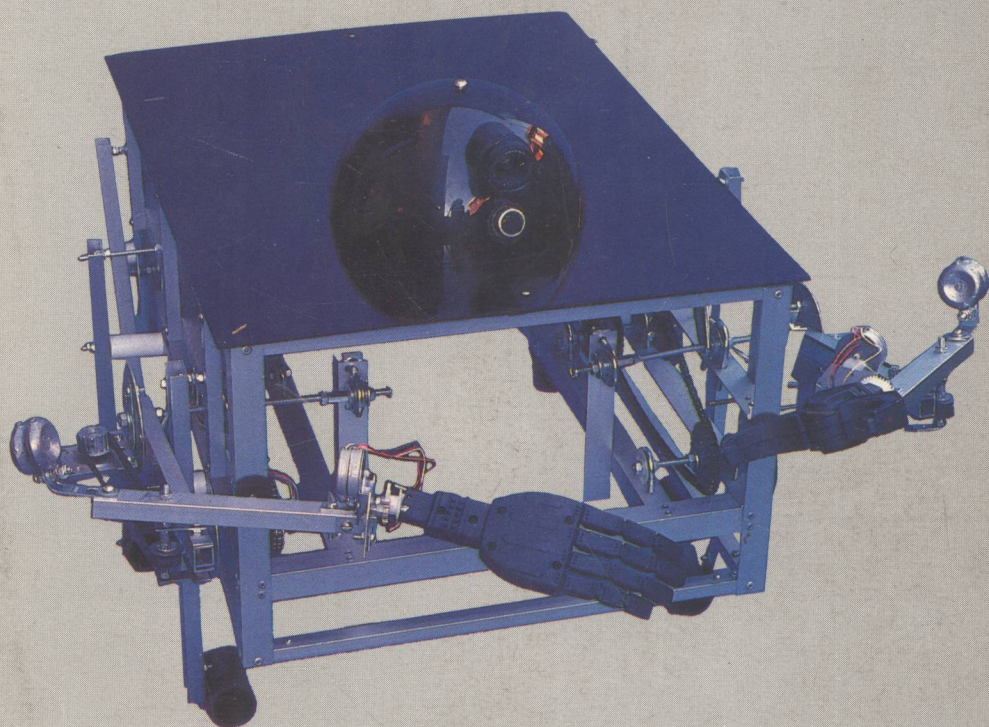


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THE

ROBOT BUILDER'S BONANZA 99 INEXPENSIVE ROBOTICS PROJECTS



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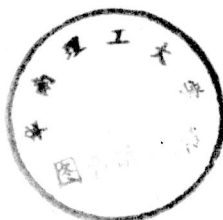
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THE
**ROBOT BUILDER'S
BONANZA:
99 INEXPENSIVE
ROBOTICS PROJECTS**

GORDON MCCOMB



TAB BOOKS Inc.

Blue Ridge Summit, PA

To my daughter, Mercedes, who still believes that a robot is a "metal man who serves drinks at parties."

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THIRD PRINTING

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Introduction

The word *robot* is defined as a mechanical device that is capable of performing human tasks or behaving in a human-like manner. No argument here. The description certainly fits.

To the robotics experimenter, however, the word robot has a completely different meaning. A robot is a special brew of motors, solenoids, wires, and assorted electronic odds-and-ends, a marriage of mechanical and electronic gizmos.

Taken together, the parts make a personable creature that can vacuum the floor, serve drinks, protect the family against intruders and fire, entertain, educate, and lots more. In fact, there's almost no limit to what a well-designed robot can do.

Robotics, like rocketry, television, and countless other technology-based industries, started small. But growth and progress have been slow. Robotics is still a cottage industry, even considering the special-purpose automata now in wide use in the car industry. The science of personal robotics—the R2-D2 and C-3PO kind of “Star Wars” fame—is even smaller—an infant in a brand new family on the block. All that this means is, for the robotics experimenter, there is plenty of room for growth. There are a lot of discoveries yet to be made.

INSIDE THE ROBOT BUILDER'S BONANZA

The Robot Builder's Bonanza takes an educational but fun approach to designing working robots. Its modular projects take you from building basic motorized platforms to giving the machine a brain—and teaching it to walk and talk and obey commands.

If you are interested in mechanics, electronics, or robotics, you'll find this book a treasure chest of information and ideas on making thinking machines. The projects include all the necessary information on how to construct the essential building blocks of a personal robot. Suggested alternative approaches, parts lists, and possible sources of electronic and mechanical components are also provided where appropriate.

