123 ROBOTICS EXPERIMENTS FOR THE EVIL GENIUS

OPEN YOUR HEAD, ADD THE CONTENTS OF THIS BOOK, STIR WITH YOUR IMAGINATION, AND BUILD SOME GREAT ROBOTICS PROJECTS

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MYKE PREDKO

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Myke's Rules of Robotics

Throughout this book, I will be keeping to my 10 rules of robotics:

1. Start small.
2. Design everything together.
3. Jerkiness in a robot is not a selling point.
4. Protect your drivetrains from the environment.
5. Keep the robot's center of mass in the center of the robot.
6. The faster a robot runs, the more impressive it is.
7. Object detectors should detect objects far enough away from the robot so that it can stop before damaging the object or itself.
8. Complexity adds weight.
9. Weight adds weight.
10. If the robot isn't doing anything, it shouldn't be expending any energy.

Contents

Section One

Introduction to Robots

When you think of the term "robot," what comes to mind? The following are some definitions that attempt to explain what a robot is:

> A true robot is a machine that can be "taught," programmed like a computer, to make different kinds of motions and perform a variety of jobs. . . . Machines that do one job only and cannot be "retrained" are not true robots, either.
>
> *The New Book of Knowledge, 1998*

> **Robotics** A field of engineering concerned with the development and application of robots, as well as computer systems for their control, sensory feedback, and information processing. There are many types of robotic devices, including robotic manipulators, robot hands, mobile robots, walking robots, aids for disabled persons, telerobots, and microelectronomechanical systems.
>
> *The McGraw-Hill Encyclopedia of Science & Technology, 8th Edition*

> A **robot** is a mechanical device that operates automatically. Robots can perform a wide variety of tasks. They are especially suitable for doing jobs too boring, difficult, or dangerous for people. The term robot comes from the Czech word *robota*, meaning *drudgery*. Robots efficiently carry out such routine tasks as welding, drilling, and painting automobile body parts.
>
> *The World Book Encyclopedia, 1995*

> A **robot** is a machine that performs a task automatically. The robot's actions are controlled by a microprocessor that has been programmed for the task. The robot follows a set of instructions that tell it exactly what to do to complete the task.
>
> *World Book's Young Scientist, 2000*

> **robot** /'ro:bot/n. **1** a machine with a human appearance or functioning like a human. **2** a machine capable of carrying out a complex series of actions automatically. **3** a person who works mechanically and efficiently but insensitively.
>
> *The Canadian Oxford Dictionary, 1998*

> Humans are the ultimate generalists, with a form designed by millions of years of evolution to respond to a very wide variety of circumstances. The science and technology of robotics is usually concerned with building machines to perform a much smaller number of tasks within a specific set of problems, such as inspection or assembly parts on production lines. Such robots generally have a much simpler form. They often consist of a jointed arm with a gripper or other devices that work like a hand and a microprocessor that functions like a brain.
>
> *Encyclopedia of Technology and Applied Sciences, 1994*

> **Robot** "A reprogrammable, multifunctional manipulator designed to move material, parts, tools or specialized devices through various programmed motions for the performance of a variety of tasks."
>
> *Robot Institute of America, 1979*

> Now, here we go on a more-detailed examination and explanation of robots, which, to coin a definition, are fully automated machines which may respond to external stimuli as well as to internal commands which have been prerecorded. It is important to note that we have here the term "robot," which is different from android, or droid for short, or from humanoid, another term associated with these machines.
>
> *The Complete Handbook of Robotics, 1984*

> **Robot** Any mechanical device that can be programmed to perform a number of tasks involving manipulation and movement under automatic control. Because of its use in science fiction, the term *robot* suggests a machine that has a humanlike appearance or that operates with humanlike

capacities; in actuality modern industrial robots have very little physical resemblance to humans.

AP Dictionary of Science and Technology

Robot

(1)A device that responds to sensory input.

(2)A program that runs automatically without human intervention. Typically, a robot is endowed with some artificial intelligence so that it can react to different situations it may encounter. Two common types of robots are *agents* and *spiders*.

Webopedia

A robot is a machine designed to execute one or more tasks repeatedly, with speed and precision. There are as many different types of robots as there are tasks for them to perform.

what is ? com

A robot has three essential characteristics:

- It possesses some form of mobility.
- It can be programmed to accomplish a large variety of tasks.
- After being programmed, it operates automatically.

