial test of the prototype. You can see the caster wheel in the front.

The components that hold the servo wheels in place use erector set pieces and foamcore board. I peeled a narrow strip of paper off the foamcore board to reveal the soft foam underneath. This allowed me to squeeze the servo into the mounting frame, which had been designed with a little extra space. The foam board pushed back firmly enough to hold the servo securely in place. I also bolted the front of the servo to the outer edge of the drive frame.

It was important to have the caster wheel extend almost as far down from the bottom of the frame as the rear wheels, but not quite as far. I wanted the frame to be a little lower in front to compensate for the fact that the heaviest components (the PDA and the batteries) were in the back directly over the drive wheels for added traction. But I didn't want the front to be too low, to ensure sufficient ground clearance.

Figure 22. "Final" prototype

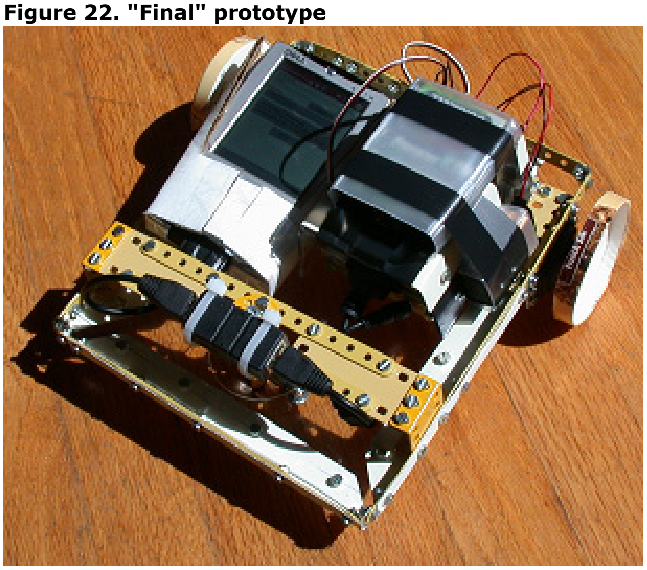


Figure 22 shows the "final" prototype robot. Actually this is a misnomer because there's nothing final about it. I consider this to be a very preliminary initial prototype. But it's "final" for the purposes of this article.

I was able to turn this robot on and have it maneuver around my floor, starting and stopping, turning and spinning, going both forward and reverse. Although it's a little heavier than the cardboard version, it performed quite a bit better. I was able to remove the rubber bands from the wheels without losing traction. This is probably because most of the weight was redistributed over the drive wheels.

You may notice that I didn't even bother to secure the PDA or the power/controller assembly in place yet. This is because I plan on adding more stuff to the robot, so I want to keep my options open about the exact placement of those two components. This didn't cause problems in my testing, but I certainly need to fix it in the future. We don't want the PDA to go flying out the side of the robot when it makes a sharp turn.

While the initial cardboard prototype took a couple of hours to develop, the second prototype took about two days. I'm sure that it would have taken a lot longer without the cardboard prototype, because I was constantly referring back to that prototype in building the second robot. The materials used in the second prototype are sturdier and more durable. But they're heavier and it takes more time to work with them. The erector set pieces are invaluable, but they do require a lot more disassembly and reconfiguration than cardboard, which is highly forgiving and completely free-form.

Now that we've actually built a starter robot, we're in a great position to talk about programming and wireless technology issues in future articles.

I'd like to thank artist Robert Cole who provided me with a lot of invaluable advice when I was developing many of the techniques presented in this article. Bob has worked in a variety of different media over the years and he knows a lot about many different materials and construction techniques.

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Resources

- The article "Evolving the wireless robot" (developerWorks, July 2003) provides an excellent overview of some work that is going on in wireless robotics. It frankly discusses some common pitfalls and how to avoid them.
- The article "Introduction to robotics technology" (developerWorks, September 2001) provides a good overview of robotics technology, and it's written from an open source perspective.
- The first article in this series, "Wireless robotics: A proposed methodology," (developerWorks, August 2005) defines the field of wireless robotics, and outlines some of the principal challenges.
- "Wireless Robotics: How to drive your wireless robot" (developerWorks, September 2005) describes how to choose a computer to control your robot's movements, selecting a motor controller, and setting up these components in a movement proof of concept. You have to complete the steps in that article before you can build the robot described in this one.
- The books *Robot Building for Beginners* and *Intermediate Robot Building*, both by David Cook, are notable because they provide such an extremely detailed, yet highly approachable, introduction to electronics for the complete beginner. The intermediate book is practically indispensable.
- Download the IBM developer kit for Linux.
- Get involved in the developerWorks community by participating in developerWorks blogs.

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About the author

Erik Zoltán got his start in AI in the late 1980s, with the invention of a proprietary neurosemantic network technology that is still under development. His current work focuses most strongly on computer perception. He gradually became involved in robotics when the field kept coming up as an important application of his work. He has taught programming to hundreds of professional developers and has worked on CBT, databases, and communication systems.

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