Several good books have been written on how to design and build your own robot. These have been aimed at making just one or two fairly sophisticated automata, and at a great price. Because of the complexity of the robots detailed in these books, they require a fairly high level of expertise and pocket money on your part.

This book is different. Its modular *cookbook* approach offers a mountain of practical, easy to follow, and inexpensive robot experiments. Taken together, the modular projects in *The Robot Builder's Bonanza* can be

combined to create several different types of highly intelligent and workable robots, of all shapes and sizes—rolling robots, walking robots, talking robots, you name it. You can mix and match projects as desired.

How to Use This Book

This text could be divided into seven sections. Each section would cover a major component of the common personal or hobby (as opposed to commercial or industrial) robot. The sections would be:

- Robot Basics—What you need to get started; setting up shop; how and where to buy robot parts.
- Body and Frame—Robots made of plastic, wood, and metal; working with common metal stock; converting toys into robots.
- Power and Locomotion—Using batteries; powering the robot; working with dc and stepper motors; gear trains; walking robot systems; special robot locomotion systems.
- Appendages—Building robot arms and hands; adding the sense of touch.
- Eyes, Ears, and Mouth—Speech synthesis; music and sound effect generation; sound detection; robot eyes; smoke, flame, and heat detection.
- Navigation—Collision detection; collision avoidance; ultrasonic ranging; infrared beacon systems; track guidance, navigation.
- Electronic Control—Infrared remote control; ultrasonic remote control; radio links; robot control with computer parallel port; computer system bus interface; on-board computer systems.

The chapters tell you how to build the many parts that go into the typical hobby robot. Most chapters present one or more projects that you can duplicate for your own robot creations. Whenever practical, I designed the components as discrete building blocks, so that you can combine the blocks in just about any configuration you desire. The robot you create will be uniquely yours, and yours alone.

If you have some experience in electronics, mechanics, or robot building in general, you can skip around and read only those chapters that provide the information you're looking for. The chapters are very much stand-alone modules, like the robot designs presented. This allows you to pick and choose, using your time to its best advantage.

If you're new to robot building, and the varied disciplines that go into it, you should take a more pedestrian

approach and read as much of the book as possible. In this way, you'll get a thorough understanding of how robots tick. When you finish the book, you'll know the kind of robot(s) you'll want to make, and how you'll make them.

Conventions Used in This Book

You need little advance information before you can jump head-first into this book, but you should take note of a few conventions I've used in the description of electronic parts, and the schematic diagrams for the electronic circuits.

TTL integrated circuits are referenced by their standard 74XX number. The "LS" identifier is assumed. I built most of the circuits using LS TTL chips, but the projects should work with the other TTL family chips: the standard (non-LS) chips, as well as those with the S, ALS, and C identifiers. If you use a type of TTL chip other than LS, you should consider current consumption, fanout, and other design criteria. These may affect the operation or performance of the circuit.

The chart in Fig I-1 details the conventions used in the schematic diagrams. Note that non-connected wires are shown by a direct cross or lines, or a broken line. Connected wires are only shown by the connecting dot.

Details on the specific parts used in the circuits are provided in the Parts List tables that accompany the schematic. Refer to the Parts List for information on resistor and capacitor type, tolerance, and watt or voltage rating.

In all full circuit schematics, the parts are referenced by component type and followed by a number.

- U means an integrated circuit (IC).
- R means a resistor or potentiometer (variable resistor).
- C means a capacitor.
- D means a diode, a zener diode, and sometimes a light sensitive phototransistor.
- Q means a transistor and sometimes a light sensitive photodiode.
- LED means a light emitting diode (most any visible LED will do, unless the Parts List specifically calls for an infrared LED).
- XTL or XTAL means a crystal or ceramic resonator.
- Finally, S means a switch; RL means a relay, SPKR means a speaker, TR means a transducer (usually ultrasonic), MIC means a microphone.