Australian Robotics and Automation Association

1. A robot may not injure a human being, or, through inaction, allow a human being to come to harm.
2. A robot must obey the orders given it by human beings except where such orders would conflict with the First Law.
3. A robot must protect its own existence as long as such protection does not conflict with the First or Second Law.

Isaac Asimov

Clearly, no one single definition encompasses what a robot is and how it is supposed to work. Different people have widely different and often conflicting ideas of what a robot is and what it isn't. Many different types of robots exist, each one meeting some of the definitions above.

In the following pages, I will investigate some of the different types of robots and introduce you to many of the skills and much of the knowledge to create your own robots.

Just remember that if you create a robot to take over the world and it fails, when the authorities come, you've never heard of me or this book.

Experiment 1
Toilet Paper Roll Mandroid

In the 1950s, scientists determined that the most likely body shape an alien from space would have would be a biped, the same as humans. A biped consists of two arms and two legs arranged symmetrically around a vertical line. The reasoning behind this conclusion was largely based on the scientists' familiarity with their own bodies: Recognizing that humans, as the result of hundreds of millions of years of evolution, are capable of carrying out an astonishingly varied range of tasks. Carrying this line of logic further, it was felt that aliens, evolved to the point where they can create machines similar to ours, must have bodies that are similar to ours.

This line of thinking is essentially what people go through when they are thinking about how robots should look. If you were asked what a robot should look like, you would probably think first of a biped robot like the Terminator or Robby the Robot. Using the logic of the scientists of the 1950s, building robots using the same body types as we have makes a lot of sense because we are comfortable with using our bodies to move around and manipulate objects.

As this book is about robots, I'm sure you want to start designing and operating robots. Because we have a successful form to follow (our own), let's start designing and building a simple biped robot out of toilet paper rolls, pipe cleaners, and some glue. Once this robot has been built, you can perform the book's first experiment for yourself—seeing how a biped robot would transition from standing straight up to walking forward. Once we have done this, we can start experimenting with other actions humans perform.

The mandroid for this experiment consists of a skeleton of used toilet paper rolls that are connected using pieces of pipe cleaner that have been glued to the inside of the toilet paper rolls. If the toilet paper rolls are analogous to the bones in your body, then the pipe cleaners are the connective tissues and your joints. In the plan view (Figure 1-1), note that I have specified locations for the pipe cleaners so that the skeleton can move (or articulate) the same way that your body can. Because we are following a human model very closely, we can expect to be successful and be able to go on to other experiments with this robot, such as having it walk over to an object and pick it up.

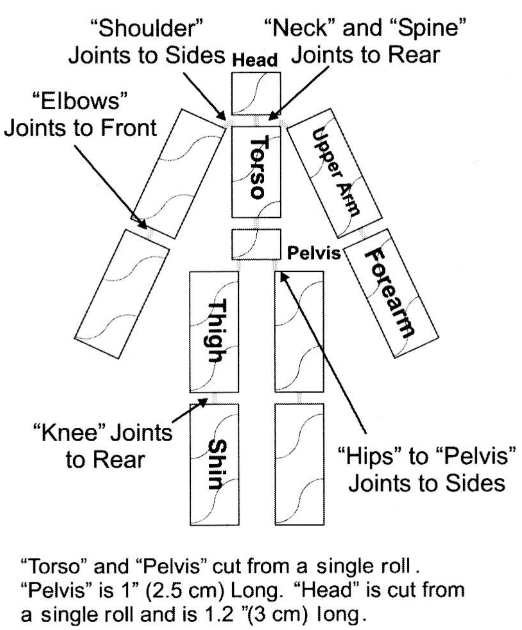
Note that for the different pipe cleaner joints, you'll see that I took into consideration their placement so that the robot would be capable of moving in the same manner as a human being.

To build the robot, I cut 10 2.5-inch-long (6.4 centimeters) pieces of pipe cleaner and collected 10 old toilet paper rolls. To cut pipe cleaners, I used a set of wire clippers—don't use scissors (especially ones that are important to other people). I shouldn't have to say this, but you should wait for toilet paper rolls to become available; don't expedite the process of getting bare toilet paper rolls. I don't want to get any angry emails from parents saying that one day they walked into their bathroom and found enough toilet paper lying on the floor to fill 10 rolls.

Once you have the cut pipe cleaners to size using a sharp knife, cut one of the rolls into two smaller cylinders, each piece 1 inch (2.5 centimeters) long. The longer piece will become the "back" of the robot with the small cylinder being the robot's "pelvis." On another toilet paper roll, cut a ring about 0.75 inches (2 centimeters) long; this will become the robot's "head."

With the other eight rolls of toilet paper, you are ready to start assembling the robot using some kind of paper or wood glue. Model airplane cement, epoxies, and contact cements are not appropriate for this task. You may want to try using a cyanoacrylate such as Krazy Glue to hold down the pipe cleaner pieces before using the paper or wood glue. Personally, I would discourage doing this as you will probably end up gluing yourself to short pieces of pipe cleaner and empty toilet rolls. After other people see this, it will be hard for them to think of you as an "Evil Genius" with any kind of seriousness.

On each toilet paper roll, put down a 1-inch (2.5-centimeter) bead of glue along the inside to affix one



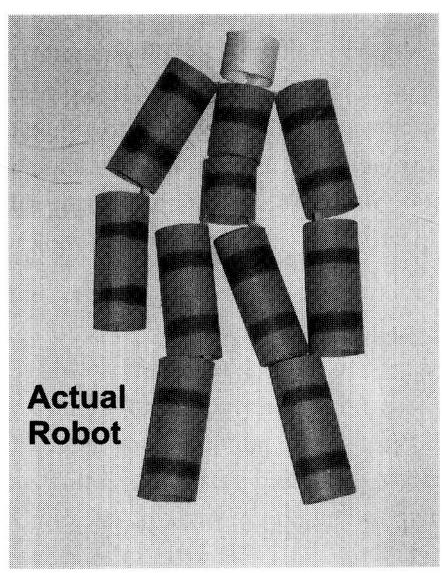


Figure 1-1 Toilet paper robot plan

end of a piece of pipe cleaner. Push 1 inch (2.5 centimeters) of pipe cleaner into the glue, leaving the other 1.5 inches (3.8 centimeters) outside the roll. When you have pushed the pipe cleaner down into the glue, put some glue on top of the pipe cleaner to make sure that it is secure. Once this is done, leave the rolls of toilet paper and pipe cleaners to dry for a day.

Next, repeat the process by gluing 1 inch (2.5 centimeters) of the exposed pipe cleaner into another toilet paper roll using exactly the same process and leave it to dry for another day. There will be 0.5 inches (1.25 centimeters) of pipe cleaner joint between the two rolls. Once the pieces have dried, glue them to the torso, one side at a time, to avoid having the glue run. When you are finished (a couple of days or so from when you started), you will have a model robot that looks like the one in Figure 1-1.

As I indicated, I would like to experiment with trying to get a robot to change from standing straight up to walking forward. With the glue on your robot dry, try to get it to stand up.

Chances are you will end up with a heap of seemingly loosely connected empty toilet rolls, similar to the pile I ended up with (Figure 1-2). You will also have the vexing problem of determining how to support the robot so that you can start experimenting with how you will make it walk.

Looking at this heap of paper, glue, and pipe cleaner, you can draw a few conclusions. The first one is that pipe cleaners are not rigid enough to support the collection of toilet paper rolls in a set position. You might be thinking of materials you could replace the pipe cleaners with, but I want to tell you to avoid going through the effort. Even if you had a robot that could support itself standing up, it is very difficult to come up with the motion required to walk without

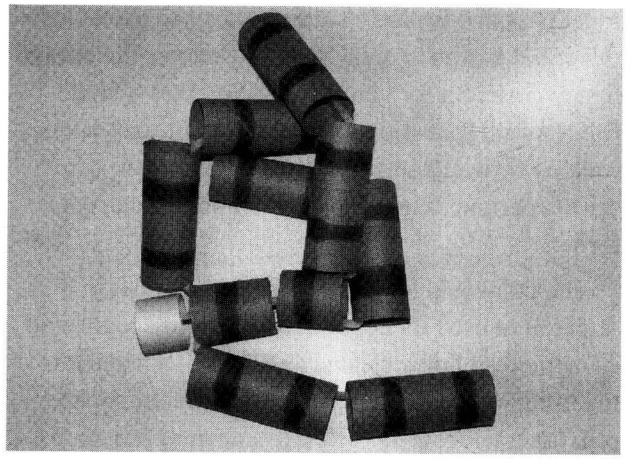


Figure 1-2 *Not an auspicious beginning to building your own robots*

the robot falling over. Remember that it took you a year or so to program yourself to stand up and walk forward, and in your case, you had all the necessary equipment to begin with. Walking forward is just one aspect of the problem—along with it, you will have to figure out how to turn and walk over uneven terrain. Stairs are a particularly vexing problem for walking robots.