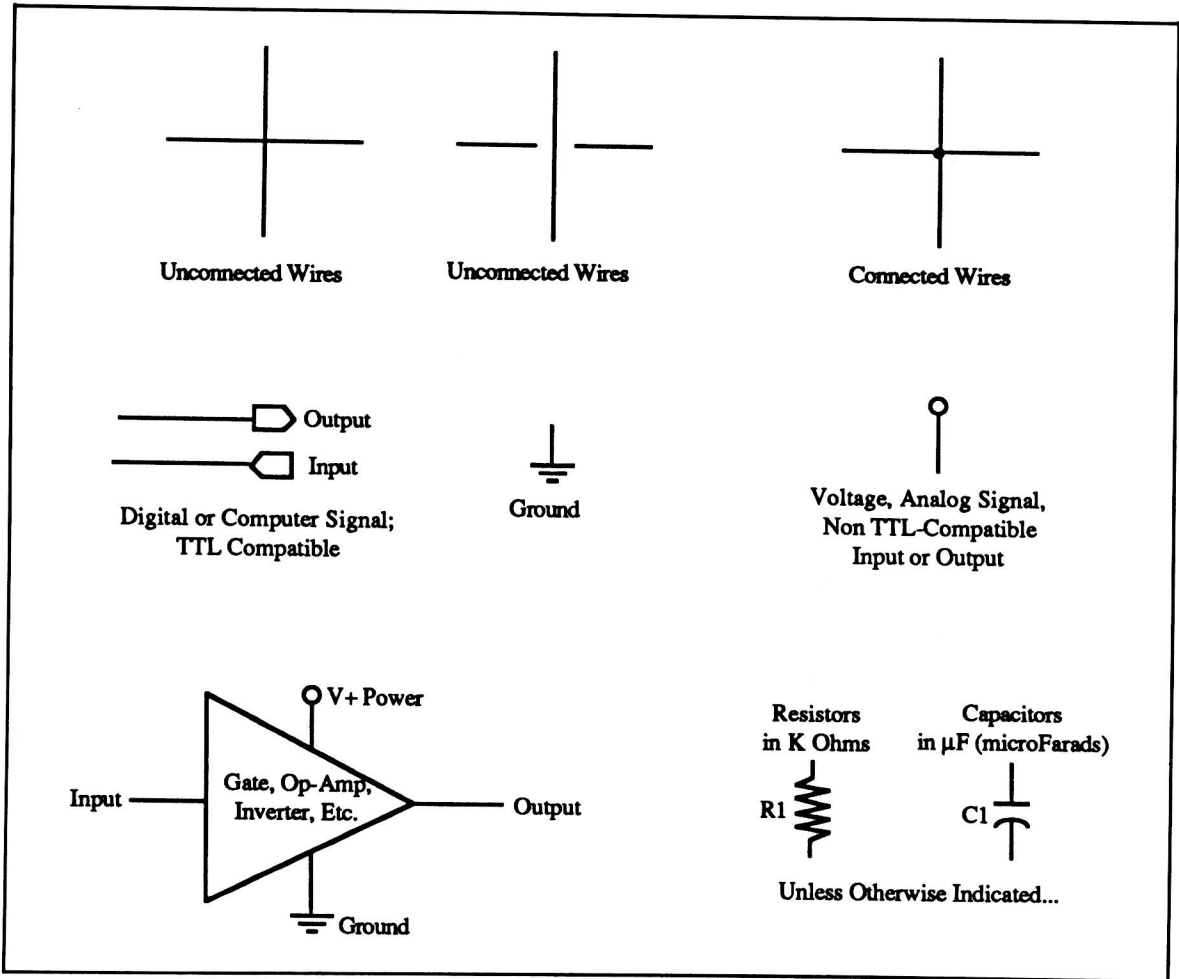


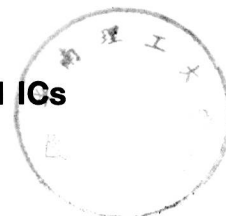
Fig. I-1. Schematic diagram conventions used in this book.

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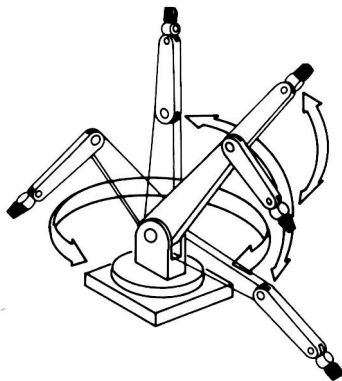


Acknowledgments

Only until after you've climbed the mountain can you look behind you and see the vast distance that you've covered, and remember those you've met along the way that made your trek a little easier. Now that this book is finally finished, after the many miles of weary travel, I look back

to those that helped me turn it into a reality, and offer my heartfelt thanks: To my good friends Ian Simpson, Eli Hollander, and Steve York, Brint Rutherford and the editors at TAB BOOKS, my agent Bill Gladstone, and my wife Jennifer Meredith.

Chapter 1



The Robot Experimenter

There he sits, as he's done countless long nights before, alone and deserted in a dank and musty basement. With each strike of his ball-peen hammer comes an ear-shattering bong, and an echo that seems to ring forever. Slowly, his creation takes shape and form—it first started as an unrecognizable blob of metal and plastic, then it transformed into an eerie silhouette, then. . .

Brilliant and talented, but perhaps a bit crazed, he is before his time: a social outcast, a misfit that belongs neither to science nor fiction. He is the robot experimenter, and all he wants to do is make a mechanical creature that serves drinks at parties and wakes him up in the morning.

Maybe this is a rather dark view of the present-day hobby robotics experimenter. But though you may find a dash of the melodramatic in it, the picture is not entirely unrealistic. It's a view many outsiders to the robot building craft hold, one that's over 100 years old; when the prospects of building a human-like machine first came within technological grasp. It's a view that will continue for another 100 years, perhaps beyond.

Like it or not, if you're a robot experimenter, you are an odd-ball, an egg-head, and—yes, let's get it all out—a little on the weird side!

In a way, you're not unlike Victor Frankenstein, the

old-world doctor from Mary Wollstonecraft Shelley's immortal 1818 horror thriller. Instead of robbing graves at the still of night, you rob electronic stores, flea markets, surplus outlets, and other specialty shops in your unrelenting quest—your thirst—for all kinds and sizes of motors, batteries, gears, wires, switches, and other odds-and-ends. Like Dr. Frankenstein, you galvanize life from these “dead” parts.

If you have yet to build your first robot, you're in for a wonderful experience. Watching your creation scoot around the floor or table can be exhilarating, breathtaking. Those around you may not immediately share your excitement, but you know that you've built something—however humble—with your own hands and ingenuity.

If you're one of the lucky few that has already assembled a working robot, then you know of the excitement I speak of. You know how thrilling it is to see your robot obey your commands, as if it were a trusted dog. You know the time and effort that went into constructing your mechanical marvel, and although others may not always appreciate it, especially when it marks up the kitchen floor with its rubber tires, you are satisfied with the accomplishment, and look forward to the next challenge.

If you have built a robot, you also know of the heart-

ache and frustration that's inherent in the process. You know that not every design works, and that even a simple design flaw can cost weeks of work, not to mention ruined parts. This book will help you—beginner and experienced robot maker alike—avoid these mistakes.

THE BUILDING BLOCK APPROACH

One of the best ways to experiment with—and learn about hobby robotics is to construct individual robot components, then combine the completed modules to make a finished, fully functional machine. For maximum flexibility, these modules should be interchangeable. You should be able to choose locomotion system “A” to work with appendage system “B,” and operate the mixture with control system “C”—or any variation thereof.

The robots you create are made from building blocks, so making changes and updates are relatively simple and straightforward tasks. When designed and constructed properly, the building blocks, as shown in diagram form in Fig. 1-1, may be shared among a variety of robots. It's not unusual to reuse parts as you experiment with new robot designs.

Most of the building block designs presented in the

following chapters are complete, working subsystems. The majority operate without ever attaching them to a mechanical mainframe or control computer. The way you interface the modules is up to you, and will require some forethought and attention on your part (I'm not doing *all* the work, you know!). Feel free to experiment with each subsystem, altering it and improving upon it as you see fit. When it works the way you want, incorporate it into your robot, or save it for a future project.

BASIC SKILLS

What skills do you need as a robot experimenter? Certainly, if you are already well versed in electronics and mechanical design, you are on your way to becoming a robot experimenter extraordinary. But an intimate knowledge of neither electronics nor mechanical design is absolutely necessary.

All you really need to start yourself in the right direction as a robot experimenter is a basic familiarity with electronic theory and mechanics. The rest you can learn as you go. If you feel that you're lacking in either beginning electronics or mechanics, pick up a book or two on these subjects at the bookstore or library. See Appendix