Designing a mobile biped robot that can stand up and walk like a human being is considered by many roboticists as the "Holy Grail" of robotics—it is an incredibly challenging task in which large, well-funded companies and laboratories are just beginning to have success. With this in mind, I would like to change the way you look at robots so you start looking at them from the bottom up, gaining the necessary skills to build the different components used in a robot. One day you may build a robot that looks and acts like a human, but for right now, let's set our sights at the bottom.

Experiment 2
Pipe Cleaner Insect

In the first experiment in this book, I gave you some idea how difficult it is to create a robot based on the human form. I mentioned that there would be problems getting the robot to walk, but didn't go into detail because I didn't know of a way to get the robot to even stand reliably. Before starting to work on actual robots, I think that it is important to come up with a platform that is stable (it can stand up reliably) and then investigate how the robot can move or manipulate objects.

When looking for ideas or a better understanding of how to approach a problem, you will often find the answer by looking at nature and seeing how different animals (and even plants) respond to the same challenge. If we want to look at a stable platform capable of movement and moving objects, then we will probably look through different multilegged animals. This should be an obvious simplification of the robot platform. As a child, you were able to learn to crawl on all fours much sooner than you were able to walk.

Looking at animals that can walk around on all fours and manipulate objects similarly to humans, the obvious animal to me is the elephant. It can move around on its legs and manipulate objects using its trunk. The problem with the elephant (and any four-legged animal) is its dynamic and unstable motion. As the elephant walks, it transfers mass between its different legs so that it never quite falls over. Implementing this motion in robots is not terribly difficult, but it has the problem of the robot falling over if it were to stop abruptly or with one leg left in the air.

As a simple test of this statement, get down on your hands and knees and crawl across the floor, stopping abruptly with one arm or leg in the air. Depending on what you are holding up when you stop, you will either fall onto your side or your face. Initially, it might be difficult for you to fall over; you will automatically compensate for the lifted limb and move your body's center of gravity so that you are stable on three limbs. You might want to conduct this experiment over a gym mat to make sure you don't hurt yourself.

By going to a lower life-form with four legs, we have solved the problem of being unstable when standing up, but we still have a problem of movement. Let's look for a lower life-form that can move on multiple legs, but is always stable. The obvious animal that meets this requirement is the bug. If you observe the motion of an ant (cockroaches are too fast), you will see that at all times, the ant has at least three legs on the ground. As I show in Figure 1-3, when an ant moves forward, two legs on one side and one leg on the other are pushing it forward while the other three legs are getting into position to take over and move the insect forward.

The legs must be hinged and driven in such a way that they can move up and down and back and forth. Moving the lower leg up and down pushes the insect off the ground, and moving back and forth is used to either propel the robot or move the leg into position to propel the insect. Figure 1-4 shows a mechanical analog of an insect leg with the side-to-side motion provided by a hinge joint on the side of the insect, and the up-and-down motion accomplished by moving the lower leg up and down.

When referring to robot arms and legs, each dimension the limb can move in is called a *degree of freedom*. Although this simple insect leg only has two degrees of freedom (up/down and backwards/forwards), you will find that other robots have limbs with as many as eight degrees of freedom to allow them to perform complex tasks.

The insect is always stable (its center of gravity is always in the center of at least three legs), and if it were to stop for any reason, it wouldn't fall over because it is always stable, unlike the four-legged animal. Along with forward movement being easily implemented, changing direction for an insect is also quite simple. This is why insect-based robots (sometimes called *insectoids*) are more popular than ones based on cats, dogs, or elephants.