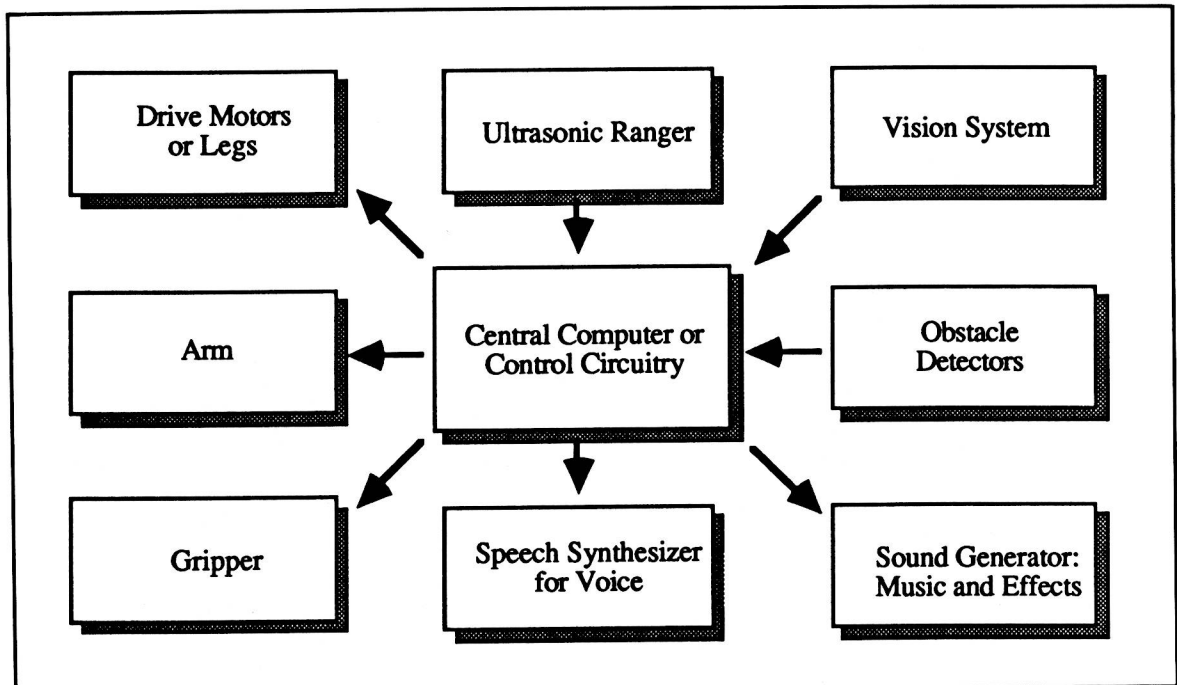


Fig. 1-1. The basic building blocks of a fully functional robot.

B for a selected list of suggested further reading.

Electronics Background

Study analog and digital electronic theory, and learn the function of resistors, capacitors, transistors, and other common electronic components. Your mastery of the subject does not need to be extensive, just enough so that you can build and troubleshoot electronic circuits for your robot. You'll start out with simple circuits with a minimum of parts, and go from there. As your skills increase, you'll be able to design your own circuits from scratch, or at the very least, customize existing circuits to match your needs.

Schematic diagrams are a kind of recipe for electronic circuits. The designs in this book, as well as most any book that deals with electronics, are in schematic form. If you don't know already, you owe it to yourself to learn how to read a schematic diagram. There are really only a dozen or so common schematic symbols, and memorizing them takes just one evening of concentrated study. A number of books have been written on how to read schematic diagrams. Once again you are referred to Appendix B for a list of suggested reading.

Sophisticated robots use a computer or microprocessor to control their actions. This book is not as computer-oriented as some, but a number of projects described throughout this book require at least some knowledge of computers and the way computers manipulate data. The popularity of personal computers means that there are plenty of instructional guides on all facets of this growing science. If you're new or relatively new to the field, start with a beginning computer book, then move up to more advanced texts. Don't start with a book on Assembly Language programming or microprocessor interfacing techniques; an introductory guide will get you going in the right direction, and the rest will follow naturally.

Mechanical Background

The majority of us are far more comfortable with the mechanical side of hobby robot building than the electronic side. After all, you can see gears meshing and pulleys moving as a robot glides across the floor; you can't see electrons flowing within a circuit. It's far easier to see how a mechanical drive train works than to see how an ultrasonic ranging system works. Whether or not you are comfortable with mechanical design, you do not need to possess a worldly knowledge of mechanical theory. You should be comfortable with mechanical and electro-

mechanical components such as motors, solenoids, and chain drives. This book provides some mechanical theory as it pertains to robot building, but you may want to supplement your learning with books or study aides.

The Workshop Aptitude

To be a successful robot builder, you must be comfortable working with your hands, and thinking problems through from start to finish. You should know how to use common shop tools and have some basic familiarity in working with wood, lightweight metals, and plastic. Once more, if you feel your skills aren't up to par, read up on the subject and try your hand at a simple project or two.

With experience comes confidence, and with both comes more professional results. Work on it long enough, and the robots you build may be indistinguishable from store-bought models (in appearance, not capability; yours will undoubtedly be far more sophisticated!).

The Two Most Important Skills

Two important skills that you can't develop from reading books are patience and the willingness to learn. Both are absolutely essential if you want to build your own working robots. Without these skills, you can't do anything, at least anything well, and you will most assuredly give up in desperation and frustration.

Give yourself time to experiment with your projects. Don't rush into things, because you are bound to make mistakes. If a problem continues to nag at you, put the project aside, letting it sit for a few days, even a few weeks. You'll be surprised how the solution to many of your most challenging problems will come when you least expect them: while dozing off for the night, while showering, while driving to work. Keep a small notebook handy and jot down your ideas so you won't forget them.

If trouble persists, perhaps you need to bone up on the subject before you can adequately tackle the problem. Take the time to study, to learn more about the various sciences and disciplines involved. While you are looking for ways to combat the current dilemma, you are increasing your general robot-building knowledge. Research is never in vain.

THE MIND OF THE ROBOT EXPERIMENTER

Robot experimenters have a unique way of looking at things. Nothing is taken for granted.

- At a restaurant, it's the robot experimenter who

collects the carcasses of lobster and crabs, to learn how nature has designed articulated joints where the muscles and tendons are inside the bone. Perhaps the articulation and structure of a lobster leg can be duplicated in the design of a robotic arm.

- At a county fair, it's the robot experimenter who studies the way the egg-beater ride works, watching the various gears mesh and spin in perfect unison. Perhaps the gear train can be duplicated in an unusual robot locomotion system.
- At a phone booth, it's the robot experimenter who listens to the dial tones that are emitted when buttons are pressed. These tones, the experimenter knows, trigger circuitry at the phone company office to call a specific telephone among the millions in the world. Perhaps these or similar tones can be used to remotely control a robot.
- At work on the computer, it's the robot experimenter who rightly assumes that if a computer can control a printer or plotter through an interface port, the same computer and interface can be used to control a robot.
- When taking a snapshot at a family gathering, it's the robot experimenter who studies the inner workings of the automatic focus system of the camera. The camera uses ultrasonic sound waves to mea-

sure distance, and automatically adjusts its lens to keep things in focus. The same system should be adaptable to a robot, enabling it to judge distances and see with sound.

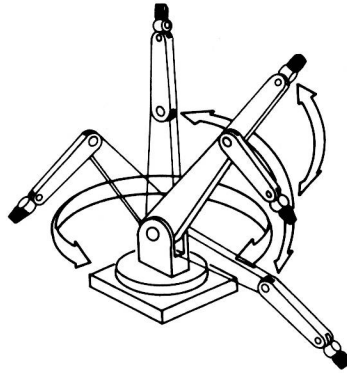
The list could go on and on. The point? All around us, from Mother Nature's designs to the latest electronic gadgets, are an infinite number of ways to make better and more sophisticated robots. Uncovering these solutions requires extrapolation—figuring out how to apply one design and make it work in another application, then experimenting with the contraption until everything works.

FOLLOW THE YELLOW BRICK ROAD

Now you know what is expected of you, and how—as a robot experimenter—you must begin to look at the world around you. Knowing your own strengths and weaknesses goes a long way in helping you develop skills so that even the most complex robot designs are within your grasp.

The following chapter discusses what makes up a robot, how the parts function and interrelate to one another, the differences between so-called smart and dumb machines, and the dream called the self-contained, autonomous robot.

Chapter 2



Anatomy of a Robot

We are fortunate. The human body is, all things considered, a nearly perfect machine: it is intelligent (usually!), it can lift heavy loads, it can move itself around, and it has built-in protective mechanisms to feed itself when hungry, avoid danger, and sense pain so it can avoid further damage. Other living creatures on this earth possess the same or similar functions, though not always in such advanced form.

Robots are often modeled after humans, if not in form, then at least in function. For decades, scientists and experimenters have tried to duplicate the human body, to create machines with intelligence, strength, mobility, and auto sensory mechanisms. That goal has not yet been realized, and in fact, probably never will be.

Nature provides a striking model for robot experimenters to mimic, and it is up to us to take up the challenge. Some, but by no means all, of nature's mechanisms—human or otherwise—can be duplicated to some extent in the robot shop. Robots can be built with eyes to see, ears to hear, a mouth to speak, and appendages and locomotion systems of one kind or another to manipulate the environment and explore surroundings.

This is fine theory; what about real life? Exactly what makes up a real hobby robot? What basic parts are necessary for a machine to have before it can be given the ti-

tle robot? Let's take a close look at the anatomy of a robot in this chapter, and the kinds of materials used to construct one. For the sake of simplicity, not every robot subsystem in existence will be covered, just the components that are most often found in hobby and personal robots.

SELF-CONTAINED VERSUS TETHERED

People like to argue the definition of a real robot. One side says that a robot is a completely *self-contained, autonomous* (self-governed) machine that needs only occasional instructions from its master to set it about its various tasks. A self-contained robot includes its own power system, brain, wheels (or legs) and manipulating devices such as claws or hands. The robot does not depend on any other mechanism or system to perform its tasks. It's complete, in and of itself.