You can very easily investigate the properties of the insect-based robot by building a simple model for

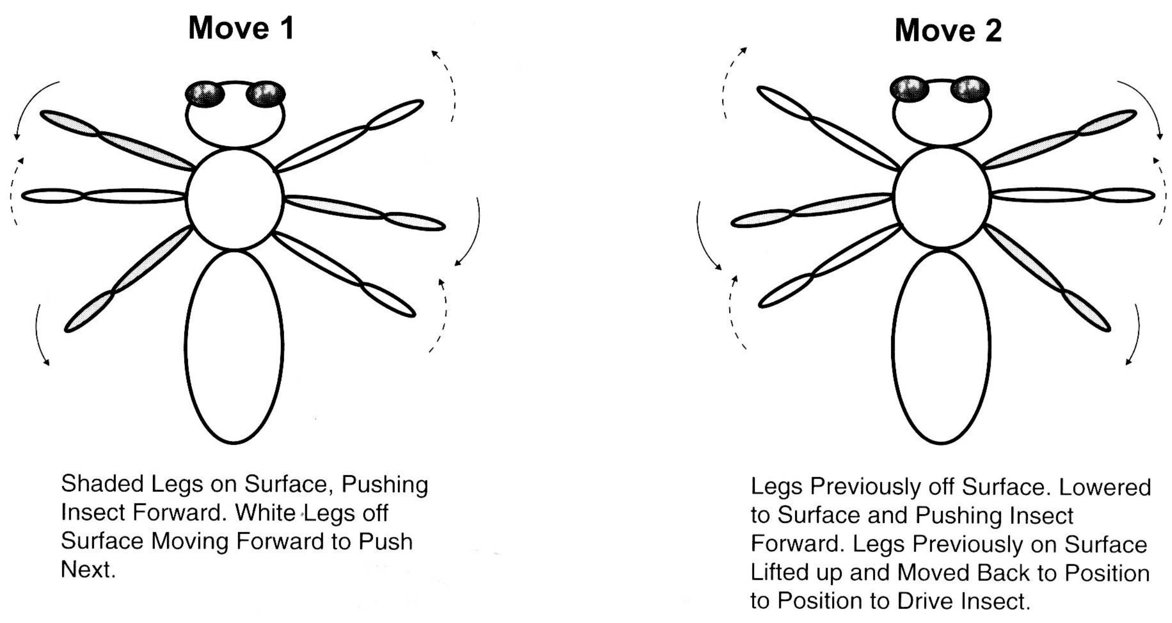


Figure 1-3 *Insect movement*

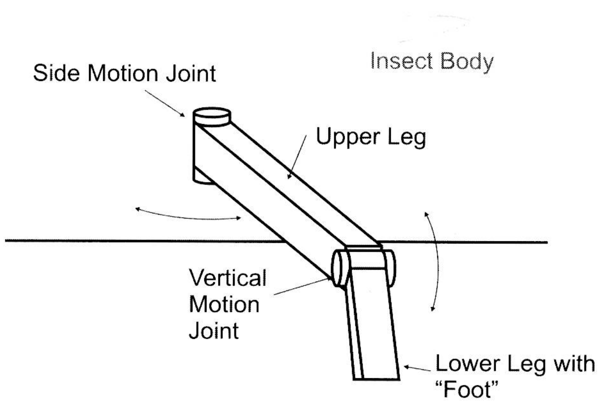


Figure 1-4 *Insect leg*

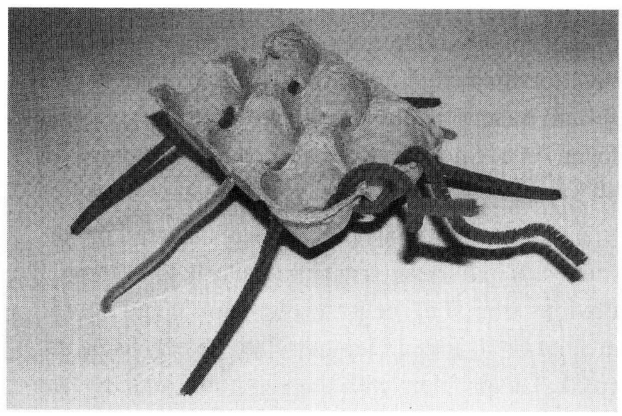


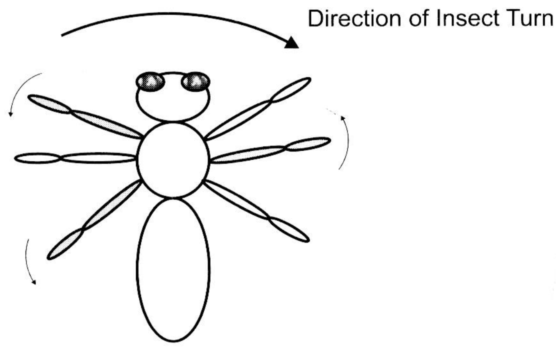
Figure 1-5 *The completed robot insect*

yourself. For my prototype, I used half of the bottom of an egg carton and, using white glue, mounted some pipe cleaner "legs." To create the legs, I poked holes in the side of the egg carton (in each well where eggs are stored), and pushed a pipe cleaner through the hole. Once I had the six legs (made out of the three pipe cleaners), I evened out the amount of pipe cleaner that was present on each side and then glued the legs into the egg carton wells. The antennae that you can see in Figure 1-5 are strictly for decoration.