The other side says that a robot is anything that moves under its own motor power, *for the purpose of performing near-human tasks* (this is, in fact, the definition of the word "robot" in most dictionaries). The mechanism that does the actual task is the robot itself; the support electronics or components may be separate. The link between robot and control components might be a wire, a beam of infrared light, even a radio signal.

In the 1969 experimental robot shown in Fig. 2-1, for example, a man sat inside the mechanism and operated it, almost as if driving a car. The purpose of the four-legged lorry was not to create a self-contained robot, but

to further the development of *cybernetic anthropomorphous machines*, otherwise known as *cyborgs*. Hardly a useless robotic endeavor.

The semantics of robot design won't be argued here

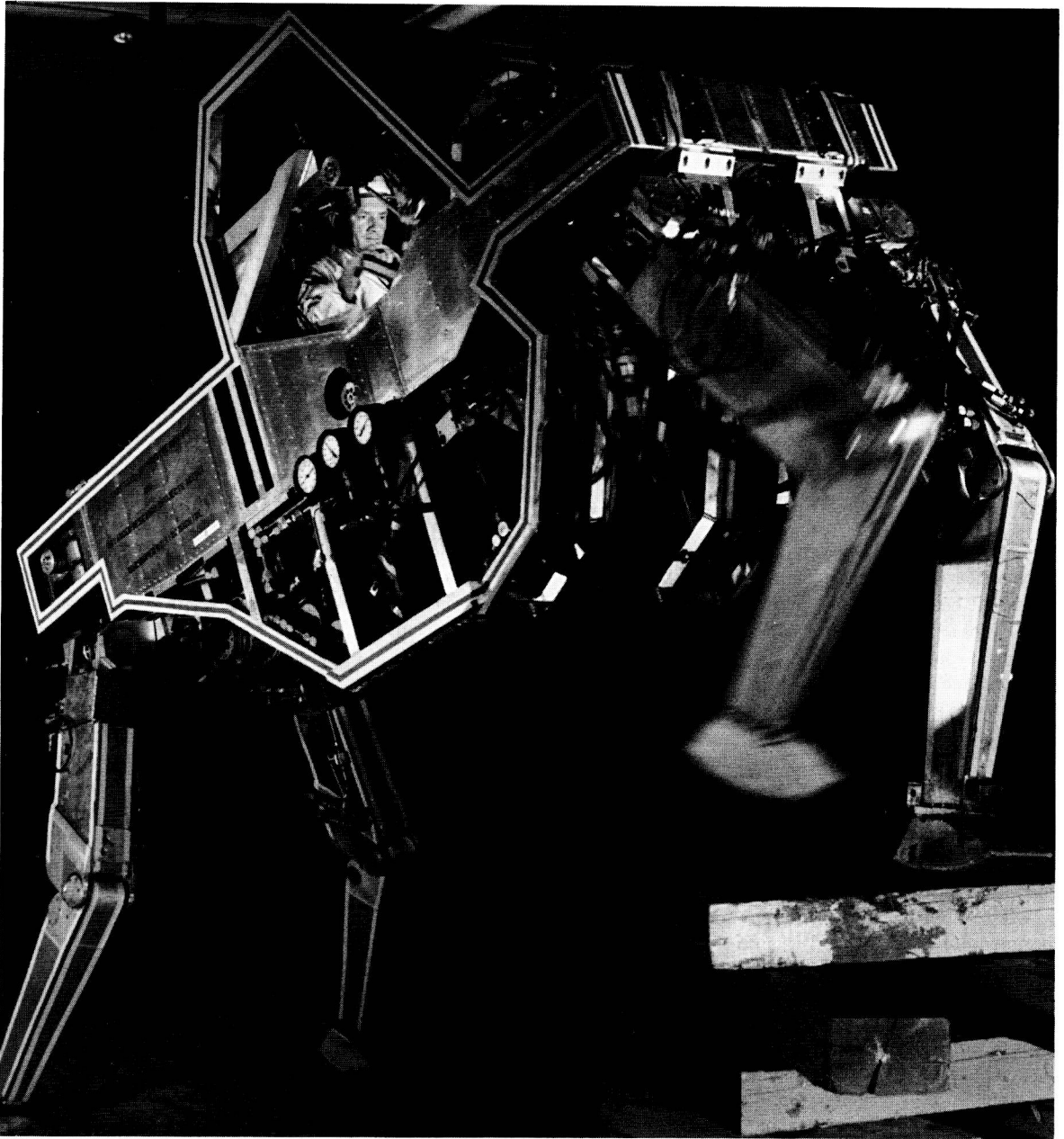


Fig. 2-1. This GE quadraped was controlled by a human operator who sat inside it. The robot was developed in the late 1960's under a contract with the U.S. government. Photo courtesy General Electric.