You will find that it will take a day for the glue to dry. Once it has dried, you can start experimenting with the motion of the legs. Using Figures 1-3 and 1-6 showing the motion for an insect, you can demonstrate how an insect moves forward quite easily.

Turning the insect is accomplished by moving the legs in a similar manner as moving forward, but instead of moving all three legs in the same direction, the single leg on one side moves in the opposite direction, causing a differential force on the insect and turning it. This can be very easily demonstrated with your pipe cleaner and egg crate ant.

Reviewing the model robot you've just built, you should see two of areas of concern. The first is the need for the robot to support itself. Depending on



Shaded legs on left side push to the rear while the shaded leg on the right side pushes forward. The white legs are above the surface, preparing to continue the turn.

Figure 1-6 *Insect turning*

how the robot is implemented, this could be a major concern as the weight of the robot may be more than what the legs (and the mechanisms that drive them) can handle. The second is the apparent complexity of the robot—you are probably feeling like there could be an easier way of developing a mobile robot.

Experiment 3
LEGO Mobile Robots

In the previous pages, I have looked at some different types of legged mobile robots. In presenting these different types, I have also noted that they have some fairly significant concerns that go with them in terms of complexity. Thinking about it, you may come to the conclusion that basing robots on some kind of life-form is not the best way to design them, and maybe we can look somewhere else for inspiration.

In our modern society, many different moving devices do not follow the human, animal, or insect form that was discussed previously in this section. For example, virtually 100 percent of the cars on the road are built using the same platform consisting of four wheels, two of which are driving and two are steering. For most modern (front-wheel drive) cars, the steering wheels are also the driving wheels.

Making the use of the car platform very attractive is the ability of many different model *remote-control* (R/C) cars to be converted into a robot format. Later in this book, I will discuss my experiences trying to convert a prebuilt car product into a base for a mobile robot.

If you want to build a car platform from scratch, you will discover two different problems that have to be overcome when you want to turn the vehicle. The first one has to do with the steering wheels. As can be seen in Figure 1-7, the "right" wheels (closest to the axis of the turn) will have to be at a sharper angle than the "left" wheels. (Actually, when you look at Figure 1-7, you will see that all four wheels are actually turning through a slightly different radius curve.) Most cars have an offset built into the steering gear pieces (known as *linkages*) that automatically turn the wheels at the required angle. This can be built into a robot, but you will have to work through the proper angles of the linkages to be successful.

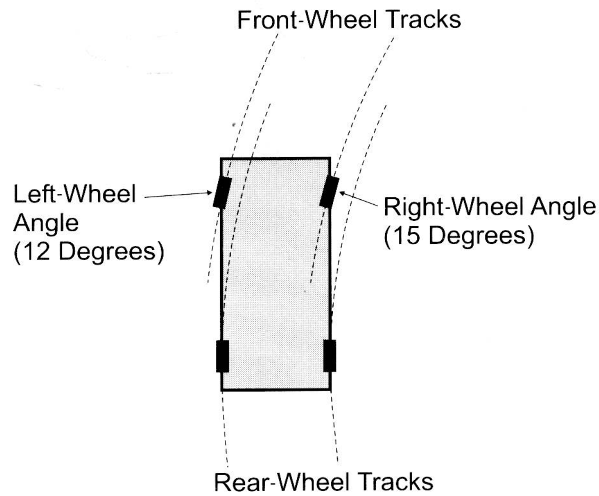


Figure 1-7 *Car turning*

Robot designers use two common solutions to this problem. The first is to just use a single steering wheel. By doing this, the robot base is known as a *tricycle* for obvious reasons. The second solution to the different angle on the steering wheels is to mount both of them on a single bar, like a toy wagon. Using a few pieces of LEGO, you can build a model of a car robot with wagon steering, like the one shown in Figure 1-8.