(this is a workbook after all, not a critique on theory), but it's still necessary to establish some basic levels of robot characteristics: what makes a robot a robot, and just not another machine? For the purposes of this book, let's consider a robot as any device that—in one way or another—mimics human or animal function. The way that the robot does this is of no concern; the fact that it does it at all is enough.

The functions that are of interest to the robot builder run a wide gamut: from listening to sounds and acting on them, to talking, walking or moving across the floor, to picking up objects, and sensing special conditions such as heat, flames, or light.

When we talk about a robot, it could very well be a self-contained automaton that takes care of itself, perhaps even programming its own brain, learning from its surroundings and environment. Or, it could be a small motorized cart, operated by a strict set of pre-determined instructions, repeating the same task over and over again until its batteries wear out, or it could be a radio controlled arm that you operate manually from a control panel. All are no less robots than the others, though some are more useful and flexible. As you'll discover in this chapter and the others that follow, the level of complexity of your robot creations is completely up to you.

THE BODY

Like the human body, the body of a robot contains

all its vital parts. It's the superstructure that prevents its electronic and electro-mechanical guts from spilling out. Robot bodies go by many names, including *frame* and *chassis*, but the idea is the same.

Skeletal Structures

In nature, and in robotics, there are two general types of support frames: endoskeleton and exoskeleton.

- *Endoskeleton* support frames are the kind found in the majority of nature's critters—including humans, mammals, reptiles, and most fish (note that the majority is species, not actual numbers of living organisms). The skeletal structure is on the inside, the organs, muscles, body tissues, and skin are on the outside. The endoskeleton is a characteristic of vertebrates.
- *Exoskeleton* support frames are the bones on the outside of the organs and muscles. Common exoskeletal creatures are spiders, all shell fish such as lobsters and crabs, and an endless variety of insects.

Which is better, endoskeleton or exoskeleton? Both. It all depends on the living conditions of the animal and its eating and survival tactics. The same is true of robots.

The main structure of the robot is generally a wood or metal frame, and is constructed a little like the frame

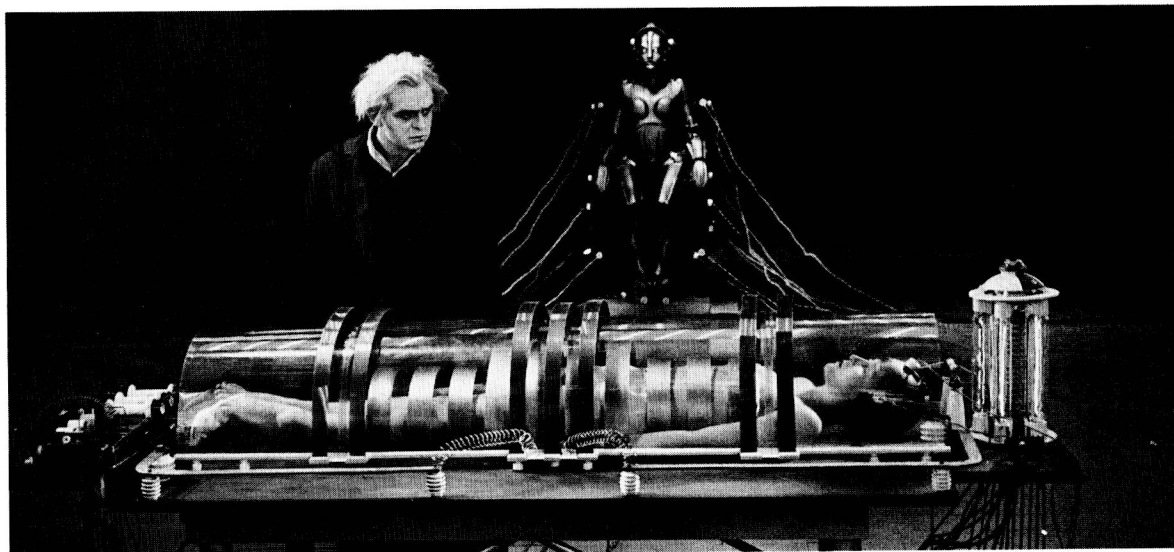


Fig. 2-2. The evil Dr. Rotwang gazes at the beautiful Maria, as his contraption is about to transform her shape to the cold steel robot who sits in the background. Today, the robot could effectively be made from materials other than steel, like plastic and aluminum. From the movie classic "Metropolis." Photo courtesy Museum of Modern Art/Film Archives.