For the examples in this experiment, I bought a LEGO Creators kit, which costs less than $10. If you have any LEGO toys in your home, chances are you will have enough parts to build the example robot models in this section without having to buy anything else. What you need is four wheels with axles attached to LEGO blocks, a vertical hinge (or small, round pieces of LEGO that will allow a block to pivot), and a few LEGO blocks to hold the model robot together.

This method works reasonably well, but can result in the robot tipping over when turning sharply, and it can have difficulty running over rough surfaces. The second issue with the car-based mobile robot is the difference in speeds between the driving wheels when the robot is turning. In the diagram of a car in a turn (Figure 1-7), you can see that the inside wheels have a smaller radius than the outside wheels. This smaller radius means that the inside wheels have to go a shorter distance in the same amount of time as the outside wheels. In a car, the solution to this problem is to build in a *differential*, which is a special type of gearbox that changes the speed of the different driving wheels depending on the angle of the turn. A differential could be built into a robot, but a much simpler solution is to just drive one wheel.

For many robot designers who want to create a steered robot, the tricycle platform, with the steered wheel being driven (the other two wheels are allowed to turn freely) is the optimum choice.

For other robot designers, after looking at the extra complexity of turning the wheels, they question the need for steering wheels at all. In Figure 1-9, I have built a simple LEGO robot with only two wheels.

This is the simplest robot that you can build and it is known as a *differentially driven* robot because the two wheels should be capable of moving independently so the robot can turn. With this robot model,

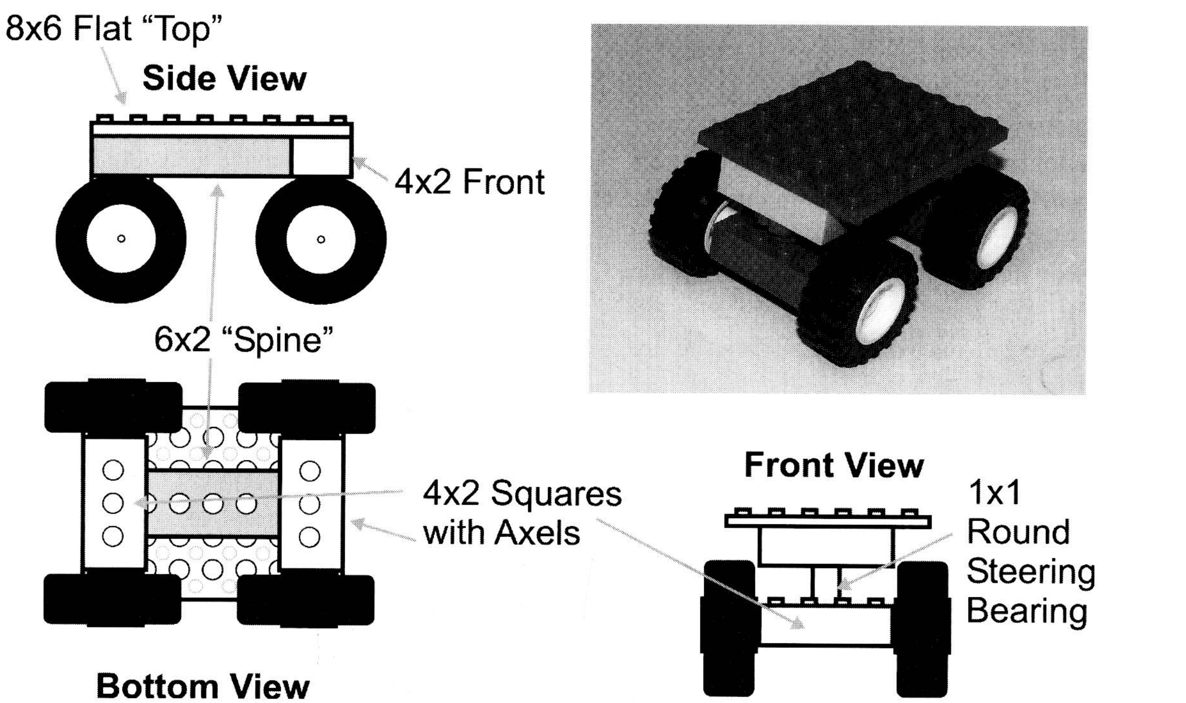


Figure 1-8 Design for a LEGO robot wagon